17èmes JOURNÉES LYONNAISES DE CHIRURGIE DU GENOU

ANTERIOR CRUCIATE LIGAMENT

AL Instability

Surgical Techniques

Future and Biology

Return to Sport

E. SERVIEN, R. BADET, D. DEJOUR,
G. DEMEY, J.-M. FAYARD, S. LUSTIG,
J.-Cl. PANISSET, B. SONNERY-COTTET,
M. THAUNAT

LYON SCHOOL of KNEE SURGERY

www.lyon-knee-surgery.com

2016

SAURAMPS MEDICAL

LYON SCHOOL of KNEE SURGERY

17èmes Journées Lyonnaises de Chirurgie du Genou

ANTERIOR CRUCIATE LIGAMENT

ANTERIOR CRUCIATE LIGAMENT

Sarl DT - 11, boulevard Henri IV - 34000 Montpellier
Dépot légal : septembre 2016
I.S.B.N. : 979-1-03030-076-5
EAN : 9791030300765

Imprimé en France

ANTERIOR CRUCIATE LIGAMENT

sous la direction de

E. SERVIEN, R. BADET, D. DEJOUR, G. DEMEY,
J.M. FAYARD, S. LUSTIG, J.C. PANISSET,
B. SONNERY-COTTET, M. THAUNAT

Avec la collaboration de :

N. Adachi, J. Barth, C. Batailler, B. Bordet, J. Borne, T.P. Branch, C.H. Brown, L. Buisson, C. Camathias, G. Carbone, P.F. Chaillot, P. Chambat, J. Chappuis, J. Chouteau, T. Cucurulo, M. Daggett, D. Dejour, G. Demey, G. Dubois De Mont-Marin, A. Elmansori, G. Estour, O. Fantino, J.M. Fayard, J.A. Feller, C. Fink, R. Gardon, A. Getgood, P. Gföller, A. Grassi, C. Guier, M. Herbort, C. Hoser, P. Imbert, N. Jan, C. Kajetanek, A.M. Kiapour, G. La Barbera, P. Landreau, T. Lording, S. Lustig, C. Lutz, R.A. Magnussen, C. Mouton, C.G. Murphy, M.M. Murray, V. Musahl, A. Nakamae, P. Neyret, M. Ochi, J.C. Panisset, A. Pinaroli, A. Ponsot, B.L. Proffen, B. Pupim, B. Quelard, O. Rachet, F. Raggi, T. Roberti di Sarsina, R. Seil, E. Servien, J.T. Sieker, C. Signorelli, A. Soni, B. Sonnery-Cottet, N. Tardy, M. Thaunat, D. Theisen, M. Valoroso, D. Wascher, K.E. Webster, F. Wein, C.A. Wijdicks, A. Williams, S. Zaffagnini, R. Zayni

SAURAMPS MEDICAL

www.livres-medicaux.com

LISTE DES AUTEURS

N. ADACHI : Professor and Chairman - Department of Orthopaedic Surgery - Integrated Health Sciences - Institute of Biomedical & Health Sciences, Hiroshima University - Hiroshima, Japan

J. BARTH : Clinique des Cèdres - Centre Ostéo-articulaire des Cèdres - Parc Sud Galaxie - 5, rue des Tropiques - 38230 Echirolles, France

C. BATAILLER : Centre Albert Trillat - Hôpital de la Croix-Rousse - Groupement Hospitalier Nord HCL - Université Lyon 1 - 103, grande rue de la Croix-Rousse - Pav R - 69004 Lyon, France

B. BORDET : Clinique du Parc Lyon - 155 ter, boulevard Stalingrad - 69006 Lyon, France

J. BORNE : Clinique du Parc Lyon - 155 ter, boulevard Stalingrad - 69006 Lyon, France

T.P. BRANCH : University Orthopaedics Decatur, Georgia, USA

C.H. BROWN : International Knee & Joint Centre - Abu Dhabi, United Arab Emirates

L. BUISSON : Centre Orthopédique Membre Inférieur du Médipôle de Savoie - 73290 Challes-les-Eaux, France

C. CAMATHIAS : Sports Medicine Research Laboratory, Department of Orthopaedic Surgery, Boston Children's Hospital, Harvard Medical School, Boston, Massachusetts, USA

G. CARBONE : Clinica Ortopedica e Traumatologica I - Lab. di Biomeccanica ed Innovazione Tecnologica, Istituto Ortopedico Rizzoli, Via di Barbiano, 1/10, 40136 Bologna, Italy

P.F. CHAILLOT : Clinique du Parc Lyon - 155 ter, boulevard Stalingrad - 69006 Lyon, France

P. CHAMBAT : Centre Orthopédique Paul Santy - 24, avenue Paul Santy - 69008 Lyon, France

J. CHAPPUIS : Hôpital Privé Pays de Savoie - 17, avenue Pierre Mendes France - 74100 Annemasse, France

J. CHOUTEAU : Cabinet de Chirurgie Orthopédique et de Chirurgie du Sport - Allée de la Mandallaz - Immeuble le Périclès B - 74370 Metz Tessy, France

T. CUCURULO : ICOS 13 - 463, rue Paradis - 13008 Marseille, France

M. DAGGETT : Kansas City University, Kansas City, Missouri, USA

D. DEJOUR : Department of Orthopaedics - Lyon-Ortho-Clinic - Clinique de la Sauvegarde - 29, avenue des Sources - 69009 Lyon, France

G. DEMEY : Department of Orthopaedics - Lyon-Ortho-Clinic - Clinique de la Sauvegarde - 29, avenue des Sources - 69009 Lyon, France

G. DUBOIS DE MONT-MARIN : Centre Orthopédique Paul Santy - 24, avenue Paul Santy - 69008 Lyon, France

A. ELMANSORI : Centre Albert Trillat - Hôpital de la Croix-Rousse - Groupement Hospitalier Nord HCL - Université Lyon 1 - 103, grande rue de la Croix-Rousse - Pav R - 69004 Lyon, France

G. ESTOUR : Centre Orthopédique Membre Inférieur du Médipôle de Savoie - 73290 Challes-les-Eaux, France

O. FANTINO : Clinique du Parc Lyon - 155 ter, boulevard Stalingrad - 69006 Lyon, France

J.M. FAYARD : Centre Orthopédique Paul Santy - 24, avenue Paul Santy - 69008 Lyon, France

J. FELLER : Orthopaedic Surgeon - OrthoSport Victoria - Level 5, 89 Bridge Rd - VIC 3121 Richmond, Australia

C. FINK : Gelenkpunkt - Center for Sports and Joint Surgery, Innsbruck; Tivoli Ost, Olympiastrasse - 39, A - 6020 Innsbruck, Austria — Research Unit for Orthopedic Sport Medicine and Injury Prevention, ISAG/UMIT, Hall, Austria

R. GARDON : Centre Orthopédique Paul Santy - 24, avenue Paul Santy - 69008 Lyon, France

A. GETGOOD : Fowler Kennedy Sport Medicine Clinic - University of Western Ontario London, Ontario, Canada

P. GFÖLLER : Gelenkpunkt - Center for Sports and Joint Surgery, Innsbruck; Tivoli Ost, Olympiastrasse - 39, A - 6020 Innsbruck, Austria

A. GRASSI : Clinica Ortopedica e Traumatologica I - Lab. di Biomeccanica ed Innovazione Tecnologica, Istituto Ortopedico Rizzoli, Via di Barbiano, 1/10, 40136 Bologna, Italy

C.A. GUIER : San Francisco Sports Medicine and Orthopaedics - 45 Castro - Suite 337 - San Francisco, CA 94114, USA

M. HERBORT : Department of Trauma, Hand and Reconstructive Surgery, Westphalian Wilhelms University Muenster, Muenster, Germany

C. HOSER : Gelenkpunkt - Center for Sports and Joint Surgery, Innsbruck; Tivoli Ost, Olympiastrasse - 39, A - 6020 Innsbruck, Austria

P. IMBERT: ICAPS, Institut de Chirurgie Articulaire et des Pathologies du Sport, St-Raphael, France

N. JAN : Centre Orthopédique Paul Santy - 24, avenue Paul Santy - 69008 Lyon, France

C. KAJETANEK : Centre Orthopédique Paul Santy - 24, avenue Paul Santy - 69008 Lyon, France

A.M. KIAPOUR : Sports Medicine Research Laboratory, Department of Orthopaedic Surgery, Boston Children's Hospital, Harvard Medical School, Boston, Massachusetts, USA

G. LA BARBERA : Department of Orthopaedics - Lyon-Ortho-Clinic - Clinique de la Sauvegarde - 29, avenue des Sources - 69009 Lyon, France

P. LANDREAU : Aspetar - Qatar Orthopaedic and Sports Medicine Hospital - P.O. Box 29222 Doha, Qatar

T. LORDING : Melbourne Orthopaedic Group - 33, The Avenue Windsor, Victoria, Australia

S. LUSTIG : Centre Albert Trillat - Hôpital de la Croix-Rousse - Groupement Hospitalier Nord HCL - Université Lyon 1 - 103, grande rue de la Croix-Rousse - Pav R - 69004 Lyon, France

C. LUTZ : Institut Chirurgie Orthopédique Sportive Strasbourg - 50, avenue des Vosges - 67000 Strasbourg, France

R. MAGNUSSEN : OSU Sports Medicine - Suite 3100 - 2050 Kenny Road - OH 43221 USA Columbus, USA

C. MOUTON : Sports Medicine Research Laboratory, Luxembourg Institute of Health

C.G. MURPHY : Centre Orthopédique Paul Santy - 24, avenue Paul Santy - 69008 Lyon, France

M. MURRAY : Sports Medicine Research Laboratory, Department of Orthopaedic Surgery, Boston Children's Hospital, Harvard Medical School, Boston, Massachusetts, USA

V. MUSAHL : University of Pittsburgh Medical Center - Department of Orthopaedic Surgery - 3200 Water Street, Pittsburgh PA 15203, USA

A. NAKAMAE : Assistant Professor - Department of Orthopaedic Surgery - Integrated Health Sciences - Institute of Biomedical & Health Sciences, Hiroshima University - Hiroshima, Japan

P. NEYRET : Centre Albert Trillat - Hôpital de la Croix-Rousse - Groupement Hospitalier Nord HCL - Université Lyon 1 - 103, grande rue de la Croix-Rousse - Pav R - 69004 Lyon, France

M. OCHI : President of Hiroshima University, Hiroshima, Japan - 1-3-2 Kagamiyama Higashi-Hiroshima, 739-8511, Japan

J.C. PANISSET : Clinique des Cèdres - Centre Ostéo-articulaire des Cèdres - Parc Sud Galaxie - 5 rue des tropiques - 38230 Echirolles, France

A. PINAROLI : Centre Orthopédique Membre Inférieur du Médipôle de Savoie - 73290 Challes-les-Eaux, France

A. PONSOT : Clinique du Parc Lyon - 155 ter, boulevard Stalingrad - 69006 Lyon, France

B.L. PROFFEN : Sports Medicine Research Laboratory, Department of Orthopaedic Surgery, Boston Children's Hospital, Harvard Medical School, Boston, Massachusetts, USA

B. PUPIM : Centre Orthopédique Paul Santy - 24, avenue Paul Santy - 69008 Lyon, France

B. QUELARD : Centre Orthopédique Paul Santy - 24, avenue Paul Santy - 69008 Lyon, France

O. RACHET : Hauteville Public Hospital Center - Inter Unit - Hauteville, France

F. RAGGI : Clinica Ortopedica e Traumatologica I - Lab. di Biomeccanica ed Innovazione Tecnologica, Istituto Ortopedico Rizzoli, Via di Barbiano, 1/10, 40136 Bologna, Italy

T. ROBERTI DI SARSINA : Clinica Ortopedica e Traumatologica I - Lab. di Biomeccanica ed Innovazione Tecnologica, Istituto Ortopedico Rizzoli, Via di Barbiano, 1/10, 40136 Bologna, Italy

R. SEIL : Centre Hospitalier - 78 rue d'Eich - 1460 Luxembourg, Gd Duche Luxembourg

E. SERVIEN : Centre Albert Trillat - Hôpital de la Croix-Rousse - Groupement Hospitalier Nord HCL - Université Lyon 1 - 103, grande rue de la Croix-Rousse - Pav R - 69004 Lyon, France

J.T. SIEKER : Sports Medicine Research Laboratory, Department of Orthopaedic Surgery, Boston Children's Hospital, Harvard Medical School, Boston, Massachusetts, USA

C. SIGNORELLI : Clinica Ortopedica e Traumatologica I - Lab. di Biomeccanica ed Innovazione Tecnologica, Istituto Ortopedico Rizzoli, Via di Barbiano, 1/10, 40136 Bologna, Italy

A. SONI : University of Pittsburgh Medical Center - Department of Orthopaedic Surgery - 3200 Water Street, Pittsburgh PA 15203, USA

B. SONNERY-COTTET : Centre Orthopédique Paul Santy - 24, avenue Paul Santy - 69008 Lyon, France

N. TARDY : Centre Orthopédique Paul Santy - 24, avenue Paul Santy - 69008 Lyon, France

M. THAUNAT : Centre Orthopédique Paul Santy - 24, avenue Paul Santy - 69008 Lyon, France

D. THEISEN : Sports Medicine Research Laboratory, Luxembourg Institute of Health

M. VALOROSO : Department of Orthopaedics - Lyon-Ortho-Clinic - Clinique de la Sauvegarde - 29, avenue des Sources - 69009 Lyon, France

D. WASCHER : Department of Orthopaedics, University of New Mexico, Albuquerque, NM, USA

K.E. WEBSTER : Orthopaedic Surgeon - OrthoSport Victoria - Level 5, 89 Bridge Rd - VIC 3121 Richmond, Australia

F. WEIN : Centre Chirurgical ADR - 13, rue Blaise Pascal - 54320 Nancy-Maxeville, France

C.A. WIJDICKS : Centre Orthopédique Paul Santy - 24, avenue Paul Santy - 69008 Lyon, France

A. WILLIAMS : Forthius Clinic, 17 Fitzhardinge St. - W1H 6EQ London, UK

S. ZAFFAGNINI : Clinica Ortopedica e Traumatologica I - Lab. di Biomeccanica ed Innovazione Tecnologica, Istituto Ortopedico Rizzoli, Via di Barbiano, 1/10, 40136 Bologna, Italy

R. ZAYNI : Centre Orthopédique Paul Santy - 24, avenue Paul Santy - 69008 Lyon, France

SOMMAIRE

THE ANTEROLATERAL LIGAMENT

ANTEROLATERAL INSTABILITY

ACL RECONSTRUCTION TECHNIQUES

FIXATION

GRAFT FEATURES

TUNNEL FEATURES

BATTLE UE/USA

FUTURE & BIOLOGY

MENISCO-CAPSULAR LESIONS (RAMP LESIONS)

ROOT LESIONS

INTRINSIC FACTORS

RETURN TO SPORT AND PREVENTION

REHABILITATION AFTER ACL RECONSTRUCTION

COMPLICATIONS

RETURN TO PLAY

ANTEROLATERAL LIGAMENT HISTORY AND SURGICAL TECHNIQUES

C. BATAILLER, S. LUSTIG, D. WASCHER,
E. SERVIEN, P. NEYRET

INTRODUCTION

The rotational stability of the knee is provided by a complex ligamento-muscular system, whose the understanding improves progressively. One of its elements is the anterolateral ligament (ALL), which aroused much interest recently. The lateral extra-articular procedures allow a therapeutic option for patients with persistent rotatory instability following anterior cruciate ligament (ACL) reconstruction. These surgical techniques are numerous and evolved in parallel with anatomic and biomechanics advances. We are providing an overview of the ALL history and current surgical techniques.

HISTORY

The avulsion fracture of Segond is the first observation of anterolateral structure's damage. It is localized just posterior to the Gerdy's tubercle, at the tibial insertion of a structure described as "a resistant, pearly, fibrous band, which, in a exaggeration of internal rotational movement, is always subjected to an extreme degree of tension" [1]. This fracture reflected the forced internal rotation at the knee. Since 1968 and the description of the rotatory instability by Slocum [2], then by Hughston in 1976 [3], the understanding of the anatomy and the biomechanics of ALL has made considerable progress.

ANATOMY AND BIOMECHANICS

The lateral capsuloligamentous tissues are composed of several elements, whose the relationships and the mechanical properties during knee motion are not completely understood. The capsulo-osseous portion of the iliotibial tract is considered as the "anterolateral ligament" of the knee [4]. It is almost universally present. According to authors, it gets some different names: "short lateral ligament", "capsule-osseous layers" of the iliotibial band (ITB), "midthird lateral capsular ligament". During some years its anatomy was unclear. Several studies have described it as an independent structure, others as a part of the ITB, with various insertion sites. Vincent have precisely described this ALL [5]. It is inserted on the lateral femoral condyle, "just anterior to the popliteus tendon insertion, blending with its fibers". Its distal attachment is on the proximal anterolateral tibia, 5mm below the joint line, posterior to the Gerdy's tubercle (fig. 1). This ligament is a distinct fibrous structure, closely associated with the lateral meniscus near the junction of its anterior and middle thirds, without cleavage plane.

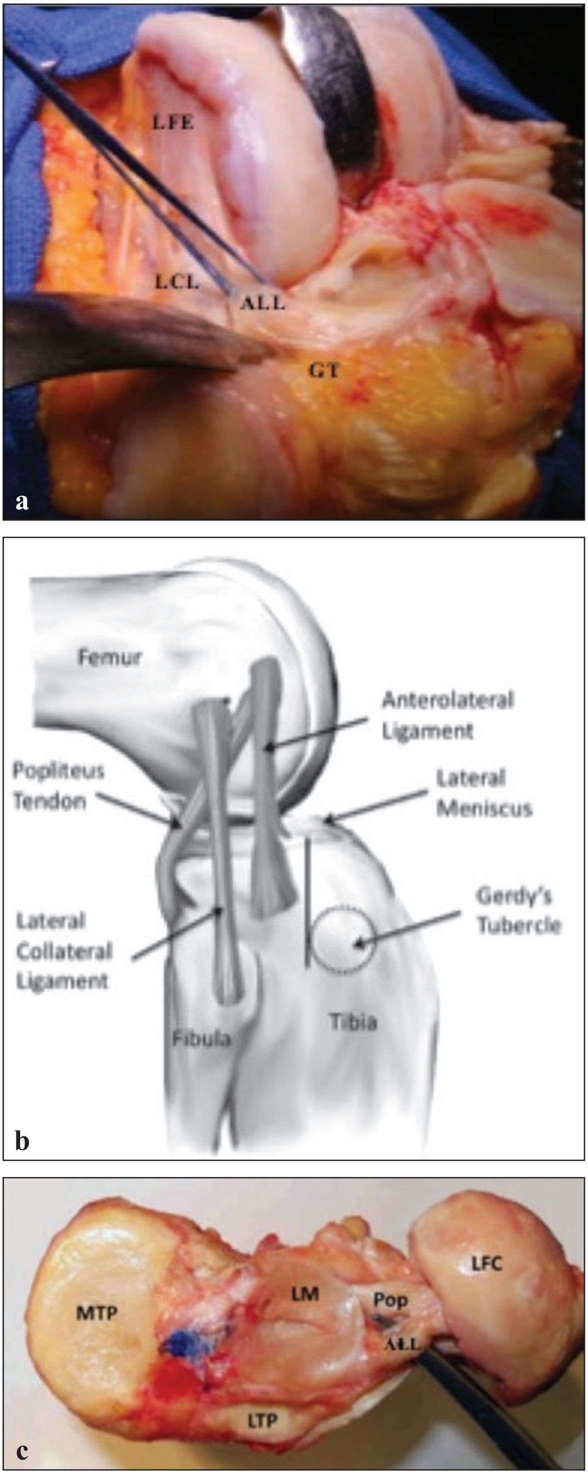


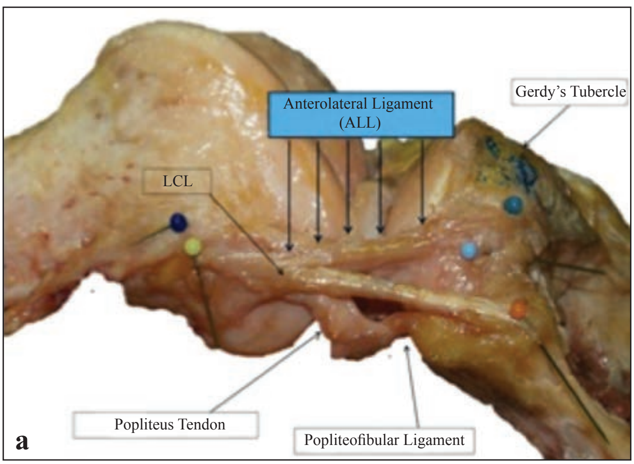
Fig. 1: ***Per-operative view during right knee arthroplasty (a), line drawing of a right knee (b) and cadaveric dissection of left knee (c) showing the ALL described by Vincent*** *(Photo a: courtesy of P. Neyret. Photo c and line drawing from Vincent and al. [5]).*

ALL, anterolateral ligament; LCL, lateral collateral ligament; LFE, lateral femoral epicondyle; PT or Pop, popliteus tendon; GT, Gerdy's tubercle; LM, lateral meniscus; LFC, lateral femoral condyle.

Terry observed that increasingly abdnormal Lachman test, pivot-shift test, and anterior drawer at 90° of flexion after ACL rupture was correlated with the integrity of the capsulo-osseous insertion of the ITB [6]. This structure refers probably to the ALL. Although the anterolateral structure is incompletely understood; its function on rotational control is undeniable. The majority of sectioning studies reported an increased internal rotatory laxity after the anterolateral capsule section in ACL deficient knee, particularly at flexion angles greater than 35°.

Claes have described another capsular structure (fig. 2), whose the femoral attachment is located on the prominence of the lateral femoral epicondyle (LFE), anterior to the fibular collateral ligament (FCL) attachment, proximal and posterior to the insertion of the popliteus tendon. Its distal insertion is on the anterolateral proximal tibia, mid-way between Gerdy's tubercle and the fibular head, with no connecting fibers to the ITB [7].

Another more superficial lateral structure has been reported by Kennedy in 2015 [8]. Its femoral attachment was on average 2.8mm posterior and 2.7mm proximal to the FCL attachment. Its distal insertion was on the anterolateral tibia, posterior to Gerdy's tubercle (fig. 3). Their mechanical properties are still poorly understood. Some reservations were expressed on the role of this ALL [9] and thus on its anatomic reconstruction.



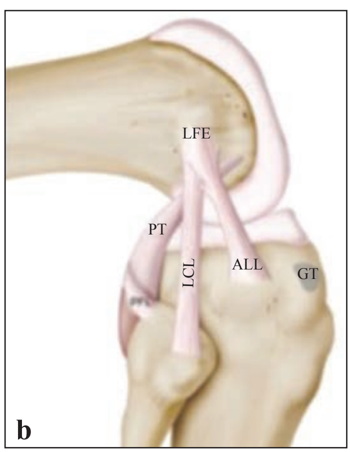


Fig. 2: ***Cadaveric dissection (a) and line drawing of a right knee (b) showing the ALL described by Claes*** *(from Claes and al. [7])*.

ALL, anterolateral ligament; LCL, lateral collateral ligament; LFE, lateral femoral epicondyle; PT, popliteus tendon; GT, Gerdy's tubercle.

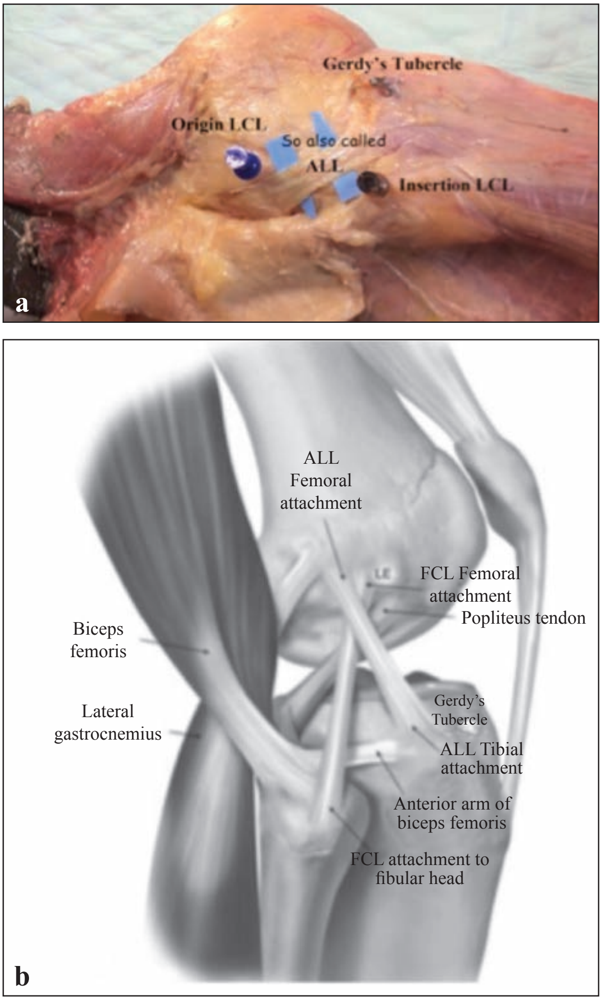


Fig. 3: *Cadaveric dissection (a) and line drawing (b) of a right knee showing the superficial lateral capsular structure (ALL), described by Kennedy* *(Photo: Courtesy of T. Branch and T. Lording. Line drawing from Kennedy and al. [8])*.

LCL or FCL, lateral or fibular collateral ligament; ALL, anterolateral ligament.

SURGICAL TECHNIQUES [10, 11]

Lateral extra-articular tenodesis procedures

The extra-articular tenodesis has been attempted historically as an isolated procedure, without ACL reconstruction. These techniques achieve a lateral reinforcement to control rotational laxity, without reproduce the ALL course.

Lemaire procedure [12]

This technique uses a strip of ITB, measuring 18cm long and 10mm wide and left attached to Gerdy's tubercle. The graft is passed under the FCL, through a femoral tunnel just above the LFE and proximally to the FCL insertion, and back under the FCL. It is fixed in tibial bone tunnel through Gerdy's tubercle, at 30° of flexion with neutral rotation. Christel and Dijan used a modified Lemaire procedure with single bundle of graft (75mm long, 10mm wide), which is passed superficial to FCL. The graft is fixed, with an interference screw, in a blind tunnel on the LFE [13].

Losee technique: "sling and reef" operation [14]

A strip of ITB (16cm long) is harvested and left attached to the Gerdy's tubercle. A tunnel was made through the lateral femoral condyle, anterior and distal to the attachment of the FCL. This femoral insertion site closely approximates the anatomic attachment. The graft is passed through this tunnel. Then it passed back through the lateral gastrocnemius tendon, exiting through the posterolateral capsule posterior to the FCL and passed under the FCL. The gastrocnemius tendon, posterolateral capsule and the graft are all sutured to the FCL at 45° of knee flexion. Then, the graft is sutured back to Gerdy's tubercle (fig. 4).

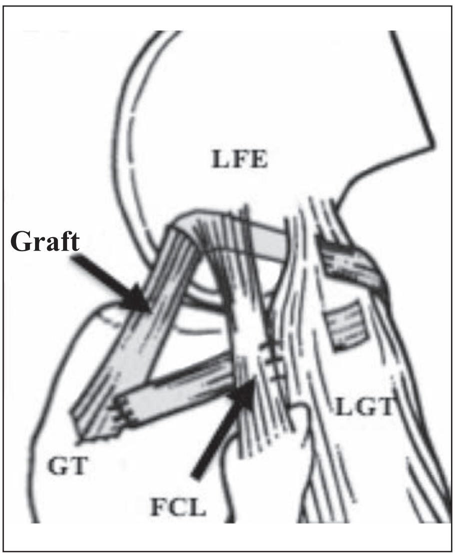


Fig. 4: ***Line drawing demonstrating the completed graft position in Losee technique [14]*** *(from Lerat and al. [26])****.***

LFE, lateral femoral epicondyle; GT, Gerdy's tubercle; FCL, fibular collateral ligament; LGT, lateral gastrocnemius tendon.

Ellison technique [15]

In 1979, Ellison described a bony transfer of the ITB distal insertion (fig. 5). A bone block of 1,5cm wide is harvested from Gerdy's tubercle. A 1.5cm strip of ITB is released from the bone block. A passage is made under the FCL. The capsule beneath the FCL is incised vertically and plicated. A small hole is then made anterior to Gerdy's tubercle, just under the lateral border of the patella tendon. The bony block is then passed underneath the FCL and into the bone trough. It is fixed with a staple at 90° of knee flexion.

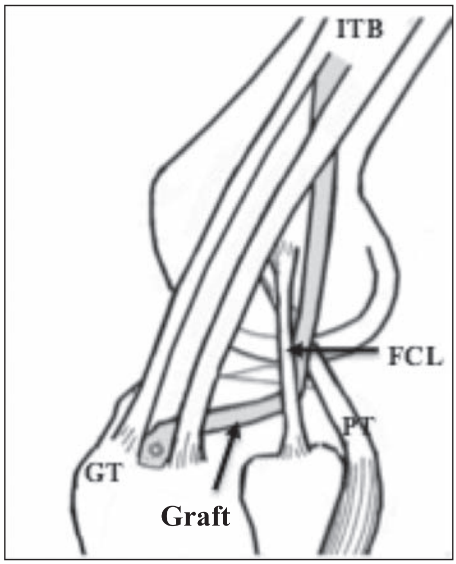


Fig. 5: ***Line drawing demonstrating the completed graft position in Ellison technique [15]*** *(from Lerat and al. [26])****.***

LFE, lateral femoral epicondyle; GT, Gerdy's tubercle; FCL, fibular collateral ligament; LGT, lateral gastrocnemius tendon.

James Andrews technique [16]

This extra-articular tenodesis used a strip of ITB of 10cm long, left attached on the tibial distal insertion. Two small drill holes were made in the distal femur, corresponding to the anterior and posterior insertions of the ACL on the femur. The proximal parts of the strip were passed through these holes. The strip of ITB could also be fixed with a screw and washer at the distal insertion of the lateral intermuscular septum on the linea aspera just anterior to the posterior femoral cortex. The ITB was then fixed superficial to the FCL at 30° of flexion with external rotation.

Müller procedure [17]

This anterolateral tenodesis was performed by isolating a 1.25cm strip from the posterior portion of the iliotibial tract. The distal and proximal attachments of this strip were preserved. The isometric point of attachment for this strip was recognized at the junction of the femoral shaft and lateral femoral condyle. The strip was fixed to this isometric point by a Steinmann pin, and the isometricity was tested. The strip was then fixed to this site by a cancellous screw with a toothed washer.

These isolated procedures have been abandoned progressively faced with unacceptably high rates of anterior laxity recurrence. They have increased the lateral compartment stresses and the degenerative changes, particularly with medial meniscal injury associated [18].

Combined intra and extra-articular reconstructions

Combined intra-articular and extra-articular reconstructions appeared necessary to restore sagittal and rotational stability in knees combining ACL and ALL deficiencies. These procedures do not want to reproduce the anatomic course of ALL. They realize a genuine lateral extra-articular augmentation of the intra-articular reconstruction, which limit the excessive internal rotation and the anterior translation of the lateral tibial plate.

They allow protecting the intra-articular graft, particularly during the healing phase. An anterolateral reconstruction decreases loads on an intra-articular graft by 43% [19]. Indeed this reconstruction allows a better rotational control by its lateral long lever arm. Ellison described the ACL as, “the hub of the wheel”, and noted, “it is easier to control rotation of a wheel at its rim than at its hub” [20].

Their main indications are: an important pivot shift; an anterior tibial translation superior to 10mm (particularly on the lateral compartment); patients with generalized hyper-laxity; revision ACL surgery, particularly with medial meniscal injury.

The combined reconstructions can be performed with two grafts in continuation, or with previous anterolateral tenodesis associated to ACL reconstruction. Various techniques are used, with different type of graft and different graft positioning. The graft femoral insertion and graft course affect length change pattern during knee flexion, and thus the reconstruction quality. Kittl and Amis observed that a graft attached proximal to the LFE and which passes deep to the FCL will provide desirable graft behavior, without excessive tightening or slackening during knee motion [21].

KJT technique [22, 23]

Neyret has described since 1996 an intra-articular reconstruction by a bone-patellar tendon-bone graft, in continuation with hamstring graft to reproduce ALL (fig. 6). The gracilis is harvested and threaded through a drill hole in tibial bone block. The femoral tunnel is created posterior and proximal to the FCL insertion. The patella tendon graft is passed from proximal to distal, locking the gracilis tendon in the femoral tunnel with the press-fit of the bony block. The free limbs are then passed deep to the FCL and through either end of a bony tunnel through Gerdy’s tubercle and sutured to one another. An interference screw is used to secure the graft in the tibial tunnel. After tensioning and cycling, the intra then extra-articular graft are fixed at 30° of flexion and neutral external rotation of the knee.

A variation of this procedure has been developed. A band of fascia lata (10cm by 10mm) is harvested and left attached on Gerdy's tubercle. This graft is passed underneath the FCL, then in femoral tunnel with the bone block of patellar tendon of intra-articular reconstruction. The fascia lata graft is tensioned at 30° of flexion in neutral external rotation of the knee while the wedge shaped patellar bone block is impacted into the femoral tunnel.

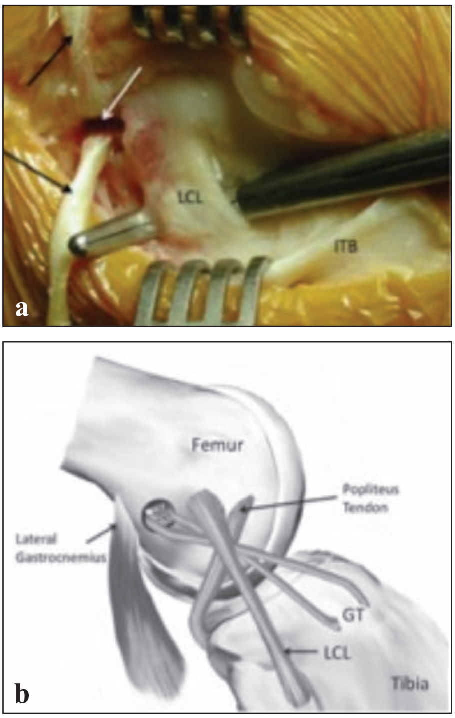


Fig. 6: ***Per operative view (a) and line drawing (b) of a right knee showing the KJT procedure, described by Neyret.*** *From Magnussen and al. [23]*. ***LCL, lateral collateral ligament; ITB, iliotibial band; GT, Gerdy's tubercle; white arrow: tibial bone block; black arrows, two limbs of gracilis tendon.***

Marcacci technique [24]

In this procedure, the gracilis and the semi tendinosus tendons are harvested and sutured to one another. They are left attached on the tibia, and are passed through the tibial tunnel of ACL reconstruction, then through the "over the top" of the lateral femoral condyle. At the exit of the femoral tunnel, they passed under the ITB but superficial to the FCL, and then are fixed on Gerdy's tubercle by two staples at 90° of flexion.

"Anatomic" anterolateral ligament reconstructions

Currently other surgical techniques called "anatomic" have been described. Their aim is to reproduce the insertion sites of the more superficial ALL, described by Kennedy [8]. They are recent and few results are reported.

The Smith technique [25] consists of an "all inside" ACL reconstruction with the semitendinosus tendon, associated with an independent extra-articular reconstruction with the gracilis tendon. Two bone tunnels are drilled: the first just anterior and superior to the FCL femoral insertion and the second halfway between Gerdy's tubercle and the fibular head. The gracilis tendon is fixed into the femoral tunnel with threaded knotless anchor, and then it is passed under the ITB and is fixed into tibial tunnel with anchor.

CONCLUSION

Various techniques are performed to control rotational stability with ACL deficient. They are based on different principles: anterolateral extra-articular augmentation or anatomic ALL reconstruction. The different studies reported satisfying results for the combined extra and intra-articular reconstructions. However few studies compared the various extra-articular procedures. The "anatomic" reconstructions are recent and should be evaluated at long term. The mechanical properties and the function of this superficial ALL are still poorly understood and need more investigations.

LITERATURE

[1] SEGOND P. Recherches cliniques et expérimentales sur les épanchements sanguins du genou par entorse. *Progrès Médicale 1879.*

[2] SLOCUM DB, RL LARSON. Rotatory instability of the knee. Its pathogenesis and a clinical test to demonstrate its presence. *J Bone Joint Surg Am 1968; 50(2): 211-25.*

[3] HUGHSTON JC, JR ANDREWS, MJ CROSS, A MOSCHI (1976). Classification of knee ligament instabilities. Part II. The lateral compartment. *J Bone Joint Surg Am 1976; 58(2): 173-9.*

[4] VIEIRA EL, EA VIEIRA, RT DA SILVA, PA BERLFEIN, RJ ABDALLA, M COHEN. An anatomic study of the iliotibial tract. *Arthroscopy 2007; 23(3): 269-74.*

[5] VINCENT JP, RA MAGNUSSEN, F GEZMEZ, A UGUEN, M JACOBI, F WEPPE, MF AL-SAATI, S LUSTIG, G DEMEY, E SERVIEN, P NEYRET. The anterolateral ligament of the human knee: an anatomic and histologic study. *Knee Surg Sports Traumatol Arthrosc 2012; 20(1): 147-52.*

[6] TERRY GC, JC HUGHSTON, LA NORWOOD. The anatomy of the iliopatellar band and iliotibial tract. *Am J Sports Med 1986; 14(1): 39-45.*

[7] CLAES S, E VEREECKE, M MAES, J VICTOR, P VERDONK, J BELLEMANS. Anatomy of the anterolateral ligament of the knee. *J Anat 2013; 223(4): 321-8.*

[8] KENNEDY MI, S CLAES, FA FUSO, BT WILLIAMS, MT GOLDSMITH, TL TURNBULL, CA WIJDICKS, RF LAPRADE. The Anterolateral Ligament: An Anatomic, Radiographic, and Biomechanical Analysis. *Am J Sports Med 2015; 43(7): 1606-15.*

[9] KITTL C, H EL-DAOU, KK ATHWAL, CM GUPTE, A WEILER, A WILLIAMS, AA AMIS. The Role of the Anterolateral Structures and the ACL in Controlling Laxity of the Intact and ACL-Deficient Knee. *Am J Sports Med 2016; 44(2): 345-54.*

[10] WASCHER DC, T LORDING, P NEYRET. Extra-articular procedures for the ACL-deficient knee: a state of the art review. *JISAKOS 0: 1-9 2016.*

[11] DUTHON VB, RA MAGNUSSEN, E SERVIEN, P NEYRET. ACL reconstruction and extra-articular tenodesis. *Clin Sports Med 2013; 32(1): 141-53.*

[12] LEMAIRE M. Ruptures anciennes du ligament croise anterieur du genou. *J Chir 1967; (Paris) 93: 311-20.*

[13] CHRISTEL P, P DJIAN. Anterio-lateral extra-articular tenodesis of the knee using a short strip of fascia lata. *Rev Chir Orthop Reparatrice Appar Mot 2002; 88(5): 508-13.*

[14] LOSEE RE, TR JOHNSON, WO SOUTHWICK. Anterior subluxation of the lateral tibial plateau. A diagnostic test and operative repair. *J Bone Joint Surg Am 1978; 60; (8): 1015-30.*

[15] ELLISON AE. Distal iliotibial-band transfer for anterolateral rotatory instability of the knee. *J Bone Joint Surg Am 1979; 61(3): 330-7.*

[16] ANDREWS JR and R SANDERS A 'mini-reconstruction' technique in treating anterolateral rotatory instability (ALRI). *Clin Orthop Relat Res 1983; (172): 93-6.*

[17] DRAGANICH LF, B REIDER, PR MILLER. An *in vitro* study of the Muller anterolateral femorotibial ligament tenodesis in the anterior cruciate ligament deficient knee. *Am J Sports Med 1989; 17(3): 357-62.*

[18] NEYRET P, JR PALOMO, ST DONELL, H DEJOUR. Extra-articular tenodesis for anterior cruciate ligament rupture in amateur skiers. *Br J Sports Med 1994; 28(1): 31-4.*

[19] ENGEBRETSEN L, WD LEW, JL LEWIS, RE HUNTER. The effect of an iliotibial tenodesis on intraarticular graft forces and knee joint motion. *Am J Sports Med 1990; 18(2): 169-76.*

[20] ELLISON AE. Anterolateral rotatory instability. *Symposium on the Athlete's Knee, Surgical Repair and Reconstruction, American Academy of Orthopaedic Surgeons 1978; 178-93.*

[21] KITTL C, C HALEWOOD, JM STEPHEN, CM GUPTE, A WEILER, A WILLIAMS and AA AMIS. Length change patterns in the lateral extra-articular structures of the knee and related reconstructions. *Am J Sports Med 2015; 43(2): 354-62.*

[22] NEYRET PA. SS, T. Chirurgie du genou. *My knee practice 2007.*

[23] MAGNUSSEN RA, M JACOBI, G DEMEY, S LUSTIG, E SERVIEN, P NEYRET. Lateral Extra-articular Augmentation of ACL Reconstruction. *Techniques in Knee Surgery 2011; 1-7.*

[24] MARCACCI M, S ZAFFAGNINI, G GIORDANO, F IACONO, ML PRESTI. Anterior cruciate ligament reconstruction associated with extra-articular tenodesis: A prospective clinical and radiographic evaluation with 10- to 13-year follow-up. *Am J Sports Med 2009; 37(4): 707-14.*

[25] SMITH JO, SK YASEN, B LORD, AJ WILSON. Combined anterolateral ligament and anatomic anterior cruciate ligament reconstruction of the knee. *Knee Surg Sports Traumatol Arthrosc 2015; 23(11): 3151-6.*

[26] LERAT JL, MOYEN B, CLADIERE F, BENAREAU I, BESSE JL. Plasties extra-articulaires antéro-externes et reconstruction du ligament croisé antérieur. Ligaments croisés du genou. Cahiers d' enseignement de la SOFCOT, N° 86. Sous la direction de P Neyret. *Ed. Scientifiques et Médicales Elsiever 2004; 78-90.*

ANATOMY OF THE ANTEROLATERAL LIGAMENT

C. LUTZ, B. SONNERY-COTTET, M. DAGGETT, P. IMBERT

INTRODUCTION

Rotational control of the knee is one of the main objectives of anterior cruciate ligament reconstruction. The insufficient control in this area by isolated intra-articular ACL reconstruction has renewed interest for the anterolateral compartment of the knee, leading, one century after P. Segond [10], to the description of the anterolateral ligament (ALL) [2]. The interest for this ligament has been highlighted in several articles regarding its anatomy, its arthroscopic description, and its radiological aspect. Nonetheless, its existence [8], its precise anatomy and its possible involvement in rotational control and stability of the knee continue to be debated.

The purpose of this article is to specify the anatomic description of the ALL based on recent published studies.

DISSECTION

The dissection technique is a key point of the anatomic analysis of the ALL: inappropriate dissection can potentially alter interpretation of the anatomical characteristics from these anterolateral structures and consequently their biomechanical characteristics.

For this dissection, we recommended the following stages inspired by the works of S. Claes [2], M. Daggett [3] and a previous study [7].

After removal of a rectangular flap of skin and subcutaneous adipose tissue, the extensor apparatus, the lateral patellar retinaculum, the superficial layer of the iliotibial tract (ITB), the distal part of the femoral biceps, and the head of the fibula are exposed (fig. 1).

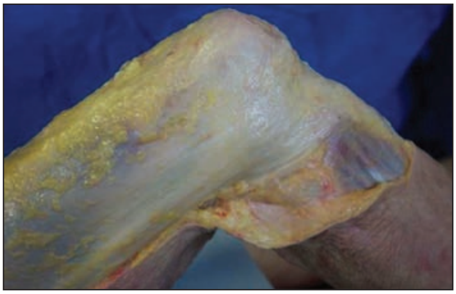


Fig 1: ***Antero-lateral knee exposure (right knee)***

ITB is then resected transversally 6cm proximally from the lateral epicondyle and pulled back distally by cutting anteriorly the lateral retinaculum and posteriorly the deep iliotibial tract layer (Kaplan's fibers) attached to the lateral intermuscular septum.

Once the ITB is reflected, an internal rotational force is applied between 30 and 60° of flexion of the knee to tighten the ALL as well as the antero-lateral capsule (fig. 2a). This internal rotation is absolutely essential to identify the ALL: in neutral rotation, its relief can disappear within the capsular thickness (fig. 2b). Once this area is exposed, isolation of the lateral collateral ligament (LCL) and the popliteus tendon is carried out. The LCL is isolated by applying varus stress and then dissected from its distal insertion onto the head of the fibula to its femoral insertion onto the lateral femoral epicondyle (fig. 3). Care is taken to not incise fibers overlapping the ALL.

Evaluation of the ALL physical characteristics is then possible: the origin is determined by placing tension on its proximal fibers; if visualization of this origin is difficult because of a confusion between proximal fibers from the ALL and the LCL, these 2 structures can be cut midbody and separated to see where the main body of each structures is attached to the lateral epicondyle, as recommended by S. Caterine [1]. Identification of the tibial insertion is done by placing tension on its distal fibers. Measurement of length, width and thickness complete this anatomical evaluation. During the dissection, connections with surrounding structures are also analyzed: ITB, lateral meniscus, antero-lateral capsule.

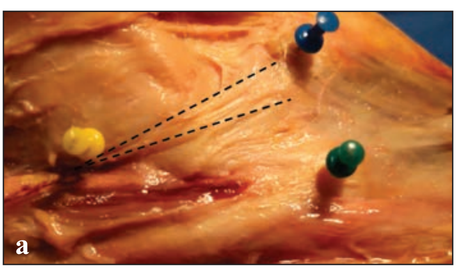


Fig. 2a: ***ALL tight in internal rotation (blue pin = Gerdy's tubercle; yellow pin = femoral lateral epicondyle, green pin = fibular head, dotted lines = anterior and posterior ALL limits).***

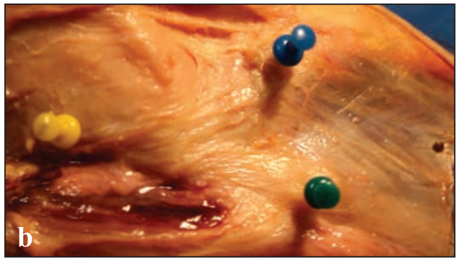


Fig. 2b: ***Difficulties to located ALL in neutral rotation (blue pin = Gerdy's tubercle; yellow pin = femoral lateral epicondyle, green pin = fibular head).***

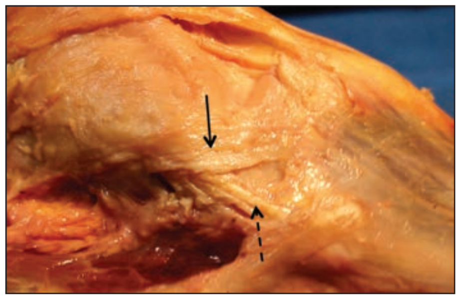


Fig. 3: ***ALL (arrow) exposure after LCL (dotted arrow) dissection and antero-lateral capsule removing.***

ANATOMICAL CHARACTERISTICS (Table 1)

Femoral origin

One of the main conflicting points about the anatomy of the ALL concerns its femoral insertion. Most of the authors agreed on the problems inherent to individualizing this insertion because of the many connections with the femoral insertion of the LCL and the fibers coming from the fascia of the lateral vastus muscle. The femoral attachment was initially described by Vincent [12], Claes [2], and Helito [5] to be anterior and distal to the femoral LCL attachment, while Dodds [4], Rezansoff [9] and our study [7] described posterior and proximal attachments. Caterine [1] explained these disparities by the existence of anatomical variations and proposed a three-stage classification according to the differences in femoral and tibial insertions.

Table 1: ***ALL anatomical characteristics***

	Vincent (2011)	Claes (2013)	Helito (2013)	Dodds (2014)	Kennedy (2015)	Caterine (2015)	Lutz (2015)
Length (mm)	34.1 + 3.4	38.5 + 6.1	37.3 ± 4	59	36.8 to 41.6	40.3 + 6.2	39.1 + 3.4
Proximal width (mm)		8.3 ± 2.1	7.4 ± 1.7			4.8 ± 1.4	5.3 ± 1
Distal width (mm)		11.2 ± 2.5				11.7 ± 3.2	15.6 ± 2.6
Thickness (mm)	2-3	1.3	2.7		1.4		
Tibial plateau distance (mm)	5	6.5 ± 1.4	4.4 ± 1.1	11 ± 2	9.5	11.1 ± 2.4	6.4 ± 2.4
Gerdy tubercle distance		21.6 ± 4		18 ± 3		23.4 ± 3.4	22.1 ± 2.6
Fibula head distance		23.2 ± 5.7		17 ± 3		23.9 ± 5.5	16 ± 4.7
Insertion/ lateral epicondyle	Distal	Distal	Distal	Proximal	Proximal	11 distal 8 proximal	2 distal 7 proximal

More recent studies [6] among of which one specifically centered on the femoral origin from the ALL [3], showed a consistent bony origin overlapping the LCL, with some variability in the femoral attachment, ranging from directly on the lateral epicondyle to posterior to the lateral epicondyle (fig. 4). The area of this proximal attachment is measured by Kennedy [6] at 67,7mm².

Tibial insertion

The tibial attachment of the ALL is more consensual, approximately midway between the center of the Gerdy tubercle and the anterior margin of the fibular head (fig. 5), on average 4,4mm to 11,1mm below the joint line [1, 2, 4, 5, 6, 7, 12]. The area of distal attachment is 64,9mm² [6].

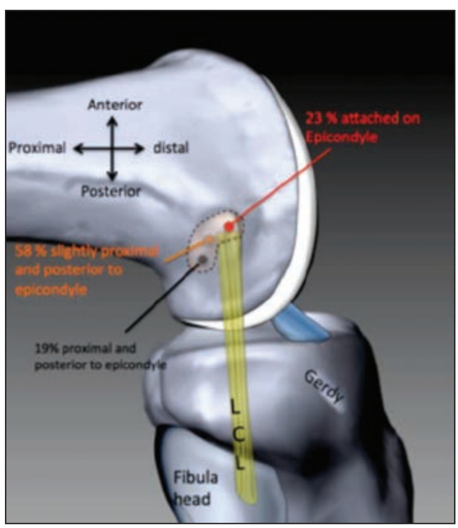


Fig. 4: ***ALL femoral origin (Matt Daggett Arthroscopy 2015).***

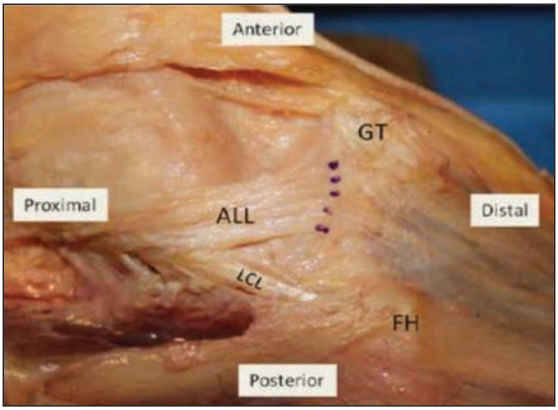


Fig. 5: ***ALL tibial origin (dotted line) (*GT = *Gerdy tubercle,* ALL = *anterolateral ligament,* LCL = *lateral collateral ligament, FH = fibular head).***

Quantitative anatomy

Length

The length of the ALL varies from 34,1mm (12) to 59mm (4), with more similar values in other studies: 37,3mm (5), 38,5mm (2), 39,1mm (7) and 40,3mm (1). The variations in length between these different authors can be explained by the problems identifying the femoral insertion of this ligament and by the knee position, in flexion and rotation, which varied from one study to another.

Kennedy [6], when measuring lengths each 15° between 0 and 90° of flexion, found an increase from 36,8mm to 41,6mm.

In a previous study [7], we observed a significant increase in the ALL length during internal rotation at 30° flexion, with a mean of 10 mm, finding similar results to those reported by Dodds [4] (mean lengthening, 9.9mm).

These variations in length during flexion and rotation are important to consider for under-standing of ALL function and reconstruction.

Width

The width of the ALL increases from proximal to distal with a mean at the femoral attachment of 4,8mm and at the tibial attachment of 11,7mm for Caterine [1], and respectively 8,3 and 11,2mm for Claes [2]. Its structure is narrow and tubular at the femoral origin and wider on the tibia.

Thickness

ALL thickness varies from 1,3 to 2,7mm [1, 2, 5, 12].

Width and thickness indicate that the ALL is a flat and broad structure.

Connections

ITB

For Dodds [4] and Claes [2], the ALL is separate from the posterior fibers of the ITB, specifically from the capsule-osseus layer. Caterine [1] described superficial fibers originating from the fascia of the lateral gastrocnemius tendon insertion, proximal to the lateral femoral condyle, overlying the proximal portion of the ALL with a unique attachment to the posterior portion of Gerdy's tubercle. These superficial fibers running in the same orientation as the ALL can be confused with the capsule-osseus layer of the ITB band and explain why authors consider ALL as a part of ITB [11, 12].

Lateral meniscus

Some authors [1, 2, 6] identified connections between the ALL and lateral meniscus. For Claes [2], this connection occurs at the periphery of the middle third of the lateral meniscal body and he suggests dividing the ALL into a meniscofemoral and a meniscotibial band. For Helito [5], this connection is located at the peripheral portion of the transition between the anterior horn and the meniscus body, approximately 19,4mm anterior to the popliteus tendon. For Dodds [4], this connection is rather due to a capsular thickening of fibers, deep to the ALL, that runs from the insertion of the popliteus tendon to the anterolateral rim of the lateral meniscus an does not continue directly down to the tibia.

Antero-lateral capsule

Connections between antero-capsule and the ALL remain controversed. For Dodds [4] and Vincent [12], ALL is superficial and distinct to the capsule as does the description from Claes [2] finding that the ALL "was easily distinguishable from the thinner joint capsule lying anterior to it".

In our study [7], we found that the ALL was the anterior part of a "triangular anterolateral capsular complex". The posterior, vertical, part of this complex was made up of capsular fibers that inserted onto the LCL, and the base, distal, comprised the insertion of the capsule on the tibia. In this triangle, during internal rotation, not only was the ALL tensed, but all the capsular fibers between the LCL and the ALL. The existence of an anatomical region including the LCL and the ALL was also proposed by Claes [2] using the term "lateral collateral ligament complex (LCLC)".

CONCLUSION

A rigorous and precise dissection is a fundamental stage for identifying the anterolateral ligament. This dissection should include dynamic movements, specifically internal rotation, to precise origin, insertion and direction from this ligament.

Even if controversies remain, the principal anatomical characteristics of the ALL are:
- a femoral origin near the lateral femoral epicondyle, mostly proximal and posterior, an anterior and distal direction and a tibial attachment midway between the Gerdy tubercle and the fibular head, 5 to 10mm distal to the joint line;
- a mean length of 40mm that increases during flexion and internal rotation;
- a narrow and tubular structure at the femoral origin (5mm) and wider on the tibia (>10mm);
- connections are established with the lateral meniscus but discussed for ITB and antero-lateral capsule.

An accurate knowledge of ALL anatomy is essential to understand its function and propose antero-lateral reconstructions.

LITERATURE

[1] CATERINE S, LITCHFIELD R, JOHNSON M, CHRONIK B, GETGOOD A. A cadaveric study of the anterolateral ligament: re-introducing the lateral capsular ligament. *Knee Surg Sports Traumatol Arthrosc 2015; 23: 3186-95 doi 10.1007/s00167-014-3117-z.*

[2] CLAES S, VEREECKE E, MAES M, VICTOR J, VERDONK P, BELLEMANS J. Anatomy of the anterolateral ligament of the knee. *J Anat 2013; 223(4): 321-8.*

[3] DAGGETT M, OCKULY A, CULLEN M, *et al.* Femoral origin of the anterolateral ligament: an anatomic analysis [published online December 22, 2015]. *Arthroscopy. doi:10.1016/j.arthro.2015.10.006.*

[4] DODDS AL, HALEWOOD C, GUPTE CM, WILLIAMS A, AMIS AA. The anterolateral ligament: anatomy, length changes and association with the Segond fracture. *Bone Joint J 2014; 96B(3): 325-31.*

[5] HELITO CP, DEMANGE MK, BONADIO MB, *et al.* Anatomy and histology of the knee anterolateral ligament. *Orthop J Sports Med 2013; 1(7):1-5.*

[6] KENNEDY MI, CLAES S, FUSO FA, *et al.* The anterolateral ligament: an anatomic, radiographic, and biomechanical analysis. *Am J Sports Med 2015; 43(7): 1606-15.*

[7] LUTZ C, SONNERY-COTTET B, NIGLIS L, FREYCHET B, CLAVERT P, IMBERT P. Behavior of the anterolateral structures of the knee during internal rotation. *Orthop Traumatol Surg Res 2015; 101(5): 523-8.*

[8] MUSAHL V, RAHNEMAI-AZAR A, VAN ECK C, GUENTHER D, FU F. Anterolateral ligament of the knee, fact or fiction? *Knee Surg Sports Traumatol Arthrosc 2016; 24: 2-3 DOI 10.1007/s00167-015-3913-0.*

[9] REZANSOFF AJ, CATERINE S, SPENCER L, TRAN MN, LITCHFIELD RB, GETGOOD AM. Radiographic landmarks for surgical reconstruction of the anterolateral ligament of the knee. *Knee Surg Sports Traumatol Arthrosc 2015; 23: 3196-201.*

[10] SEGOND P. Recherches cliniques et expérimentales sur les épanchements sanguins du genou par entorse. *Progrés Med 1879; 7: 297-341.*

[11] VIEIRA ELC, VIEIRA EA, DA SILVA RT, DOS SANTOS BERLFEIN PA, ABDALLA RJ, COHEN M. An anatomic study of the iliotibial tract. *Arthroscopy. 2007; 23(3): 269-74.*

[12] VINCENT JP, MAGNUSSEN RA, GEZMEZ F, *et al.* The anterolateral ligament of the human knee: an anatomic and histologic study. *Knee Surg Sports Traumatol Arthrosc. 2012; 20(1): 147-52.*

BIOMECHANICS OF THE ANTEROLATERAL LIGAMENT

M. THAUNAT, C.A. WIJDICKS, P. IMBERT,
C. LUTZ, J.M. FAYARD, B. SONNERY-COTTET

INTRODUCTION

With the advent of recent reports, there has been a renewed interest in extra-articular reconstruction combined with reconstruction of the anterior cruciate ligament (ACL) in order to obtain better rotational control. The quest for improved rotational control after ACL reconstruction has continued to evolve. Evidence of residual rotational instability after a single-bundle ACL reconstruction, confirmed by a positive pivot-shift led to the development of a more anatomic graft placement in addition to other surgical techniques. Double-bundle ACL reconstruction emerged as an attempt to further improve rotational control after ACL reconstruction, however current data has failed to prove its superiority to date.

Historically, extra-articular lateral tenodesis in concurrence with ACL reconstruction has been attempted to improve rotational control of the tibia with disappointing results. However, recent insights into the anatomical and isometric characteristics of the ALL have provided a more complete understanding of this important structure.

The ALL has been placed under the scientific microscope to closely examine its associated biomechanics which range from native structural properties to native and reconstructed kinematics. These studies focus in on the ALL, while not losing sight of surrounding lateral structures and the ACL. The reason for this close examination stems from the common goal of utilizing an ALL reconstruction in the setting of an ACL deficiency which thereby may eliminate residual rotational knee laxity and reduce the risk of ACL graft rupture in select patients. These patients may include ACL revision cases, the clinical presentation of joint hyperlaxity, and those with either high-demand for pivoting sports and/or presenting with a high grade pivot-shift diagnosis. Due to all of these recent studies, a consensus is now defined on what the ALL is and what role it plays in overall lateral knee stability. Furthermore, this information has provided the foundation to build effective and reproducible ALL reconstructions in combination with the treatment of a torn ACL.

STRUCTURAL PROPERTIES AND INVOLVEMENT IN ROTATIONAL CONTROL OF THE KNEE

Structural property tensile testing of the isolated ALL utilizing similar specimen setup and crosshead speed (20mm/min) has produces mean ultimate load values of 189 Newtons (N)

and stiffness of 31 N/mm, when averaging the values of all 29 unpaired specimens [1,2]. This structural data provides the rationale to select the appropriate autografts in conjunction with adequate fixation methods for reconstruction of the ALL.

In vitro robotic assessments of the ALL in the setting of an ACL injury have defined the ALL as a significant lateral knee stabilizer [3]. Specifically, as a secondary stabilizer during internal rotation torque and simulated pivot-shift test in the ACL-deficient state.

These results were further confirmed by other investigators utilizing a surgical navigation system [4]. Twelve fresh-frozen cadaveric knees were tested in internal rotation at 20° and 90° of flexion and then subsequently tested using a simulated pivot-shift test consisting of coupled axial rotation at 30° of flexion. Serial sectioning of the ACL, ALL, and ITB was performed. On the contralateral knee, sectioning was performed in the reverse order. Measurements were collected using a surgical navigation system before and after each sectioning. This study demonstrated that the ALL is involved in rotational control of the knee at varying degrees of knee flexion and during a simulated pivot shift. Concomitant to an ACL or ITB transection, sectioning the ALL further increased rotational laxity.

Within the discussion of these two papers, it became clear that a reconstruction of the ALL in conjunction with a torn ACL should be met with critical data, as the significant biomechanical importance lends itself to the need for sufficient and reproducible surgical techniques. Key points in this surgical treatment would involve techniques that provide stability without overconstraint while maintaining a minimally invasive, yet reproducible, surgical approach for this secondary stabilizer.

ISOMETRIC BEHAVIOR

Recently, anatomical and functional characteristics of the ALL have been reported demonstrating a structure that originates near the lateral epicondyle on the femur and inserts broadly in a fan-like attachment on the tibia between Gerdy tubercle and the fibular head.

The purpose of the study published by Imbert [5] was to measure the variations in length during flexion and internal tibial rotation of the 3 different femoral insertions of the ALL (proximal-posterior; lateral epicondyle; distal-anterior) while maintaining a fixed tibia insertion (fig. 1). His hypothesis was that the different femoral insertions will exhibit different variations in length throughout the range of motion (ROM) of the knee. This study shows varying behavior of the ALL dependent on the 3 different anatomic femoral described insertions. The proximal and posterior to epicondyle femoral position is the only position with a favorable isometry. The presumed function of the ALL is to prevent excessive tibial internal rotation near full extension of the knee as evidenced here at IR20. To assume this function, the ALL should be maximally tensioned at IR20. It should also not restrain knee ROM, figured here by evaluating the isometry from 0 to 120 of knee flexion as well as at IR90, during which it should stay relaxed. To answer these requirements, the distance between the couple of points during knee motion from full extension to 120 flexion and IR90 should not exceed the maximal distance at IR20. The proximal-posterior femoral location was the only position to reveal a decrease in length during knee flexion. This relaxation when knee going to flexion is appropriate to allow maximal ALL tensioning at IR20 without restraining the tibial internal rotation at 90. For rotation, a similar internal rotation at 20 was observed as in the other femoral positions, but at 90 the internal rotation was significantly increased as a result of the relaxation during flexion. Both the epicondyle and distal-anterior femoral locations resulted in significant length increases with knee flexion. Additionally, there were length increases noted in the distal femoral insertion with internal rotation forces at both 20 and 90. With increasing degrees of knee flexion in the intact knee, the internal tibial rotation also increases. This suggests that the internal rotation restraint of the knee should relax through knee flexion.

Ideally an ALL reconstruction should follow this behavior to control internal tibial rotation around 20 of flexion without limitation of ROM during flexion and internal tibial rotation at 90. Our results show that this can be achieved only with the proximal-posterior femoral location. A graft positioned at the epicondyle femoral position will slightly tighten in flexion and can potentially overconstrain the knee in internal rotation at 90 of flexion. The anterior-distal femoral location should be avoid ed because of the risk of flexion limitation and overconstraint of the knee with internal rotation at 90 of flexion. To avoid these limitations, the ALL could be fixed at 90 of flexion, but this would subsequently ind uce a slack graft in extension and be inefficient in restraining internal tibial rotation.

The study of Imbert showed that the ALL did not show an isometric behavior at any of the femoral insertion locations but had different length change patterns during knee flexion and internal tibial rotation. The proximal and posterior to epicondyle femoral position is the only position with a favorable isometry, as

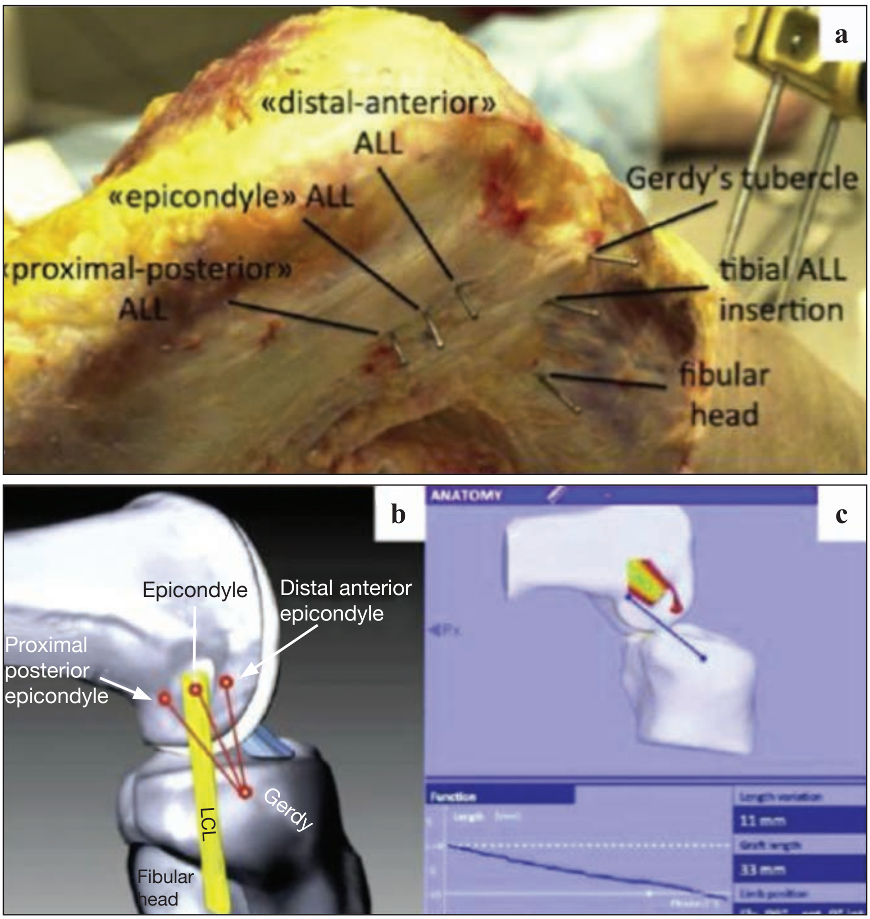


Fig. 1: ***Cadaveric view of the lateral aspect of the right knee figuring metallic pins on the femoral and tibial benchmarks, (b) schematic of the 3 couples paired points in red, corresponding to the different ALL anatomic descriptions, and (c) screen view of the sample from the navigation system during isometry measurements.***

shown by being tight in extension and in internal rotation at 20 and then relaxed with the knee going to flexion at 120 and during internal rotation at 90. Previous work exploring extra-articular lateral tenodesis highlights the importance of an isometric, anatomic reconstruction to avoid complications such as postoperative stiffness, excessive constraint of internal tibial rotation, and alteration of kinematics. Maximizing ROM while providing a competent ALL reconstruction is crucial for post-operative success.

This was scientifically tested in part two of the in vitro robotic assessment with special attention to a combined reconstruction of the ALL and ACL [6]. In this study, the ALL reconstruction was able to further reduce the knee laxity when tested in conjunction with an ACL reconstruction. A primary finding was that during a simulated pivot-shift test, a significant reduction in internal rotation at 30°, 45°, and 60° of knee flexion was noted for the ACL reconstruction in conjunction with an ALL reconstruction. This was statistically significant when compared to the ACL reconstruction with deficient ALL testing state.

CONCLUSION

The future of biomechanical testing should include previously validated methodology, adequate sample size, and clinically translational study groups. Biomechanical optimization of surgical techniques can only go a certain extent to impact patient outcomes due to the primary limitation of time-zero study design. Therefore, proposed techniques should be objectively monitored in clinical cohort studies to examine the positive effects that have arisen from their biomechanical data.

LITERATURE

[1] KENNEDY MI, CLAES S, FUSO FA, WILLIAMS BT, GOLDSMITH MT, TURNBULL TL, WIJDICKS CA, LAPRADE RF. The Anterolateral Ligament: An Anatomic, Radiographic, and Biomechanical Analysis. *Am J Sports Med 2015 Jul; 43(7):1606-15. PMID: 25888590*

[2] HELITO CP, BONADIO MB, ROZAS JS, WEY JM, PEREIRA CA, CARDOSO TP, PÉCORA JR, CAMANHO GL, DEMANGE MK. Biomechanical study of strength and stiffness of the knee anterolateral ligament. *BMC Musculoskelet Disord 2016 Apr 30; 17(1):193. PMID: 27129387.*

[3] RASMUSSEN MT, NITRI M, WILLIAMS BT, MOULTON SG, CRUZ RS, DORNAN GJ, GOLDSMITH MT, LAPRADE RF. An *In Vitro* Robotic Assessment of the Anterolateral Ligament, Part 1: Secondary Role of the Anterolateral Ligament in the Setting of an Anterior Cruciate Ligament Injury. *Am J Sports Med 2016 Mar; 44(3): 585-92. PMID: 26684663.*

[4] SONNERY-COTTET B, LUTZ C, DAGGETT M, DALMAY F, FREYCHET B, NIGLIS L, IMBERT P. The Involvement of the Anterolateral Ligament in Rotational Control of the Knee. *Am J Sports Med 2016 Feb 10. [Epub ahead of print] PMID: 26865395.*

[5] IMBERT P, LUTZ C, DAGGETT M, NIGLIS L, FREYCHET B, DALMAY F, SONNERY-COTTET B. Isometric Characteristics of the Anterolateral Ligament of the Knee: A Cadaveric Navigation Study. *Arthroscopy 2016 May 4.*

[6] NITRI M, RASMUSSEN MT, WILLIAMS BT, MOULTON SG, CRUZ RS, DORNAN GJ, GOLDSMITH MT, LAPRADE RF. An *In Vitro* Robotic Assessment of the Anterolateral Ligament, Part 2: Anterolateral Ligament Reconstruction Combined With Anterior Cruciate Ligament Reconstruction. *Am J Sports Med 2016 Mar; 44(3): 593-601. PMID: 26831632.*

SECONDARY RESTRAINTS TO INTERNAL ROTATION: THE ROLE OF THE ANTEROLATERAL LIGAMENT, ILIOTIBIAL BAND AND LATERAL MENISCUS

T. LORDING, A. GETGOOD, T.P. BRANCH

INTRODUCTION

Injury to the anterior cruciate ligament (ACL) is common, and affects a predominantly young and active population. Isolated intra-articular reconstruction, the accepted standard of operative treatment, may fail to restore rotational stability to the joint [1, 2]. Residual rotational laxity, which may manifest as the pivot shift, is associated with inferior subjective outcomes [3, 4].

Recent interest in the anterolateral ligament has refocused attention on the secondary restraints to rotation, and the role these structures may play in both the spectrum of observed instability and residual laxity after intra-articular reconstruction. In addition to the ACL, the anterolateral ligament (ALL) [5], iliotibial band (ITB) [6], the lateral meniscus [7, 8] and medial meniscotibial ligament [9] have all been shown to restrain internal rotation at the knee.

THE ANTEROLATERAL LIGAMENT

Anatomical and radiological studies over the past 40 years have described structures connecting the lateral femoral condyle, the lateral meniscus, and the lateral tibial plateau on the anterolateral aspect of the knee [10-17]. These structures have been described as capsular thickenings, components of the ilio-tibial tract, or ligaments in their own right, and have been variously referred to as the “middle one third of the lateral capsular ligament” or simply the “lateral capsular ligament” [10], the “anterolateral femoro-tibial ligament” [12], the “capsulo-osseous layer of the iliotibial tract” [13], the “retrograde tract fibres” [18], the “anterior oblique band” [15], and the “lateral femorotibial ligament” [16]. This non-standardized nomenclature, coupled with vague anatomical descriptions, has contributed to ongoing confusion regarding the anatomy of the anterolateral knee.

In 2013, Claes and colleagues published their description of the anterolateral ligament [19]. They described an extra-capsular structure, originating just anterior to the lateral collateral ligament (LCL), posterior and proximal to the popliteus tendon insertion, and inserting onto the proximal tibia midway between Gerdy’s tubercle and the fibula head. The structure had a strong connection to the body of the lateral meniscus, but lacked attachments to the ITB, and was identified in 40 of 41 specimens.

Since this time, a number of authors have furthered our understanding of this structure,

with anatomical and histological studies [20-24], and descriptions of radiographic landmarks [25, 26]. While the tibial insertion appears relatively constant in these descriptions, variation has been reported in the femoral attachment. Some authors have described this origin as being proximal and posterior to the LCL [22-24], while others have described an anterior and distal origin [19, 20]. Caterine identified both variants, and also identified a peripheral nervous innervation, suggesting a role in proprioception [21].

Kennedy investigated the biomechanical properties and failure mechanisms of the ALL, finding a mean maximum load of 175 N and stiffness of 20 N/mm [23]. In 12 specimens, four mechanisms of failure were identified; ligamentous tear at the femoral attachment in four specimens, at the tibial insertion in one, in the mid substance in four, and by a bony avulsion (Ségond fracture) in six, although it should be noted that the line of pull in these experiments was non-physiologic. Dodds determined the ligament to be isometric from 0-60° of flexion, and to lengthen with internal tibial rotation, suggesting a role in internal rotational control [22]. Kittl studied the isometry of the native anterolateral structures as well as potential points for the fixation of an extra-articular reconstructions [27]. He found an ALL with an origin posterior and proximal to the LCL to be relatively isometric, whilst an ALL with a distal and anterior origin was lax approaching extension and unlikely to be effective in controlling the pivot shift.

A number of authors have now investigated the role of the ALL in rotational control of the knee, with conflicting results. Lording and Branch performed a cadaveric experiment investigating the effect of cutting the ALL and ITB at 30° of flexion [28]. They used a custom robot replicating the clinical internal/external rotation or dial test, while tracking the free floating tibia in six degrees of freedom [29, 30]. They found division of the ALL in the ACL intact knee increased internal rotation at 30° of knee flexion by 2.4° (fig. 1). However, there was wide variation in the effect of ALL sectioning between specimens, which in one specimen was not significant but in another caused an increase in internal rotation approaching 40% (fig. 2). Sonnery-Cottet, in a navigation based study, demonstrated increased internal rotation after division of the ALL in the ACL deficient knee at 20° and 90°, as well as increased coupled axial rotation during the pivot shift [31]. Again using navigation, Spencer demonstrated an increase in internal rotation during a simulated early stage pivot shift after division of the ALL in an ACL deficient knee [32]. Parsons, using a six degree of freedom robotic system, found the ALL to be the primary restraint to internal rotation at knee flexion angles greater than 35°, with the ACL providing the greatest restraint closer to extension [5]. Of note, the ITB was removed from all specimens in this study prior to testing. Consistent with this finding, Lording and Getgood, in a navigation based study with manually applied forces, found the ALL to play a significant role in internal rotational control only at knee flexion angles greater than 30° [33] (fig. 3).

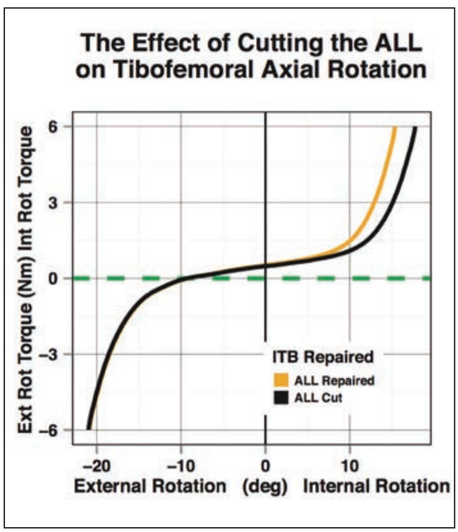


Fig. 1: ***Effect of cutting the ALL on tibial rotation. Ext rot, External rotation; Int Rot, Internal rotation.***

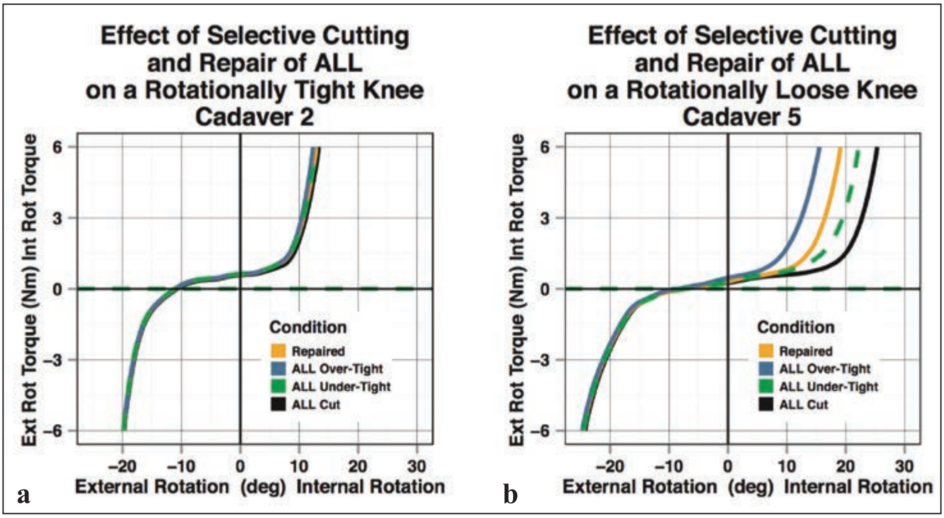


Fig. 2: ***Variation in impact of ALL sectioning on rotation between specimens, with little effect in cadaver 2 (a) and large effect in cadaver 5 (b). Ext rot, External rotation; Int Rot, Internal rotation. a) Extension, b) 45°.***

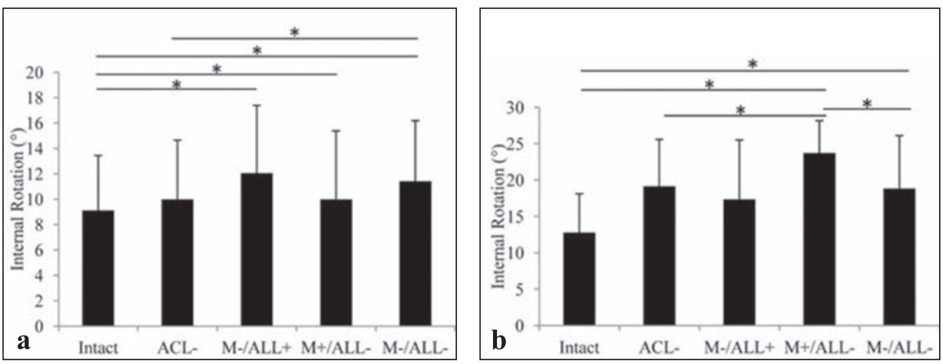


Fig. 3: ***Internal rotation in extension (a) and at 45° of flexion (b). In extension loss of the lateral meniscal posterior root causes a significant increase in internal rotation, while at 45° loss of the ALL is more important. ACL-, ACL deficient state; M-/ALL+, Meniscal root sectioned with ALL intact; M+/ALL-, Meniscal root intact, ALL sectioned; M-/ALL-, both meniscal root and ALL sectioned.***

In contrast, Kittl found the ALL played no significant role in rotational control [6]. In a robotic experiment similar to that of Parsons, using a six degree of freedom system, he determined the superficial and deep components of the ITB to be the primary restraints to internal rotation from 30-90°, with the ACL having a significant contribution at 0° only. Al Saiegh found no increase in internal rotation after division of the ALL in a navigation based study, although the ALL was identified in only six of 14 specimens in this study [34].

THE ILIOTIBIAL BAND

The idea that the iliotibial band contributes to rotational control of the knee is not new. In fact, the term "anterolateral ligament" was probably first used by Kaplan in his 1958 morphological study of the iliotibial tract [35], and was subsequently used by Terry in 1986 to describe the function of the deep and capsulo-osseous layers thereof [13]. In 1979, Fetto was able to induce a pivot shift in an ACL intact knee after division of the ITB [36]. Jakob noted increased internal rotation but a paradoxical decrease in the pivot shift after release of the ITB from its distal femoral attachment, reflecting the complex and multifactorial nature of the pivot shift phenomenon [37]. When he released the ITB distally by osteotomy of Gerdy's tubercle, rotational subluxation during the pivot shift manoeuver became so marked in the ACL deficient knee that reduction did not occur before 60° of flexion.

Anatomically, the insertion of the ITB onto the lateral distal femur, known as Kaplan's fibres, has been shown to be a true tendon enthesis [38]. This could be considered to divide the ITB into a proximal, tendinous part, and a distal, ligamentous part that could contribute to the control of internal rotation. Terry's anatomical study describes the capsulo-osseous layer as inserting behind Gerdy's tubercle and identifies it as the "fibrous pearly band" attached to Ségond's eponymous fracture [13, 39].

A number of recent biomechanical studies support a role for the ITB in the control of internal rotation. Gadikota, in a robotic study investigating the effect of increasing ITB load, found that internal rotation was significantly reduced between 20° and 30° of knee flexion with an ITB load of 50 N, and from 15° to 30° with a load of 100 N, suggesting a dynamic function [40]. Lording et al measured an increase in internal rotation of 2.6° in the ACL intact knee at 30° after division of the ITB at Gerdy's tubercle [28] (fig. 4). This increase was similar in magnitude to that noted after division of the ALL (2.4°) but with less variability between specimens. Butler investigated the impact of ITB division and tenodesis after single- and double-bundle ACL reconstructions in cadaveric knees using a navigation system [41]. The deep layers of the ITB were released from the femur. Under a coupled anterior translational force and internal rotational torque at 30° of knee flexion, internal rotation increased by 3.9° in the single-bundle group and by 2.9° in the double-bundle group. Under pure rotational torque, internal rotation increased in the single-bundle group at 30° of flexion by 4.4° and in the double-bundle group at 90° of flexion by 3.4°. ITB tenodesis using the superficial ITB reduced internal rotation compared to the reconstructed knee in all tests. Kittl found the superficial and deep layers of the ITB to be the most important stabilizers of internal rotation, with the superficial layer more important at deeper flexion angles and the deep layer especially important in extension and at 30° of flexion in the ACL deficient knee [6]. In his study, the superficial and deep layers of the ITB were also the primary restraints to the pivot shift. In Sonnery-Cottet's study, division of the ITB in the ACL intact knee caused a significant increase in internal rotation at 20° of flexion and of coupled axial rotation during the pivot shift [31]. Sectioning of the ITB after the ACL and ALL also caused increased internal rotation at 20°, 90° and during the pivot shift.

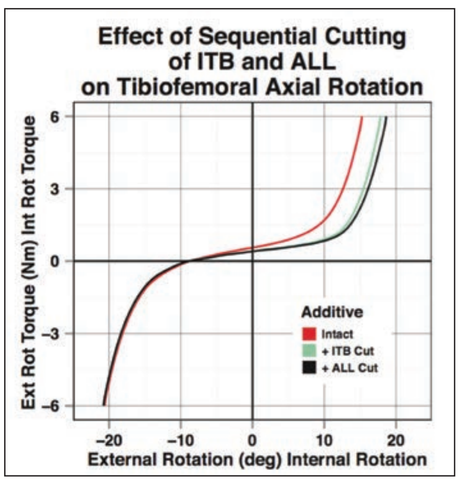


Fig. 4: ***Sequential cutting of the ITB and ALL increased internal rotation by 2.6° and 3.4°.***

There is evidence of ITB injury occurring with ACL injury and contributing to the spectrum of instability seen. At operation, Terry found that injury to the deep and capsulo-osseous layers occurred in 84 and 71% of ACL ruptures respectively, and that injury to these structures correlated with the pivot shift findings [42]. The majority of these injuries occurred at the femoral insertion.

THE MENISCI

The role of the medial meniscus as a secondary stabilizer to anterior translation is well documented [43, 44]. Much less has been published regarding the role of the menisci in controlling rotation.

Musahl examined the effect of medial and lateral meniscectomy in the ACL deficient knee using navigation and a mechanized pivot shifter [7]. Medial meniscectomy significantly increased anterior tibial translation during the Lachman test, but did not increase lateral compartment translation during the pivot shift. Lateral meniscectomy, on the other hand, caused a significant increase in lateral compartment translation during the pivot shift but had no effect on the Lachman examination. Petrigliano reported increased rotational instability after uni- and bi-compartmental meniscectomy, although they did not differentiate in their report which compartment was meniscectomized first [45].

Shybut investigated the impact of tears of the posterior root of the lateral meniscus on stability in the ACL deficient knee [8]. Using an infrared motion analysis system, loss of the meniscal root was shown to increase lateral compartment translation during the pivot shift. Lording and Getgood examined the role of the ALL and posterior lateral meniscal root on internal rotation in the ACL deficient knee [33]. Loss of the meniscal root significantly increased internal rotation in extension and at knee flexion angles under 30°, while the ALL significantly controlled rotation only at higher degrees of flexion (fig. 3).

Some medial meniscal lesions may also play a role in rotational instability. Peltier investigated the effect of very peripheral medial medial meniscal tears, termed “ramp” lesions [9]. He found increased anterior translation after creation of a ramp lesion in the ACL deficient knee, but also increased internal rotation after division of the meniscotibial ligament of the posterior horn. It seems likely that this measured internal rotation represents posteromedial rotation, and the relevance of this finding to clinical instability in the ACL deficient knee is unclear.

DISCUSSION

The anterolateral ligament, iliotibial band and lateral meniscus all contribute to the restraint of anterolateral rotatory instability at the knee. Considered together, these structures could be considered to constitute the “anterolateral corner” of the knee. As outlined above, biomechanical studies suggest the contribution of these structures is dependent on knee flexion angle, with the lateral meniscus being more important near extension and the anterolateral ligament exerting greater control at deeper flexion angles above 30°.

The indications for surgical management for the anterolateral extra-articular structures are yet to be fully determined. The results of intra-articular reconstruction are satisfactory for the majority of patients, and as such extra-articular reconstruction should be reserved for those most likely to benefit from the additional intervention. This may include those at higher risk of failure, such as younger patients [46] and those returning to pivoting sports [47], and those undergoing revision procedures. Excessive tibial rotation in the non-injured knee is a risk factor for both ACL injury and poor outcomes after ACL surgery [48, 49], and may also be an indication for an extra-articular procedure.

The degree of clinical laxity has also been proposed as an indication; however, it seems likely that the severity of this laxity reflects

injury to the secondary stabilizers. Advances in imaging technology and technique may allow for accurate diagnosis of and targeted treatment for these injuries. LaPrade reported 95% accuracy in diagnosing injury to the meniscotibial portion of the mid-third lateral capsular ligament using magnetic resonance imaging (MRI) [14], while Claes has also identified a high rate of ALL abnormalities in association with ACL injury [50]. In a recent case series of 90 knees with ACL injury shown on MRI, 41% were noted to have an abnormality of the ALL [51]. Of those knees with an intact ALL, 31% were observed to have a lateral meniscus tear. In contrast, 61% of knees with an ALL injury had a lateral meniscus tear. Mansour retrospectively reviewed 200 MRI scans and found a significant correlation between ACL and ITB injury [52]. The site of ITB injury, however, was not reported.

The ideal lateral extra-articular procedure is also unclear. ALL reconstruction is an attractive option, due to its anatomical nature. However, recent biomechanical studies suggest the native ALL is important only at deeper flexion angles, and as such anatomical ALL reconstruction may not control the pivot shift. This suggestion is supported by the study of Spencer, who found anatomical ALL reconstruction did not restore internal rotational control in a simulated early phase pivot shift [32]. More traditional ITB based reconstructions, such as the Lemaire procedure, may be superior in terms of functional rotational control.

Tears involving the posterior root of the lateral meniscus have been reported in up to 12% of ACL injured knees [53]. Injuries to the meniscal roots have biomechanical consequences similar to total meniscectomy [54, 55], and may lead to meniscal extrusion and progressive chondral degeneration [56-58]. These effects may be mitigated to a degree in the lateral compartment by the presence of intact meniscofemoral ligaments [59-61]. Biomechanical studies of transosseous repair techniques for lateral root tears generally show a reduction in contact pressures to near normal levels compared to the injured state [61-63]. Clinical studies show encouraging results. Anderson reported the mid-term results of eight radial root tear suture repairs and 16 posterior horn reattachments performed through the tibial ACL tunnel [64]. 22 of 24 repairs functioned successfully, with better subjective results in the transosseous repair group. Ahn reported second look arthroscopic results for eight patients treated with either side-to-side or transosseous techniques, with almost complete healing noted in all cases at a mean of 18 months [65].

We recommend careful inspection of the lateral meniscal root for injury during ACL reconstruction, and repair of these lesions where possible. Such a repair has two potential benefits; improved rotational control, and long term maintenance of the chondroprotective function of the meniscus.

CONCLUSION

The anterolateral ligament, iliotibial band and lateral meniscus all contribute to the restraint of anterolateral rotatory instability at the knee, and together can be considered to constitute the "anterolateral corner" of the knee. Injury to these secondary stabilizers contribute to the spectrum of instability seen with ACL injury, and surgery should aim to address these lesions where possible. The indications and ideal technique for anterolateral extra-articular procedures are yet to be determined. Repair of lateral meniscal root injuries has potential benefits for both knee stability and chondral protection, and should be undertaken where possible.

LITERATURE

[1] TASHMAN S, COLLON D, ANDERSON K, KOLOWICH P, ANDERST W. Abnormal rotational knee motion during running after anterior cruciate ligament reconstruction. *Am J Sports Med 2004; 32(4): 975-83.*

[2] RISTANIS S, STERGIOU N, PATRAS K, VASILIADIS HS, GIAKAS G, GEORGOULIS AD. Excessive Tibial Rotation During High-Demand Activities Is Not Restored by Anterior Cruciate Ligament Reconstruction. *Arthroscopy 2005; 21(11): 1323-9.*

[3] KOCHER MS. Relationships Between Objective Assessment of Ligament Stability and Subjective Assessment of Symptoms and Function After Anterior Cruciate Ligament Reconstruction. *Am J Sports Med 2004; 32(3): 629-34.*

[4] AYENI OR, CHAHAL M, TRAN MN, SPRAGUE S. Pivot shift as an outcome measure for ACL reconstruction: a systematic review. *Knee Surg Sports Traumatol Arthrosc 2012; 20(4): 767-77.*

[5] PARSONS EM, GEE AO, SPIEKERMAN C, CAVANAGH PR. The Biomechanical Function of the Anterolateral Ligament of the Knee. *Am J Sports Med 2015; 43(3): 669-74.*

[6] KITTL C, DAOU EL H, ATHWAL KK, *et al.* The Role of the Anterolateral Structures and the ACL in Controlling Laxity of the Intact and ACL-Deficient Knee. *Am J Sports Med 2016; 44(2): 345-54.*

[7] MUSAHL V, CITAK M, O'LOUGHLIN PF, CHOI D, BEDI A, PEARLE AD. The Effect of Medial Versus Lateral Meniscectomy on the Stability of the Anterior Cruciate Ligament-Deficient Knee. *Am J Sports Med 2010; 38(8): 1591-7.*

[8] SHYBUT TB, VEGA CE, HADDAD J, *et al.* Effect of Lateral Meniscal Root Tear on the Stability of the Anterior Cruciate Ligament-Deficient Knee. *Am J Sports Med 2015; 43(4): 905-11.*

[9] PELTIER A, LORDING T, MAUBISSON L, BALLIS R, NEYRET P, LUSTIG S. The role of the meniscotibial ligament in posteromedial rotational knee stability. *Knee Surg Sports Traumatol Arthrosc 2015; 23(10): 2967-73.*

[10] HUGHSTON JC, ANDREWS JR, CROSS MJ, MOSCHI A. Classification of knee ligament instabilities. Part II. The lateral compartment. *J Bone Joint Surg Am 1976; 58(2): 173-9.*

[11] JOHNSON LL. Lateral capsular ligament complex: anatomical and surgical considerations. *Am J Sports Med 1979; 7(3): 156-60.*

[12] MÜLLER W. The Knee. *Springer-VERLAG; 1983.*

[13] TERRY GC, HUGHSTON JC, NORWOOD LA. The anatomy of the iliopatellar band and iliotibial tract. *Am J Sports Med 1986 ;14(1): 39-45.*

[14] LAPRADE RF, GILBERT TJ, BOLLOM TS, WENTORF F, CHALJUB G. The magnetic resonance imaging appearance of individual structures of the posterolateral knee. A prospective study of normal knees and knees with surgically verified grade III injuries. *Am J Sports Med 2000; 28(2): 191-9.*

[15] CAMPOS JC, CHUNG CB, LEKTRAKUL N, *et al.* Pathogenesis of the Segond Fracture: Anatomic and MR Imaging Evidence of an Iliotibial Tract or Anterior Oblique Band Avulsion. *Radiology 2001; 219(2): 381-6.*

[16] VIEIRA ELC, VIEIRA EÁ, TEIXEIRA DA SILVA R, SANTOS BERLFEIN DOS PA, ABDALLA RJ, COHEN M. An Anatomic Study of the Iliotibial Tract. *Arthroscopy 2007; 23(3): 269-74.*

[17] VINCENT JP, MAGNUSSEN RA, GEZMEZ F, *et al.* The anterolateral ligament of the human knee: an anatomic and histologic study. *Knee Surg Sports Traumatol Arthrosc 2011;20(1): 147-52.*

[18] LOBENHOFFER P, POSEL P, WITT S, PIEHLER J, WIRTH CJ. Distal femoral fixation of the iliotibial tract. *Arch Orth Traum Surg 1987; 106(5): 285-90.*

[19] CLAES S, VEREECKE E, MAES M, VICTOR J, VERDONK P, BELLEMANS J. Anatomy of the anterolateral ligament of the knee. *J Anat 2013; 223(4): 321-8.*

[20] HELITO CP, DEMANGE MK, BONADIO MB, *et al.* Anatomy and Histology of the Knee Anterolateral Ligament. *Orthop J Sports Med 2013; 1(7):2325967113513546.*

[21] CATERINE S, LITCHFIELD R, JOHNSON M, CHRONIK B, GETGOOD A. A cadaveric study of the anterolateral ligament: re-introducing the lateral capsular ligament. *Knee Surg Sports Traumatol Arthrosc 2015; 23(11): 3186-95.*

[22] DODDS AL, HALEWOOD C, GUPTE CM, WILLIAMS A, AMIS AA. The anterolateral ligament: Anatomy, length changes and association with the Segond fracture. *Bone Joint J 2014; 96-B(3): 325-31.*

[23] KENNEDY MI, CLAES S, FUSO FAF, *et al.* The Anterolateral Ligament: An Anatomic, Radiographic, and Biomechanical Analysis. *Am J Sports Med 2015; 43(7): 1606-15.*

[24] DAGGETT M, OCKULY AC, CULLEN M, *et al.* Femoral Origin of the Anterolateral Ligament: An Anatomic Analysis. *Arthroscopy. December 2015.*

[25] HELITO CP, DEMANGE MK, BONADIO MB, *et al.* Radiographic Landmarks for Locating the Femoral Origin and Tibial Insertion of the Knee Anterolateral Ligament. *Am J Sports Med 2014; 42(10): 2356-62.*

[26] REZANSOFF AJ, CATERINE S, SPENCER L, TRAN MN, LITCHFIELD RB, GETGOOD AM. Radiographic landmarks for surgical reconstruction of the anterolateral ligament of the knee. *Knee Surg Sports Traumatol Arthrosc 2015; 23(11): 3196-201.*

[27] KITTL C, HALEWOOD C, STEPHEN JM, *et al.* Length Change Patterns in the Lateral Extra-articular Structures of the Knee and Related Reconstructions. *Am J Sports Med 2015; 43(2): 354-62.*

[28] LORDING TD, STINTON S, DEJARNETTE N, MADDEN C, NEYRET P, BRANCH TP. The Effect of Cutting and Repair of the Anterolateral Ligament and Iliotibial Band on Tibial Axial Rotation. *Paper presented at Asia-Pacific Orthopaedic Association (APOA) Congress, Melbourne Australia, 2016.*

[29] STINTON SK, SIEBOLD R, FREEDBERG H, JACOBS C, BRANCH TP. The use of a robotic tibial rotation device and an electromagnetic tracking system to accurately reproduce the clinical dial test. *Knee Surg Sports Traumatol Arthrosc 2016; 24(3): 815-22.*

[30] BRANCH T, STINTON S, STERNBERG M, *et al.* Robotic axial lower leg testing: repeatability and

reproducibility. *Knee Surg Sports Traumatol Arthrosc 2015; 23(10): 2892-9.*

[31] SONNERY-COTTET B, LUTZ C, DAGGETT M, *et al.* The Involvement of the Anterolateral Ligament in Rotational Control of the Knee. *Am J Sports Med Advance online publication 2016 doi:10.1177/0363546515625282.*

[32] SPENCER L, BURKHART TA, TRAN MN, *et al.* Biomechanical Analysis of Simulated Clinical Testing and Reconstruction of the Anterolateral Ligament of the Knee. *Am J Sports Med 2015; 43(9): 2189-97.*

[33] LORDING T, CORBO G, BURKHART TA, GETGOOD AM. The Synergistic Contribution of the Anterolateral Ligament and the Lateral Meniscus to the Control of Rotational Knee Laxity. *Paper presented at American Academy of Orthopedic Surgeons (AAOS) Annual Meeting, Orlando USA, 2016.*

[34] SAIEGH ALY, SUERO EM, GUENTHER D, *et al.* Sectioning the anterolateral ligament did not increase tibiofemoral translation or rotation in an ACL-deficient cadaveric model. *Knee Surg Sports Traumatol Arthrosc September 2015: 1-7.*

[35] KAPLAN EB. The iliotibial tract; clinical and morphological significance. *J Bone Joint Surg Am 1958; 40(4): 817-32.*

[36] FETTO JF, MARSHALL JL. Injury to the anterior cruciate ligament producing the pivot-shift sign. *J Bone Joint Surg Am 1979; 61(5): 710-4.*

[37] JAKOB RP, HASSLER H, STAEUBLI HU. Observations on rotatory instability of the lateral compartment of the knee. Experimental studies on the functional anatomy and the pathomechanism of the true and the reversed pivot shift sign. *Acta Orthop Scand Suppl 1981; 191: 1-32.*

[38] FAIRCLOUGH J, HAYASHI K, TOUMI H, *et al.* The functional anatomy of the iliotibial band during flexion and extension of the knee: implications for understanding iliotibial band syndrome. *J Anat 2006; 208(3): 309-16.*

[39] SÉGOND P. Recherches Cliniques Et Expérimentales Sur Les Épanchements Sanguins Du Genou Par Entorse. *Progès Médicale 1879: 297-341.*

[40] GADIKOTA HR, KIKUTA S, QI W, NOLAN D, GILL TJ, LI G. Effect of increased iliotibial band load on tibiofemoral kinematics and force distributions: a direct measurement in cadaveric knees. *J Orthop Sports Phys Ther 2013; 43(7): 478-85.*

[41] BUTLER PD, MELLECKER CJ, RUDERT MJ, ALBRIGHT JP. Single-bundle versus double-bundle ACL reconstructions in isolation and in conjunction with extra-articular iliotibial band tenodesis. *Iowa Orthop J 2013; 33: 97-106.*

[42] TERRY GC, NORWOOD LA, HUGHSTON JC, CALDWELL KM. How iliotibial tract injuries of the knee combine with acute anterior cruciate ligament tears to influence abnormal anterior tibial displacement. *Am J Sports Med 1993; 21(1): 55-60.*

[43] LEVY IM, TORZILLI PA, WARREN RF. The effect of medial meniscectomy on anterior-posterior motion of the knee. *J Bone Joint Surg Am 1982; 64(6): 883-8.*

[44] SHOEMAKER SC, MARKOLF KL. The role of the meniscus in the anterior-posterior stability of the loaded anterior cruciate-deficient knee. Effects of partial versus total excision. *J Bone Joint Surg Am 1986; 68(1): 71-9.*

[45] PETRIGLIANO FA, MUSAHL V, SUERO EM, CITAK M, PEARLE AD. Effect of meniscal loss on knee stability after single-bundle anterior cruciate ligament reconstruction. *Knee Surg Sports Traumatol Arthrosc 2011; 19(S1): 86-93.*

[46] WEBSTER KE, FELLER JA, LEIGH WB, RICHMOND AK. Younger Patients Are at Increased Risk for Graft Rupture and Contralateral Injury After Anterior Cruciate Ligament Reconstruction. *Am J Sports Med 2014; 42(3): 641-7.*

[47] SALMON L, RUSSELL V, MUSGROVE T, PINCZEWSKI L, REFSHAUGE K. Incidence and risk factors for graft rupture and contralateral rupture after anterior cruciate ligament reconstruction. *Arthroscopy 2005; 21(8): 948-57.*

[48] BRANCH TP, BROWNE JE, CAMPBELL JD, *et al.* Rotational laxity greater in patients with contralateral anterior cruciate ligament injury than healthy volunteers. *Knee Surg Sports Traumatol Arthrosc 2010; 18(10): 1379-84.*

[49] BRANCH TP, SIEBOLD R, FREEDBERG HI, JACOBS CA. Double-bundle ACL reconstruction demonstrated superior clinical stability to single-bundle ACL reconstruction: a matched-pairs analysis of instrumented tests of tibial anterior translation and internal rotation laxity. *Knee Surg Sports Traumatol Arthrosc 2011; 19(3): 432-40.*

[50] CLAES S, BARTHOLOMEEUSEN S, BELLEMANS J. High prevalence of anterolateral ligament abnormalities in magnetic resonance images of anterior cruciate ligament-injured knees. *Acta Orthop Belg 2014; 80(1): 45-9.*

[51] VAN DYCK P, CLOCKAERTS S, VANHOENACKER FM, *et al.* Anterolateral ligament abnormalities in patients with acute anterior cruciate ligament rupture are associated with lateral meniscal and osseous injuries. *Eur Radiol 2016; 1-9.*

[52] MANSOUR R, YOONG P, McKEAN D, TEH JL. The iliotibial band in acute knee trauma: patterns of injury on MR imaging. *Skeletal Radiol 2014; 43(10): 1369-75.*

[53] WEST RV, KIM JG, ARMFIELD D, HARNER CD. Lateral meniscal root tears associated with anterior cruciate ligament injury: classification and management. *Arthroscopy 2004; 20: e32-e33.*

[54] ALLAIRE R, MURIUKI M, GILBERTSON L, HARNER CD. Biomechanical consequences of a tear of the posterior root of the medial meniscus. Similar to total meniscectomy. *J Bone Joint Surg Am 2008; 90(9): 1922-31.*

[55] MARZO JM, GURSKE-DEPERIO J. Effects of Medial Meniscus Posterior Horn Avulsion and Repair on Tibiofemoral Contact Area and Peak Contact Pressure With Clinical Implications. *Am J Sports Med 2008; 37(1): 124-9.*

[56] BRODY JM, LIN HM, HULSTYN MJ, TUNG GA. Lateral Meniscus Root Tear and Meniscus Extrusion with Anterior Cruciate Ligament Tear 1. *Radiology 2006; 239(3): 805-10.*

[57] HEIN CN, DEPERIO JG, EHRENSBERGER MT, MARZO JM. Effects of medial meniscal posterior horn avulsion and repair on meniscal displacement. *Knee 2011; 18(3): 189-92.*

[58] LERER DB, UMANS HR, HU MX, JONES MH. The role of meniscal root pathology and radial meniscal tear in medial meniscal extrusion. *Skeletal Radiol 2004; 33(10).*

[59] BAO HRC, ZHU D, GONG H, GU GS. The effect of complete radial lateral meniscus posterior root tear on the knee contact mechanics: a finite element analysis. *J Orthop Sci 2012; 18(2): 256-63.*

[60] FORKEL P, HERBORT M, SCHULZE M, *et al.* Biomechanical consequences of a posterior root tear of the lateral meniscus: stabilizing effect of the meniscofemoral ligament. *Arch Orthop Trauma Surg 2013; 133(5): 621-6.*

[61] PEREZ-BLANCA A, ESPEJO-BAENA A, AMAT TRUJILLO D*, et al.* Comparative Biomechanical Study on Contact Alterations After Lateral Meniscus Posterior Root Avulsion, Transosseous Reinsertion, and Total Meniscectomy. *Arthroscopy 2015; 0(0).*

[62] FORKEL P, HERBORT M, SPRENKER F, METZLAFF S, RASCHKE M, PETERSEN W. The biomechanical effect of a lateral meniscus posterior root tear with and without damage to the meniscofemoral ligament: efficacy of different repair techniques. *Arthroscopy 2014; 30(7): 833-40.*

[63] LAPRADE CM, JANSSON KS, DORNAN G, SMITH SD. Altered tibiofemoral contact mechanics due to lateral meniscus posterior horn root avulsions and radial tears can be restored with in situ pull-out suture repairs. *J Bone Joint Surg Am 2014; 96(6): 471-9.*

[64] ANDERSON L, WATTS M, SHAPTER O, *et al.* Repair of Radial Tears and Posterior Horn Detachments of the Lateral Meniscus: Minimum 2-Year Follow-Up. *Arthroscopy 2010; 26(12): 1625-32.*

[65] AHN JH, LEE YS, CHANG JY, CHANG MJ, EUN SS, KIM SM. Arthroscopic all inside repair of the lateral meniscus root tear. *Knee 2009; 16(1): 77-80.*

ANTEROLATERAL LIGAMENT IMAGING

B. BORDET, J. BORNE, A. PONSOT, P.F. CHAILLOT, O. FANTINO

We now know that the Segond fracture is an injury of the anterolateral ligament (ALL).

This small image of an avulsion involving the lateral aspect of the tibial plateau is visible on the AP view of the knee X-ray.

Pathognomonic for an anterior cruciate ligament (ACL) tear, it is therefore an avulsion of the ALL's distal enthesis (fig. 1).

Seven teams have studied MR imaging of the ALL since 2014 [1].

Fig. 1: ***AP view of knee X-ray. Segond fracture*** *(arrow)***.**

The ALL is certainly visible with MRI but the diagnostic capabilities vary depending on the different portions identified.

Some of these studies use 2D acquisition protocols with a 3 to 4 mm section thickness. It appears to be difficult to study a thin structure of under 2 mm with sections of this thickness and it is therefore logical to assume that certain poor results are due to the acquisition protocols.

The ligament appears as a physiological hyposignal. It is relatively relaxed on the MRI, which is performed with the knee bent at 20° to 30° with a distal tibial enthesis curved on coronal sections.

It is also possible to see the ALL's meniscal attachments, whose morphology varies.

For greater precision and efficacy, ideally 3D 1mm-section sequences should be taken. They are available on all new 3 Tesla MRIs and on the latest generation 1.5 Tesla MRIs. With these sequences, the MPR mode can be used to study the ALL much more precisely.

In routine practice, we use T2-weighted 3D sequences without a fat suppression technique. The ligament is clearly visible as a physiological hyposignal relative to its surroundings. The lateral inferior genicular artery is clearly visible, in contact with the wall of the lateral meniscus and the meniscal ligament expansions can be studied [2, 3] (fig. 2).

Several projects are underway to study the ALL in cases of ACL injury. Helito has shown an injury in 30% of cases but these injuries are predominantly proximal [4].

To date, two ultrasonography studies have described the ALL [5, 6]. Mary Faruch *et al.*'s study correlated ultrasonographic data and cadaveric dissections. A recent Japanese study using real time virtual sonography showed that the ligament was identified in 100% of cases [7].

In our experience [8] it is possible to explore the ALL by ultrasound using high frequency waves.

We study the ligament in a resting position with the knee bent at 20° and we perform dynamic flexion and double rotation maneuvers to tense it in an internal knee rotation.

In a resting position, we clearly see this small, relaxed, curved fibrillar structure that crosses the lateral inferior genicular artery (LIGA), located deeper, in contact with the lateral meniscal wall. Above, we can see the thin ligament that crosses the surface of the LCL. Its femoral enthesis is more difficult to distinguish due to a large insertion very close to that of the LCL (fig. 3).

The dynamic maneuvers make the ligament tense by flexion and internal rotation, with the ligament approaching the lateral aspect of the tibial plateau and straightening (fig. 4).

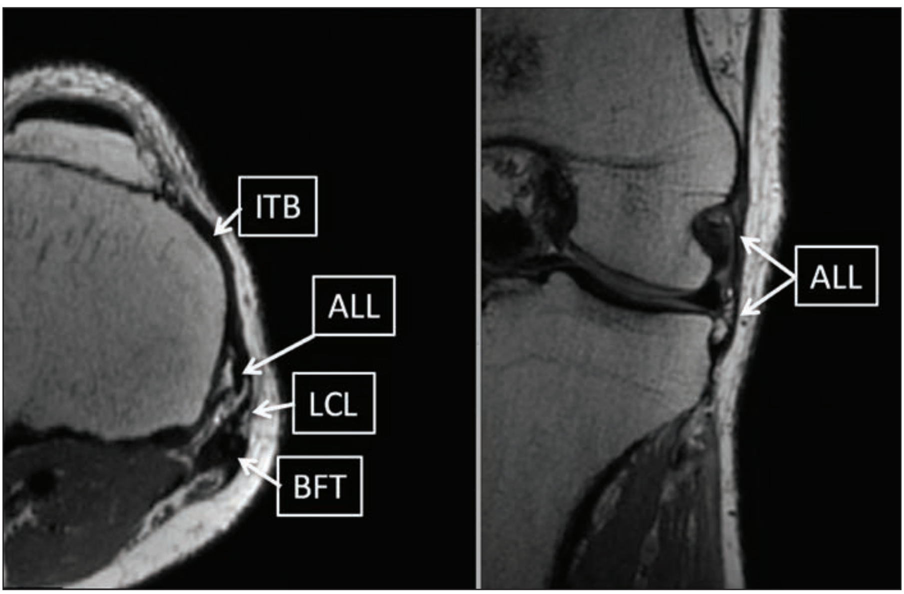


Fig. 2: ***MRI of the ALL. 3D 1 mm-section MRIs, T2-weighted images. Axial and coronal multiplanar reconstructions.*** **ALL*:*** ***anterolateral ligament,*** **ITB*:*** ***iliotibial band,*** **LCL*:*** ***lateral collateral ligament,*** **BFT*:*** ***biceps femoris tendon.***

Thus, it is possible to look for a stretched and/or torn ALL using ultrasound.

When an ALL injury is identified using MRI, today we routinely conduct further explorations using dynamic ultrasound (fig. 5, 6).

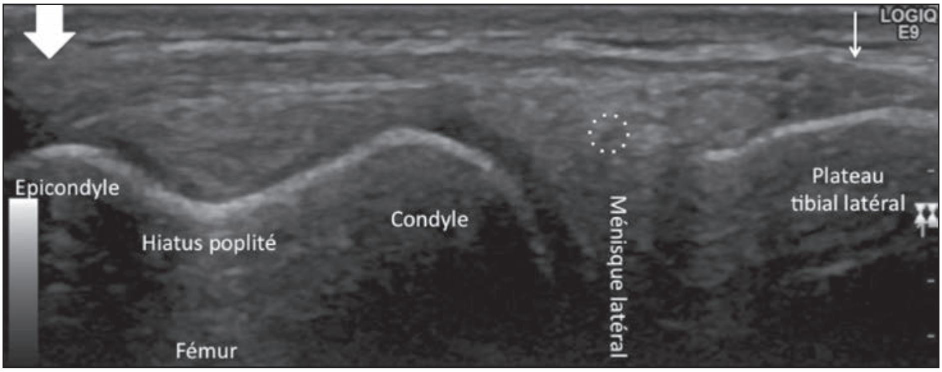


Fig. 3: ***Ultrasound of the ALL. Study with a high frequency 12 MHz superficial transducer. Normal appearance in resting position in a longitudinal section. The ligament is thicker at its femoral enthesis*** *(large arrow)* ***and thinner at its tibial enthesis*** *(small arrow)****. It crosses the lateral inferior genicular artery*** *(dotted circle)****.***

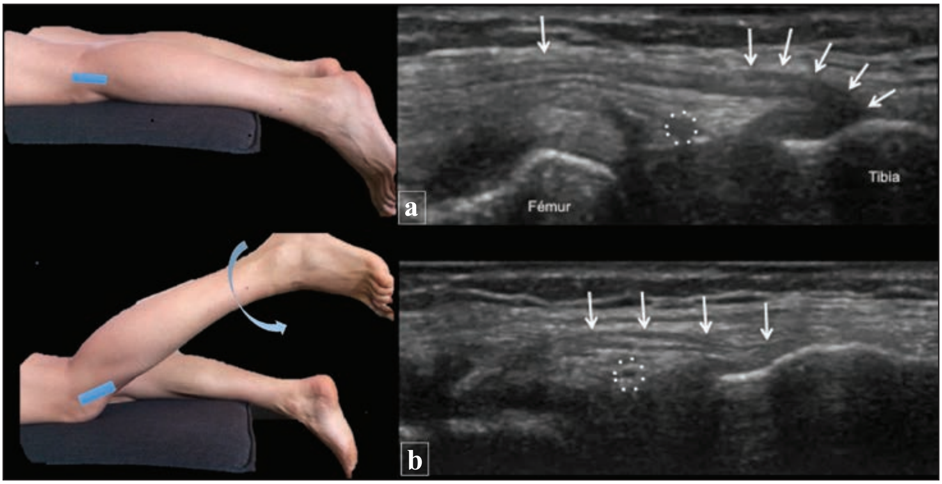


Fig. 4: ***Ultrasound of the ALL. Study of the ligament (arrows) with a very high frequency 15 MHz superficial transducer. Ligament in resting position*** *(figure a)****, relaxed at its tibial enthesis. Dynamic flexion and internal rotation maneuver*** *(figure b)* ***making the ligament tense so that it straightens.***

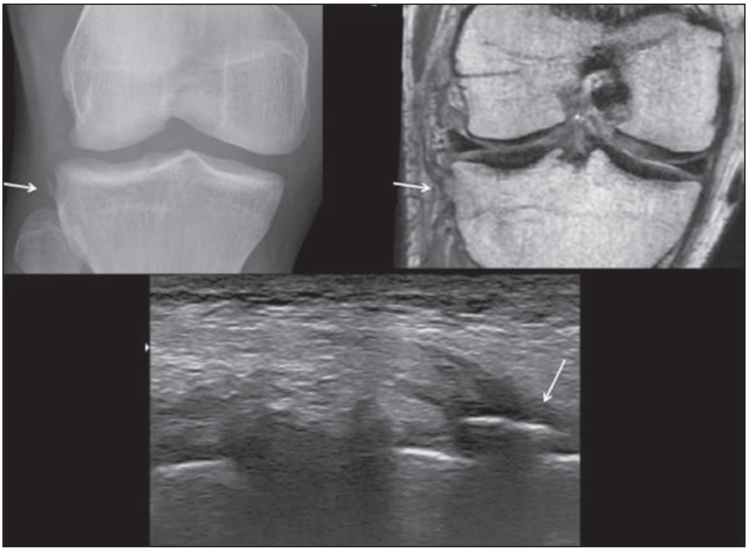


Fig. 5: ***Example of ALL tear by distal avulsion*** *(arrow)****. The standard radiography shows a Segond fracture. The 3D T2-weighted MRI and ultrasound show the pathological thickening of the ALL and its bony avulsion at the distal enthesis. Note the anterior cruciate ligament tear on the MRI*** *(asterisk)****. Thanks to Marie Faruch.***

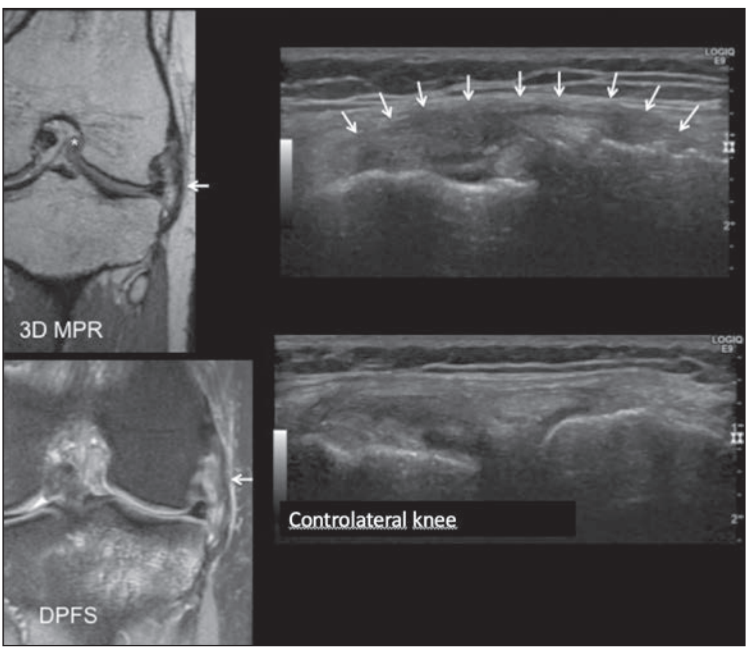


Fig. 6: ***Example of an ALL tear without any bone injury. Severe damage to the ALL under MRI and ultrasound without any bone injury. The ligament is completely infiltrated and thickened under MRI with a clearly visible pathological hypersignal on the sections using a fat suppression technique. Associated anterior cruciate ligament tear*** *(asterisk)****. Comparative ultrasound sections clearly show the hypoechoic ligament, which is thickened and distended on the injured side*** *(arrows)****.***

CONCLUSION

The ALL is visible using MRI and 3D acquisition protocols are necessary.

The ALL can also be studied using ultrasound, which has both the advantage of being a comparative examination and enabling dynamic maneuvers.

LITERATURE

[1] KOSY JD, MANDALIA VI, ANASPURE R. Characterization of the anatomy of the anterolateral ligament of the knee using magnetic resonance imaging. *Skeletal Radiol 2015; 44(11): 1647-53.*

[2] YOKOSAWA K, SASAKI K, MURAMATSU K, ONO T, IZAWA H, HACHIYA Y. Visualization of Anterolateral Ligament of the Knee Using 3D Reconstructed Variable Refocus Flip Angle-Turbo Spin Echo T2 Weighted Image. *Nihon Hoshasen Gijutsu Gakkai Zasshi 2016; 72(5): 416-23.*

[3] BORDET B, BORNE J, FANTINO F. Identification du ligament antérolatéral du genou en IRM. *Journées françaises de radiologie 2014; Paris, France.*

[4] HELITO CP, HELITO PV, COSTA HP, DEMANGE MK, BORDALO-RODRIGUES M. Assessment of the Anterolateral Ligament of the Knee by Magnetic Resonance Imaging in Acute Injuries of the Anterior Cruciate Ligament. *Arthroscopy 2016; Epub ahead of print.*

[5] CIANCA J, JOHN J, PANDIT S, CHIOU-TAN FY. Musculoskeletal ultrasound imaging of the recently described anterolateral ligament of the knee. *Am J Phys Med Rehabil 2014; 93(2): 186.*

[6] CAVAIGNAC E, WYTRYKOWSKI K, REI-NA N, MURGIER J, LAUMOND G, FARUCH M. *et al.* Ultrasonographic Identification of the Anterolateral Ligament of the Knee. *Arthroscopy 2016: 120-6.*

[7] OSHIMA T, NAKASE J, NUMATA H, TAKATA Y, TSUCHIYA H. Ultrasonography imaging of the anterolateral ligament using real-time virtual sonography. *Knee 2016; 23(2): 198-202.*

[8] FARUCH M, BORDET B, LAPEGUE F, CAVAIGNAC E, BORNE J, FANTINO O, SANS N. Echographie du LAL : LOL ? Actualités en échographie de l'appareil locomoteur. *Paris : Sauramps medical 2015; p. 95-112.*

ANTEROLATERAL LIGAMENT OF THE KNEE

B. SONNERY-COTTET, R. ZAYNI

INTRODUCTION

The 2013 publication by Steven Claes [1] in the *Journal of Anatomy* about the knee's anterolateral ligament (ALL) generated significant media attention related to the discovery of a "new knee ligament". Since then, more than 85 anatomical and biomechanical studies on this anatomical structure have been published. These described the ALL's anatomy in detail and more importantly, established its role in knee kinematics.

Despite this large research effort, there is still a great deal of controversy surrounding the ALL. Some authors feel this anatomical structure does not exist [2] nor contribute to knee stability [3]. But other studies have identified the ALL in all dissected knees [4-6]. It was described as having ligament-like properties [7, 8], and being involved in rotational control of the knee [9, 10].

The main questions for surgeons in 2016 are whether the ALL is truly a ligament structure, if it actually has a role in controlling knee rotation and above all, if it needs to be repaired during anterior cruciate ligament (ACL) reconstruction.

HISTORY

This structure was first described in 1879 by a French surgeon, Paul Segond [11]. While dissecting cadaver knees, he noted the presence of a "pearly, resistant, fibrous band over the anterolateral aspect of the joint. This band invariably was under extreme tension during forced internal rotation of the knee. Gerdy's tubercle never fails, only a bone segment immediately behind it". The Segond fracture was named based on these observations and its location has recently been confirmed [12].

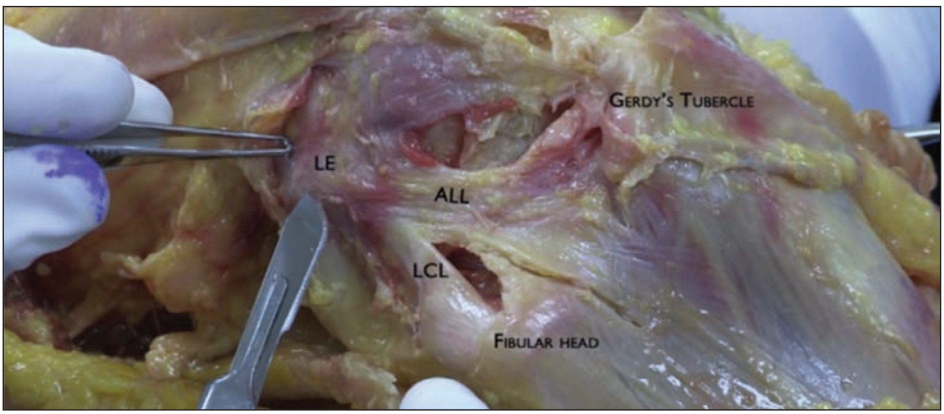
This structure was then in large part forgotten, until Jack Hughston published several articles on various types of knee rotational instability in 1976 [13, 14]. He referred to a "mid-third lateral capsular ligament" that inserted on the lateral meniscus and was divided in menisco-

femoral and meniscotibial segments. According to Hughston, this “capsular ligament” was “strong and supported superficially by the iliotibial band” and it played a significant role in the knee’s anterolateral stability. In 1986, Terry *et al.* [15] also referred to an anatomical structure deep to the fascia lata that acts as an “anterolateral ligament of the knee”. The presence of this structure was confirmed by Vieira [16] and then described in depth by various teams [1, 7, 8].

ANATOMY

In 2016, we described a simple, reproducible method to dissect and identify the ALL surgically [4]. Dissection starts at the ALL’s tibial insertion. Distal detachment of the biceps femoral exposes the lateral collateral ligament and also reveals the more superficial ALL. Flexing the knee and maximally rotating the tibia internally places tension on the ALL, making it easy to identify. The ALL’s femoral insertion has been the most controversial. The current consensus is that it is located proximal and posterior to the epicondyle [5, 6, 17, 18].

Near the joint line, the ALL has projections on the lateral meniscus [8] and the anterolateral capsule; most of its fibres fan out and insert distally on the tibia between the fibular head and Gerdy’s tubercle. Its tibial insertion is more than 10mm wide [6]. It is located on average 21.6mm posterior to Gerdy’s tubercle and 23.2mm anterior to the fibular head [1], and is 10mm distal to the joint line [1, 7, 8, 17].



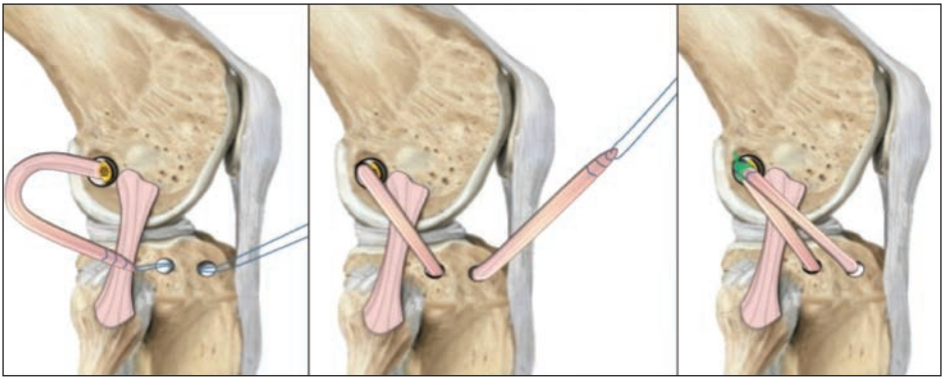
SURGICAL TECHNIQUE

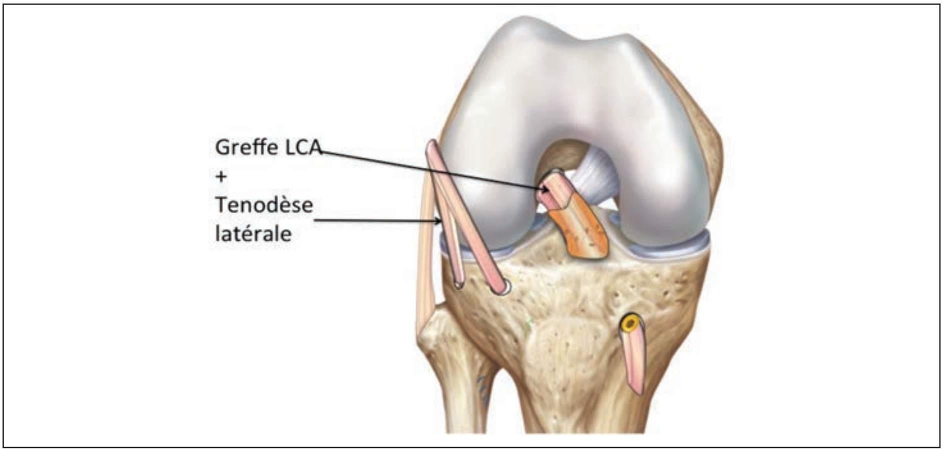
We have previously described several ALL reconstruction techniques that are performed alone or in combination with ACL reconstruction [19, 20]. The patient is placed in a standard supine position with a lateral pad at the tourniquet and a distal pad placed to keep the knee at 90° intraoperatively.

Combined ACL/ALL reconstruction [19]

We use the semitendinosus (ST) and gracilis (G) tendons as grafts; they are harvested using an open tendon stripper to preserve their tibial attachment points. The ST is used to reconstruct the ACL; it is tripled to provide a 12-cm long graft from its tibial attachment. The gracilis is then detached from its tibial insertion; one part is used to quadruple the ST and its distal end is used to reconstruct the ALL. This results in an 8-10mm diameter ACL graft. Two skin incisions less than 1cm long are made to prepare the ALL distal attachment sites: in front of the fibular head and behind Gerdy's tubercle for the tibia. Next, two 4.5-mm connected tunnels are made from these points to reproduce the ALL's tibial attachment. A third incision is made at the femur, posterior and proximal to the epicondyle. A suture is used to ensure that the distance between these three points differs when the knee is moved – the ALL must be tight in extension and slack in flexion.

The ACL's tibial tunnel is made in the standard manner. Using an outside-in guide, the ACL's femoral tunnel is placed over the femur's isometric point (i.e. proximal to the epicondyle), which corresponds to the ALL's femoral insertion. After passing the ACL graft from inferior to superior, it is secured with interference screws at the tibia and femur. The pre-sutured gracilis strand is passed subcutaneously and under the fascia lata, and then retrieved through the superolateral incision on the tibia; a traction suture is used to pull it out of the anterior tibial tunnel. It is then retrieved through the proximal incision over the femoral tunnel and sutured to itself. With the knee fully extended, this graft is secured with an interference screw at the anterior tibial tunnel to ensure it is tight in extension and slack in flexion. The tibia must not be rotated.

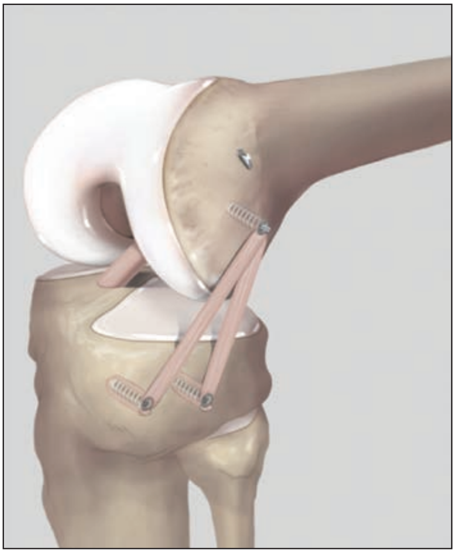




Isolated ALL reconstruction [20]

The gracilis tendon is used as a graft. Two K-wires are inserted through two, less than 1-cm long skin incisions: one on the posterior edge of Gerdy's tubercle and one anterior to the fibular head. A third K-wire is placed posterior and proximal to the epicondyle. A suture is used to ensure that the distance between these three points differs when the knee is moved – the ALL must be tight in extension and slack in flexion. After the isometry has been checked, 6 x 20mm tunnels are made in the femur and tibia.

The gracilis graft is secured to the femur using a 5.5-mm suture anchor (SwiveLock®, Arthrex). The two distal ends are retrieved subcutaneously through the distal incisions, making sure they pass under the fascia lata. Tibial fixation of the two strands is carried out with the knee fully extended to avoid fixation in external rotation.



CLINICAL OUTCOMES

The “rediscovery” of the ALL has redirected the attention of orthopaedic surgeons to peripheral knee structures that contribute to rotational instability. Published studies have shown that lateral tenodesis associated with ACL reconstruction can reduce rotational instability, but that it does not necessarily have a significant effect on clinical outcomes. Only one article has reported clinical outcomes after combined ALL/ACL reconstruction [21]. In 2015, Sonnery-Cottet and colleagues described 92 ACL reconstruction cases performed concurrently with percutaneous ALL reconstruction. The semitendinosus tendon was used for the ACL. A double-bundle gracilis tendon was used for the percutaneous ALL reconstruction to reproduce its triangular shape with large tibial attachment. The mean follow-up was 32.4 months (24-39). Pre-operatively, 47 patients had a grade 1 pivot shift, 22 had grade 2 and 23 had grade 3. After the surgery, 82 patients had no pivot shift and 10 had a grade 1 pivot shift. There were no specific complications related to the surgical technique. One patient had an ACL rerupture 1 year after the surgery, while six patients had a contralateral ACL tear. These findings were confirmed in a retrospective study of more than 600 ACL-deficient patients operated between 2011 and 2014 who were reviewed after 40 months. The rerupture rate was significantly lower in the group with combined ACL/ALL reconstruction than in the group with isolated ACL reconstruction (patellar tendon or hamstring graft).

The excellent stability and functional outcome, the simplicity of the surgical technique, the small aesthetic impact of the percutaneous technique and the low failure rate have allowed us to expand our indications considerably over the past 5 years. Combined reconstruction is now performed in nearly 50% of our ACL reconstruction patients. We strongly believe that this combined technique not only provides better control over rotational stability, but also reduces the rerupture rate in high-risk patients (e.g. under 20 years of age, competitive athletes, pivot sports, lateral notch, etc.).

CONCLUSION

In our hands, combined ACL/ALL reconstruction performed in more than 1000 patients has led to good clinical outcomes with no specific complications related to the ALL reconstruction. Along with satisfactory rotational control, the significantly lower rerupture rate versus isolated reconstruction techniques (BPTB, HG) has lead us to expand our indications. A prospective randomised study has been initiated to address the absence of a control group and the need for longer follow-up.

LITERATURE

[1] CLAES S, VEREECKE E, MAES M, VICTOR J, VERDONK P, BELLEMANS J. Anatomy of the anterolateral ligament of the knee. *J Anat 2013; 223(4): 321-8.*

[2] MUSAHL V, RAHNEMAI-AZAR AA, VAN ECK CF, GUENTHER D, FU FH. Anterolateral ligament of the knee, fact or fiction? *Knee Surg Sports Traumatol Arthrosc 2016; 24(1): 2-3.*

[3] KITTL C, EL-DAOU H, ATHWAL K, *et al.* The role of the anterolateral structures and the ACL in controlling laxity of the intact and ACL-deficient knee. *Am J Sports Med 2016; 44(2): 345-54.*

[4] DAGGETT M, BUSCH K, SONNERY COTTET B. Surgical dissection of the anterolateral ligament. *Arthroscopy Techniques 2016 ; (1): e185-8.*

[5] DAGGETT M, OCKULY A, CULLEN M, *et al.* Femoral origin of the anterolateral ligament: an anatomic analysis. *Arthroscopy 2016; 32(5): 835-41.*

[6] LUTZ C, SONNERY-COTTET B, NIGLIS L, FREYCHET B, CLAVERT P, IMBERT P. Behavior of the anterolateral structures of the knee during internal rotation. *Orthop Traumatol Surg Res 2015; 101(5): 523-8.*

[7] VINCENT JP, MAGNUSSEN RA, GEZMEZ F, *et al.* The anterolateral ligament of the human knee: an anatomic and histologic study. *Knee Surg Sports Traumatol Arthrosc 2012; 20: 147-52.*

[8] HELITO CP, DEMANGE MK, BONADIO MB, *et al.* Anatomy and histology of the knee anterolateral ligament. *Orthop J Sports Med 2013; 1(7): 1-5.*

[9] SONNERY-COTTET B, LUTZ C, DAGGETT M, DALMAY F, FREYCHET B, NIGLIS L, IMBERT P. The Involvement of the Anterolateral Ligament in Rotational Control of the Knee. *Am J Sports Med 2016; pii: 0363546515625282.*

[10] RASMUSSEN MT, NITRI M, WILLIAMS BT, MOULTON SG, CRUZ RS, DORNAN GJ, GOLDSMITH MT, LAPRADE RF. An *In Vitro* Robotic Assessment of the Anterolateral Ligament, Part 1: Secondary Role of the Anterolateral Ligament in the Setting of an Anterior Cruciate Ligament Injury. *Am J Sports Med 2016; 44(3): 585-92.*

[11] SEGOND P. Recherches cliniques et expérimentales sur les épanchements sanguins du genou par entorse. *Progrès Médical (Paris) : 1-85, 1879. Disponible sur http://www.patrimoine.edilivre.com/recherches-cliniques-et-experimentales-surles-epanchements-sanguins-du-genou-par-entorse-parpaul-segond-segond-paul-ferdinand-dr-1879-ark-12148-bpt6k5712206r.html.*

[12] CLAES S, LUYCKX T, VEREECKE E, BELLEMANS J. The Segond fracture: a bony injury of the anterolateral ligament of the knee. *Arthroscopy 2014; (11): 1475-82.*

[13] HUGHSTON JC, ANDREWS JR, CROSS MJ, MOSCHI A. Classification of knee ligament instabilities. Part I. The medial compartment and cruciate ligaments. *J Bone Joint Surg Am 1976; 58(2): 159-72.*

[14] HUGHSTON JC, ANDREWS JR, CROSS MJ, MOSCHI A. Classification of knee ligament instabilities. Part II. The lateral compartment. *J Bone Joint Surg Am 1976; 58(2): 173-9.*

[15] TERRY GC, HUGHSTON JC, NORWOOD LA. The anatomy of the iliopatellar band and iliotibial tract. *Am J Sports Med 1986; 14: 39-45.*

[16] VIEIRA ELC, VIEIRA EA, DA SILVA RT, DOS SANTOS BERLFEIN PA, ABDALLA RJ, COHEN M. An anatomic study of the iliotibial tract. *Arthroscopy 2007; 23(3): 269-74.*

[17] DODDS AL, HALEWOOD C, GUPTE CM, WILLIAMS A, AMIS AA. The anterolateral ligament: Anatomy, length changes and association with the Segond fracture. *Bone Joint J 2014; 96-B(3): 325-31.*

[18] KENNEDY MI, CLAES S, FUSO FA, WILLIAMS BT, GOLDSMITH MT, TURNBULL TL, WIJDICKS CA, LAPRADE RF. The Anterolateral Ligament: An Anatomic, Radiographic, and Biomechanical Analysis. *Am J Sports Med 2015; 43(7): 1606-15.*

[19] SONNERY-COTTET B, THAUNAT M, FREYCHET B, PUPIM BH, MURPHY CG, CLAES S. Outcome of a Combined Anterior Cruciate Ligament and Anterolateral Ligament Reconstruction Technique With a Minimum 2-Year Follow-up. *Am J Sports Med 2015; 43(7): 1598-605.*

[20] SONNERY COTTET B, BARBOSA NC, TUTEJA S, DAGGETT M, KAJETANEK C, THAUNAT M. Minimally invasive Anterolateral Ligament reconstruction in the setting of Anterior Cruciate Ligament injury. *Arthroscopy Techniques 2016; 5(1): e211-5.*

THE ILIOTIBIAL BAND WITH ITS FEMORAL ATTACHMENTS AT THE KNEE IS THE MOST IMPORTANT LATERAL SOFT TISSUE RESTRAINT TO "ALRI"

A. WILLIAMS

INTRODUCTION

Nearly all cases of ACL rupture are associated with a "subluxation" of the lateral compartment of the knee. This explains the characteristic bone bruising associated with ACL rupture on the middle of the lateral femoral condyle and the posterior portion of the lateral tibia. To achieve this "subluxation", lateral soft tissues must yield. Not surprisingly on an MRI scan following an acute ACL rupture there is usually significant oedema in the lateral soft tissues. Furthermore, acute exploration of the lateral side of the knee after ACL rupture will show haemorrhage in the tissues [1]. It is likely that most of these injured tissues heal spontaneously. Nevertheless, the fact that they are ruptured at the time of ACL injury implies there may be some role of these tissues in controlling anterolateral rotatory instability (ALRI). Since not all ACL reconstructions, even if undertaken technically perfectly, result in abolition of the pivot shift, nor total patient confidence, lateral surgical procedures to augment intra-articular ACL reconstruction may have benefit.

Of course, in the past many different lateral procedures were used in this context. With the success of intra-articular ACL reconstruction however, in large parts of the world, these procedures were abandoned as they were thought to be the cause of complications and both biomechanically and clinically unnecessary. This was certainly the approach in the English-speaking world. Particularly in France, and especially Lyon, the use of such procedures persisted with good affect. When abandoned the various tenodeses were criticized for being associated with failure due to stretching, and stiffness, and lateral osteoarthritis. The suggestion was that the morbidity of the surgery caused stiffness and that over constraint of the lateral compartment caused osteoarthritis. However, if one looks back to the era during which lateral surgical procedures such as the Macintosh and Lemaire were undertaken, it is worth noting that the postoperative rehabilitation often involved prolonged periods immobilised in a cast with the knee flexed and the leg in external rotation. Also many cases had previously had total meniscectomies. Of course in many cases no intra-articular ACL reconstruction was undertaken and so biomechanical success was unlikely in this situation. Because of these mitigating factors and the potential for lateral soft tissue procedures being beneficial, it is time to re-evaluate not only the procedures, but the lateral soft tissue anatomy itself.

THE ANTEROLATERAL LIGAMENT

In recent times the first description of an "anterolateral ligament" was in a study from Lyon [2]. Shortly before this the senior author of the aforementioned article, P[r] Philippe Neyret, collaborated with a group at Imperial College, London, to set out the logic for lateral soft tissue surgery with ACL reconstruction [3] but it was following an article in 2013 by Claes *et al.* [4] that an extraordinary amount of interest was shown, even in the popular press and social media. In this study embalmed Cadavers were dissected to demonstrate a structure on the lateral side of the knee termed the "anterolateral ligament". The authors described a well-defined attachment to the tibia midway between the lateral collateral ligament (LCL) attachment to the fibular head and Gerdy's tubercle. But their description of the attachment of the femoral end of the ligament was vague. A few months later another article from Imperial College by Dodds *et al.* [5], which employed dissection of fresh frozen Cadavers confirmed the tibial attachment described by Claes *et al.* [4] and defined the correct position of the femoral attachment proximal and posterior to the LCL attachment to the femur.

Fig. 1: ***Dissection of a knee at 90 degrees flexion demonstrating the anterolateral ligament.***
Red ***pin = femoral attachment of LCL;*** *green* ***pin = Gerdy's tubercle. The anterolateral ligament is highlighted by white arrows, and is seen passing obliquely superficial to the LCL from its femoral attachment proximal and posterior to the femoral LCL attachment, to the mid-point between the LCL attachment to the fibula and Gerdy's tubercle.*** *(Courtesy of Am J of Sports Med)***.**

Subsequently published collaboration between Steven Claes and Robert LaPrade's group [6] confirmed the femoral attachment described by Dodds *et al.* [5].

As is often the way with anatomic "discoveries", the anterolateral ligament has almost certainly been described previously in many publications but with different naming. For example as long ago as 1976 Hughston *et al.* [7] described the "mid third capsular ligament".

Many studies have been published recently that seem to confirm the existence of an anterolateral ligament. Nevertheless the structure is not always easy to dissect free and may not be present in some cases. Some authors resort to define the ligament by internal rotation and sharp dissection of a fold that appears in the deep soft tissue.

THE ILIOTIBIAL BAND AND ITS ATTACHMENTS TO THE DISTAL LATERAL FEMUR

It has been long realised that there are strong, easily identifiable fibrous attachments from the iliotibial band to the distal lateral femur. These have been referred to as Kaplan's fibres due to the description in 1959 [8]. These lead into the posterior portion of the iliotibial band described by Terry as the deep capsulo-osseous layer [1]. The band of tissue thus formed from the fibres attached to the femur pass distally within the posterior iliotibial band to Gerdy's tubercle provide a thick, strong band of tissue that is ideally located and aligned to resist internal rotation of the tibia.

Having previously studied the ALL at *Imperial College* [5] and described its anatomy our research focus was on this structure. However with further exploration of the lateral side of the knee it became obvious that, not only was the anterolateral ligament flimsy, but often hard to find. In comparison the IT band and its attachments to the lateral femur was present in every knee and robust. We felt this worthy of further study. The Kaplan's fibres are arranged in three specific attachments (retrograde, and supracondylar attachments and proximal).

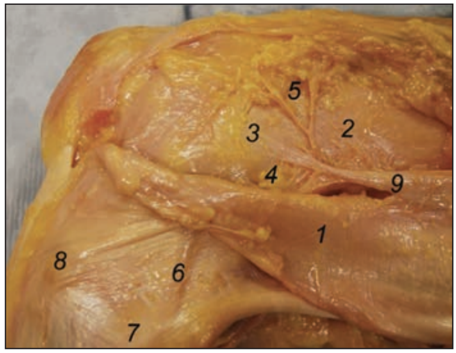


Fig. 2: ***Lateral soft tissues exposed by refection of ITB.***
Lateral aspect of a left knee: the femur extends proximally to the right, and the tibia extends distally toward the bottom left with the patella at the top left:* 1*), Superficial layer of the iliotibial tract (ITT) flapped down;* 2*) proximal femoral insertion of the ITT;* 3*) supracondylar insertion of the ITT;* 4*) retrograde insertion or capsulo-osseous layer;* 5*) superior genicular artery;* 6*) lateral collateral ligament;* 7*) fibular head;* 8*) Gerdy tubercle; and* 9*) intermuscular septum. *(Courtesy of Am J of Sports Med)***.**

BIOMECHANICAL STUDIES OF LATERAL SOFT TISSUES

In our lab at Imperial College, London, a classic cutting study using a 6-degree-of-freedom robot was undertaken [9]. Sequentially structures were sectioned and the same motion was replayed by the robot, whilst measuring the resistance to movement. In this way the percentage contribution to resisting certain movements could be calculated for the structures that had been cut. This was undertaken with the knee at straight, 30, 60 and 90 degrees. As one would expect, throughout the range of motion tested the anterior cruciate ligament is the primary restraint to anterior tibial translation.

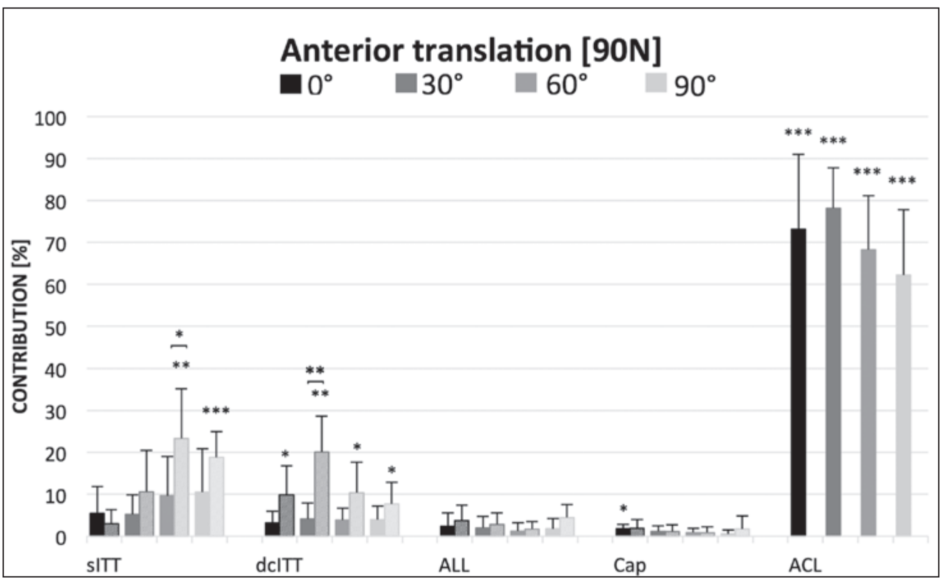


Fig. 3: ***Contribution of tested structures in restraining 90-N anterior tibial translation at 0°, 30°, 60°, and 90° of flexion. Crosshatched areas indicate results from the ACL-deficient group. Shown as mean + SD; n=8. Statistically significant change from the initial knee state (brackets indicate significant difference between ACL intact*** *vs* ***deficient): *P<.05, **P<.01, and ***P<.001.*** **ACL,** ***anterior cruciate ligament;*** **ALL,** ***anterolateral ligament;*** **Cap,** ***anterolateral capsule;*** **dcITT,** ***deep and capsulo-osseous layer of the iliotibial tract;*** **sITT,** ***superficial layer of the iliotibial tract.*** *(Courtesy of Am J of Sports Med)***.**

It was a surprise, however, that the ACL was only important in resisting internal rotation close to extension. For the rest of the range of knee motion tested, the ITB with its femoral attachments was the primary restraint to internal rotation and a simulated pivot shift by some way, whereas the ALL and capsule contributed only little.

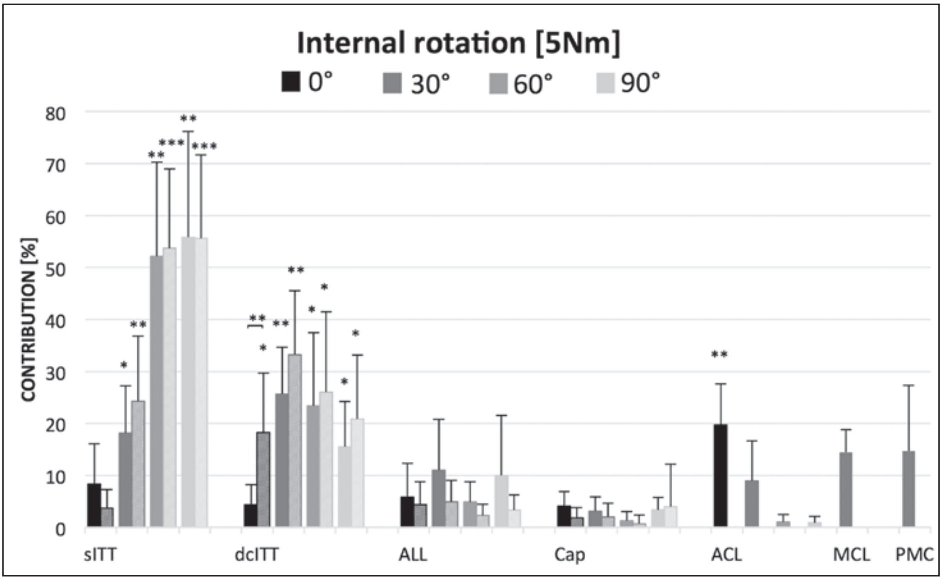


Fig. 4: ***Contribution of tested structures in restraining a 5-N·m internal rotation torque at 0°, 30°, 60°, and 90° of flexion. There is only 1 result each for the medial collateral ligament (MCL) and the posteromedial corner (PMC) because they were only tested at 30° of flexion on 4 knees. Crosshatched areas indicate results from the ACL-deficient group. Shown as mean + SD; n=8 (apart from the MCL and PMC: n=4). Statistically significant change from the initial knee state (bracket indicates significant difference between ACL intact vs deficient): *P<.05, **P<.01, and ***P<.001.*** **ACL*, anterior cruciate ligament;* ALL*, anterolateral ligament;* Cap*, anterolateral capsule;* dcITT*, deep and capsulo-osseous layer of the iliotibial tract;* sITT*, superficial layer of the iliotibial tract.*** *(Courtesy of Am J of Sports Med)*.

By attachment of metal “eyelets” through which sutures were passed attached to strain gauges, length changes of lateral soft tissue structures and of soft tissue grafts for various operative techniques were tested [10].

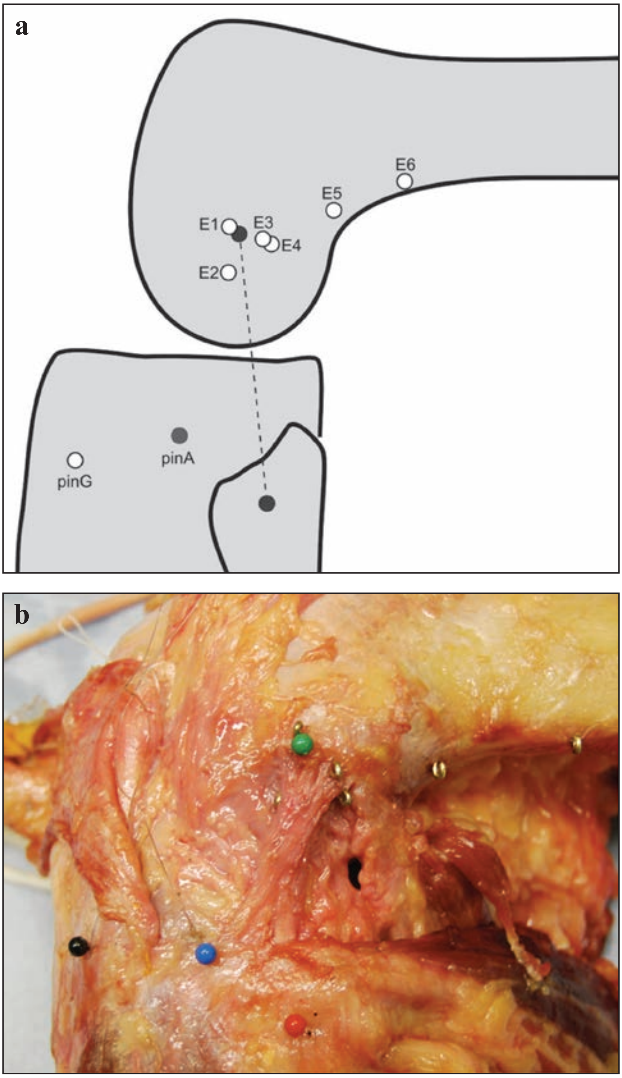


Fig. 5: ***Femoral eyelet positioning. Tibiofemoral point combinations account for structures on the lateral side, extra-articular soft tissue reconstructions, and femoral isometric points. (a) pinG, Gerdy tubercle; pinA, area of the Segond avulsion; dashed line, lateral collateral ligament. (b)*** *black* ***pin, Gerdy tubercle;*** *blue* ***pin, area of the Segond avulsion;*** *red* ***pin, fibular head;*** *green* ***pin, lateral epicondyle.*** *(Courtesy of Am J of Sports Med)****.***

In this testing length changes for the anterolateral ligament described by Claes *et al.* [4] and the anterolateral ligament described by Dodds *et al.* [5]. In addition he studied the length change of suture from Gerdy's tubercle to Kaplan's fibres, and also for attachmnent points for Lemaire and MacIntosh lateral tenodeses. For the tenodeses the sutures were placed superficial and also tested deep to the LCL. The findings showed that the most isometric lateral anatomical soft tissue was the iliotibial band with its connection to the femur. The anterolateral ligament attachment according to Dodds *et al.* [5] with the femoral attachment proximal and posterior to the femoral attachment to the LCL tightened towards extension and slackened in flexion. An ALL attachment point to the femur distal to the LCL attachment to the femur was loose in extension and tight in flexion, which was not surprising! All of the lateral tenodesis procedures performed better than the best ALL reconstruction so as long as the suture was taken deep to the lateral collateral ligament.

Subsequent unpublished data shows that testing reconstructive techniques shows superiority of ITB-based tenodeses taken deep to the LCL, as compared to a Lemaire procedure taken superficial to the LCL, and an ALL reconstruction in the position described by Dodds *et al.* [5]. Unfortunately surgical techniques employing a femoral attachment distal to the LCL attachment to the femur for ALL reconstruction have been poularised. Not only are these illogical but, since they loosen extension, they cannot be effective; and since they tighten with flexion they could be harmful to patients.

In summary, the biomechanical testing we have undertaken at *Imperial College* has conclusively shown that the anterolateral ligament is of little significant, although it does exist, but that the main restraint to internal rotation in the lateral soft tissue envelope is the ITB with its attachment to the femur.

REPORTS TO THE CONTRARY IN THE LITERATURE

There are a number of papers that have been written showing apparent importance of the anterolateral ligament. Unfortunately the experimental designs for these often include removal or defunctioning of the iliotibial band. This means that if the main restraint has been removed it is not surprising that something that would normally be less effective becomes apparently more effective.

The amount of interest in the anterolateral ligament has been truly astonishing and, at times, worrying. The concept has been seized upon and has been rushed to surgery without the due diligence of proper scientific evaluation. For some reason the concept has been assumed to be the truth, and nothing but the truth, and therefore many of the publications that have followed are examples of "conformational bias". When a concept is embedded in the human brain everything else seems to fit this theory. This can be explained by saying "the eye sees what the brain knows".

The proper way to deal with a "new discovery", even if it is old (!), is to work through the subject step by step, evaluating the anatomy followed by the biomechanics, testing proposed reconstructions in a laboratory and finally having a committed approach to long term clinical outcome follow up.

LITERATURE

[1] TERRY GC, NORWOOD LA, HUGHSTON JC, CALDWELL KM. How Iliotibial Tract Injuries of the Knee Combined with Acute Anterior Cruciate Ligament Tears to Influence Abnormal Anterior Tibial Displacement. *Am J of Sports Med 1993; 21: 55-60.*

[2] VINCENT JP, MAGNUSSEN RA, GEZMEZ F, UGEN A, JACOBI M, WEPP F, AL-SAATI MF, LUSTIG S, DEMEY G, SERVIEN E, NERYRET P. The Anterolateral Ligament of The Human Knee; An Anatomic and Histologic Study. *Knee Surg Sports Traumatol Arthrosc 2012; 20(1): 147-52.*

[3] CM GUPTE, NEYRET P, WILLIAMS AM, AMIS A. Extra-articular Techniques in Anterior Cruciate Ligament Reconstruction *Dodds JBJS(Br) 2011; 93-B: 1440-8.*

[4] CLAES S, VEREECKE E, MAES M, VICTOR J, VERDONK P, BELLEMANS J. Anatomy of the Anterolateral Ligament of the Knee. *J Anat 2013; 223: 321-8.*

[5] AL DODDS, C HALEWOOD, CM GUPTE, A WILLIAMS, AA AMIS. The Anterolateral Ligament: Anatomy, length changes and association with the Segond fracture. *Bone Joint J 2014; 96-B: 325-31.*

[6] KENNEDY MI, CLAES S, FUSO FA, WILLIAMS BT, GOLDSMITH MT, TURNBULL TL, WIJDICKS CA, LAPRADE RF. The Anterolateral Ligament: An Anatomic, Radiographic, and Biomechanical Analysis. *Am J Sports Med 2015; 43: 1606-15.*

[7] HUGHSTON JC, ANDREWS JR, CROSS MJ, MOSCHI A. Classification of knee ligament instabilities: Part Two The Lateral Compartment. *JBJS (Am) 1976; 58-A: 173-9).*

[8] KAPLAN EB The Ilio-Tibial Tract- clinical and morphological significance. *JBJS(Am) 1958; 40-A: 817-32.*

[9] C KITTL, H EL-DAOU, KK ATHWAL, CM GUPTE, A WEILER, A WILLIAMS, AA AMIS. The role of the anterolateral structures and the ACL in controlling laxity of the intact and ACL-deficient knee. *Am J Sports Med 2016; 44: 345-54.*

[10] C KITTL, C HALEWOOD, J STEPHEN, GUPTE C, A WEILER, A. WILLIAMS, AA AMIS. Length change patterns of the lateral extra-articular structures of the knee and related reconstructions. *Am J Sports Med 2015; 43(2): 354-62.*

Acknowledgements

Imperial College, London, Laboratory Work: Alex Dodds; Christoph Kittl, Eivint Inderhaug, Hadi El-Daou, Camilla Halewood.
Supervision: Pr Andrew Amis (Imperial College, London) and Jo Stephen (Imperial College and Fortius Clinic, London).

Disclosure

3 Fellows part-funded by Smith and Nephew German Speaking Association of Arthroscopy (AGA) part sponsored C. Kittl.

PIVOT SHIFT TEST: HOW DOES IT WORK

A. SONI, V. MUSAHL

INTRODUCTION

Pivot shift test is considered as gold standard clinical examination for diagnosis of anterior cruciate ligament (ACL) injury. It evaluates the combined tibio-femoral internal rotation and anterior tibial translation that occurs when the ACL is injured or deficient. In 1972, Galway and Macintosh *et al.* [1] described the test in its current form and named it "Pivot shift test". They used the pivot shift for clinical examination in patients complaining of "giving way" of the knee and described it as the most prominent form of instability of the knee in patients recovering from severe soft tissue injury to the knee. This pathological motion was graded into 3 grades. Subsequently, various authors like Slocum and Larson, Hughston, Losee, Lemaire and Jacob studied this phenomenon and published several modified techniques to assess this anterolateral instability [2]. But, Pivot shift test still remains the most popular and reliable assessment tool [3]. It has been routinely utilized for pre and post-operative assessment of the ACL surgery and considered as most specific test for the diagnosis of ACL injury, if performed under anaesthesia [4].

Post-operative pivot shift grading has been shown to have direct correlation with patient satisfaction, return to sport and future risk of development of osteoarthritis [2]. As there is significant inter-observer variation in knee laxity assessment, an attempt to measure laxity in a quantitative & reproducible manner has been a topic of immense interest lately. This interest has led to development of tools, which can provide repeatable and objective quantification. Improvement in the objective assessment of knee laxity provides clinicians with better insight into the injury profile, and can help to specifically shape treatment protocols. In this chapter, we have discussed various aspects of pivot shift test along with recent advances in making it a quantitative assessment tool for development of individualized treatment algorithms.

PATHOMECHANICS & ELEMENTS OF PIVOT SHIFT

The pivot shift is a complex, multiplanar manoeuvre that incorporates two main components: translation (the anterior subluxation of the lateral tibial plateau followed by its reduction) and rotation (the rotation of the tibia relative to the femur). The examiner applies an internal rotation and valgus force to the extended knee and if there is ACL incompetence, the tibia will usually sublux anterolaterally on the femur. A flexion and valgus force is then applied to the knee and while flexing the knee; the illiotibial

band changes it role from being an extender to a flexor of the knee and will visibly reduce any subluxation. Clinically, the magnitude of the pivot shift is graded in accordance with the subjective feel of the reduction as the anteriorly subluxed tibia reduces. This subluxation/reduction event occurs in the lateral compartment at approximately 20-30 degrees of flexion. It is always important to compare the exam to the contralateral knee to determine if the patient may have some underlying laxity when performing this test.

COMING UP WITH A STANDARDIZED MANEUVER

Differences in the amount of anterior tibial subluxation during pivot shift testing have been shown to vary considerably between examiners [5], which may complicate the assessment of this maneuver. These differences likely reflect differences in the applied axial, valgus, and rotational forces, as well as differences in the position of the leg and knee flexion during the maneuver. These subtle differences are further amplified by variation in grading between examiners for the same degree of subluxation. Various systems of grading the pivot shift have been recommended to allow for more uniform evaluation of rotatory laxity.

To bring uniformity to the testing technique and possibly decrease the effect of some of above-mentioned variables, we described a standardized pivot shift test maneuver [6]. It was designed on the basis of Galway and MacIntosh flexion type procedure [1]. Its applicability was tested on 12 world renowned, high volume ACL surgeons. Quantitative results of their preferred pivot shift test technique was compared to standardized testing maneuver. It was found that the variation of acceleration during the pivot shift test across different surgeons utilizing their preferred technique was significantly reduced by performing the pivot shift test in a standardized maneuver.

To assess left knee, the steps for this standardized maneuver are as follows (fig. 1).

Step 1: Stand facing the patient at foot level and hold the heel with left hand. Abduct the hip followed by internally rotating with left hand.

Step 2: Put right hand with thumb up just distal to joint line and apply gentle valgus stress, thus allowing spontaneous flexion.

Step 3: Flex the knee with the right hand and release the rotational stress. Reduction movement can be felt with the right.

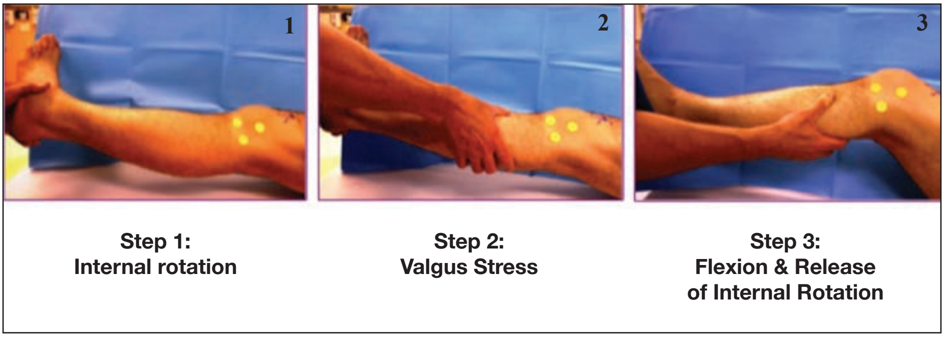


Fig. 1: *Standardized maneuver in three steps.*

CLINICAL GRADING AND FACTORS AFFECTING PIVOT SHIFT

Pivot shift can be graded clinically according to the amount of pathological motion observed and is used in IKDC score.

0- Normal
1- Subtle change in motion or glide
2- Distinct reduction or clunk
3- Significant clunk with locking (impingement of the posterolateral tibial plateau against lateral femoral condyle)

Other simplistic way to describe pivot shift is to divide it into low grade or high grade. Low grade includes both grade 0 and 1 of IKDC where as high grade includes grade 2 and 3.

There are various anatomical and structural factors, which play role in exaggerating or masking the pivot shift grading. They are summarized in Table 1.

QUANTIFICATION OF THE TEST-INSTRUMENTED ASSESSMENT OF ROTATORY KNEE INSTABILITY

To eliminate subjective grading, attempts have been made in developing devices to objectively quantify the pivot shift test. The primary reason for the difficulty to establish an evaluation system is the complexity of the pivot shift movement that is composed of a six degree-of-freedom tibial internal-external (i-e) rotation, varus-valgus (v-v) rotation, and anterior-posterior (a-p) translation. Computer assisted surgical navigation systems and electro-magnetic tracking devices are among the technologies that can provide kinematic data during the pivot shift test [7]. These technologies provide accurate kinematic data, but limitations exist such as invasiveness, bulkiness, and cost. In recent years, non-invasive technologies have been developed that can help clinicians to objectively quantify the pivot shift test. These technologies measure different aspects of bony motion during the pivot shift test. We have been using two these systems image analysis and inertial sensor technology.

IMAGE ANALYSIS TECHNOLOGY

While performing the pivot shift, anterior tibial translation in lateral compartment of the knee is more than that of the medial compartment. This translation correlates with the subjective grading of the pivot shift [8]. Based on this finding, we developed PIVOT software that uses a computer tablet's camera to record the motion of markers attached to the lateral aspect of the knee during the pivot shift maneuver

Table 1: ***Anatomical & Morphological factors affecting Pivot shift test***

Factors leading to increased Pivot shift test	*Factors masking Pivot shift test*
Lateral Meniscus injury Illiotibial band injury Anterolateral capsule injury Posterolateral corner injury Increased lateral tibial plateau posterior slope Small size of lateral tibial plateau	Medial Collateral ligament injury Illiotibial band laxity Patient guarding/Haemarthrosis Flexion contracture of knee Osteoarthritis

(fig. 2). The skin markers are attached to three bony landmarks on lateral side of the knee i.e, lateral epicondyle, Gerdy's tubercle, and the fibular head. The software is able to calculate the relative motion of tibia in relation to femur by recording and analyzing the video of the knee motion during pivot shift test. The lateral compartment translation measured by this technique has shown to be strongly correlated with bony motion measured invasively by electromagnetic tracking system. In distances less than or equal to 175cm between iPad and marker position this calculation has less than 6% error, which provides sufficient accuracy for the clinical set-up. Considering the analysis time of 10-15 seconds, image analysis constitutes an easily applicable tool for the daily clinical work [9].

INERTIAL SENSOR TECHNOLOGY

The acceleration during the tibial reduction of the pivot shift is significantly higher in ACL deficient knees and correlates with the clinical grading of the pivot shift [7]. Different types of inertial sensors (accelerometers, gyroscopes, micro-electromechanical system sensors) have been used to quantify this acceleration, rotation and velocity of the bony motion. Similar to the principle of image analysis, the sensors are attached to the lateral aspect of the proximal tibia, close to Gerdy`s tubercle. Transmitting the gathered acceleration *via* Bluetooth to a tablet software, named Kira (Orthokey LLC, Lewes, DE, USA), the data is subsequently analyzed, plotted and saved in a patient data base (fig. 3). The applicability and reliability of this technology was demonstrated in laboratory setting as well as in the clinical use [10]. Together these devices provide comprehensive insight to joint rotatory laxity.

During a test, the tablet's camera records the movement of the markers while the knee is being examined (fig. 3). The software scans the images in real time and utilizes custom algorithms that shade the entire image except the markers by adjusting the brightness and contrast. The software then automatically tracks the movement of the markers and calculates the translation of the pivot point defined by the intersection of the line between markers on the fibular head and Gerdy's

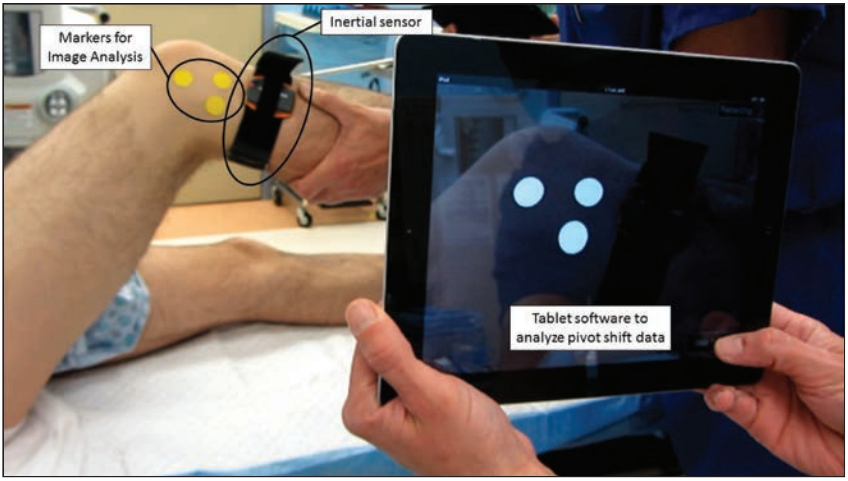


Fig. 2: ***Testing set-up for the quantitative pivot shift measurement by image analysis technology and inertial sensors. For image analysis technology markers are attached to the bony landmarks fibular head, Gerdy's tubercle and femoral epicondyle to quantify lateral compartment translation. Inertial sensors are utilized to measure the acceleration of the tibia in the reduction phase of the pivot shift. Both systems use tablet-software to acquire and analysis the data.***

tubercle with a perpendicular line crossing the femoral condyle marker (fig. 4). After tracking the markers, the software provides a reduction plot that represents reduction of the tibia during pivot shift test. From this plot the amount of translation can be determined by selecting the maximum and minimum points of the plot at the time of the reduction, hence providing us with a quantifiable number.

These devices provide objective quantification of rotatory knee instability and avoid second-

Fig. 3: ***Screenshot of the Ipad showing acceleration plot for right knee during pivot shift testing, created by Image sensor technology Kira (Orthokey LLC, Lewes, DE, USA). White highlighted part in the curve shows the points of maximum and minimum acceleration. Acceleration range is calculated by subtracting minimum acceleration from maximum acceleration. Higher recorded peaks that occurred after pivot shift phenomenon are due to the sudden full extension of the extremity.***

Fig. 4: ***Configuration of skin markers and display of software interface for PIVOT application for the I-pad. A pivot shift test is performed in the photograph on the upper right with skin markers placed on the lateral femoral condyle, Gerdy's tubercle, and the fibular head. Tracking of the skin markers as observed on the iPad interface are shown in the two lower left boxes prior to and during the performance of the pivot shift. The change in the anterior-posterior position of the femur in relation to Gerdy's tubercle is recorded as a function of time as observed in the lower right image. The lateral compartment translation during pivot shift test was calculated by subtracting the highest and lowest values along the graph, which in this case is 5.627mm.***

guessing with subjective grading scales. Using them pre-operatively, different injury patterns and instability grades can be characterized based on patient factors. This can help us to devise individualized treatment plan for the patient. The future application of widespread quantitative evaluation technologies will help correlate patient reported outcome with objective findings of knee instability with the goal of improved patient outcomes.

SUMMARY

Pivot shift test is the most specific tool for assessment of anterolateral instability of the knee. It has application at all levels of care in ACL injured patient, right from pre operative phase to return to play decisions. Various anatomical and morphological factors can enhance or mask the pivot shift. Use of Standardized Pivot shift technique can bring uniformity to testing techniques. Quantitative assessment of pivot shift helps with the development of individualized treatment algorithm for the ACL-injured patient with the goal of achieving maximum athletic potential while at the same time preventing post-traumatic OA. In the future, quantitative pivot shift testing will aid surgeons in their indications for additional procedures such as extra articular tenodesis or meniscus allograft reconstruction.

LITERATURE

[1] GALWAY HR, BEAUPRÉ A, MACINTOSH DL. Pivot shift. A clinical sign of anterior cruciate ligament instability. *J Bone Joint Surg 1972; [Br] 54: 763.*

[2] LANE C, WARREN R, PEARLE A.The pivot-shift. *J Am Acad Orthop Surg 2008; 16: 679-88.*

[3] JONSSON H, RIKLUND-AHLSTROM K, LIND J. Positive pivot shift after ACL reconstruction predicts later osteoarthrosis: 63 patients followed 5-9 years after surgery. Acta Orthop Scand 2004; 75(5):594-9.

[4] VAN ECK CF, VAN DEN BEKEROM MP, FU FH, POOLMAN RW, KERKHOFFS GM. Methods to diagnose acute anterior cruciate ligament rupture: a meta-analysis of physical examinations with and without anaesthesia. *Knee surgery, sports traumatology, arthroscopy: official journal of the ESSKA. 2013; 21(8):1895-903. doi:10.1007/s00167-012-2250-9.*

[5] PEELER J, LEITER J, MacDONALD P. Accuracy and reliability of anterior cruciate ligament clinical examination in a multidisciplinary sports medicine setting. *Clinical journal of sport medicine: official journal of the Canadian Academy of Sport Medicine. 2010; 20(2): 80-5. doi:10.1097/JSM.0b013e3181ceca45.*

[6] HOSHINO Y, ARAUJO P, AHLDEN M, MOORE CG, KURODA R, ZAFFAGNINI S, KARLSSON J, FU FH, MUSAHL V. Standardized pivot shift test improves measurement accuracy. *Knee Surg Sports Traumatol Arthrosc 2012; 20(4): 732-6.*

[7] HOSHINO Y, KURODA R, NAGAMUNE K, YAGI M, MIZUNO K, YAMAGUCHI M *et al.* In vivo measurement of the pivot-shift test in the anterior cruciate ligament-deficient knee using an electromagnetic device. *The American journal of sports medicine. 2007; 35(7): 1098-104. doi:10.1177/0363546507299447.*

[8] BEDI A, MUSAHL V, LANE C, CITAK M, WARREN RF, PEARLE AD. Lateral compartment translation predicts the grade of pivot shift: a cadaveric and clinical analysis. *Knee surgery, sports traumatology, arthroscopy 2010; 18(9): 1269-76. doi:10.1007/s00167-010-1160-y.*

[9] MULLER B, HOFBAUER M, RAHNEMAI-AZAR AA, WOLF M, ARAKI D, HOSHINO *Y et al.* Development of computer tablet software for clinical quantification of lateral knee compartment translation during the pivot shift test. *Computer methods in biomechanics and biomedical engineering. 2015; 1-12. doi:10.1080/10255842.2015.1006210.*

[10] ARAUJO PH, AHLDEN M, HOSHINO Y, MULLER B, MOLONEY G, FU FH *et al.* Comparison of three non-invasive quantitative measurement systems for the pivot shift test. *Knee surgery, sports traumatology, arthroscopy: official journal of the ESSKA. 2012; 20(4): 692-7. doi:10.1007/s00167-011-1862-9.*

STATIC ROTATIONAL KNEE LAXITY MEASUREMENTS AND ANTEROLATERAL INSTABILITY

R. SEIL, C. MOUTON, D. THEISEN

INTRODUCTION

Rotatory knee laxity is controlled by the cruciate ligaments and secondary restraints, such as the capsule, menisci, collateral ligaments, and the iliotibial band (ITB). Clinical diagnosis of rotatory knee laxity can be performed by static and dynamic rotatory laxity tests. Static laxity testing is simple and non-invasive. It measures rotation of the tibia with respect to the femur and is not yet used in daily clinical practice. The goal of knee laxity measurements is to identify the laxity pattern of an individual patient, improve the diagnosis of anterior cruciate ligament (ACL) and peripheral injuries as well as the clinical outcome following ACL reconstruction surgery. The contribution of rotational laxity in this concept still needs to be defined.

Historically, Wang and Walkers analyzed rotational laxity in cadavers. They recorded torque-rotation graphs from each cadaver knee they examined and noticed a high inter-individual variability. Our own experiments showed that cutting the PL bundle of the ACL lead in average to a 10% increase in rotation, whereas the section of both bundles induced a 15% increase in rotation with a torque of 5 N/m at 30° of flexion (Lorbach).

A first attempt to measure rotation in vivo has been performed by Zarins in 1983. With increasing awareness of the importance of rotational control after ACL reconstruction, several devices to analyze rotation were developed by groups from Pittsburgh (Musahl), Vermont (Shultz), Luxembourg (Lorbach, Mouton, Seil), Decatur (Branch) with devices analyzing rotation. Each device is different, and the applied measurement conditions vary widely, mainly with respect to patient positioning, knee flexion angle, and the applied torques. The amount of torque applied usually varies between 5 and 15 Nm depending on lower limb fixation and patient comfort. Knee rotation is higher if the knee is flexed at 90° compared to 20° and if the hip is extended compared to the flexed position at 90°. To avoid overestimation of the measurements when rotation is measured at the foot, a solution is to measure tibial rotation directly at the proximal tibia *via* electromagnetic sensors (Alam).

In our experimental device, the Rotameter (Lorbach), the subject is lying prone to reproduce the dial test position. Hips are extended and knees flexed at 30°. The Rotameter overestimates the total range of rotation at 5, 10, and 15 Nm by an average of 5, 10, and 25°, respectively. Our current version yields lower values for rotational laxity than the first prototype of the device due to improvements in the standardization of the patient installation and joint fixation. The Minimum Detectable Change (MDC) has been determined to reach 4.2° for internal rotation and 5.9° for external rotation (Mouton). Individualized normative references have been established taking into account gender and body mass.

PHYSIOLOGICAL LAXITY

Systematic evaluations of patient and control cohorts have shown that contralateral knees of ACL-injured patients display greater anterior and rotational knee laxity than knees of healthy individuals (Branch, Mouton). As such, increased physiological laxity has been determined as a potential risk factor for ACL injuries. In addition, it has been shown that exercise and fatigue increases anterior and rotational knee laxity in such patients. Gender has a big influence on rotational knee laxity, with women having up to 40% higher knee rotation in comparison to men. It may represent one of the factors explaining the higher risk for ACL injuries in females. Body mass also influences rotational laxity with increased body mass being related to lower knee rotation. Neither age nor the menstrual cycle seem to influence rotational knee laxity measurements in adults.

Although laxity measurements overestimate knee laxity, normative references must be established to define normal laxity for each device. Mouton *& al.* proposed a methodological approach to calculate standardized laxity scores for anterior and rotational knee laxity taking into account influencing individual characteristics. Sex and body mass were found to significantly influence rotational laxity and to explain a non-negligible amount of the variability in internal and external rotation (46 to 60%). As a consequence, the latter parameters were taken into account to calculate an individualized score which has the advantage to allow for the direct comparison of individuals, regardless of differences in sex or body mass.

KNEE LAXITY IN THE INJURED KNEE

Diagnosis of ACL injuries

The diagnosis of ACL injuries with arthrometers is based on the side-to-side difference (SSD) observed in anterior laxity measurements between the injured and the healthy knee. According to the IKDC objective score, a SSD greater than 3 mm relates to an ACL injury regardless of the device used to measure anterior knee laxity. At this threshold, the KT-1000® performed at a maximal manual force seem to display the highest sensitivity and specificity for the diagnosis of complete ACL injuries compared to other devices. It is important to highlight that most studies reported the sensitivity and the specificity of arthrometers to diagnose ACL injuries by only considering complete ACL tears, which are the easiest to detect. With newer devices like the GNRB®, for all types of ACL tears (including total tears, partial tears, and ligament remnants) and regardless of associated meniscocapsular injuries, the sensitivity and specificity of the GNRB® reached, respectively, 75 and 95% for the ATD at 200 N and an optimal threshold of 1.2 mm (Mouton).

To improve the diagnosis of ACL injuries, additional analysis of rotational knee laxity has been proposed. Cadaveric studies revealed that the section of the ACL led to an increase of 2.4 to 4° in internal rotation in knee flexion angles below 30° (Lane, Nielsen). This accounts for approximately 10-15° of the internal rotational range. Subtypes of ACL tears like posterolateral bundle injuries induced an increase of 3° at 5 Nm in internal rotation (Lorbach). Similarly, recent findings showed an increase in internal rotation after sectioning of the ACL + anterolateral ligament of 3° at 20° of knee flexion (Sonnery-Cottet).

Although they may be clinically relevant, these differences induced by sequential sectioning of different intra- and extraarticular structures are relatively minor. This is getting problematic when the measurements need to be performed *in vivo*. So far, the only device measuring static

rotational laxity for which the sensitivity and specificity to detect an ACL injury has been reported in the literature is the Rotameter. A threshold of 3.2° for the SSD in internal rotation at 5 Nm allowed to correctly identify 38% of patients (sensitivity) and reject 95% of healthy subjects (specificity). This threshold is similar to the induced changes after sequential sectioning in cadaveric knees. Hence it shows that *in vivo* static rotational laxity measurements need to be improved to produce reliable clinically useful information.

Combining static anterior and rotational knee laxity measurements as well as exploiting the features offered by new arthrometers like the slope of the load-displacement curve improves the diagnosis of ACL tears. With this combination, a positive result confirmed an ACL tear (sensitivity: 81%) regardless of the sub-type of the ACL tear and the associated injuries. This performance is similar to the one reported for MRI (sensitivity 81%, specificity 96%). Despite this high diagnostic precision, the performance of arthrometers needs to be improved, especially when it comes to the measurement of rotational laxity and the effect of associated intra- or extraarticular lesions. Tibial rotation being influenced by lesions of the collateral ligaments, meniscal roots, the ITB and the Kaplan fibers or other peripheral capsuloligamentous structures, there is currently a paucity of both *in vivo* and *in vitro* studies analysing these variables individually.

Knee laxity after anterior cruciate ligament reconstruction

ACL reconstruction surgery should aim to restore knee laxity in all directions. Knee laxity measurements are therefore of interest as a postoperative control to follow the graft evolution and detect potential abnormalities like graft elongation, recurrent tears, increased postoperative laxities. These may occur in graft malpositioning or graft failures. Numerous studies reported knee laxity measurements at a specific time point after ACL reconstruction. Their conclusions are difficult to generalize, due to the diversity of graft types, surgical techniques, fixations, associated injuries, rehabilitation approaches, but also the laxity measurement techniques. Prospective follow-up studies with systematic measurements of knee laxity are missing, so that the current knowledge on postoperative changes like the influence of the graft ligamentisation process on knee laxity is poor.

This lack of methodological scientific evidence may explain why many studies have shown no difference in anterior laxity after different types of surgical reconstruction between a bone-patellar tendon-bone (BPTB) and a semitendinosus (ST) autograft (Ahlden). The current knowledge on knee laxity after ACL reconstructions as well as after many other surgical interventions thus needs to be improved. Little is known about the postoperative changes of ALL reconstructions. A recent study by Schon *& al.* indicated that current ALL reconstruction techniques may lead to a decrease of internal rotation and overconstraint of the knee joint.

CONCLUSIONS

Static knee laxity measurements offer the possibility to improve the understanding of the capsuloligamentous knee envelope, both in healthy and injured knees as well as after different types of reconstruction procedures. The recent development of rotational laxity measurement devices has added significant knowledge to the field. The combination of knee laxities is now possible and has led to the concept of knee laxity profiles in healthy knees. The high variability between individuals as well as the ability to identify knees with increased physiological knee laxity may be of interest in the screening and prevention programs for athletes. Indeed, subjects with excessive physiological knee laxity may have a greater risk to sustain an ACL injury as well as to display inferior outcomes after an ACL reconstruction.

The combination of multidirectional laxity assessments in ACL-injured knees improves the diagnostic capacity of arthrometers.

Although the knowledge of preoperative knee laxity measurements is evolving, some factors are still insufficiently understood. Current rotational arthrometers seem to be insufficiently precise to evaluate the influence the laxity increase induced by extraarticular injuries in general and anterolateral instabilities in particular.

LITERATURE

[1] AHLDEN M, KARTUS J, EJERHED L, KARLSSON J, SERNERT N (2009) Knee laxity measurements after anterior cruciate ligament reconstruction, using either bone-patellar-tendon-bone or hamstring tendon autografts, with special emphasis on comparison over time. *Knee Surg Sports Traumatol Arthrosc 17(9): 1117-24.*

[2] ALAM M, BULL AM, THOMAS RD, AMIS AA (2011) Measurement of Rotational Laxity of the Knee: *In Vitro* Comparison of Accuracy Between the Tibia, Overlying Skin, and Foot. *Am J Sports Med 39(12): 2575-81.*

[3] BRANCH TP, BROWNE JE, CAMPBELL JD, SIEBOLD R, FREEDBERG HI, ARENDT EA, *& al.* (2010) Rotational laxity greater in patients with contralateral anterior cruciate ligament injury than healthy volunteers. *Knee Surg Sports Traumatol Arthrosc 18(10):1379-84.*

[4] LANE JG, IRBY SE, KAUFMAN K, RANGGER C, DANIEL DM (1994) The anterior cruciate ligament in controlling axial rotation. An evaluation of its effect. *Am J Sports Med 22(2): 289-93.*

[5] LORBACH O, PAPE D, MAAS S, ZERBE T, BUSCH L, KOHN D, *& al.* (2010) Influence of the anteromedial and posterolateral bundles of the anterior cruciate ligament on external and internal tibiofemoral rotation. *Am J Sports Med 38(4): 721-7.*

[6] LORBACH O, WILMES P, MAAS S, ZERBE T, BUSCH L, KOHN D, *& al.* (2009) A non-invasive device to objectively measure tibial rotation: verification of the device. *Knee Surg Sports Traumatol Arthrosc 17(7): 756-62.*

[7] MOUTON C, SEIL R, MEYER T, AGOSTINIS H, THEISEN D (2014) Combined anterior and rotational laxity measurements allow characterizing personal knee laxity profiles in healthy individuals. *Knee Surg Sports Traumatol Arthrosc;10.1007/s00167-014-3244-6.*

[8] MOUTON C, THEISEN D, MEYER T, AGOSTINIS H, NUHRENBORGER C, PAPE D, *& al.* (2015) Combined anterior and rotational knee laxity measurements improve the diagnosis of anterior cruciate ligament injuries. *Knee Surg Sports Traumatol Arthrosc 23(10): 2859-67.*

[9] NIELSEN S, OVESEN J, RASMUSSEN O (1984) The anterior cruciate ligament of the knee: an experimental study of its importance in rotatory knee instability. *Arch Orthop Trauma Surg 103(3): 170-4.*

[10] SCHON GM, MOATSHE G, BRADY AW, SERRA CRUZ R, CHAHLA J, DORNAN GJ, TURNBULL TL, ENGEBRETSEN L, LAPRADE RF (2016) Anatomic anterolateral ligament reconstruction of the knee leads to overconstraint at any fixation angle. *Am J Sports Med, in press.*

[11] SONNERY-COTTET B, LUTZ C, DAGGETT M, DALMAY F, FREYCHET B, NIGLIS L, IMBERT P (2016) The involvement of the anterolateral ligament in rotational control of the knee. *Am J Sports Med 44: 1209-14.*

[12] WANG CJ, WALKER PS (1974) Rotatory laxity of the human knee joint. *J Bone Joint Surg Am 56(1): 161-70.*

[13] ZARINS B, ROWE CR, HARRIS BA, WATKINS MP (1983) Rotational motion of the knee. *Am J Sports Med 11(3): 152-6.*

ACCELEROMETER FOR PIVOT SHIFT ASSESSMENT

S. ZAFFAGNINI, G. CARBONE, A. GRASSI, F. RAGGI,
T. ROBERTI DI SARSINA, C. SIGNORELLI

INTRODUCTION

The anterior cruciate ligament (ACL) has been found to be the primary restraint to tibia antero-posterior displacement, allowing knee stability and control of joint kinematics. Because of that diagnosis of tibio-femoral joint laxity was historically based on Lachman and anterior drawer tests, measuring static laxity, involving only one degree of freedom.

Contrasting to unidirectional tests, pivot shift test evaluates dynamic laxity (defined when more than two degrees of freedom are involved), by applying multi-directional loads through a range of movement of the knee. A positive pivot shift is described as the anterior subluxation of the lateral tibial plateau and its reduction during flexion associated with internal rotation and valgus stress.

This sign is closely related to a functional ACL insufficiency and its grade is proportional to clinical symptoms [1], reduced sport activity [2], articular cartilage [3] and meniscal damages [4, 5]. The limit of pivot shift is its great variability in the performance and interpretation, making it a highly surgeon-subjective clinical examination.

In the last years, to solve this limit, various devices have been developed to measure the pivot shift; many of them, like open MRI, complex software, special markers, robot and electromagnetic software, are too complex and expensive to be used in daily clinical practice. Instead, inertial sensors have been spread in the clinical practice thanks to its low cost, simplicity and reliability [6].

DISCUSSION

Inertial sensors are specialized non-invasive devices constituted of an accelerometer to evaluate linear acceleration and a gyroscope to quantify angular velocity; they contain an internal mass attached to a spring. When the sensor is accelerated by the forces acting on the knee during a pivot shift test, it begins to move in the same direction of the force while the internal mass do not move because of inertia. This relative movement will produce a lengthening of the spring which is directly proportional to the acceleration. Calculating the integral of acceleration allows to obtain velocity.

In 2012, Lopomo *et al.* [7] has reported the results using a specific type of inertial wireless sensors linked to a tablet PC equipped with dedicated software (KiRA, Orthokey LLC, Lewes, DE, USA) while pivot shift maneuver was performed on 66 consecutive ACL-injured patients. Actually the system, an evolution of the originally developed, consists of a sensor inlaid into a three - axial accelerometer and three orthogonal gyroscope Bluetooth connected to a tablet PC. The sensor is fixed, completely non-invasive, by a strap on the tibia, between the lateral aspect of the anterior tuberosity and Gerdy's tubercle. It's the optimal position to reach a good stability of the sensor and to minimize skin artefacts during pivot shift execution. Furthermore this position is located in the lateral compartment of the knee, which is the most influenced by the presence of the pivot shift phenomenon. To validate this system and evaluate its reliability, it was compared to an invasive navigation system, by measuring knee joint kinematics during pivot shift concomitantly by an accelerometer fixed to the skin and a navigation system [8]. The authors found good intra-rater reliability in the acceleration range and in the mean acceleration waveform, justifying the use of inertial sensor in the daily clinical practice. The limitations of the methodology is the intrinsic variability of pivot shift depending on variance among examiners and muscular resistant offered by the patient, as demonstrated by a recent multicenter cohort study reporting significant differences in the grading of the pivot shift in awake and anesthetized patients [9].

A different inertial sensor, The MEMSense™ sensor, has been tested by Labbé *et al.* [10] to quantify pivot shift in 13 ACL-injured patient. This device uses an embedded micro-electromechanical system sensor integrating a triaxial accelerometer, gyroscope and magnetometer to evaluate acceleration and velocity of the tibiofemoral joint during pivot shift execution. Authors demonstrated that both acceleration and velocity of femur and tibia correlate well with the clinical grade of the pivot shift.

Petrigliano *et al.* [11] validated the use of another device, The ITG-3200 (ITG-3200, Invensense, CA), to quantify the pivot shift phenomenon in cadaveric specimens. It's a non-invasive microelectromechanical gyroscope, but, unlike MEMSense™, it's a single axis device that can be site on the lower extremity to measure tibial external rotation in the transverse plane during pivot shift. Authors found that the angle of rotation was higher in the ACL deficient knees compared to the intact specimens, but tibial rotation and rotational velocity are not closely related to the clinical grade of pivot shift. So these findings, confirmed by Borgstrom *et al.* [12] who used the same device to correlate analytic data with clinical grade, suggest that tibial rotation and rotational velocity alone can not define clinical grade of pivot shift and gyroscope data could be associated to acceloremeter data to give a more definite assessment of pivot shift.

CONCLUSION

Among several tests proposed to evaluate laxity of the knee joint, pivot shift test is the most specific test for ACL-injury, being closely correlates to clinical symptoms. Because its complexity and its inter-individual variability, its quantification represent a challenge among orthopaedics involved in ACL surgery.

Development of several systems to assess pivot shift could help surgeon to quantify pivot shift, improving diagnostic capabilities. Although navigation systems increased our understanding about knee kinematics, they are invasive, complex ad expensive; for these reasons their use is proposed for intra-operative analysis.

Unlike navigation systems, inertial sensors are non-invasive, intuitive, simple to use, in-expensive and reliable way to quantify pivot shift phenomenon. Their use allows to compare the injured knee to the healthy one, using it as reference. Measuring acceleration, velocity and rotation of the tibia relative to the femur during pivot shift, it's possible correlates analysis data with clinical grade of symptoms.

Use of inertial sensors, thanks to its reliability, could be encouraged in the daily clinical practice both in diagnostic phase and in postoperative evaluation; moreover it could be use as a teaching tool in instructing young surgeon to perform the pivot shift in a more standardized way.

LITERATURE

[1] KOCHER MS, STEADMAN JR, BRIGGS KK *et al.* Relationships between objective assessment of ligament stability and subjective assessment of symptoms and function after anterior cruciate ligament reconstruction. *The American journal of sports medicine 2004; 32: 629-34.*

[2] KAPLAN N, WICKIEWICZ TL, WARREN RF. Primary surgical treatment of anterior cruciate ligament ruptures. A long-term follow-up study. *The American journal of sports medicine 1990; 18: 354-8.*

[3] KIEVIT AJ, JONKERS FJ, BARENTSZ JH *et al.* A cross-sectional study comparing the rates of osteoarthritis, laxity, and quality of life in primary and revision anterior cruciate ligament reconstructions. Arthroscopy: the journal of arthroscopic & related surgery: official publication of *the Arthroscopy Association of North America and the International Arthroscopy Association 2013; 29: 898-905 DOI: 10.1016/j.arthro.2013.01.020.*

[4] NOYES FR, MATTHEWS DS, MOOAR PA *et al.* The symptomatic anterior cruciate-deficient knee. Part II: the results of rehabilitation, activity modification, and counseling on functional disability. *The Journal of bone and joint surgery American volume 1983; 65: 163-74.*

[5] NOYES FR, MOOAR PA, MATTHEWS DS *et al.* The symptomatic anterior cruciate-deficient knee. Part I: the long-term functional disability in athletically active individuals. *The Journal of bone and joint surgery American volume 1983; 65: 154-62.*

[6] ZAFFAGNINI S, LOPOMO N, SIGNORELLI C *et al.* Innovative technology for knee laxity evaluation: clinical applicability and reliability of inertial sensors for quantitative analysis of the pivot-shift test. *Clinics in sports medicine 2013; 32: 61-70 DOI: 10.1016/j.csm.2012.08.007.*

[7] LOPOMO N, ZAFFAGNINI S, SIGNORELLI C *et al.* An original clinical methodology for non-invasive assessment of pivot-shift test. *Computer methods in biomechanics and biomedical engineering 2012; 15: 1323-8 DOI: 10.1080/10255842.2011.591788.*

[8] LOPOMO N, SIGNORELLI C, BONANZINGA T *et al.* Quantitative assessment of pivot-shift using inertial sensors. *Knee surgery, sports traumatology, arthroscopy: official journal of the ESSKA 2012; 20: 713-717 DOI: 10.1007/s00167-011-1865-6.*

[9] LOPOMO N, SIGNORELLI C, RAHNEMAI-AZAR AA *et al.* Analysis of the influence of anaesthesia on the clinical and quantitative assessment of the pivot shift: a multicenter international study. *Knee surgery, sports traumatology, arthroscopy: official journal of the ESSKA 2016: DOI: 10.1007/s00167-016-4130-1.*

[10] LABBE DR, LI D, GRIMARD G *et al.* Quantitative pivot shift assessment using combined inertial and magnetic sensing. Knee surgery, sports traumatology, arthroscopy: *official journal of the ESSKA 2015; 23: 2330-2338 DOI: 10.1007/s00167-014-3056-8.*

[11] PETRIGLIANO FA, BORGSTROM PH, KAISER WJ *et al.* Measurements of tibial rotation during a simulated pivot shift manoeuvre using a gyroscopic sensor. *Knee surgery, sports traumatology, arthroscopy: official journal of the ESSKA 2015; 23: 2237-43 DOI: 10.1007/s00167-014-3015-4.*

[12] BORGSTROM PH, MARKOLF KL, FOSTER B *et al.* Use of a gyroscope sensor to quantify tibial motions during a pivot shift test. *Knee surgery, sports traumatology, arthroscopy: official journal of the ESSKA 2014; 22: 2064-9 DOI: 10.1007/s00167-013-2610-0.*

GRAFT FIXATION

J. CHAPPUIS, J. BARTH, J.C. PANISSET

INTRODUCTION

Anterior cruciate ligament rupture is a common injury.

However, controversy still exists regarding the best surgical technique, graft choice and graft fixation.

The forces transmitted through the ACL vary based on the integrity of the menisci, the other knee ligaments, and the position of the knee. Brand and coworkers [1] demonstrated ACL loads during daily activities (Table 1).

Noyes and coworkers [2] have estimated that the ACL strength needed for most activities was 454 N. Therefore, the initial fixation strength of an ACL graft required for these activities should be greater than 450 N.

It is well recognized that graft fixation is the weakest link in the early postoperative period after ACL reconstruction.

Table 1: ***From Brand and coworkers [1]***

Activities	ACL (N)	PCL (N)
Level Walking	169	352
Ascending stairs	67	641
Descending stairs	445	262
Descending ramp	93	449
Ascending ramp	27	1215

GRAFT FIXATION

Graft fixation must be strong enough to avoid failure, stiff enough to restore load displacement response and allow biological incorporation of the graft into the bone tunnels and secure enough to resist slippage under cyclic loading. It should also be reproducible, biocompatible, MRI possible and easy to revise.

During the first 6 to 12 weeks after surgery, when conversion from mechanical to biologic fixation is occuring, the fixation must be able to withstand the demands of an accelerated rehabilitation program.

There are a variety of methods by which the bone and soft tissue grafts can be fixed, and this can be done either in the bone tunnel or through a cortical based fixation away from the joint [3] (fig. 1). Historically, the revolution was the Kurosaka screw [4] (fig. 2).

Fixation strength is especially important on the tibial side, which is usually the site of fixation failure, because the metaphyseal region of the tibia has less bone density than the femur and the graft experiences forces that are more collinear within the tibial tunnel [5].

Efficiency of graft fixation depends on the characteristics of the fixation devices, on the site of fixation (aperture or nonaperture), on the density of the bone (tibia or femur) and on the type of graft.

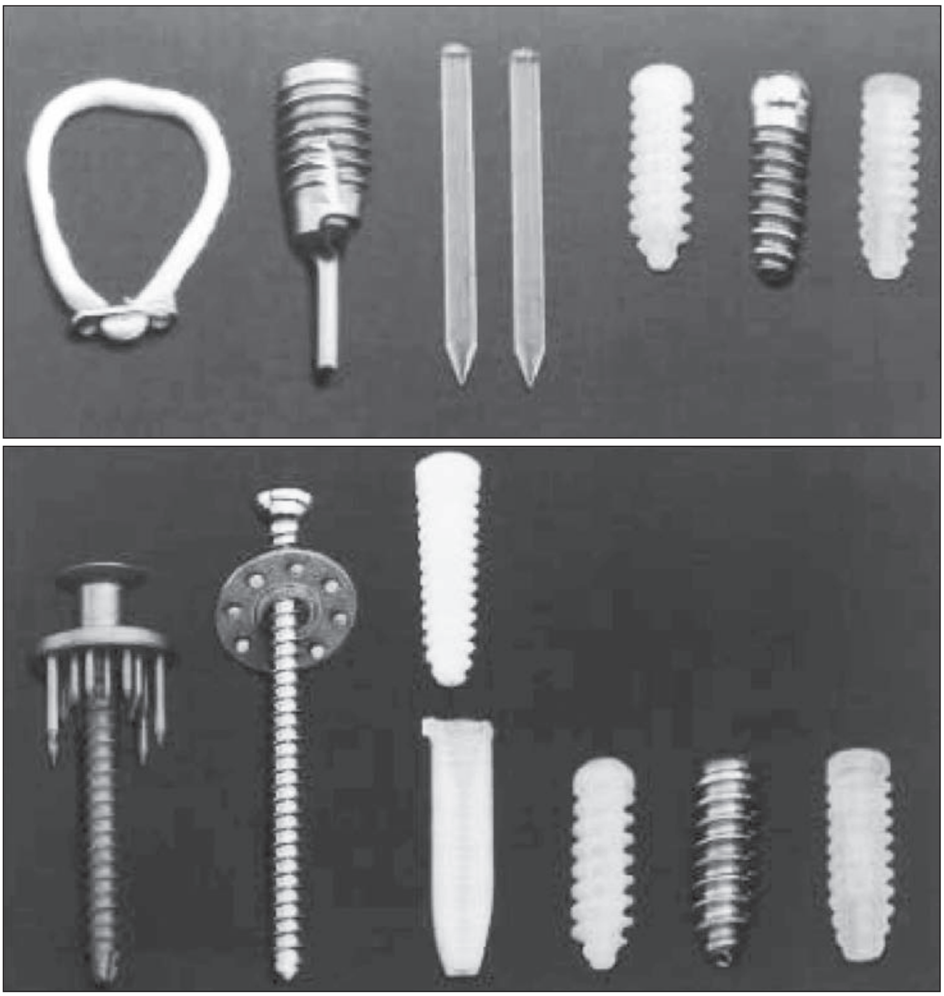


Fig. 1: ***From Kousa and coworkers*** [3]

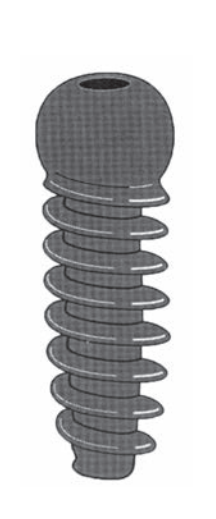


Fig. 2: ***From Kurosaka and coworkers*** [4]

Currently, available fixation options include interference screws (metal and bioabsorbable), staples, suture and post, cross pins, expansion bolts, suspension devices (cortical, cancellous or cortical cancellous), or even an implant-free press-fit fixation technique. All these fixation devices have an ultimate load failure that exceeds the 450 N safe early physiological loading threshold proposed by Noyes and coworkers (Table 2).

FEMORAL FIXATION

For Bone Patellar Tendon Bone (BPTB) graft, most surgeons prefer to use interference screws because it results in the creation of a stiffer construct. Interference screws were initially in

Table 2: ***From West and coworkers*** [5]

Fixation	Ultimate Load to Failure (N)	Stiffness (N/m)
Patellar tendon		
Metal interference screw	558	-
Biobsorbable interference screw	552	-
Soft tissue (Femoral)		
Bone Mulch™ Screw (Biomet. Inc.)	1.112	115
EndoButton® (Smith & Nephew Endoscopy)	1.086	79
RigidFix® (DePuy Synthe)	868	77
SmartScrew® ACL (ConDed Linvatec)	794	96
BioScrew® (ConMed Linvatec)	589	66
RCI™ Screw (Smith & Nephew Endoscopy)	546	68
Soft tissue (Tibial)		
Intrafix® (DePuy Synthes)	1.332	223
WasherLoc™ (Arthrotek)	975	87
Tandem spiked washer (Arthrotek)	769	69
SmartScrew® ACL	665	115
BioScrew®	612	91
SoftSilk™ (Acufex Microsurgical. Mansfield, MA)	471	61

metal but are now available in bioabsorbable material. They have the same initial strength and ease of insertion but the bioabsorbable screws have several advantages, including MRI compatibility, decreased risk of graft laceration and facilitation of revision surgery. However, they have also disadvantages, including screw breakage, foreign body reaction and increased cost [5].

Cross-pin fixation [6] can be used with results similar to interference screws but with the risk of bone plugs fracture if the bone plug size is less than 9mm.

Suspensory device can also be used.
In Lyon, we like to use the "Chambat" method which consist of a press-fit fixation without any material, with good fixation strength [7].

For hamstring and other soft tissue graft, as for BPTB, you can use suspensory fixation devices, cross-pin fixation and interference screws.

Endobutton (Smith and Nephew) is a cortical-based suspensory fixation device that has enjoyed a great popularity with good biomechanical results and clinical outcomes [8] (Table 3). One concern of this device is widening of the tunnel greater than with aperture fixation. One hypothesis is more graft-bone motion known as "bungee-effect" even if Brown and coworkers showed no difference in graft-bone motion between suspensory and aperture fixation in their cadaveric study [8].

New adjustable suspensory devices such as Tightrope (Arthrex) and Togglelock (Biomet) seem to have a problem of lengthening greater than 3mm in a recent study [9].

Cross-pin fixation such as RigidFix (Depuy Synthes) and TransFix (Arthrex) have shown similar results compared to the Endobutton [1]. The advantage of suspensory or cross-pin fixation is a better contact between the graft and the tunnel.

Table 3: ***From Brown and coworkers*** [8]

Variable	Bio-Interference Screw 8 X 23mm	EndoButton. EndoButton Tape 20mm	EndoButton Continuous Loop 20mm	LinX HT	Bone Mulch Screw	TransFix	PT Screw 7 X 25mm	PT Suture Button
Steady-state graft-bone motion (mm)	0.35 ± 0.15 n = 9	0.55 ± 0.17 n = 7	0.51 ± 0.14 n = 7	0.54 ± 0.27 n = 7	0.36 ± 0.08 n = 8	0.44 ± 0.23 n = 9	0.34 ± 0.15 n = 7	0.67 ± 0.17 n = 10
Maximum Graft-Bone displacement after 1.000 cycles (mm)	4.34 ± 3.16 n = 7	5.82 ± 1.81 n = 7	2.13 ± 0.26 n = 6	2.20 ± 0.95 n = 7	2.24 ± 0.53 n = 7	2.37 ± 1.43 n = 7	1.53 ± 0.42 n = 5	4.42 ± 1.53 n = 8
Graft-bone displacement After 20 cycles (% of max)	42 % n = 7	79 % n = 7	72 % n = 6	71 % n = 7	70 % n = 7	59 % n = 7	62 % n = 5	75 % n = 9
Ultimate failure load (N)	562 ± 69 n = 9	644 ± 91 n = 10	1.345 ± 179 n = 11	687 ± 129 n = 10	977 ± 238 n = 10	934 ± 296 n = 10	710 ± 224 n = 8	664 ± 132 n = 10
Linear stiffness (N/mm)	257 ± 37 n = 9	182 ± 20 n = 10	179 ± 39 n = 11	230 ± 32 n = 10	257 ± 50 n = 10	240 ± 74 n = 10	298 ± 36 n = 8	207 ± 36 n = 10
Displacement to failure (mm)	3.00 ± 0.66 n = 9	6.27 ± 2.16 n = 10	9.89 ± 2.41 n = 11	3.74 ± 1.05 n = 10	6.49 ± 2.66 n = 10	7.37 ± 371 n = 10	3.17 ± 0.87 n = 8	6.02 ± 2.47 n = 10

TIBIAL FIXATION

For BPTB graft, as for femoral fixation, interference screws are more commonly used but staples and screw post and suture can also be used.

For hamstring and other soft tissue grafts, similar to bone plug fixation, soft tissue fixation on the tibial side can be achieved with the use of interference screws, staples, a screw and washer, or a screw post and suture.

But this is usually the site of fixation failure mostly by slippage because there is no bone plug and it seems that a double fixation should be the best option when using screw fixation. Another option may be the use of adjustable suspensory device such as Tightrope (Arthrex) or Pull-up (SBM), for example, but further studies are needed to evaluate these devices on the tibial side and to be sure there is no distension.

Robert and coworkers have shown in an in vitro study the superiority of the tape locking screw (TLS FH Orthopedics) and the Delta Screw (Arthrex) over the Washerlock (Biomet) and Tightrope (Arthrex), but further clinical studies are needed [10].

CONCLUSION

Actually, there is no ideal fixation devices.
For fixation of bone plugs, interference screws remain the gold standard.

The surgeon can either use a metal or a bioabsorbable screw.

There is currently no recognized gold standard for soft tissue fixation, and the surgeon is encouraged to weigh the risks and benefits of using different devices.

LITERATURE

[1] BRAND J, WEILER A, CABORN DNM, BROWN CH, JOHNSON DL. Graft fixation in cruciate ligament reconstruction. *Am J Sports Med 2000 Sep-Oct; 28(5): 761-74.*

[2] NOYES FR, BUTLER DL, GROOD ES, *et al.* Biomechanical analysis of human ligament grafts used in knee-ligament repairs and reconstructions. *J Bone Joint Surg Am 1984 Mar; 66(3): 344-52.*

[3] KOUSA P, JARVINEN TLN, VIHAVAINEN M, *et al.* The fixation strength of six hamstring tendon graft fixation devices in anterior cruciate ligament reconstruction-Part I: Femoral site and Part II: Tibial site. *Am J Sports Med 2003 Mar-Apr; 31(2): 174-88.*

[4] KUROSAKA M, YOSHIYA S, ANDRISH JT. A biomechanical comparison of different surgical techniques of graft fixation in anterior cruciate ligament reconstruction. *Am J Sports Med 1987 May-Jun; 15(3): 225-9.*

[5] WEST RV, HARNER CD. Graft selection in anterior cruciate ligament reconstruction. *J Am Acad Orthop Surg 2005 May-Jun; 13(3): 197-207.*

[6] ZANTOP T, WELBERS B, WEIMANN A, *et al.* Biomechanical evaluation of a new cross-pin technique for the fixation of different sized bone-patellar tendon-bone grafts. *Knee Surg Sports Traumatol Arthrosc 2004 Nov; 12(6): 520-7.*

[7] ARNOLD MP, BURGER LD, WIRZ D *et al.* The biomechanical strenght of a hardware-free femoral press-fit method for ACL bone-tendon-bone graft fixation. *Knee Surg Sports Traumatol Arthrosc 2016 Jan 7.*

[8] BROWN CH JR, WILSON DR, HECKER AT *et al.* Graft-bone motion and tensile properties of hamstring and patellar tendon anterior cruciate ligament femoral graft fixation under cyclic loading. *Arthroscopy 2004 Nov; 20(9): 922-35.*

[9] BARROW AE, PILIA M, GUDA T, *et al.* Femoral suspension devices for anterior cruciate ligament reconstruction: do adjustabl loops lengthen? *Am J Sports Med 2014 Feb; 42(2): 343-9.*

[10] ROBERT H, BOWEN M, ODRY G *et al.* A comparison of four tibial-fixation systems in hamstring-graft anterior ligament reconstruction. *Eur J Orthop Surg Traumatol 2015 Feb; 25(2): 339-47.*

GRAFT CHOICE AND RESULTS: WHAT DOES THE LITERATURE SAY?

R.A. MAGNUSSEN

INTRODUCTION

Which graft is the best for anterior cruciate ligament (ACL) reconstruction? The literature is replete with studies attempting to answer this seemingly simple question, yet no definitive conclusion has been reached. The reason for lack of consensus is found not in the quality of the studies attempting to answer this question, but in the question itself. There is no "best" ACL graft any more than there is a "best" type of food. Each graft has its advantages and disadvantages. Our responsibility as surgeons and researchers is to identify and communicate the advantages and disadvantages of each graft to our patients to arrive at an informed decision. Thus, the question we should be asking is "Which graft is the best for this patient?"

The answer to this question is based on both patient and surgeon factors. Patient physical factors including age, activity level, height and weight, and prior graft harvests must be considered, along with patient preferences regarding time to return to sport, concerns about scar and cosmesis, and possible complications of each graft type. Surgeon factors including familiarity with graft harvest and fixation techniques must also be considered. Most importantly, these decisions should be firmly grounded in data from the literature.

ALLOGRAFT *VERSUS* AUTOGRAFT

When narrowing down the choice of graft, the first question is whether to utilize allograft or autograft tissue. Autograft is the gold standard for ACL reconstruction, while allograft has inherent advantages and disadvantages. On the positive side, allograft certainly reduces harvest site morbidity and early post-operative pain. Concerns about allograft include disease transmission, low availability in some countries, and increased failure risk in certain populations. Allograft tissue has been associated with increased failure risk in younger, more active patient populations [4, 9] while allograft has yielded similar results to autograft in older patients [11]. The MARS group similarly demonstrated poorer outcomes in young, active patients who underwent revision ACL reconstruction with allograft tissue [12]. Further, when using allograft, one must has a clear understanding of the processing of the graft as certain sterilization

techniques, particularly high-dose gamma irradiation have been shown to decrease graft strength [13].

AUTOGRAFT CHOICE

The question of whether hamstring or patellar tendon autograft yields better outcomes following ACL reconstruction is one of the most researched and contested questions in orthopaedic sports medicine. Numerous systematic review articles have yielded conflicting findings over the years regarding which graft is best, but most demonstrate no clear difference in outcomes [6]. A detailed review at the data reveals several differences between the grafts, some of which has been further confirmed by large cohorts and registries.

The most common question is whether a difference in failure risk exists between these grafts. A systematic review of eight prospective studies with minimum 5-year follow-up from 2011 demonstrated a trend toward increased failure risk with hamstring grafts (odds ratio 1.59, 95% confidence interval: 0.79 - 3.22) that did not reach statistical significance [6]. A recent systematic review limited to only high quality randomized controlled trials (6 studies) demonstrated an increased failure risk in the hamstring group (15.8%) relative to the patellar tendon group (7.2%) (p=0.02) [15]. Several large registries have recently published data regarding differences in failure risk between hamstring and patellar tendon autografts. The Scandinavian ACL registries, together reporting on 45,998 primary ACL reconstructions, noted the risk of revision surgery in the hamstring autograft group was 1.59 (95% CI, 1.35-1.89) times that of the patellar tendon group [3]. They noted elevated risk with hamstring graft across all age groups, but noted the effect to be greater in patients participating in cutting and pivoting sports. The MOON group in the US noted a similar odds ratio for graft failure with a hamstring autograft versus patellar tendon autograft (1.60; 95% CI, 0.89-2.90) in 2683 knees, but the finding did not reach statistical significance (p=0.12) [5]. The Kaiser database in California noted that patients under age 21 had a 1.61 times (95% CI, 1.20-2.17) higher risk of graft failure when treated with a hamstring autograft compared to the patellar tendon autograft [9]. Interestingly, they noted no such difference in older patients.

Numerous factors do and should play a role in graft selection beyond absolute failure risk. Knee laxity as measured with the Lachman and especially pivot-shift may be less in patients reconstructed with patellar tendon grafts [6, 17]. The clinical relevance of these findings is not completely clear as these data have not been demonstrated to translate into improved patient-reported outcome score. Systematic review data are clear that patients who undergo reconstruction with patellar tendon grafts are at increased risk of anterior knee pain and kneeling pain a 5-year minimum follow-up compared to those treated with hamstring autograft [6, 17]. While data are less consistent, patients reconstructed with patellar tendon autograft may also have increased risk of development of osteoarthritis than those treated with hamstring grafts [6, 18].

Quadriceps tendon grafts have been gaining in popularity in recent years as many feel they are able to provide results similar to those obtained with patellar tendon autografts without the associated morbidity of a patellar tendon graft harvest. A recent review by Stone *et al.* that included 1154 quadriceps autograft ACL reconstructions demonstrated the safety of the graft and preliminarily confirmed the comparable results and decreased morbidity of this graft choice relative to patellar tendon grafts [16]. Larger studies and more experience with this graft are needed for a definitive assessment of failure risk and potential morbidity of this graft choice.

CONSIDERATIONS FOR SPECIFIC GRAFT TYPES

Allograft

Advantages of allograft include faster surgery and less harvest site morbidity. Increased failure risk has been noted in young active patients, particularly if irradiated tissue is used [13]. Although exceeding rare, patients should be counseled about possible disease transmission via allograft. Bacterial infection risk with allograft is comparable to that noted after autograft ACL reconstruction.

Patellar Tendon Autograft

Patellar tendon grafts have long been considered the gold standard for ACL reconstruction. They consistently have similar or lower failure risk compared to all other graft types. The risk of anterior knee pain at minimum 5 years following ACL reconstruction is between 25 and 38%, while the risk of kneeling pain at this time point has been reported from 19 to 72% [6]. The risk of osteoarthritis at minimum of 5 years following ACL reconstruction varies greatly (9 to 72%) and may be slightly higher than that noted with other graft types, particularly in the patellofemoral joint [6, 18]. Patellar tendon harvest is typically associated with larger scars than hamstring tendon autograft, although techniques exist to harvest that graft through smaller transverse incisions with improved cosmesis.

Hamstring Autograft

Hamstring autograft has been shown in numerous studies to yield similar patient-reported outcomes to patellar tendon grafts, but may be associated with slightly increased failure risk, particularly in younger, more active patients. A major concern with hamstring autografts is the influence of graft size on outcome. Grafts smaller than 8 to 8.5mm in diameter have been associated with increased failure risk relative to larger hamstring autografts in young active patients [8, 10, 14]. The intra-operative problem of a small hamstring graft can be solved in multiple ways, including folding the graft differently to increase diameter, switching to a different autograft source, or adding allograft tendon to the small graft to increase its diameter [7].

Early data suggest that allograft augmentation may be associated with failure risks comparable to those encountered with the use of small grafts [1].

Quadriceps Autograft

Quadriceps autograft has excellent potential as a graft choice for ACL reconstruction as it can minimize harvest morbidity and provide outcomes similar to those of other autografts [16]. Harvest site cosmesis is a concern with this graft, particularly if a long, vertical incision is used for harvest. Minimally invasive harvest techniques that utilize specialized instrumentation allow harvest through a smaller transverse incision with improved cosmesis [2].

CONCLUSION

Numerous graft choices are available for ACL reconstruction and there is no one graft type that is ideal for all patients. Surgeons and patients should discuss the relative risks and benefits of each graft type and select the most appropriate graft for each patient based on all these considerations.

LITERATURE

[1] BURRUS MT, WERNER BC, CROW AJ, *et al.* Increased Failure Rates After Anterior Cruciate Ligament Reconstruction With Soft-Tissue Autograft-Allograft Hybrid Grafts. *Arthroscopy Dec 2015; 31(12): 2342-51. PMID: 26276093.*

[2] FINK C, HERBORT M, ABERMANN E, HOSER C. Minimally invasive harvest of a quadriceps tendon graft with or without a bone block. *Arthrosc Tech Aug 2014; 3(4): e509-513. PMID: 25264512.*

[3] GIFSTAD T, FOSS OA, ENGEBRETSEN L, *et al.* Lower risk of revision with patellar tendon autografts compared with hamstring autografts: a registry study based on 45,998 primary ACL reconstructions in Scandinavia. *Am J Sports Med Oct 2014; 42(10): 2319-28. PMID: 25201444.*

[4] KAEDING CC, AROS B, PEDROZA A, *et al.* Allograft Versus Autograft Anterior Cruciate Ligament Reconstruction: Predictors of Failure From a MOON Prospective Longitudinal Cohort. *Sports Health. Jan 2011; 3(1): 73-81. PMID: 23015994.*

[5] KAEDING CC, PEDROZA AD, REINKE EK, HUSTON LJ, SPINDLER KP. Risk Factors and Predictors of Subsequent ACL Injury in Either Knee After ACL Reconstruction: Prospective Analysis of 2488 Primary ACL Reconstructions From the MOON Cohort. *Am J Sports Med. Jul 2015; 43(7): 1583-90. PMID: 25899429.*

[6] MAGNUSSEN RA, CAREY JL, SPINDLER KP. Does autograft choice determine intermediate-term outcome of ACL reconstruction? *Knee Surg Sports Traumatol Arthrosc. Mar 2011; 19(3): 462-72. PMID: 20953764.*

[7] MAGNUSSEN RA, KAEDING CC, TAYLOR DC. Solutions to small hamstring autograft harvest: A survey of the ACL Study Group. *Current Orthop Practice. 2015; 26(1): 42-44. PMID.*

[8] MAGNUSSEN RA, LAWRENCE JT, WEST RL, TOTH AP, TAYLOR DC, GARRETT WE. Graft size and patient age are predictors of early revision after anterior cruciate ligament reconstruction with hamstring autograft. *Arthroscopy. Apr 2012; 28(4): 526-31. PMID: 22305299.*

[9] MALETIS GB, CHEN J, INACIO MC, FUNAHASHI TT. Age-Related Risk Factors for Revision Anterior Cruciate Ligament Reconstruction: A Cohort Study of 21,304 Patients From the Kaiser Permanente Anterior Cruciate Ligament Registry. *Am J Sports Med. Feb 2016; 44(2): 331-6. PMID: 26637284.*

[10] MARISCALCO MW, FLANIGAN DC, MITCHELL J, *et al.* The influence of hamstring autograft size on patient-reported outcomes and risk of revision after anterior cruciate ligament reconstruction: a Multicenter Orthopaedic Outcomes Network (MOON) Cohort Study. *Arthroscopy. Dec 2013; 29(12): 1948-53. PMID: 24140144.*

[11] MARISCALCO MW, MAGNUSSEN RA, MEHTA D, HEWETT TE, FLANIGAN DC, KAEDING CC. Autograft versus nonirradiated allograft tissue for anterior cruciate ligament reconstruction: a systematic review. *Am J Sports Med. Feb 2014; 42(2): 492-9. PMID: 23928319.*

[12] MARS. Effect of graft choice on the outcome of revision anterior cruciate ligament reconstruction in the Multicenter ACL Revision Study (MARS) Cohort. *Am J Sports Med. Oct 2014; 42(10): 2301-10. PMID: 25274353.*

[13] PARK SS, DWYER T, CONGIUSTA F, WHELAN DB, THEODOROPOULOS J. Analysis of irradiation on the clinical effectiveness of allogenic tissue when used for primary anterior cruciate ligament reconstruction. *Am J Sports Med. Jan 2015; 43(1): 226-35. PMID: 24477819.*

[14] PARK SY, OH H, PARK S, LEE JH, LEE SH, YOON KH. Factors predicting hamstring tendon autograft diameters and resulting failure rates after anterior cruciate ligament reconstruction. *Knee Surg Sports Traumatol Arthrosc. May 2013; 21(5): 1111-8. PMID: 22688502.*

[15] REINHARDT KR, HETSRONI I, MARX RG. Graft selection for anterior cruciate ligament reconstruction: a level I systematic review comparing failure rates and functional outcomes. *Orthop Clin North Am. Apr 2010; 41(2): 249-62. PMID: 20399364.*

[16] SLONE HS, ROMINE SE, PREMKUMAR A, XEROGEANES JW. Quadriceps tendon autograft for anterior cruciate ligament reconstruction: a comprehensive review of current literature and systematic review of clinical results. *Arthroscopy. Mar 2015; 31(3): 541-54. PMID: 25543249.*

[17] XIE X, LIU X, CHEN Z, YU Y, PENG S, LI Q. A meta-analysis of bone-patellar tendon-bone autograft versus four-strand hamstring tendon autograft for anterior cruciate ligament reconstruction. *Knee. Mar 2015; 22(2): 100-10. PMID: 25547048.*

[18] XIE X, XIAO Z, LI Q, *et al.* Increased incidence of osteoarthritis of knee joint after ACL reconstruction with bone-patellar tendon-bone autografts than hamstring autografts: a meta-analysis of 1,443 patients at a minimum of 5 years. *Eur J Orthop Surg Traumatol. Jan 2015; 25(1): 149-59. PMID: 24748500.*

GRAFT HARVESTING COMPLICATIONS IN ANTERIOR CRUCIATE LIGAMENT RECONSTRUCTION

J. CHOUTEAU

INTRODUCTION

The quality, tension and position of the graft within the femoral and tibial tunnels, are of prime importance for success of anterior cruciate ligament (ACL) reconstruction. Complications of harvest sites can impact the graft quality as well as postoperative outcomes. We hereby describe the complications depending on the time of their onset on and on the surgical technique used.

INTRA-OPERATIVE COMPLICATIONS

Kenneth Jones (KJ) procedure with bone-patellar tendon-bone (BPTB) graft

Graft too thin/narrow

- It is typically recommended to harvest a graft 9 mm wide. In the past, double-bladed bistouries produced narrower grafts, measuring 7 to 8 mm.
- Insufficient graft width was also described following double-incision techniques, due to the surgical instrumentation used, and to limited visibility of the patellar tendon during harvesting (fig. 1).

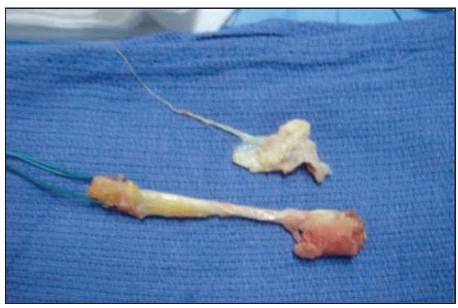


Fig. 1: ***Bone-Patellar Tendon-Bone (BTPB) graft with thinning after harvesting using a double incision approach.***

'Stripping' of tendon near the patella

Incorrect use of gouge chisels, particularly superficial insertion near the patella, could lead to detachment of the patellar tendon from its insertion site. In such cases, the tendon graft does not incorporate a full bone plug, but rather pre-patellar bone fragments. This complication could compromise fixation within the bone tunnels.

Fracture of the bone plug

Both femoral and tibial bone plugs could break, either during graft harvesting, or while drilling traction holes.

Fracture of the patella

Harvesting the patellar bone plug could lead to intra-operative patellar fracture particularly in cases of very dense bone. Chouteau *& al.* described a technique in which two holes are drilled either side of the horizontal saw line of the patella, to limit the risks of pre- and post-operative patellar fracture [1].

Hamstrings Tendon graft procedures

The tibial insertion of the hamstrings tendon (HT) is highly variable. It can be spread out to different extents, and the tendinous portion could start more or less distally, and could be difficult to locate. Adhesions and septum between the tendons could complicate their harvesting. The vincula, combining tendons and aponevrosis, can also present traps during stripping. They can lead to wrong way and insufficient graft length.

There are various intra-operative complications that can occur while harvesting the hamstrings tendon.

Wrong way of stripper

In most cases, this complication arises due to an unsectioned vinculum that deviates the stripper and yields a short harvested graft.

Tendon retraction during stripping and subsequent graft loss

This complication occurs in case of tendon detachment from its distal insertion and requires use of a closed stripper. The tendon could retract and get lost in case of stripper blockage over an adhesion.

Inability to detach the tendon distally over dense periosteum

This complication occurs if the surgeon uses a retrograde harvesting technique through postero-medial cutaneous incision. It therefore requires an antero-medial counter-incision to liberate the distal tendon insertion.

Absence of semitendinosus tendon leading to use of gracillis alone

This complication could occur, and cannot be anticipated, just as the presence of a double gracillis tendon, that could be short and/or thin, therefore unusable.

Insufficient size of harvested graft

This complication occurs relatively rarely, with the possibility of performing a multibrin transplant of the semitendinosus tendon. Nevertheless, in such cases conversion to a KJ procedure may be necessary.

POST-OPERATIVE COMPLICATIONS

Post-operative complications are chiefly related to of sensitive subcutaneous troubles. The positioning and coverage of deficient zones depend on the graft type (fig. 2). They were clearly described by Dejour *(symposium of the Société Française d'Arthroscopie in 2007)* who reported that 68% of patients present a hypoesthesia over a mean area of 11.2 cm^2 using the KJ technique, compared to 32% over a mean area of 9 cm^2 using the HT technique [2].

Anterior pains are difficult to characterize and are equally frequent. Dejour [2] reported 33% for KJ techniques, compared to 25% for HT techniques. Zaffagnini also found significant differences between the two techniques, 36% using KJ compared to 12% using the HT [3]. In this study, they are particularly frequent during

kneeling after KJ techniques (72%) but also surprisingly frequent for HT techniques (44%). The literature reports numerous different causes for anterior pains.

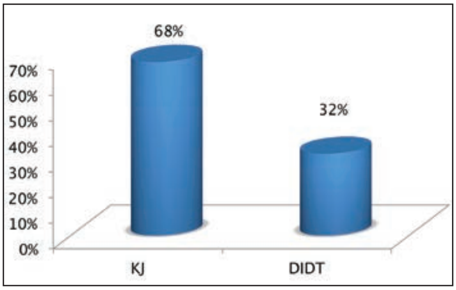


Fig. 2: ***Incidence of sensitive troubles using different techniques (according to Dejour [2]).***

Post-operative complications after semitendinosus grafts from the HT

Muscle lesions, notably elongation or short tears, have been observed in the graft harvest zone. Such complications require adjustment of the rehabilitation program, particularly muscle reinforcement exercises.

Postoperative complications after KJ procedures

- Patellar fractures could occur post-operatively. Chouteau *& al.* reported an incidence of 0.24% in a consecutive series of 1234 ACL reconstructions [1].

- Patellar tendon pathologies are well reported and understood. They are usually treated through a multidisciplinary approach with the recent use of isokinetic techniques.

CONCLUSION

Iatrogenic complications of graft harvesting during ACL reconstruction remain relatively rare. Nevertheless, their incidence can have significantly impact patient satisfaction and functional outcomes. They can be avoided, ideally through rigorous and meticulous surgical techniques.

LITERATURE

[1] CHOUTEAU J, LAPTOIU D, LERAT JL, MOYEN B. Fracture de la patella après prélèvement os-tendon patellaire-os pour ligamentoplastie de reconstruction du ligament croisé antérieur : incidence du type de prélèvement. *Rev Chir Orthop Reparatrice Appar Mot. 2008; 94(6): 561-5.*

[2] DEJOUR D, POTEL JF, GAUDOT F, PANISSET JC, CONDOURET J. Symposium, congrès SFA, Lyon, décembre 2007 : Quelle plastie du LCA, pour quelle laxité, pour quel patient ? La rupture du ligament croisé antérieur, de l'analyse préopératoire du type de rupture à l'évaluation finale à deux ans, retentissement selon le transplant choisi sur les résultats subjectifs et objectifs. *Rev Chir Orthop Reparatrice Appar Mot. 2008; Volume 94, n° 8S, pp. 356-61.*

[3] ZAFFAGNINI S, MARCACCI M, LO PRESTI M, GIORDANO G, IACONO F, NERI MP. Prospective and randomized evaluation of ACL reconstruction with three techniques: a clinical and radiographic evaluation at 5 years follow-up. *Knee Surg Sports Traumatol Arthrosc. 2006; 14(11): 1060-9.*

ANTEVERSION AND LENGTH OF THE FEMORAL TUNNEL IN ACL RECONSTRUCTION: Comparison between rigid and flexible instrumentation

F. WEIN

SUMMARY

Introduction

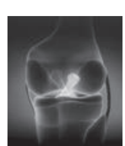
The outcome of ACL (anterior cruciate ligament) reconstruction relates directly to the positioning of the graft and therefore the positioning of the tunnels. When drilling the femoral tunnel (FT), the use of in-out techniques with standard rigid instrumentation via an antero-medial portal may result in a perforation of the posterior cortex, cause common peroneal nerve damage and produce a femoral tunnel that is too short. To correctly antevert the femoral tunnel and therefore limit such risks, flexing the knee more than 110° is recommended, which, in turn, may cause potential surgical problems. Flexible instrument technology is supposed to require less knee flexion than the antero-medial portal to position the anatomic femoral tunnel with greater length and with less potential for injury compared with rigid instrumentation. The goal of our study was to evaluate this ability. For this reason we compared the anteversion and length of the FT drilled *via* an antero-medial portal using a rigid system with a knee flexion of 120° and a flexible system with a 90° flexion.

Population and method

We conducted a prospective, comparative and randomised study on a population of 86 individuals having undergone single-bundle ACL reconstruction surgery, performed by a single surgeon, using two techniques to drill the femoral tunnel: the first technique used rigid instrumentation with the knee flexed at 120° (Rigid Population); the second technique used flexible instrumentation with the knee flexed at 90° (Flexible Population). We compared the morphometric features of these two populations (size, gender), the length of the femoral tunnel measured during the operation and the positioning of the femoral tunnel measured on post-operative X-rays.

Results

The Flexible and Rigid Populations were comparable (no significant differences) in terms of:
- *number* (Rigid: n=37; Flexible: n=43),
- *sex* (Rigid and Flexible: 67% men and 33% women),
- *height of individuals* (Rigid: mean = 174cm [162-190] ; Flexible: mean = 176cm [158-194]),



However, the length of the femoral tunnel was significantly ($p<0.05$) longer in the Flexible population (Rigid: 34mm [25-45]; Flexible: 41mm [35-50]), as was the anteversion (Rigid: 20° [5-25]; Flexible: 40° [35-45]).

Discussion/Conclusion

The use of the antero-medial portal and rigid instrumentation to correctly position the femoral tunnel may cause problems during surgery (e.g. the need to flex the knee by more than 110°). The results of this study show that it is possible to avoid these problems during surgery by using flexible instrumentation, as it allows the femoral tunnel to be placed in an ideal position with the knee flexed at 90°.

INTRODUCTION

The results of anterior cruciate ligament reconstruction primarily depend on the anatomic intra-articular positioning of the transplant. As we now have a better understanding of the anatomy of the ACL, the ideal positioning of the transplant is well established.

When drilling the femoral tunnel, the surgeon must therefore endeavour to place the femoral tunnel aperture as close as possible to the insertion site of the native ACL. For this, two aimer methods are available: an out-in method and an in-out method. For in-out aimers, two portals are possible: a transtibial portal, where the femoral aimer is inserted into the tibial tunnel; and an antero-medial portal, where the aimer is inserted *via* an antero-medial instrument portal.

Several publications have reported a high rate of incorrect positioning of the femoral tunnel in the notch when using the transtibial portal, which, in most cases, resulted in an excessively medial and anterior positioning. However, there is a risk with the antero-medial portal, which is more tangential to the axis of the femur, of causing common peroneal nerve damage [1-3] when placing the guide pin, or of perforating the posterior cortex when drilling the tunnel [1, 2, 4] or of drilling a femoral tunnel that is too short [1, 4], which may compromise the fixation and osseointegration of the transplant. To antevert the femoral tunnel and therefore limit such risks, flexing the knee beyond 110° [2, 5] is recommended when placing the guide pin and drilling.

However, the following problems may be encountered when flexing the knee beyond 110° during the surgery [1, 4, 5]: difficulties performing on obese patients, gradual closure of the antero-medial portal when increasing the flexion of the knee, problems visualising the joint and femoral footprint, risk of ovalisation of the femoral tunnel and internal condyle lesions.

The benefit of using flexible instrumentation (flexible pin and flexible reamer) is precisely to avoid such surgical problems, as it allows satisfactory anteversion of the femoral tunnel without hyperflexion of the knee [6-8]. In fact, with this instrumentation, the orientation of the femoral tunnel is guided by the direction of the guide pin, which is flexible and inserted *via* an aimer with an extremity angled at 42°; consequently, with the knee flexed at 90°, the guide pin and the femoral tunnel should be anteverted at 42°.

Flexible instrument technology is supposed to require less knee flexion than the antero-medial portal to position the anatomic femoral tunnel with greater length and with less potential for injury compared with rigid instrumentation. The goal of our study was to evaluate this ability.

We compared the anteversion and length of the femoral tunnel drilled using two different techniques; one technique used rigid instrumentation with the knee flexed at 120° while the other used flexible instrumentation with the knee flexed at 90°.

PATIENTS AND METHODS

Patients: This was a prospective, comparative, randomised and monocentric study involving a continuous series of 80 single-bundle ACL reconstructions, at the middle-third patellar tendon, carried out by a single surgeon from May 2012 to December 2013. Using the

antero-medial portal, we compared two femoral tunnel-drilling techniques: the first technique used rigid instrumentation with the knee flexed at 120° (Rigid Population) and the second used flexible instrumentation with the knee flexed at 90° (Flexible Population). Excluded from the study were: revision of ligament reconstructions, ligament reconstructions with an extra-articular lateral tenodesis, ligament reconstructions of hamstring tendons and double-bundle ligament reconstructions.

Surgical technique and instruments

Patients were positioned with their leg hanging down and their thigh placed on a leg holder. An arthroscopic investigation confirmed the ligament rupture.

The femoral tunnel was drilled via the antero-medial portal using rigid or flexible instrumentation, as determined by randomisation. The two Rigid and Flexible instruments were from the same Versi-Tomic® system (Stryker®) (fig. 1, 2).

Regarding the Rigid instrumentation, the knee was flexed at 120°; the rigid guide pin was inserted into the femur using an aimer offset by 6mm hooked behind the lateral condyle. The femoral tunnel was then drilled 10mm using a rigid reamer following the axis of the guide pin.

Regarding the flexible instrumentation, the knee was flexed at 90°; an aimer hooked behind the lateral condyle and offset by 6mm was used; however, its articular extremity was anteverted at 42° thereby providing the flexible pin with a 42° forwards angularity; during the drilling, the 10mm flexible reamer then followed the direction imposed by the pin.The tunnels were blind-ended in both cases, and an endobutton systematically used for fixation.

Fig. 1: ***Rigid instruments***

Fig. 2: ***Flexible instruments***

Evaluation method

The height of the patient was measured during the pre-surgical consultation.

The length of the femoral tunnel was measured during the procedure by directly reading the gauge intended for this purpose (fig. 3). The positioning of the femoral tunnel was measured on the post-surgical radiography profile, by an independent operator (radiologist) (fig. 4).

Fig. 3: ***Femoral tunnel measure***

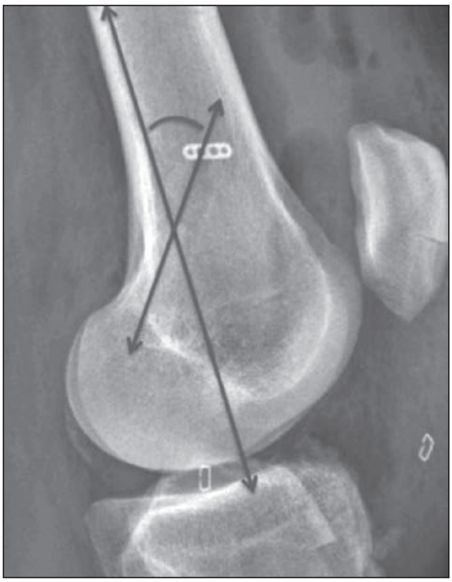


Fig. 4: ***Anteversion measure***

Statistical method

IBM SPSS Statistics software was used for the statistical analysis. A *Chi2* test was used to compare the qualitative data and Kruskall-Wallis and Mann/Whitney tests to compare the quantitative data. The alpha threshold was 5%.

RESULTS

Pre-surgical features of the two populations

The Rigid Population was composed of 37 patients: 25 men (67%) and 12 women (33%); the Flexible Population was composed of 43 patients: 29 men (67%) and 14 women (33%). These two populations were considered comparable in terms of numbers (p=0.6) and gender (p=0.8).

The mean height of individuals in the Rigid Population group was 174cm [162-190]; the mean height of individuals in the Flexible Population group was 176cm [158-194]. These two populations were considered comparable in terms of height (p=0.8).

Length and anteversion of the femoral tunnel

The length of the femoral tunnel in the Rigid Population was 34mm [25-45]; its mean length was 41mm [35-50] in the Flexible Population; this difference was considered as significant (p=0.0001).

The mean anteversion of the femoral tunnel in the Rigid Population was 20° [5-25]; it was 40° [35-45] in the Flexible population; this difference was considered as significant (p=0.0001) (fig. 5 and 6).

Fig. 5: ***Pos-op X-Ray with rigid instruments***

Fig. 6 : ***X-Ray with flexible instruments***

DISCUSSION

The lesions described when drilling the femoral tunnel, via the antero-medial portal, using rigid instrumentation are ***1)*** lesions of the posterior/external structures when passing the guide pin [1-3] and ***2)*** perforation of the posterior bone/cartilage [1, 2] during the drilling.

On cadaveric knees, using the rigid instrumentation, Basdekis *et al.* [5] systematically reported contact between the guide pin and the posterior cortex with a 90° flexion and, Steiner *et al.* [6], reported a 50% perforation of the posterior cortex at 110° of flexion. Clinically, this violation of the posterior femoral cortex could compromise graft fixation and healing.

Hall *et al.* [3] assessed the relationship between knee flexion and the risk of the common peroneal nerve injury. The mean distance from the guide pin at 120° of flexion was 44.3mm, compared with 28.6mm at 90° of flexion and 22.8mm at 70° of flexion. The differences between all 3 groups were statistically significant.

The other risk mentioned when using the antero-medial portal was producing too short a femoral tunnel [1, 4], which could potentially compromise the fixation and osseointegration of the transplant. A minimum femoral tunnel length for ACL reconstruction has not been established, but a minimum length of 25mm for interference screw fixation and a minimum length of 35mm for suspensory-type fixation have been suggested [7, 9].

However, in the antero-medial portal technique, with rigid pins, the length of the femoral tunnel is often inadequate, particularly when the knee is not in hyperflexion. Basdekis *et al.* [5] compared the length of the femoral tunnel according to the knee flexion; at a flexion of 90°, the length of the tunnel was 27mm; while at 110°, 130° and at maximum flexion, the mean length was approximately 39mm.

To avoid perforating the posterior cortex, damaging the nerves and drilling a femoral tunnel that is too short, it is recommended that the knee should be flexed at 110° or more [3, 5]. However, as Lubowitz [1] points out, positioning the knee in hyperflexion during ligament reconstruction raises operative challenges: *"inability to maintain the position of a properly seated aimer when the knee is brought into the requisite, hyperflexion position; difficulty bringing the acorn reamer over the Beath pin and through the AM portal with the knee in hyperflexion, because hyperflexion causes the portal to tighten; difficulty avoiding iatrogenic damage to the cartilage of the medial femoral condyle as the acorn reamer is advanced over the Beath pin in the hyperflexed knee; difficulty passing the reamer over the Beath pin because of a bend in the pin when the knee slips out of hyperflexion; difficulty visualizing the reamer because of ingress of the fat pad, which also occurs when the acorn reamer is advanced over the pin in hyperflexion; difficulty maintaining the position of the arthroscope (generally held by an assistant) in the hyperflexion position; difficulty visualizing the depth markings on the acorn reamer despite proper arthroscope positioning during socket creation, because of the combination of reaming debris and poor flow of arthroscopic fluid, which occurs in hyperflexion."*

It is precisely to overcome these surgical difficulties that it is worthwhile using instrumentation with a flexible system, first introduced by Cain and Clancy [8], as the positioning of the pin is achieved, not through changing the angle of the knee, but through the positioning of the aimer. The joint is easier to visualise [4] and the femoral tunnel easier to position [6].

The purpose of our study was to confirm the ability of the flexible system to drill a femoral tunnel *via* an antero-medial portal without the risk of causing posterior bone/cartilage lesions and common peroneal nerve damage, with the knee at 90°. To compare the risks involved when drilling the tunnel, our study measured the position of the femoral tunnel on post-operative profile X-rays [10]. As the posterior structures are most likely to be compromised, we noted a correlation between the degree of anteversion and a lowering of the risk of damage to these structures.

In our work, the anteversion obtained using the flexible system, with a knee flexed at 90°, was 40°; it was only 20° with the rigid system, at a flexion of 120°. The difference between these two angularities was significant.

The length of the femoral tunnel drilled with a flexible system was also on average 41mm, a length significantly longer than the one obtained with a rigid system at a flexion of 120° (34mm).

Our study therefore confirmed the option of using flexible instrumentation via the antero-medial portal at 90° of flexion, with a longer femoral tunnel and with fewer risks of posterior perforation of the lateral condyle and posterior/external lesions when drilling the femoral tunnel compared with rigid instrumentation at a flexion of 120°.

CONCLUSION

With the flexible system, it is possible to drill a femoral tunnel via an antero-medial portal, with the knee flexed at 90°. This option makes it easier to perform ligament reconstructions, as the intra-articular view and surgical procedure are easier at 90° compared with higher flexion angles. With this system, the risk of posterior bone/cartilage lesions and common peroneal nerve damage, described when using the antero-medial portal, is lower. The femoral tunnel is also long enough to allow the use of all types of fixation and encourage good osteointegration.

LITERATURE

[1] LUBOWITZ JH. Anteromedial portal technique for the anterior cruciate ligament femoral socket: pitfalls and solutions. *Arthrosc J Arthrosc Relat Surg Off Publ Arthrosc Assoc N Am Int Arthrosc Assoc 2009 Jan; 25(1): 95-101.*

[2] FARROW LD, PARKER RD. The relationship of lateral anatomic structures to exiting guide pins during femoral tunnel preparation utilizing an accessory medial portal. *Knee Surg Sports Traumatol Arthrosc Off J ESSKA 2010 Jun; 18(6): 747-53.*

[3] HALL MP, RYZEWICZ M, WALSH PJ, SHERMAN OH. Risk of iatrogenic injury to the peroneal nerve during posterolateral femoral tunnel placement in double-bundle anterior cruciate ligament reconstruction. *Am J Sports Med 2009 Jan; 37(1): 109-13.*

[4] PASTRONE A, FERRO A, BRUZZONE M, BONASIA DE, PELLEGRINO P, D'ELICIO D, *et al.* Anterior cruciate ligament reconstruction creating the femoral tunnel through the anteromedial portal. Surgical technique. *Curr Rev Musculoskelet Med 2011 Jun; 4(2): 52-6.*

[5] BASDEKIS G, ABISAFI C, CHRISTEL P. Influence of knee flexion angle on femoral tunnel characteristics when drilled through the anteromedial portal during anterior cruciate ligament reconstruction. *Arthrosc J Arthrosc Relat Surg Off Publ Arthrosc Assoc N Am Int Arthrosc Assoc 2008 Apr; 24(4): 459-64.*

[6] STEINER ME, SMART LR. Flexible instruments outperform rigid instruments to place anatomic anterior cruciate ligament femoral tunnels without hyperflexion. *Arthrosc J Arthrosc Relat Surg Off Publ Arthrosc Assoc N Am Int Arthrosc Assoc 2012 Jun; 28(6): 835-43.*

[7] SILVER AG, KAAR SG, GRISELL MK, REAGAN JM, FARROW LD. Comparison between rigid and flexible systems for drilling the femoral tunnel through an anteromedial portal in anterior cruciate ligament reconstruction. *Arthrosc J Arthrosc Relat Surg Off Publ Arthrosc Assoc N Am Int Arthrosc Assoc 2010 Jun; 26(6): 790-5.*

[8] CAIN EL JR, CLANCY WG JR. Anatomic endoscopic anterior cruciate ligament reconstruction with patella tendon autograft. *Orthop Clin North Am 2002 Oct; 33(4): 717-25.*

[9] BASDEKIS G, ABISAFI C, CHRISTEL P. Effect of knee flexion angle on length and orientation of posterolateral femoral tunnel drilled through anteromedial portal during anatomic double-bundle anterior cruciate ligament reconstruction. *Arthrosc J Arthrosc Relat Surg Off Publ Arthrosc Assoc N Am Int Arthrosc Assoc 2009 Oct; 25(10): 1108-14.*

[10] PANISSET JC, BOUX DE CASSON F. Navigated anterior cruciate ligament reconstruction: correlation between computer data and radiographic measurements. *Orthopedics 2006 Oct; 29(10 Suppl): S133-6.*

IS THE ANATOMIC FEMORAL TUNNEL MANDATORY?

S. ZAFFAGNINI, G. CARBONE, A. GRASSI, F. RAGGI, T. ROBERTI DI SARSINA, C. SIGNORELLI

INTRODUCTION

The anterior cruciate ligament (ACL) is divided into two bundles, based on their insertion in the tibial footprint, the anteromedial (AM) and the posterolateral (PL). They are parallel in extension, but change into being crossed in flexion. AM bundle is tight in knee flexion, conversely PL is tight in knee extension.

The native ACL femoral footprint occupies a very large area, extended about 115-230mm^2 [1] and it was demonstrated that a 9 mm graft would cover about 33% of the footprint cross-sectional area and 50% of the isometric profile of the native ACL profile [2].

Because of that it's very difficult to duplicate the large anatomic footprint and surgical techniques that try to reproduce anatomical insertion represent a challenge as well for more experienced surgeons. Isometric point is located in a small area of the ACL insertion, the over-the-top position, sited high in the femoral notch. Isometric placement of the graft is easier to reproduce and allows avoiding change in graft length and tension during flexion and extension of the knee.

DISCUSSION

In order to understand how to restore the better stability and kinematics in ACL reconstruction, several studies have investigated about anatomy and biomechanics of the femoral insertion of the ACL.

An anatomical study [3] has demonstrated that femoral insertion area of ACL is a large oval area, whose mean length of the long axis is 17.7 ± 2.7mm; it could be divided into a direct insertion with a four-layered structure and a two-layered indirect insertion, where Sharpey like fibers were found.

The direct insertion plays a more important role in the mechanical link between ligament and bone than indirect insertion. Instead indirect insertion is a dynamic anchorage of soft tissue to bone, allowing shear movements, but it has a weaker strength than direct insertion [4].

Kawaguchi *et al.* [5] has demonstrated that a sequential cutting of the different areas of the femoral ACL attachment produces a progressive reduction of the force required to realize a 6mm anterior displacement at any angle of knee flexion, but analysing contribution of each area in resisting to anterior tibial displacement they founded that the central direct insertion area plays a primary role in knee antero-posterior stability. According to them the most important fibers to reproduce the action of the ACL to resist tibial anterior displacement attach to the central/proximal part of the femoral insertion, corresponding approximately to the AM fiber bundle. So, on these bases, the graft in ACL reconstruction should be located near the roof of the femoral intercondylar notch, at the centre of effort of ACL sited at mean of 2 hours 2 minutes ±18minutes (clock-face position), when viewed through the intercondylar notch from posterior to anterior, parallel to the roof of the notch (Blumensaat's line). This position is similar to the over-the-top position, as showed by MRI imaging (fig. 1a-1b).

ACL behaviour during passive range of motion was investigated by Zaffagnini *et al.* [6]. They found a very characteristic behaviour, inasmuch as the angles, that two bundles of ACL create with tibial plateau and femoral

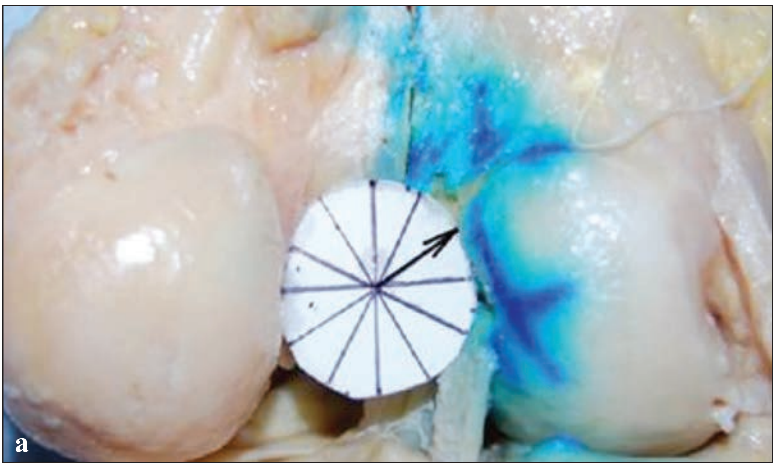
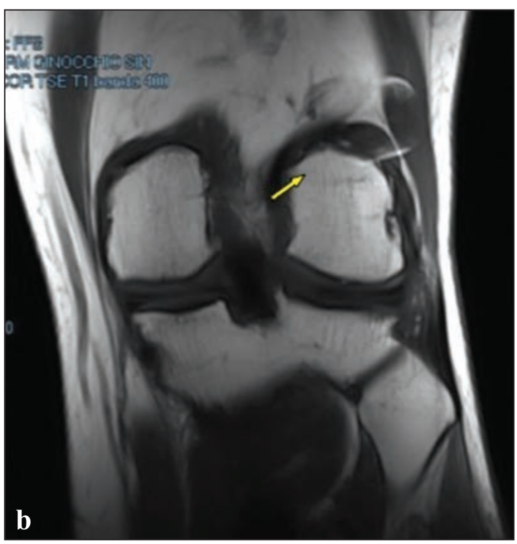


Fig. 1: ***The center of effort of the ACL is located at mean of 2 hours 2 minutes ±18minutes (clock-face position), when viewed through the intercondylar notch from posterior to anterior, parallel to the roof of the notch (Blumensaat's line) [5] (a). This position is similar to the over-the-top position, as showed by MRI imaging (b).***



notch, change during passive range of motion. With respect to the tibial plateau AM bundle is more vertical in the first 80 degrees of flexion, whereas PL bundle is more vertical between 80° and 120°. Considering angle between ACL and femoral notch, it increases progressively with flexion, and at 120° of flexion AM and PL have the same orientation, whereas there is a difference in orientation of 10° at full extension. Comparing AM and PL bundles behaviour during flexion, a major increase of the angle of PL with femoral notch during flexion could be noted.

These findings suggest that ACL forms a very complex system and the goodness of its reconstruction cannot be depend only on the reproduction of the exact insertion location, but also the orientation of the graft should be considered. ACL creates an isotropic system, difficult to reproduce in ACL reconstruction; so the best compromise to restore normal biomechanics and normal kinematics after ACL injury is an isometric reconstruction.

The isometric placement of the graft avoids changes in graft length and tension during knee flexion and extension to avoid graft failure by overstretching. Several studies have shown that positioning the femoral tunnel position inside the anatomical footprint results in knee kinematics closer to a normal knee than isometric tunnel [7]. To capture the entire footprint, a double boundle reconstruction is desirable, but the greater technical expertise and potential for complication make it non-universally accepted. So surgeon that decide to perform an anatomical femoral tunnel should select a portion of the native femoral attachment where prepare the tunnel. The rationale for an anatomic AM reconstruction is that the AM bundle is large and more isometric [8].

However Cross *et al.* [9], comparing antero-medial versus central single bundle position, has demonstrated that two compared anatomical technique were equally effective in controlling anterior tibial translation during a Lachman examination, but neither is able to restore native knee kinematics, as indicated by decreased control of anterior translation of the lateral compartment during pivot shift.

Over the top technique associated to lateral plasty, described by Marcacci *et al.* [10], allows good results associating an intra-articular reconstruction and an extra-articular reconstruction in order to reproduce the antero-lateral ligament and its function. Positioning graft in over the top position reproduce the anatomical insertion of the major functional part of the ACL. It’s showed that creating a groove in the lateral femoral condyle at the junction with the roof (11 or 1 o’clock position) led to a modified over-the-top position with approximation to an isometric placement.

Long-term follow up has demonstrated good results in terms of rate of failure and rate of osteoarthritis [11].

Moreover it was demonstrated that over the top associated to lateral plasty provides to restore a good stability and kinematics of the knee: it reduces anterior displacement of the lateral compartment of the tibia and controls internal and external rotation at 90° of flexion [12]. It’s less effectiveness in controlling dynamic laxity than anatomic double bundle procedure, but it’s easier and more reliable. Moreover it’s less aggressive to the joint, as it doesn’t require a femoral tunnel and it doesn’t violate any lateral structure.

Furthermore McCarthy *et al.* [13] demonstrated good results of over the top technique in pediatric reconstruction, similar to all epyphiseal reconstruction.

CONCLUSION

Among several technique proposed for ACL reconstruction, “over the top” technique shows many advantages that make it the ideal surgery. “Over the top” technique allows an isometric placement, respecting anatomical origin of ACL; not using femoral tunnel, it avoids malposition of the femoral tunnel and, consequently, of the graft on the femur. Biomechanically, it ensures good results if compared to anatomic double boundles reconstruction and other techniques. It represents a good option for skeletally immature patient and for revision cases. Finally, it's an easy surgery, very reliable and cheap, because it doesn't require dedicate instruments.

LITERATURE

[1] KOPF S, MUSAHL V, TASHMAN S *et al.* A systematic review of the femoral origin and tibial insertion morphology of the ACL. *Knee surgery, sports traumatology, arthroscopy: official journal of the ESSKA 2009; 17: 213-219 DOI: 10.1007/s00167-008-0709-5.*

[2] ROBINSON J, STANFORD FC, KENDOFF D *et al.* Replication of the range of native anterior cruciate ligament fiber length change behavior achieved by different grafts: measurement using computer-assisted navigation. *The American journal of sports medicine 2009; 37: 1406-11 DOI: 10.1177/0363546509331941.*

[3] SASAKI N, ISHIBASHI Y, TSUDA E *et al.* The femoral insertion of the anterior cruciate ligament: discrepancy between macroscopic and histological observations. *Arthroscopy: the journal of arthroscopic & related surgery: official publication of the Arthroscopy Association of North America and the International Arthroscopy Association 2012; 28: 1135-46 DOI: 10.1016/j.arthro.2011.12.021.*

[4] WEILER A, HOFFMANN RF, BAIL HJ *et al.* Tendon healing in a bone tunnel. Part II: Histologic analysis after biodegradable interference fit fixation in a model of anterior cruciate ligament reconstruction in sheep. *Arthroscopy: the journal of arthroscopic & related surgery: official publication of the Arthroscopy Association of North America and the International Arthroscopy Association 2002; 18: 124-35.*

[5] KAWAGUCHI Y, KONDO E, TAKEDA R *et al.* The role of fibers in the femoral attachment of the anterior cruciate ligament in resisting tibial displacement. *Arthroscopy: the journal of arthroscopic & related surgery: official publication of the Arthroscopy Association of North America and the International Arthroscopy Association 2015; 31: 435-44 DOI: 10.1016/j.arthro.2014.08.033.*

[6] ZAFFAGNINI S, MARTELLI S, ACQUAROLI F. Computer investigation of ACL orientation during passive range of motion. *Computers in biology and medicine 2004; 34: 153-63 DOI: 10.1016/S0010-4825(03)00041-6.*

[7] MUSAHL V, PLAKSEYCHUK A, VANSCYOC A *et al.* Varying femoral tunnels between the anatomical footprint and isometric positions: effect on kinematics of the anterior cruciate ligament-reconstructed knee. *The American journal of sports medicine 2005; 33: 712-8 DOI: 10.1177/0363546504271747.*

[8] PEARLE AD, SHANNON FJ, GRANCHI C *et al.* Comparison of 3-dimensional obliquity and anisometric characteristics of anterior cruciate ligament graft positions using surgical navigation. *The American journal of sports medicine 2008; 36: 1534-41 DOI: 10.1177/0363546508315536.*

[9] CROSS MB, MUSAHL V, BEDI A *et al.* Anteromedial versus central single-bundle graft position: which anatomic graft position to choose? *Knee surgery, sports traumatology, arthroscopy: official journal of the ESSKA 2012; 20: 1276-81 DOI: 10.1007/s00167-011-1737-0.*

[10] MARCACCI M, ZAFFAGNINI S, IACONO F *et al.* Arthroscopic intra- and extra-articular anterior cruciate ligament reconstruction with gracilis and semitendinosus tendons. *Knee surgery, sports traumatology, arthroscopy: official journal of the ESSKA 1998; 6: 68-75 DOI: 10.1007/s001670050075.*

[11] MARCACCI M, ZAFFAGNINI S, GIORDANO G *et al.* Anterior cruciate ligament reconstruction associated with extra-articular tenodesis: A prospective clinical and radiographic evaluation with 10- to 13-year follow-up. *The American journal of sports medicine 2009; 37: 707-14 DOI: 10.1177/0363546508328114.*

[12] ZAFFAGNINI S, SIGNORELLI C, LOPOMO N *et al.* Anatomic double-bundle and over-the-top single-bundle with additional extra-articular tenodesis: an *in vivo* quantitative assessment of knee laxity in two different ACL reconstructions. *Knee surgery, sports traumatology, arthroscopy: official journal of the ESSKA 2012; 20: 153-159 DOI: 10.1007/s00167-011-1589-7.*

[13] McCARTHY MM, TUCKER S, NGUYEN JT *et al.* Contact stress and kinematic analysis of all-epiphyseal and over-the-top pediatric reconstruction techniques for the anterior cruciate ligament. *The American journal of sports medicine 2013; 41: 1330-9 DOI: 10.1177/0363546513483269.*

WHY DO I PREFER OUTSIDE-IN IN ANTERIOR CRUCIATE LIGAMENT RECONSTRUCTION?

G. LA BARBERA, M. VALOROSO, G. DEMEY, D. DEJOUR

INTRODUCTION

The optimal treatment of anterior cruciate ligament (ACL) rupture remains controversial in literature [1, 2]. Different techniques for anterior cruciate ligament reconstruction (ACLR) are described: trans-tibial (TT), outside-in (OI), inside-out (IO) and all-inside technique. The aim of the surgery is to restore the knee stability and kinematics in order to facilitate the return to work and sport activities [1].

Van eck *& al.* [3] define the concept of the "anatomic reconstruction" as the "functional restoration of ACL to its native dimensions, collagen orientation and insertion sites". The principal advantage of anatomic ACL reconstruction is to restore the normal knee kinematic and stability. Several studies report that anatomic reconstruction more closely recovers normal biomechanics than does non-anatomic reconstruction, probably reducing the risk of osteoarthritis [4]. In this context, the OI, IO and all-inside technique should be preferred to the TT one [2]. However, the results of these techniques are still controversial. Data from the Danish Knee Ligament Reconstruction Register show that the relative risk for revision ACL surgery in IO group is 2,04 compared to the TT group. This finding could be explained because the IO procedure is more technically demanding, thus some technical errors may lead to a non anatomical reconstruction [5].

SURGICAL TECHNIQUE

The patient is prepared for general or local-regional anaesthesia, placed in the supine position on the operating table. The tourniquet is positioned on the proximal thigh. The knee is placed at 90° flexion with a foot-rest and a lateral thigh post.

Usually, the bone-patellar tendon-bone (BPTB) or hamstring tendons are harvested in a standard fashion depending on the characteristics of the patient (type and level of sport activity, age, previous ACL surgery). During BPTB, the central third of the patellar tendon (10mm) is harvested using a catamaran blade. A trapezoidal tibial bone block (10mm wide and 20mm long) and a rectangular patellar bone block (10mm wide and 15mm long) are then cut with an oscillating saw. Hamstring tendons are harvested with a tendon stripper possibly maintaining their distal insertion (depending on their length) or detaching it. We prefer to leave the graft attached at its tibial insertion obtaining a 13cm long double-stranded graft.

Knee arthroscopy is performed through two anterior portals: the antero-lateral (AL) portal is done close to the patellar tendon and the antero-medial (AM) one is performed at the same level and 15mm medially to the patellar tendon. After standard knee examination, meniscal and cartilage lesions are addressed if required. The anterior fat pad is debrided to allow adequate notch visualization, paying attention to preserve the native ACL tibial and femoral insertions, as they serve as anatomic landmarks for tunnel positioning [6] (fig. 1). The center of the ACL femoral insertion site can be located using the residual ACL footprint and the lateral intercondylar and bifurcate ridges [7] (fig. 2). With the knee at 90° of flexion, a 5mm offset outside-in femoral guide (SBM SA, Lourdes, France) is introduced through the AM portal and placed at ACL femoral insertion site. The external part of the femoral guide is located on the lateral compartment of the knee. A lateral longitudinal skin incision of 2cm is performed at the point indicated by the femoral guide. The incision is straight to the bone through and parallel to the iliotibial band fibers. The inferior limit of the incision is represented by the proximal insertion of the lateral collateral ligament and postero-lateral complex. The OI femoral guide is positioned at 45° in the axial plane and 30° in the frontal plane. Finally the pin is drilled [8] (fig. 3).

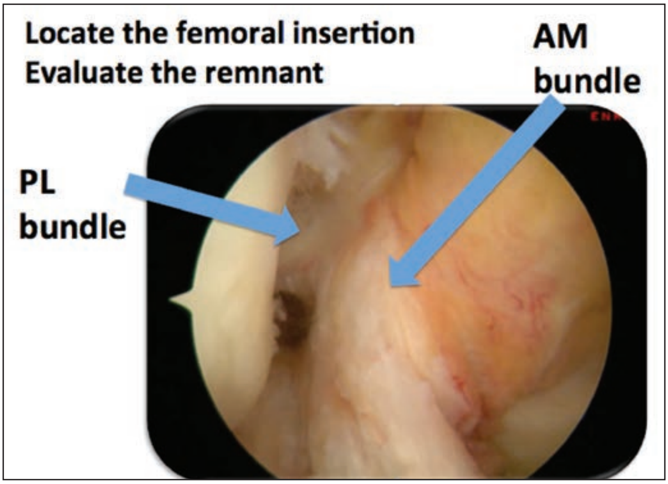


Fig. 1: ***ACL bundles evaluation. The preservation of the native ACL tibial and femoral insertions is useful because they serve as anatomic landmarks for tunnel positioning.***

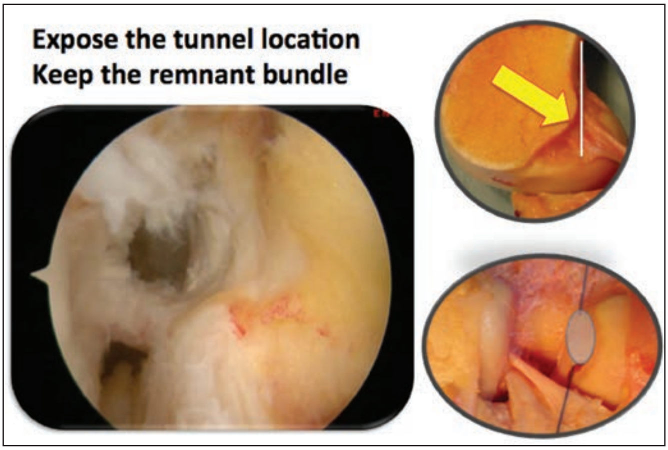


Fig. 2: ***The center of the ACL femoral insertion site can be located using the residual ACL stump. Femoral tunnel location is exposed keeping intact the remnant bundle. Femoral footprint is half a circle behind the posterior cortical line.***

Then, the tibial guide is positioned through the AM portal, using as anatomic landmarks the posterior border of the anterior horn of the lateral meniscus, the anterior border of the PCL and the interspinous area. The tibial guide has to be set with an orientation between 55° and 65° regarding the horizontal plane and with a 25° of inclination in the sagittal plane of the tibia, close to the medial collateral ligament. Finally the tibial pin is drilled and its position is tested during the range of motion to ensure that there is no impingement. The tibial and femoral tunnels are performed using a 6mm drill. The pins are adjusted according to ACL fibers orientation and the tunnels are re-drilled according to proper graft size (fig. 4).

Tunnel lengths are measured. The graft is passed in the tunnels through pulling sutures. BPTB graft is pulled from the femoral to the tibial tunnel. The trapezoidal tibial bone block should be inserted in the femoral tunnel with the cancellous bone facing forward. The patellar block is pulled into the tibia, and 90° internally rotated in order to simulate the ACL bundles orientation. Then, femoral press-fit fixation is achieved. It is recommended to tap the tibial block until it is flush with the tunnel entry point at the articular side. When hamstring tendons are detached, the graft passage is performed similarly from the femoral to the tibial tunnel. In case of the tibial insertion is preserved, the graft is pulled from

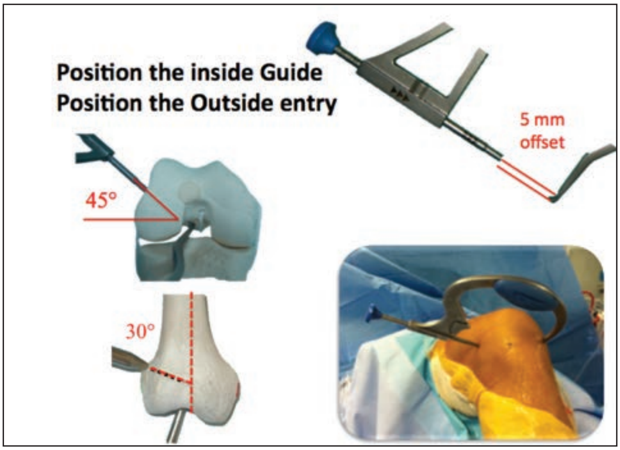


Fig. 3: ***5 mm offset outside-in femoral guide is positioned at ACL femoral insertion site with an orientation of 45° in the axial plane and 30° in the frontal plane.***

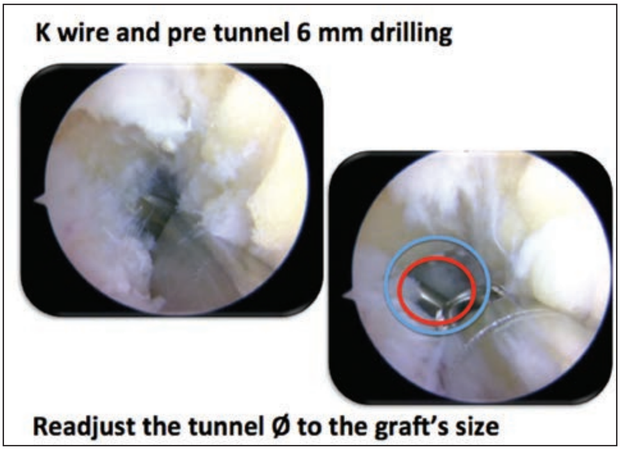


Fig. 4: ***After K wire positioning; the femoral pre tunnel is performed with 6mm drill. The pins are adjusted according to ACL orientation and the tunnels are re-drilled according to the proper graft size.***

the tibia to the femoral tunnel. The femoral fixation is then achieved with bioabsorbable interference screw (SBM SA, Lourdes, France).

The knee is then cycled to achieve graft tensioning. Finally, the tibial fixation is performed using a bioabsorbable interference screw with the knee flexed at 10°-20° and applying a posterior drawer in order to correct the anterior tibial translation. Lastly, it is mandatory to evaluate the graft tension, knee stability, full range of motion and the eventual graft impingement.

DISCUSSION

The femoral tunnel can be performed through different techniques including TT, IO, and OI. However, in the TT procedure the anatomical placement of the femoral tunnel is challenging because of the tibial constraint [2, 9]. As result, the interest of IO and OI techniques is increasing because of the possibility to create an independent femoral tunnel. Nevertheless, IO technique has some disadvantages, such as a short femoral tunnel, a possible posterior wall breakage and a poor visual field [10, 11].

ADVANTAGES

Better footprint coverage

The principal advantages of OI technique are the more predictable anatomic placement and footprint coverage, achieving better antero-posterior and rotatory stability [2].

In a cadaveric study comparing the three different techniques (TT, IO, and OI), Robert *& al.* [12] show that the average distance from the tunnel center to the native femoral footprint center is 6,8±2,68mm for the TT, 2,84±1,26mm for the IO, and 2,56±1,39mm for the OI techniques. The average percentages of the femoral tunnel within the ACL footprint are 32%, 76%, and 78% for the TT, IO, and OI techniques, respectively. In addition to the femoral position, the surgeon has to consider also the orientation of the tunnel drilling to improve the coverage of the femoral ACL stump. Matsubara *& al.* [13], in a 3D CT study, evaluate the optimal position for the OI femoral tunnel position in order to achieve a better coverage of the ACL stump. They report that the mean percentages of the femoral footprint covered are significantly higher with an inclination of 45° in the proximal-distal plane. This orientation provides an oval shape tunnel that covers and restores the native ACL stump as nearly as possible.

No risk in posterior tunnel breakage

OI technique is a safer procedure because the posterior wall preservation is better ensured and there is no risk of medial condyle cartilage damaging during femoral tunnel drilling compared to IO technique [2] (fig. 5). The intact posterior wall allows femoral press-fit fixation in case of BPTB graft. Posterior wall breakage is one of the disadvantages of IO procedure, reporting an incidence of 23,8-33% [14].

Remnant preservation

To our knowledge, in literature there are no studies that compare the remnant preservation using the three different techniques. However, it is advantageous to conserve the remnant because it improves the graft vascularization, the ligamentization and the proprioception of the knee [15].

Revision surgery

OI technique can be used easily in revision surgery where it may be necessary to drill a femoral tunnel with a different orientation avoiding previously enlarged and misplaced tunnels [8].

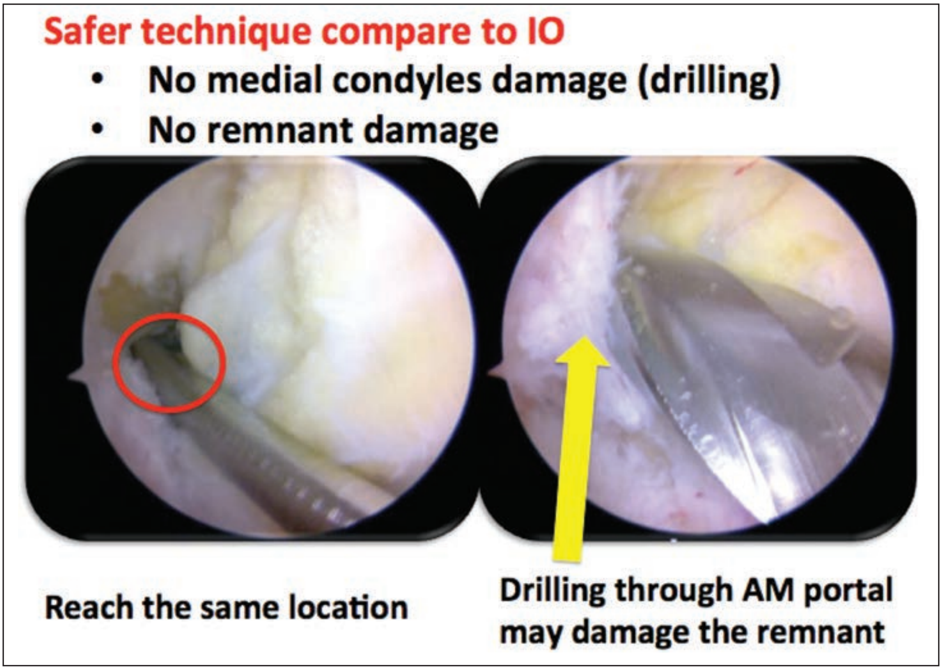


Fig. 5: ***OI technique is a safer procedure compared to IO. IO technique allows the anatomic ACL reconstruction. However, drilling through AM portal could damage the remnant and the medial condyle.***

Femoral tunnel length

The tunnel length is another factor that has to be considered. In case of a too anterior tunnel placement, a tunnel length shorter than 30mm could be drilled. It is reported that it predisposes to tunnel enlargement, graft loosening, loss of flexion and intercondylar roof impingement [2].

A short femoral tunnel socket is one of the disadvantages of the IO procedure. In order to reduce this problem, the knee should be over flexed because the femoral tunnel length increases at higher knee flexion angles. A short femoral tunnel can reduce the amount of the graft in the tunnel compromising the healing process. Therefore, the OI technique would be more advantageous in graft healing than the IO technique mainly when a suspensory fixation device is used [2].

Disadvantages

OI technique it is a more demanding procedure [2, 8]. In a recent 3D CT scan study, Park *& al.* [14] observe a more acute femoral graft bending angle in OI technique. It is supposed that this can increase the stresses on the ACL graft, damaging it and enlarging the tunnel. We suggest to smooth the tunnel entry with the shaver in order to reduce the femoral graft bending. Comparing IO and OI, Otsubo *& al.* register an average difference in the femoral graft bending angle of 6.6° [16].

The graft passage, especially using BPTB, and the second incision are other disadvantages described for OI technique. However, the risk of lateral structure damage is limited.

CONCLUSION

The OI technique allows a superior positioning of the ACL femoral tunnel at the center of the native ACL footprint compared to TT technique. Comparing IO and OI, each technique has some advantages and disadvantages. OI procedure ensures a predictable anatomic placement and footprint coverage of the ACL stump, posterior wall preservation and adequate socket length. This technique allows the ACL remnant preservation and it is useful in the revision surgery. However, it is a demanding technique requiring a second incision and the smoothing of the entry point.

LITERATURE

[1] GETELMAN MH, FRIEDMAN MJ. Revision anterior cruciate ligament reconstruction surgery. *J Am Acad Orthop Surg 1999; 7(3): 189-98.*

[2] ROBIN BN, JANI SS, MARVIL SC, REID JB, SCHILLHAMMER CK, LUBOWITZ JH. Advantages and Disadvantages of Transtibial, Anteromedial Portal, and Outside-In Femoral Tunnel Drilling in Single-Bundle Anterior Cruciate Ligament Reconstruction: A Systematic Review. *Arthrosc J Arthrosc Relat Surg. 2015: 1-6.*

[3] VAN ECK CF, SCHREIBER VM, MEJIA HA, *& al.* "Anatomic" anterior cruciate ligament reconstruction: a systematic review of surgical techniques and reporting of surgical data. *Arthroscopy 2010; 26(9 Suppl): S2-S12.*

[4] AHN JH, KIM JG, WANG JH, JUNG CH, LIM HC. Long-term results of anterior cruciate ligament reconstruction using bone-patellar tendon-bone: an analysis of the factors affecting the development of osteoarthritis. *Arthroscopy 2012; 28(8): 1114-23.*

[5] RAHR-WAGNER L, THILLEMANN TM, PEDERSEN AB, LIND MC. Increased risk of revision after anteromedial compared with transtibial drilling of the femoral tunnel during primary anterior cruciate ligament reconstruction: results from the Danish Knee Ligament Reconstruction Register. *Arthroscopy 2013; 29(1): 98-105.*

[6] COLOMBET P, DEJOUR D, PANISSET J-C, SIEBOLD R. Current concept of partial anterior cruciate ligament ruptures. *Orthop Traumatol Surg Res. 2010; 96(8 Suppl): S109-S118.*

[7] KOPF S, MUSAHL V, TASHMAN S, SZCZODRY M, SHEN W, FU FH. A systematic review of the femoral origin and tibial insertion morphology of the ACL. *Knee Surgery, Sport Traumatol Arthrosc. 2009; 17(3): 213-9.*

[8] GILL TJ, STEADMAN JR. Anterior cruciate ligament reconstruction the two-incision technique. *Orthop Clin North Am 2002; 33(5): 727-35, vii.*

[9] MILLER MD, GERDEMAN AC, MILLER CD, *& al.* The effects of extra-articular starting point and transtibial femoral drilling on the intra-articular aperture of the tibial tunnel in ACL reconstruction. *Am J Sports Med 2010; 38(4): 707-12.*

[10] SOHN OJ, LEE DC, PARK KH, AHN HS. Comparison of the Modified Transtibial Technique, Anteromedial Portal Technique and Outside-in Technique in ACL Reconstruction. *Knee Surg Relat Res. 2014; 26(4): 241-8.*

[11] GOLISH SR, BAUMFELD JA, SCHODERBEK RJ, MILLER MD. The effect of femoral tunnel starting position on tunnel length in anterior cruciate ligament reconstruction: a cadaveric study. *Arthroscopy 2007; 23(11): 1187-92.*

[12] ROBERT HE, BOUGUENNEC N, VOGELI D, BERTON E, BOWEN M. Coverage of the anterior cruciate ligament femoral footprint using 3 different approaches in single-bundle reconstruction: a cadaveric study analyzed by 3-dimensional computed tomography. *Am J Sports Med 2013; 41(10): 2375-83.*

[13] MATSUBARA H, OKAZAKI K, OSAKI K, *& al.* Optimal entry position on the lateral femoral surface for outside-in drilling technique to restore the anatomical footprint of anterior cruciate ligament. *Knee Surg Sports Traumatol Arthrosc. November 2014.*

[14] PARK JS, PARK JH, WANG JH, *& al.* Comparison of femoral tunnel geometry, using *in vivo* 3-dimensional computed tomography, during transportal and outside-in single-bundle anterior cruciate ligament reconstruction techniques. *Arthroscopy 2015; 31(1): 83-91.*

[15] TIE K, CHEN L, HU D, WANG H. The difference in clinical outcome of single-bundle anterior cruciate ligament reconstructions with and without remnant preservation: A meta-analysis. Knee. *May 2016.*

[16] OTSUBO H, SHINO K, NAKAMURA N, NAKATA K, NAKAGAWA S, KOYANAGI M. Arthroscopic evaluation of ACL grafts reconstructed with the anatomical two-bundle technique using hamstring tendon autograft. *Knee Surg Sports Traumatol Arthrosc 2007; 15(6): 720-8.*

ACL RECONSTRUCTION TECHNIQUES: WHY I DO INSIDE-OUT DRILLING OF THE ACL FEMORAL TUNNEL

C.H. BROWN

The Ideal Anatomic ACL Reconstruction Technique Should:

- Allow the surgeon to reproducibly place the ACL femoral and tibial tunnels within the native ACL attachment sites;
- Be able to be used with any type of ACL graft;
- Allow the use of suspensory and or aperture fixation devices;
- Achieve adequate femoral and tibial tunnel lengths;
- Allow the surgeon to preserve intact ACL tissue;
- Require minimal, inexpensive instrumentation.

THREE PORTAL TECHNIQUE FOR ANATOMIC SINGLE-BUNDLE ACL RECONSTRUCTION

Anatomic ACLR is facilitated by using a 3 portal technique. In the 3 portal technique, the anterolateral (AL) and anteromedial (AM) portals are used as viewing portals and the ACL femoral tunnel is drilled through an accessory anteromedial (AAM) portal (fig. 1).

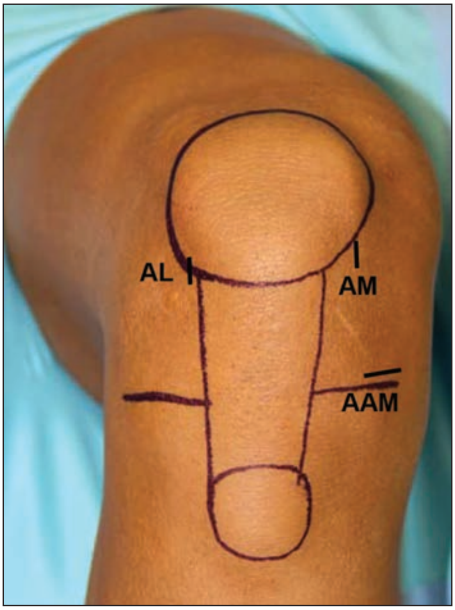


Fig. 1: ***Surface landmarks and arthroscopic portals: anterolateral portal (AL), anteromedial portal (AM), accessory anteromedial portal (AAM).***

There are many advantages of the 3 portal technique compared to the traditional 2 portal approach:

- The 3 portal technique allows the surgeon to interchange the working and viewing portals according to the specific task that is being performed.

- In the 3 portal technique, the lateral wall of the intercondylar notch can be viewed orthogonally through the AM portal while the AAM portal is used as a working portal for instrumentation. This approach allows the surgeon to look and work in the same direction, making it easier to achieve more consistent and accurate placement of the ACL femoral tunnel within the native ACL femoral attachment site (fig. 2).

Fig. 2: ***Using the AM portal as a viewing portal and drilling the femoral tunnel through the AAM portal allows you to see exactly what part of the ACL femoral footprint your femoral tunnel will cover.***

- Viewing the lateral wall of the intercondylar notch through the AM portal also eliminates the need to perform a notchplasty for visualization purposes.

- Drilling the ACL femoral tunnel through the AAM portal increases the obliquity of the ACL femoral tunnel relative to lateral wall of the intercondylar notch resulting in a longer femoral tunnel.

- The 3 portal technique is versatile and can be used when performing an anatomic ACL reconstruction with any type of ACL graft and most ACL graft fixation methods.

- The 3 portal technique can be used for any primary, revision, single- or doublebundle ACL reconstruction.

- The technique is particularly useful in cases where only one of the two ACL bundles is torn or there is a large remnant of the native ACL present. In these situations, an augmentation or tissue preserving procedure can be performed. Augmentation and tissue preserving procedures cannot be performing using a transtibial or an all-inside technique.

- Avoids a lateral incision.

- Requires minimal instrumentation (no need for expensive retro drills).

DISADVANTAGES OF DRILLING THE ACL FEMORAL TUNNEL THROUGH A MEDIAL PORTAL

- Requires the knee to be positioned in hyperflexion.

LITERATURE

ARAUJO PH, VAN ECK CF, MACALENA JA, FU FH. Advances in the three-portal technique for single- or double-bundle ACL reconstruction. *Knee Surg Sports Traumatol Arthrosc 2011; 19: 1239-42.*

BROWN CH, SPALDING T, ROBB C. Medial portal technique for single-bundle anatomical anterior cruciate (ACL) reconstruction. *Int Ortho 2013; 37: 253-69.*

COHEN SB, FU FH. Three-portal technique for anterior cruciate ligament reconstruction: use of a central medial portal. *Arthroscopy 2007; 23: 325.e1-325.e4.*

LUBOWITZ JH. Anteromedial portal technique for the anterior cruciate ligament femoral socket: pitfalls and solutions. *Arthroscopy 2009; 25: 95-101.*

SPALDING T, ROBB C, BROWN CH. Femoral bone tunnel placement (arthroscopically and with fluoroscopy). In: Siebold R, Dejour D, Zaffagnini S, eds. Anterior Cruciate Ligament Reconstruction: A Practical Surgical Guide. *Heidelberg New York Dordrecht London: Springer 2014; 159-79.*

VERSTEEG AL, PIJNENBURG ACM, BROWN CH. Anatomic ACL Reconstruction: Surgical Techniques. *Sports Injuries, Springer-Verlag Berlin Heidelberg 2014.*

BRIDGE-ENHANCED ACL REPAIR: PRECLINICAL STUDIES

C. CAMATHIAS, B.L. PROFFEN, J.T. SIEKER, A.M. KIAPOUR, M.M. MURRAY

The anterior cruciate ligament (ACL) has long been thought to have reduced healing capacity with a substantially high rate of failure after surgical repair using suture [3]. As early as 1938, Ivar Palmer described how a torn ACL fails to heal spontaneously. He concluded that a repair should be sutured as soon as possible after the injury. Subsequently, suturing the (ACL) was adopted as a treatment option; however, this led to mixed outcomes [8].

Mainly, suture techniques in which the ends of the torn ACL could be re-approximated under compression reported satisfactory results in lower-demand patients. But even these methods failed in high-demand patients. Therefore, surgeons abandoned the repair in favor of ACL reconstruction, or replacing the torn ligament with a graft of tendon, because the results of suturing were too unpredictable.

However, a stable repair of a torn ACL could provide several advantages compared to a reconstruction. It is obvious that a sutured ACL would secure the characteristics of the natural ligament, in particular, its insertion sites, and possibly even the multiple bundle morphology. A repair of the ACL could likely also better preserve the complex physiology, including the proprioception provided by an innervated ligament structure, which might be able to better protect the knee. Both of these effects may, in turn, lead to a decreased risk of posttraumatic osteoarthritis.

In contrast to the ACL, the medial collateral ligament (MCL) heals uneventfully in the majority of cases, even without surgical repair. Several factors might be responsible for this discrepancy in tissue healing including the "hostile" environment of synovial fluid, alterations in the post-injury inflammatory response and cell metabolism, intrinsic cell deficiencies, a different vascular environment, and load bearing characteristics [7, 12].

For a successful healing in ligaments, several basic biological principles are essential. To understand the biological differences between the healing of an ACL (intra-articular) and an MCL (extra-articular), a closer look at the environment is necessary. After an injury, an elevated growth factor synthesis is observed in the MCL [7]. Cells in both the torn ACL and MCL are capable of migration *in vitro* after a simulated tissue wound. Cells from both ligaments are also found to proliferate and produce essential matrix components, including collagens, both *in vitro* and *in vivo* after injury [2]. However, in contrast to the MCL, the ACL lacks a scaffold bridging the wound site. Between the ends of a ruptured MCL, a blood clot is formed, which serves as a structure or scaffold for different cells to migrate into. These cells are the starting point for formation of a fibrovascular scar which can remodel into relatively normal ligament tissue. Certainly, an injured ACL bleeds as well; however, enzymes in the synovial fluid prevent formation of a clot or a bridging scaffold in the ACL wound site. A fibrin clot is hardly formed in a post-traumatic intraarticular milieu. Quite contrary, due to enzymes in the synovial fluid, a rapid clot breakdown occurs [1]. This lack of a provisional scaffold bridging a torn ACL might be the reason for a healing failure.

In consequence, developing a sponge-like scaffold to absorb blood and stabilize the clot within the ACL wound site in the synovial fluid environment may facilitate healing of the repaired ACL.

In the same context, growth factors have also gained a lot of traction in the treatment of soft tissue injuries. A wide range of these factors, such as insulin-like growth factor (IGF), TGF-β, platelet-derived growth factor (PDGF), vascular endothelial growth factor (VEGF), fibroblast growth factor (FGF) and nerve growth factor (NGF), have been used to try to improve ligamentous and tendon tissue repair. All of these factors stimulate type I collagen production in ACL-derived cells *in vitro*, except for insulin-like growth factor. Kobayashi *et al.* noted in an *in vivo* study that Fibroblast Growth Factor 2 improved healing and neovascularization of partially lacerated ACLs in canines. Also, injections of recombinant human hepatocyte growth factor and TGF- β1 yielded improved biomechanical results and histological healing properties in a rabbit model [4]. However, to deliver these growth factors to a localized wound site of a torn ACL *in vivo* remains a major barrier for effective use of these purified factors.

Another source of many of these growth factors, platelet-rich-plasma (PRP), has been the center of attention as a novel, non-invasive treatment for sports related injuries. Although PRP is capable of forming a clot, its use to stimulate ACL graft healing has delivered mixed results. In a porcine model using a transected ACL, when used alone, PRP did not stimulate functional healing [11]. A fact that may explain the different results in using PRP is that the main structural protein in clotted PRP is fibrin. After an injury, the synovial fluid contains a large amount of fibrin-degrading enzymes. Therefore, the fibrin-based PRP clot may be prematurely dissolved in the post-traumatic or postsurgical environment. This situation could be the reason why PRP on its own fails to stimulate tissue healing even though it is capable of delivering stimulatory growth factors to the wound site. In consequence, carriers to maintain the PRP at the tear of the ACL and protect it from being washed out of the wound site have been developed. A substance more resistant to degradation by plasmin is a copolymer formed of collagen mixed with fibrin [1]. Furthermore, collagen activates platelets in a sustained fashion and releases platelet-associated factors over a period of 10 to 14 days. In contrast, platelets activated by thrombin are released physiologically within the first few hours. Thus collagen has been explored as a carrier for platelets for ACL repair.

Unlike a primary suture repair alone, an ACL repair supplemented with a collagen-PRP biomaterial improved the biomechanical properties of the repaired ACL in an *in vivo* pig model after four weeks [11]. Further experiments demonstrated that the use of whole blood was more effective than using PRP to stimulate wound healing of the ACL. While neither the collagen scaffold itself nor PRP alone was found to be effective in promoting ACL healing or repair, the combination of blood, collagen scaffold and suture stent in the novel technique of Bridge-Enhanced ACL Repair (fig. 1) led to biomechanical properties of the repaired ACL equivalent to those of an ACL reconstruction after 3, 6, and 12 months of healing in the porcine model [10]. Moreover, the bridge-enhanced ACL repair significantly reduced the amount of cartilage damage usually seen 12 months after an untreated ACL transection or an ACL reconstruction [5, 6]. These findings might suggest that a bridge-enhanced repair of the ACL protects the cartilage against early onset of osteoarthritis, which in contrast is

frequently observed after ACL injury and reconstruction in human patients. However, the underlying mechanism of the cartilage protection is still not understood. The question how collagen-platelet composites affect intra-articular tissues is unknown but a subject of ongoing investigation.

A collagen-platelet composite suffices as a provisional scaffold and allows healing of an immediately repaired ACL in the porcine model. However, this technique was less effective in the case of a repair performed with a delay of two or six weeks. The reason might be apoptosis, inflammation, or a matrix degradation within the ACL after an injury.

To understand the reaction of the ACL to an injury, different biological principles have been described, as well as the intra-articular milieu, where healing would occur. Within the ligament, fibroblasts undergo nitric oxide-induced and caspase 9-mediated apoptosis early after injury. Moreover, protein fragments increase, indicating a type I collagen breakdown [9]. These findings suggest a degradative environment, modulated by highly activated matrix metalloproteinases which break down collagen proteins. The synovial membrane, as well as the injured ligament itself after an injury, produces these enzymes [2, 9]. Addressing the synovial fluid milieu could enhance the understanding or possible counteractions of these processes and improve the results of ACL repair [5].

To decrease the cartilage breakdown in the knee by injecting therapeutic agents could be a potential strategy to slow or prevent the development of post-traumatic osteoarthritis after an ACL injury. A scenario may include caspase inhibition to decrease fibroblast apoptosis or to apply antagonists of inflammatory cytokines (e.g., interleukin 1 receptor antagonist). Also, reducing the activity of metalloproteinase might help. Therefore, short-term intra-articular treatment with these therapeutic agents might influence the detrimental biological processes that initiate ligament and cartilage degradation after ACL injury [5, 6].

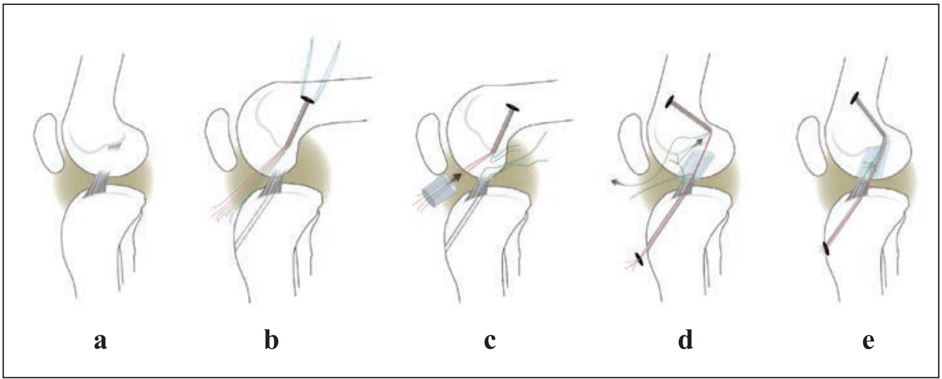


Fig. 1: ***Bridge-enhanced ACL repair. (a) Transected ACL. (b) Femoral and tibial tunnels (dashed lines) and EndoButton (Smith & Nephew Endoscopy, Andover, MA) pulled through femoral tunnel and placed on femoral cortex. The EndoButton is loaded with 3 sutures, resulting in 6 free-ending strands (4 red and 2 green). (c) A Kessler suture is placed in the tibial ACL stump, and a collagen scaffold is threaded onto 4 strands (red), pushed into the notch, and saturated with 3mL of autologous blood. (d) The 4 suture strands running through the scaffold (red) are passed through the tibial tunnel, whereas the remaining suture (green) is tied to the tibial Kessler suture, using it as a pulley to reduce and stabilize the tibial ACL stump. (e) The transtibial sutures (red) are tightened and tied over an extracortical button. The free ends of the ACL suture pulley (green) are knotted to secure the reduced ACL in the collagen-platelet composite. Reprinted with permission [10].***

SUMMARY

Suturing a ruptured ACL has been largely supplanted by the ACL reconstruction. The primary reason can be found in the outcomes of the original procedure. A primary ACL repair most likely failed and was unreliable. Torn ends could not be approximated enough, resulting in a gap that prevented a healing of the ligament. In contrast, the MCL heals successfully because the gap is filled with a blood clot which allows surrounding cells to invade and produce a functional fibrovascular scar. Such a bridging mass is not observed in the ACL, likely because of premature dissolution of blood clot by enzymes in the synovial fluid. If the tissue does not heal, the sutures of the primary repair eventually fatigue and fail.

A scaffold can be used to stabilize a provisional blood clot between the torn ACL ends for several weeks. This stabilized clot has been found to heal a torn ACL with similar mechanical properties as an ACL reconstruction in animal models. Moreover, there are favorable effects, which might decrease the risk of posttraumatic osteoarthritis. However, these promising findings derive from preclinical studies; clinical data are not yet available. Nevertheless, the bridge-enhanced repair of the ACL could be a viable option for patients with ACL injuries in the future.

LITERATURE

[1] ANDERSEN RB, GORMSEN J. Fibrin dissolution in synovial fluid. *Scand J Rheumatol 1987; 16(1): 319-33. doi:10.3109/03009747009165385.*

[2] BEYE JA, HART DA, BRAY RC, McDOUGALL JJ, SALO PT. Injury-induced changes in mRNA levels differ widely between anterior cruciate ligament and medial collateral ligament. *Am J Sports Med 2008; 36(7): 1337-46. doi:10.1177/0363546508316283.*

[3] FEAGIN JA, CURL WW. Isolated tear of the anterior cruciate ligament: 5-year follow-up study. *Am J Sports Med 1976; 4(3): 95-100.*

[4] KOBAYASHI D, KUROSAKA M, YOSHIYA S, MIZUNO K. Effect of basic fibroblast growth factor on the healing of defects in the canine anterior cruciate ligament. *Knee Surg Sports Traumatol Arthrosc 1997; 5(3): 189-94. doi:10.1007/s001670050049.*

[5] MURRAY MM, FLEMING BC. Biology of anterior cruciate ligament injury and repair: Kappa delta ann doner vaughn award paper 2013. *J Orthop Res 2013; 31(10): 1501-6. doi:10.1002/jor.22420.*

[6] MURRAY MM, FLEMING BC. Use of a bioactive scaffold to stimulate anterior cruciate ligament healing also minimizes posttraumatic osteoarthritis after surgery. *Am J Sports Med 2013; 41(8): 1762-70. doi:10.1177/0363546513483446.*

[7] MURRAY MM, SPINDLER KP, BALLARD P, WELCH TP, ZURAKOWSKI D, NANNEY LB. Enhanced histologic repair in a central wound in the anterior cruciate ligament with a collagen-platelet-rich plasma scaffold. *J Orthop Res 2007; 25(8): 1007-17. doi:10.1002/jor.20367.*

[8] PALMER I. On the Injuries to the Ligaments of the Knee Joint: a Clinical Study. 1938. *Vol 454. 2007:17-22-discussion 14. doi:10.1097/BLO.0b013e31802c7915.*

[9] PROFFEN BL, SIEKER JT, MURRAY MM. Bridge-enhanced repair of the anterior cruciate ligament. *Arthroscopy 2015; 31(5): 990-7. doi:10.1016/j.arthro.2014.11.016.*

[10] VAVKEN P, FLEMING BC, MASTRANGELO AN, MACHAN JT, MURRAY MM. Biomechanical outcomes after bioenhanced anterior cruciate ligament repair and anterior cruciate ligament reconstruction are equal in a porcine model. *Arthroscopy 2012; 28(5): 672-80. doi:10.1016/j.arthro.2011.10.008.*

[11] VAVKEN P, SADOGHI P, MURRAY MM. The effect of platelet concentrates on graft maturation and graft-bone interface healing in anterior cruciate ligament reconstruction in human patients: a systematic review of controlled trials. *Arthroscopy 2011; 27(11): 1573-83. doi:10.1016/j.arthro.2011.06.003.*

[12] WOO SL, VOGRIN TM, ABRAMOWITCH SD. Healing and repair of ligament injuries in the knee. *J Am Acad Orthop Surg 2000; 8(6): 364-72.*

IS THERE A PLACE FOR A SYNTHETIC LIGAMENT?

J.A. FELLER

INTRODUCTION

Synthetic devices have been available since the 1970s for the treatment of anterior cruciate ligament (ACL) injury. Such devices have a number of potential benefits including the avoidance of donor site morbidity, provision of a strong stabilising construct – thereby allowing aggressive rehabilitation and an early return to sport – and the absence of the potential for disease transmission. Despite these potential benefits, the use of synthetic ligaments for ACL reconstruction remains controversial. Devices implanted in the late 1970s and 1980s had poor outcomes including high failure rates and significant complications such as synovitis, osteolysis and osteoarthritis. More recent devices appear to have better reported outcomes in the short to mid-term, but have not gained widespread support.

HISTORICAL OVERVIEW

A full historical account of the use of synthetic devices in for ACL reconstruction is beyond the scope of this chapter, but a brief summary is provided as a background to current thinking. A more detailed account can be found in the article by Mascarenhas and MacDonald [6]. One of the major concerns with earlier synthetic grafts was synovitis. It was attributed to abrasion and breakage of the synthetic devices resulting in free debris and particles within the joint and there was concern that because of the non-absorbable nature of the synthetic ligaments, there was an increased risk of developing osteoarthritis.

There was considerable interest in the potential of carbon fiber as a scaffold for ligament regeneration in the 1970s. A number of carbon fiber devices were developed but were associated with high failure rates, synovitis and dissemination of carbon fiber to regional lymph nodes. Modifications were made to include polylactic acid and polycapralactone coating in an ultimately unsuccessful attempt to reduce problems with carbon wear particles.

Various devices have been developed from polyester composites. The Leeds-Keio synthetic ligament was woven from polyester and was intended to serve as a scaffold for ingrowth of ligamentous tissue. Conflicting results with regard to ingrowth and clinical out come were reported and concerns were raised about the presence of foreign body giants cells containing polyester debris. Like other synthetic ligaments, the Leeds-Keio ligament fell into disuse.

The Dacron artificial ligament was made of polyester strips and was designed as an augmentation. It was nonetheless used by some surgeons as a prosthetic ligament in "salvage" cases. Despite initial promising results, longer-term follow-up showed high failure rates, osteolysis, synovitis and high rates of osteoarthritis and the device was subsequently withdrawn from the market.

The Goretex device made from expanded polytetrafluoroethylene (PTFE) was used between the mid 1980s and mid 1990s. Intended as a permanent implant, an important property was its ultimate tensile strength of approximately 5300N, higher than any counterparts. However, once again initial promising results were overtaken by poor outcomes in the mid-term, with ligament failure and effusion being the predominant adverse findings. Importantly, poor positioning of the graft was recognized as a factor contributing to the risk of graft abrasion and failure. The device was eventually withdrawn from the market.

In the early 1980s Kennedy proposed the use of a polypropylene braid as a Ligament Augmentation Device (LAD) to protect patellar tendon grafts in the early post-operative period. It was sutured to the autograft to form a composite graft. It was supposed that the LAD could protect the autograft during its remodelling and it was assumed that potential stress shielding of theautograft would be minimized by the relatively low tensile strength of the LAD and the fact that only one end of device was fixed. Studies failed to show any advantage over autografts alone and failures with intra-articular debris and effusions were reported. As a result, usage of the Kennedy LAD ceased.

MODERN DEVICES

A second generation Leeds Keio (LKII) device was made available in 2003 with the addition of radio-frequency generated glow discharge treatment. A number of polyethylene terephthalate (PET) devices have also been developed and include the Trevira-Hochfest, Proflex, Pro-Pivot and Ligament Advanced Reinforcement System (LARS) devices. Of these, the LARS device has been most widely used and reported. The results are discussed below in more detail.

SYSTEMATIC REVIEWS

There have been three recent systematic reviews of the results of synthetic ligaments for cruciate ligament injury.

Mulford *et al.* evaluated the efficacy of PET artificial ligaments in the ACL reconstruction [7]. A total of 23 papers published between 1970 and 2010 were included. Twelve papers were related to the LARS and the remaining 11 focused on the long-term outcomes of other PET ligaments. In studies of the LARS, the mean follow-up period was 28 months (range 4-60 months. In 655 cases the documented graft rupture rate was 2% (14 cases). The authors did however note the poor methodological quality of the included studies.

In their 2013 systematic review that included many of the papers included in the review by Mulford *et al.*, Newman *et al.* evaluated studies of the LARS device for ACL reconstruction [8]. There were nine papers, including one randomized control trial, and all were published between 1990 and 2010. Not surprisingly, there was a similar failure rate of 2.5%. Most failures were attributed to tunnel malposition. Again, only one case of synovitis was reported. Return to sports took two to six months, earlier than that for patients having an autograft procedure. However, the poor methodological quality of the papers and the need for high quality longer-term studies was once again highlighted.

More recently, Batty *et al.* systematically reviewed the literature related to the clinical application of artificial ligaments in cruciate ligament surgery [2]. With regard to the ACL, the highest failure rate was observed with the Dacron device with a cumulative failure rate of 33.6%. Non-infective synovitis and effusion were most frequently seen with the Gore-Tex artificial ligament (up to 27.6%).

With regard to more recent synthetic devices, three studies published between 1994 and 2010 reported on ACL reconstruction with the Trevira-Hochfest device. One of these studies also reported on two other PET devices, the Proflex and Pro-Pivot. All studies were prospective cases series and included a total of 265 reconstructions. Only one of the three studies used multiple outcome measurements. The mean follow-up time ranged from 40 to 225 months. Overall, the failure rate was 9.4% (25 failures from 265 reconstructions).

As mentioned previously, more recent designs of synthetic ligament devices include the LARS and LK II. Fourteen studies in the Batty *et al*. systematic review reported outcomes for these designs LARS (n=13) and the LK II (n=1). The 14 included studies reported an overall low failure rate of 2.6%, over a follow-up period that ranged from 22 to 95 months. However, the single report on the LK II device had the shortest mean follow up time and meaningful interpretation of the results is difficult as only 13 patients were included.

On the basis of the systematic review, the results of the LARS device appear encouraging, with [19] documented failures in 736 patients (2.6%). In those studies that reported Lysholm scores, the mean post-operative score was 88, compared to a mean pre-operative score of 54. KT-1000 arthrometer side-to-side difference was measured in 7 studies in 394 knees with a mean side-to-side difference of 2.2mm (range, 1.2 to 4.2mm). Pivot-shift was recorded for 497 patients in 4 studies with a grade 2 pivot (clear shift and visible reduction) present in 6.4%. The overall reported incidence of synovitis was 0.2% (one reported case from 483 knees).

In terms of comparative studies, the 1 RCT compared 26 LARS devices with 27 patellar tendon autografts. At 24 months there was no significant difference between the groups in terms of IKDC or KOOS scores. One retrospective study compared 30 patellar tendon autografts with 32 LARS reconstructions with a minimum follow-up of 4 years. There were no differences between the groups in terms of Lysholm, Tegner, IKDC, and KT-1000 assessments. In a second retrospective study, 32 four-strand hamstring ACL reconstructions were compared with 28 LARS ACL reconstructions, also with a minimum follow-up of 4 years. Again, there was no difference in Lysholm, IKDC, or Tegner scores, but the LARS group had significantly less anterior displacement as measured by KT-1000.

However, it should also be noted that in the Batty *et al.* systematic review, the MINORS score was used to assess the methodologic quality of included studies. The ideal score was 16 points for non-comparative studies and case series and 24 points for comparative studies. The mean MINORS score for the non-comparative LARS studies was only 7.6 points (SD, 1.2 points) and 17.3 points (SD, 1.5 points) for the comparative studies.

Given such low levels of evidence, the findings of the systematic review should therefore be interpreted with caution. For example, although the overall rate of synovitis and effusion for the LARS device was lower than reported for earlier synthetic devices, half of the included studies made no mention of these outcomes.

Closer analysis of individual papers can also be revealing. Parchi *et al.* reported on 26 of 29 patients at mean follow-up of 7.9 years [9]. The mean age of the patients at the time of follow-up was 38.5 years. Joint stability and range of motion were reported to be satisfactory in 24 patients. For the KOOS score, 11 patients (42.3%) rated optimal (>90) and 13 (50%) good (70-89). However, there was a wide range of scores, from 10 to 100. Similar findings were found for the Cincinnati knee rating scale with 92.3% rating optimal (61.5%) or good (30.8%). Again, there was a wide range was from 22 to 100. Although the authors' message was that the LARS device might be "a suitable option for ACL reconstruction in carefully selected cases", the following points should be noted; there was no control group, the patients were relatively older compared to the usual group reported in follow-up of ACL reconstruction, included patients elected to have a LARS procedure (potential for selection bias), despite generally satisfactory outcomes some patients did badly, and no data was provided regarding return to pre-injury activities.

CURRENT STATUS

In spite of the generally satisfactory results reported for the LARS in the above systematic reviews, questions remain about its role. Indeed, in many countries it has either not been approved for use, is not available, or has fallen from favor. One explanation for this apparent contradiction is the potential for publication bias, whereby poor outcomes are less likely to be reported. This potential needs to be acknowledged when interpreting the results of systematic reviews. This was highlighted by Waterman and Johnson in a response to the Batty *et al.* review [11]. However, their response also included the following statement with regard to the LARS device; “Anyone who has worked with this graft option is well aware of its high failure rate in active cohorts.” Such anecdotal experience is obviously not included in a systematic review and can be quite at odds with the findings of a review.

In a recent study, Tiefenboeck *et al.* came to a conclusion in keeping with this sentiment [10]. They stated that the LARS device should “not be suggested as a potential graft for the primary reconstruction of the ACL”. Twenty-six patients underwent primary isolated ACL reconstruction with the LARS between 2000 and 2004. Final evaluation was completed in 18 at the mean age of 29, with a mean follow-up period of 151 months. The high failure rate was the authors’ principal source of concern. Eleven patients had either KT-2000 side-to-side difference in anterior knee laxity of more than 5mm (4 patients) or a revision procedure due to re-injury (5 patients) or revision due to deep infection (2 patients). Feller *et al.* have also reported a high (60%) failure rate of the LARS device in professional footballers, despite a 100% rate of return to sport [3]. Disabling synovitis has also been reported [4].

The LARS device has also been used as an augmentation of hamstring autografts. Hamido *et al.* reported on its use as an augmentation for small diameter or short grafts in 112 patients with a mean age of 26 at the time of surgery [5]. The follow-up period was 45 months. Relatively little detail about post-operative assessment is provided. However, on IKDC evaluation 67% patients rated normal and 28.6% rated nearly normal. Eighty-two percent of patients returned to their pre-injury sports activities. No patient had a graft rupture, synovitis, screw loosening or bone-tunnel enlargement on radiological examination. Annear *et al.* have also reported high rates of an early return to sport with a LARS/hamstring hybrid graft (n=16) compared to a double-bundle hamstring graft (n=9), with one graft rupture in each group, at 3 years and 18 months respectively [1].

CONCLUSION

Historically, the results of synthetic grafts for ACL reconstruction have been poor due to high failure rates, synovitis, tunnel widening and screw loosening. Recent systematic reviews suggest that the results of the LARS device may be more encouraging, but the lack of high quality studies is a recurrent theme in their analyses. Selection bias is a particular problem with included patients often being older. Publication bias may mean that poor results are less frequently reported. If synthetic ligaments have a role in ACL reconstruction it may be as a graft in older, lower demand patients who require an early return of function, or as an augmentation of autografts to allow an earlier return to sport. However, the potential for synovitis remains a concern. High quality studies using modern and appropriate assessment tools are still required to establish the place of synthetic ligaments.

LITERATURE

[1] ANNEAR P, KELLY D, HILLE D, FALCONER T. Early return to sport in high competitive and elite athletes: A comparative study of double-bundle hamstring and hamstring/LARS hybrid anterior cruciate reconstruction. *Australian Orthopaedic Association Annual Scientific Meeting. Brisbane, Australia; 2015.*

[2] BATTY LM, NORSWORTHY CJ, LASH NJ, WASIAK J, RICHMOND AK, FELLER JA. Synthetic devices for reconstructive surgery of the cruciate ligaments: a systematic review. *Arthroscopy 2015; 31(5): 957-68.*

[3] FELLER JA, LAI CCH, WEBSTER KE. The demands placed on the ACL in professional football: Australian Football League. *19th Asia Pacific Orthopaedic Association Congress. Melbourne, Australia; 2016.*

[4] GLEZOS CM, WALLER A, BOURKE HE, SALMON LJ, PINCZEWSKI LA. Disabling synovitis associated with LARS artificial ligament use in anterior cruciate ligament reconstruction: a case report. *Am J Sports Med 2012; 40(5): 1167-71.*

[5] HAMIDO F, MISFER AK, AL HARRAN H, *et al.* The use of the LARS artificial ligament to augment a short or undersized ACL hamstrings tendon graft. *Knee 2011; 18(6): 373-8.*

[6] MASCARENHAS R, MacDONALD PB. Anterior cruciate ligament reconstruction: a look at prosthetics-past, present and possible future. *Mcgill J Med 2008; 11(1): 29-37.*

[7] MULFORD JS, CHEN D. Anterior cruciate ligament reconstruction: a systematic review of polyethylene terephthalate grafts. *ANZ J Surg 2011; 81(11): 785-9.*

[8] NEWMAN SD, ATKINSON HD, WILLIS-OWEN CA. Anterior cruciate ligament reconstruction with the ligament augmentation and reconstruction system: a systematic review. *Int Orthop 2013; 37(2): 321-6.*

[9] PARCHI PD, GIANLUCA C, DOLFI L, *et al.* Anterior cruciate ligament reconstruction with LARS artificial ligament results at a mean follow-up of eight years. *Int Orthop 2013; 37(8): 1567-74.*

[10] TIEFENBOECK TM, THURMAIER E, TIEFENBOECK MM, *et al.* Clinical and functional outcome after anterior cruciate ligament reconstruction using the LARS system at a minimum follow-up of 10 years. *Knee 2015; 22(6): 565-8.*

[11] WATERMAN BR, JOHNSON DH. Synthetic Grafts-Where is the Common Sense? *Arthroscopy 2015; 31(10): 1849-50.*

ACL RECONSTRUCTION USING MINIMAL INVASIVE HARVESTED QUADRICEPS TENDON

C. FINK, M. HERBORT, P. GFÖLLER, C. HOSER

The selection of a graft for reconstructing the anterior cruciate ligament (ACL) continues to be a controversial issue. While the patellar tendon was long considered the "gold standard" for ACL reconstructions, in recent years it was surpassed in popularity by the semitendinosus and gracilis tendons. Meanwhile, relatively little attention was given to the quadriceps tendon (QT) as a graft source. During the 1990s, only a few surgeons favored the QT for ACL reconstruction. Stäubli *et al.* [10] demonstrated the advantages of the graft in their anatomic, biomechanical and clinical studies. While many knee surgeons currently regard the QT as a good revision graft, to date it has not been widely utilized as a standard graft for primary ACL reconstructions despite excellent clinical results [1, 4, 6, 7, 9]. We feel that this is mainly because harvesting of the QT graft is more technically demanding and often yields less favorable cosmetic results when using a conventional technique.

Neither a QT graft nor a patellar tendon graft is inherently round [3, 8]. Only the reaming technique makes it necessary to harvest a cylindrical bone plug that will fit snugly in a classic bone tunnel. These considerations led us to develop a technique for creating rectangular bone tunnels that conform to graft shape. Furthermore, this modification has been shown to have a biomechanical advantage with respect to rotational laxity [5, 8]. We also wanted to simplify the technique for harvesting the QT graft and reduce donor-site morbidity, particularly from a cosmetic standpoint [2, 3].

OPERATING TECHNIQUE

Harvesting a QT Graft with a Bone Plug

A transverse skin incision approximately 2-3 cm long (or a longitudinal incision of equal length) is made over the superior border of the patella. The bursal layer are then dissected aside to expose the QT, and a long Langenbeck retractor is introduced. Next a tendon knife with two parallel blades is advanced to the 6 cm mark (measured from the superior patellar border) to define the width of the graft (9, 10, or 12 mm) (fig. 1a). The thickness of the graft is then defined with the tendon separator, which is set to a depth of 5 mm (fig. 1b) and is also advanced to the 6 cm mark. Finally, graft length is determined with the quadriceps tendon cutter, a punch-action instrument that is introduced 1-2 cm proximal to the superior patellar border. It is advanced to the desired length (6 cm) and activated to free the proximal end of the gr*aft* (fig. 1c). The graft is now reflected distally, and the distal end of the graft

is outlined with a scalpel, cutting down to the patella. Next an oscillating saw with a narrow blade (0.5-0.7 cm) and a chisel are used to harvest a bone plug 1.5 cm long with a width and thickness conforming to graft geometry. To avoid patellar fractures, it is advisable (as in the conventional harvesting technique) to finish by sawing parallel to the anterior patellar surface in a proximal-to-distal direction with the narrow saw blade (fig. 2). At that point the bone plug is easily mobilized with a chisel. The free end of the tendon is whipstitched with two nonabsorbable N° 2 lead sutures. The bone plug is tailored to form a rectangle of the desired size. Rounding the proximal corners of the bone plug will facilitate later graft passage into the joint. Two 1.5 mm holes are drilled in the bone plug, which is then tied to a FlippTack® fixation button (Karl Storz, Germany) with a nonabsorbable suture (e.g. Fibre Wire®, Arthrex Naples FL).

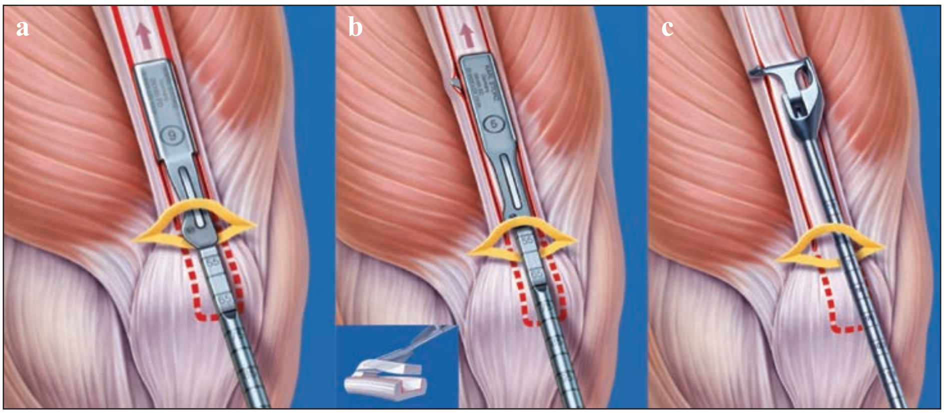


Fig. 1: ***(a) Subcutaneous advancement of the tendon knife. The cutting edges are spaced at the desired graft width. (b) Insertion and advancement of the 5 mm tendon separator. (c) Subcutaneous advancement of the quadriceps tendon cutter.***

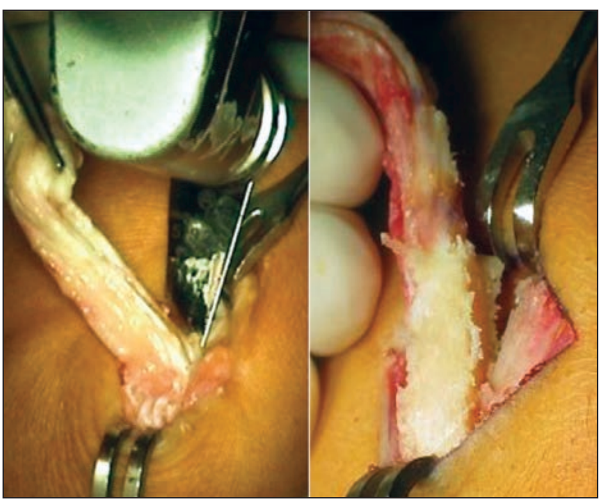


Fig. 2: ***Harvesting the bone plug with the oscillating saw. The last cut is made in a proximal-to-distal direction, tailoring the thickness of the bone plug to the graft thickness.***

Harvesting the Graft without a Bone Plug

Another option is to use the QT without a bone plug. The initial steps are the same as for a QT-bone graft. If the graft is freed directly at the superior patellar border, it should be harvested in a length of 7 cm. As an alternative to the bone plug, a periosteal strip equal to the graft width and 1.5-2 cm thick can be dissected from the anterior patellar surface (fig. 3a). The strip is then folded over (fig. 3b) and whipstitched with two nonabsorbable N° 2 sutures. This yields a rounded end that will facilitate later graft passage. Double lead sutures are placed in the distal end of the graft as in the bone plug technique (fig. 3c).

In both techniques the donor defect in the tendon is closed superficially with sutures. We do not recommend definitive wound closure at this time. Packing the donor site with a subcutaneous gauze sponge can provide good hemostasis and reduce any extravasation that may occur (from opening the suprapatellar pouch).

Femoral Bone Tunnel

A standard arthroscope portal is placed just lateral to the patellar tendon at the level of the patellar apex. A low medial portal is then placed under vision, using a trial needle to determine the portal site. The cruciate ligament remnants are resected, leaving a tibial stump. Generally it is unnecessary to perform a notchplasty. With the knee flexed 90°, the anatomic femoral insertion site of the ACL is marked with a microfracture awl. The position of this point can be checked by viewing through the medial arthroscope portal. A 2.4 mm guide wire is now introduced through the medial arthroscope portal using a femoral drill guide.

When the correct position of the guide wire has been confirmed, it is overdrilled with a 4.5 mm drill bit. Then a rasp (8mm for an 8 or 9 mm tendon graft or 10 mm for a 10 or 12 mm graft) is passed through the medial portal. A Half Pipe® can be used to facilitate rasp insertion. With the knee flexed 115°, the rasp should be aligned parallel to the tibial plateau (fig. 4). The

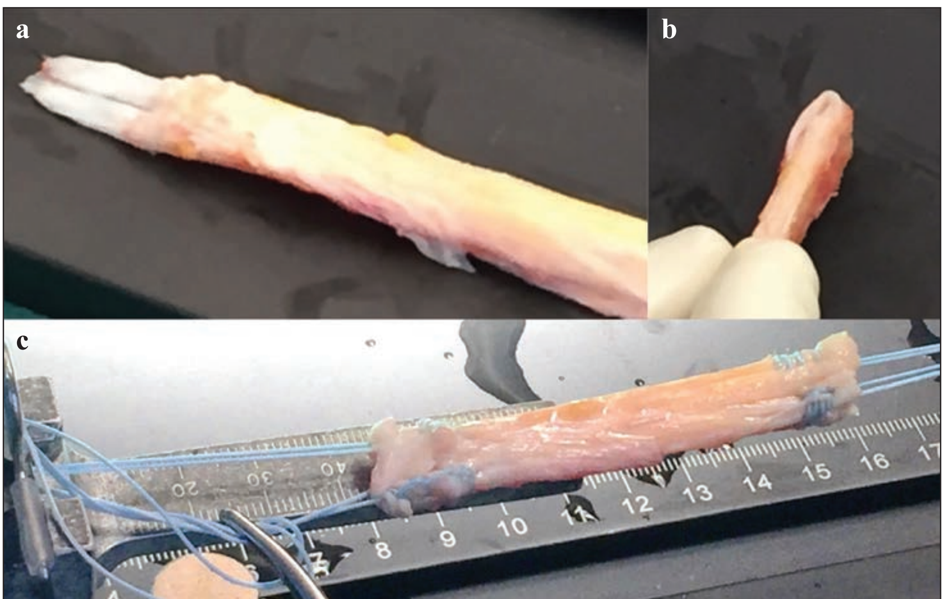


Fig. 3: ***(a) Harvesting a QT graft with a 2 cm-long periosteal strip conforming to the graft width. (b) The periosteal strip is folded over and (c) whipstitched with two nonabsorbable N° 2 sutures.***

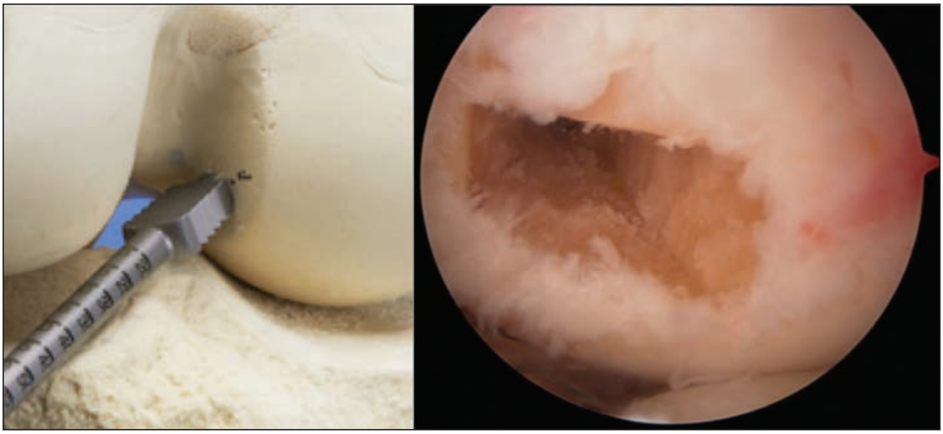


Fig. 4: ***The rasp (8 or 10 x 5 mm) is driven into the bone tunnel with the knee flexed approximately 110°. The instrument should be parallel to the tibial plateau, and its smooth surface should face the posterior cruciate ligament.***

smooth surface of the rasp should face the posterior cruciate ligament to protect that structure from injury. A socket is formed by driving the rasp in slowly to a depth of approximately 25-30 mm (1 cm longer than the bone plug). The rasp is then tapped back out, and if necessary a dilator of the same dimensions is inserted using the same technique.

Tibial Bone Tunnel

The tibial drill guide is introduced through the medial arthroscope portal. Then a vertical or horizontal skin incision approximately 1.5 cm long is made medial to the tibial tuberosity. The first guide wire is now drilled in through the center of the drill sleeve, and its relation to the roof of the intercondylar notch is evaluated by extending the knee. If the wire is correctly placed, the guide sleeve is removed and a cannulated 10 mm (or 12 mm) drill bit is advanced over the wire. It is predrilled to a depth of 0.5-1 cm to create a countersunk bed for the later placement of an EndoTack® (Karl Storz, Germany). Now the drill sleeve is reintroduced and fixed securely in the predrilled hole. Depending on the position of the first guide wire in relation to the notch roof, a second guide wire is drilled in parallel to the first at a slightly more anterior or posterior site. Next, each wire is overdrilled with a 5 mm drill bit (for a planned 5.5 x 9.5 mm tibial tunnel) or a 5.5 mm drill bit (for a 5.5 x 10.5 mm or 12.5 mm tibial tunnel. Both wires are removed, and any bony bridges that remain between the drill holes are disrupted with a shaver. Now a guide wire is inserted for orientation purposes, and a rasp of the correct width (8 or 10mm) is carefully driven into the tunnel. Finally a tibial dilator of the appropriate size is carefully tapped into place to complete the tibial tunnel (fig. 5).

Since the placement of a rectangular tibial bone tunnel is more technically demanding, a conventional round tunnel may also be created.

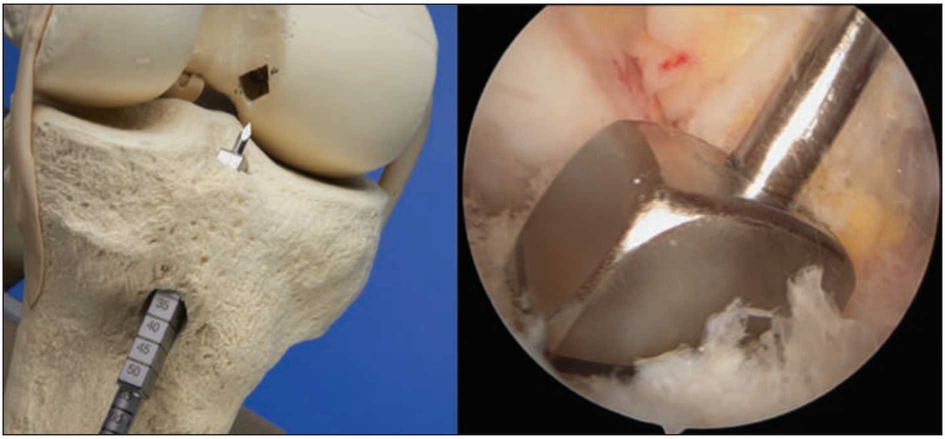


Fig. 5: ***A tibial dilator of the appropriate size is carefully driven into place.***

Graft Passage

The suture loop from the bone plug or the free suture ends from the tendon end of the graft (= end without bone) to the FlippTack® are now tied off to equal the measured length of the femoral tunnel. When a bone plug is used, its distal end should fit flush with the intra-articular cortex.

Correct graft rotation is an important consideration during graft passage. It is easier to achieve correct graft rotation with the knee slightly extended. Once the plug has been properly rotated, the knee is flexed and the graft is pulled completely into the joint. When it is confirmed that the fixation button has been flipped, the graft is pulled back through the tibial tunnel to seat the button securely against the femoral cortex. Now the knee joint is taken through 10 cycles of flexion-extension while traction is maintained on the distal leads. Then, with the knee flexed approximately 20°, the tibial end of the graft is fixed with a 7 or 8 x 28 mm absorbable interference screw inserted on the lateral side of the graft. Additionally, the sutures are tied over an EndoTack® (Karl Storz, Germany) (fig. 6a).

Fig. 6: ***(a) Radiographic result and (b) Cosmetic results after ACL reconstruction with a QT graft and minimally invasive subcutaneous harvesting technique.***

POSTOPERATIVE CARE

While still in the operating room, the knee is positioned in an extension brace following application of the wound dressing and a Cryo cuff.

If the patient is hospitalized, drains are removed and radiographs are obtained on the first postoperative day. A 0-0-90° knee brace is applied, and the patient is mobilized under the direction of a physical therapist.

Partial weight bearing at approximately 20-30 kg should be maintained for the first two postoperative weeks. The brace and crutches can be discontinued by the third postoperative week. In most cases the patient is discharged on the second or third postoperative day and continues outpatient physical therapy 2 or 3 times per week for at least 6 weeks.

In patients with associated injuries and/or concomitant procedures (torn medial collateral ligament, meniscus repairs, etc.), the rehabilitation protocol should be modified accordingly.

SUMMARY

The quality of the QT is often underestimated in cruciate ligament surgery. The tendon is very flexible in its dimensions and can be used with or without a bone plug. It is superior to the patellar tendon in donor-site morbidity, especially with regard to kneeling [7]. Based on the results of clinical and biomechanical studies, the QT also appears to be a suitable graft for primary anatomic reconstructions of the anterior cruciate ligament [9]. To date, we feel that a major obstacle to the widespread use of the QT as a primary graft is the more technically demanding harvesting technique and the frequently poorer cosmetic result. These disadvantages can be significantly reduced, however, by the development of a standardized, minimally invasive technique for harvesting the graft (fig. 6b).

LITERATURE

[1] CHEN CH, CHUANG TY, WANG KC, CHEN WJ, SHIH CH. Arthroscopic anterior cruciate ligament reconstruction with quadriceps tendon autograft: clinical outcome in 4-7 years. *Knee Surg Sports Traumatol Arthrosc 2006; 14(11): 1077-85.*

[2] FINK C, HERBORT M, ABERMANN E, HOSER C. Minimally invasive harvest of a quadriceps tendon graft with or without a bone block. *Arthrosc Tech 2014; 3(4): e509-13.*

[3] FINK C, HOSER C. Einzelbündeltechnik: Quadrizepssehne in Portaltechnik. *Arthroskopie 2013; 26(1): 35-41.*

[4] GEIB TM, SHELTON WR, PHELPS RA, CLARK L. Anterior cruciate ligament reconstruction using quadriceps tendon autograft: intermediate-term outcome. *Arthroscopy 2009; 25(12): 1408-14.*

[5] HERBORT M, TECKLENBURG K, ZANTOP T, RASCHKE MJ, HOSER C, SCHULZE M, PETERSEN W, FINK C. Single-bundle anterior cruciate ligament reconstruction: a biomechanical cadaveric study of a rectangular quadriceps and bone-patellar tendon-bone graft configuration versus a round hamstring graft. *Arthroscopy 2013 Dec; 29(12): 1981-90.*

[6] HOEHER J, BALKE M, ALBERS M. Anterior cruciate ligament (ACL) reconstruction using a quadriceps tendon autograft and press-fit fixation has equivalent results compared to a standard technique using semitendinosus graft: a prospective matched-pair analysis after 1 year. *Knee Surg Sports Traumatol Arthrosc 2012; 20: 147.*

[7] LUND B, NIELSEN T, FAUNO P, CHRISTIANSEN SE, LIND M. Is quadriceps tendon a better graft choice than patellar tendon? A prospective randomized study. *Arthroscopy 2014; 30(5): 593-8.*

[8] SHINO K, NAKATA K, NAKAMURA N, TORITSUKA Y, HORIBE S, NAKAGAWA S, SUZUKI T. Rectangular tunnel double-bundle anterior cruciate ligament reconstruction with bone-patellar tendon-bone graft to mimic natural fiber arrangement. *Arthroscopy 2008; 24(10): 1178-83.*

[9] SLONE HS, ROMINE SE, PREMKUMAR A, XEROGEANES JW. Quadriceps tendon autograft for anterior cruciate ligament reconstruction: a comprehensive review of current literature and systematic review of clinical results. *Arthroscopy 2015; 31(3): 541-54.*

[10] STÄUBLI HU, SCHATZMANN L, BRUNNER P, RINCON L, NOLTE LP. Mechanical tensile properties of the quadriceps tendon and patellar ligament in young adults. *Am J Sports Med 1999; 27(1): 27-34.*

REPAIR OF MENISCAL RAMP LESIONS THROUGH A POSTEROMEDIAL PORTAL DURING ACL RECONSTRUCTION: outcome study with a minimum 2-year follow up

M. THAUNAT, N. JAN, J.M. FAYARD, C. KAJETANEK, C.G. MURPHY, B. PUPIM, R. GARDON, B. SONNERY-COTTET

INTRODUCTION

Data from anterior cruciate ligament (ACL) registries show that 47-61% of ACL tears are associated with meniscal lesions [1, 2]. The most common intra-articular lesion associated with ACL ruptures involves the posterior horn of medial meniscus (MM) [3]. A specific type of MM lesion consists in meniscosynovial or meniscocapsular tears which can be difficult to diagnose arthroscopically from the anterior compartment. These lesions have been described in the 1980's by Strobel *et al.* who called them "ramp" lesions [4]. Increased attention has been paid to this entity over the last years [5, 6]. Among the arthroscopic techniques, the all-inside repair through standard anterior portal with meniscal suture anchor devices implants has increased in popularity because of its easy application [7]. However, complications have been reported with these devices [8]. Biomechanically, the horizontal sutures of these devices have inferior strength compared to the vertical sutures [9]. Morgan described the vertical suture of the posterior segment of the MM through a posteromedial portal with a suture hook but this technique fell out of favor possibly due it being so technically demanding [10]. However improved healing rate for posterior horn MM lesions may be expected with better visualization; allowing for an improved diagnosis, an improved quality of the debridement prior to the repair and the control of a complete closure of the lesion through a posteromedial portal with a simple vertical suture [11].

The purpose of this article is to evaluate the results of arthroscopic all-inside suture repair of ramp lesions of the medial meniscus through a posteromedial portal during ACL reconstruction. We hypothesize that the technique of arthroscopic vertical posterior suture through a postero-medial portal with a suture hook device for these peripheral and longitudinal posterior tears of the MM encountered during ACL reconstruction will provide clinical results at least equal to other meniscal repair systemswith no associated morbidity.

MATERIAL AND METHODS

Patients

All patients who underwent a medial meniscal repair with the Suture lasso device (Suture lasso, Arthrex, Naples, FL) in conjunction with primary or revision ACL reconstruction betwesen October 1st 2012 and March 15th 2013 were entered into a prospective ACL reconstruction database. The procedures were performed by 3 senior surgeons. Inclusion

criteria for this study were longitudinal medial meniscal tears of the peripheral third (capsulomeniscal junctionor red/red zone) or junction of the peripheral third with the middle third (red/white). Complete and partial tears were included (fig. 1). Exclusion criteria were

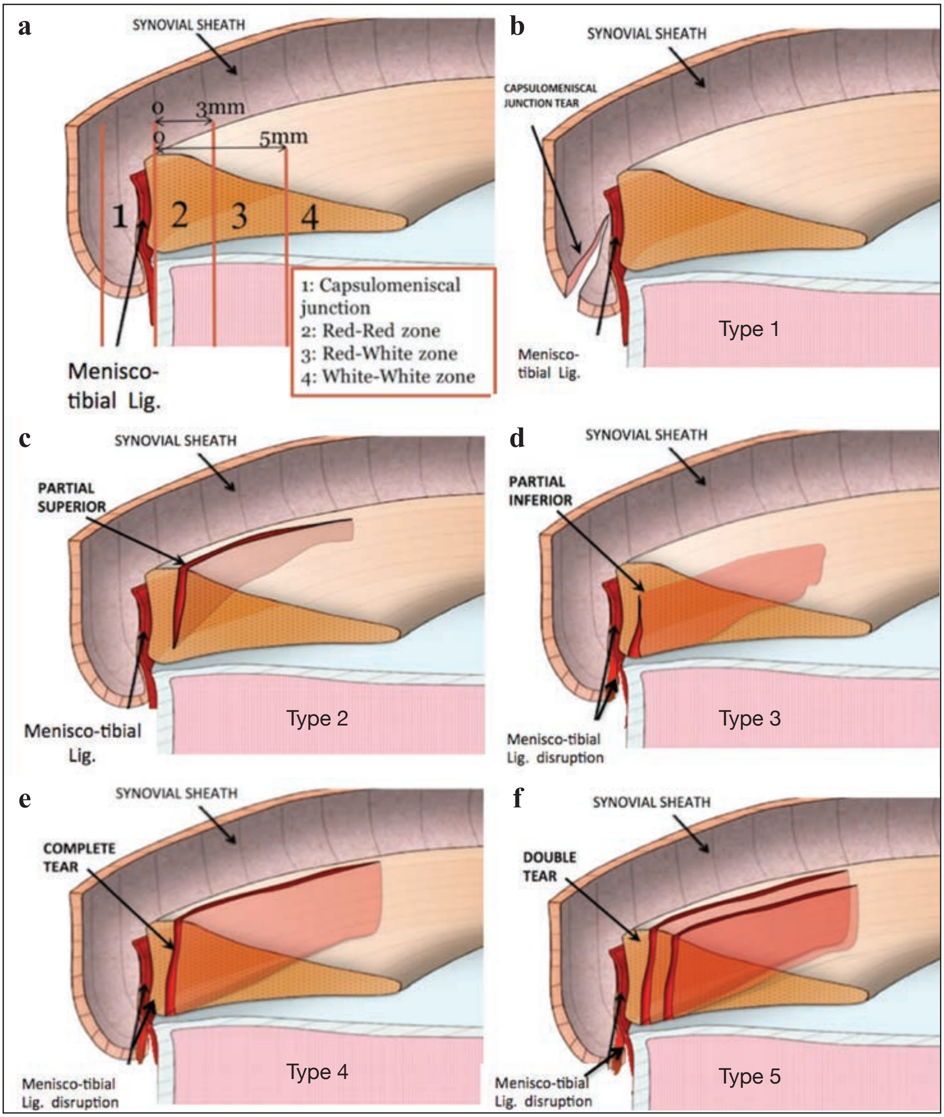


Fig. 1: ***Tear patterns of ramp lesions of the medial meniscus : (a) These tears can then further classified by their proximity to meniscus blood supply, namely whether they are located in the capsulomeniscal junction 1) "red-red" 2), "red-white" 3), or "white-white" 4) zones. (b): Type 1: Meniscocapsular junction tear. Very peripherally located in the synovial sheath. Mobility at probing is very low. (c): Type 2: Partial superior lesions. It is stable and can be diagnosed only by trans-notch approach. Mobility at probing is low. (d): Type 3: Partial inferior or hidden lesions. It is not visible with the trans-notch approach, but it may be suspected in case of mobility at probing, which is high because of the disruption of the menisco-tibial ligament. (e): Type 4: Complete tear in the red-red zone. Mobility at probing is very high (f): Type 5: Complete tears.***

tears located in the central third of the medial meniscus (white/white zone) for which an isolated suture with an all-inside suture implant (Fas T Fix device, Smith & Nephew, Andover, MA) or a partial meniscectomy was performed knee dislocations, major concomitant procedures such as high tibial osteotomy or other knee ligament reconstructions. We prospectively evaluated 132 consecutive patients in whom 132 medial menisci underwent a medial meniscus repair through a posteromedial approach in conjunction with ACL reconstruction. An MRI had been performed systematically preoperatively. A tear of the medial meniscus had been suspected on the preoperatively on MRI for only 80 of the 132 patients. A systematic arthroscopic exploration of the posterior horn of the MM was performed. The first stage of the exploration was achieved through standard anterior portals including a meticulous probing of the posterior horn. Then, the posterior horn of the MM was explored through the anterolateral portal with the scope positioned deep in the notch, for visualization of the posterior rim of the posterior horn. In cases where a meniscal lesion was suspected, probing of the posterior horn through an additional posteromedial portal was done in order to diagnose hidden tears [11]. Repair was performed within the rim of less than 3mm (capsulomeniscal junctionand red-red zone) or 3 to 5mm (red-white zone) of an unstable torn meniscus, including bucket handle tears. All were longitudinal tears, and were repaired at the same time as ACL reconstruction.

Surgical technique

During the procedure, the patients are placed supine on the operating table with a tourniquet placed high on the thigh. The knee is placed at 90° of flexion with a foot support to allow for a full range of knee motion. We use a standard high lateral parapatellar portal for the arthroscope and the medial parapatellar portal for the instruments. In case of a dislocated bucket-handle tear, reduction is performed. The possibility of engaging the probe in the posterior segment of the meniscus and of bringing it under the condyle is an indirect sign of lesion and instability criteria. The direct visualization of the posteromedial compartment must always be done in order to diagnose and repair these lesions.

Even if no sign of unstable meniscus is diagnosed through the anterior approach, a systematic exploration of the posterior segment is performed. A trans-notch visualization of the posteromedial compartment is systematically performed with the knee in 90°. The arthroscope is introduced by the anterolateral portal in the triangle limited by the medial condyle, the PCL and the tibial spines. After the contact with this zone, the arthroscope can pass through the space at the condyle border when applying a valgus force first in flexion and then in extension. An internal rotation is applied to the tibia to help visualization; this causes the posterior tibial plateau to subluxe and a posterior translation of the middle thirds segment. With this maneuver two thirds of peripheral lesions from the posterior segment up to the medium segment can be seen. In case of tear of the posterior segment, a posteromedial approach is performed. Transillumination allows the surgeon to observe the veins and nerves that must be avoided. The point where the needle is introduced is above the hamstring tendons, 1cm posterior to the medial femoro-tibial joint line. The knee must be flexed at 90° to avoid the popliteal structures. The needle must be introduced from outside to inside, in the direction to the lesion. The approach is done with a number 11- blade scalpel under arthroscopic control, and dissection via the same approach, again under arthroscopic control. The all inside suture can then be performed (fig. 2). Firstly, the lesion is debrided and edges of the tear are trimmed with a shaver. A left curved hook is used for a right knee and vice versa. The 25° hook (Suture lasso, Arthrex, Naples, FL) loaded with a N° 2 nonresorbable braided composite suture (Fiberstick, Arthrex, Naples, FL) is introduced through the posteromedial portal. The foot is positioned in maximal internal rotation in order to take away the medial condyle from the posterior segment of the meniscus. The suture hook is manipulated by hand so that the sharp tip penetrates the peripheral wall of the medial meniscus from outside to inside. Next, the suture hook is passed through the central (the inner portion) of the medial meniscus. The free end of the suture in the posteromedial space is grasped and brought up to posteromedial portal. A sliding knot (fishing knot type) is applied to the most posterior part of the meniscus with the help of a knot pusher and then cut. This manoeuver is repeated as required depending on the length of the tear (one knot was inserted every 5mm for tears limited to the posterior segment ("limited tears") (fig. 3a)). Care is taken during this technique to avoid tangling the sutures. Once the posteromedial tying is finished, the knee is positioned in valgus, near extension and the suture is tested and repeated if necessary. For some patients, the tear extends to the midportion of the meniscus and requires an additional repair through standard anterior portal with meniscal suture anchor and/or an outside-in suture ("extended tear"). The posterior suture is then completed with a repair through standard anterior portal with a meniscal suture anchor (Fas T Fix device, Smith & Nephew, Andover, MA) when the tear extends to the pars intermedia and/or by Outside-In sutures with PDS 1 (Ethicon, Inc., Somerville, NJ) if the tear extends to the anterior segment of the meniscus (fig. 3b). The stability of the suture is then tested with the probe.

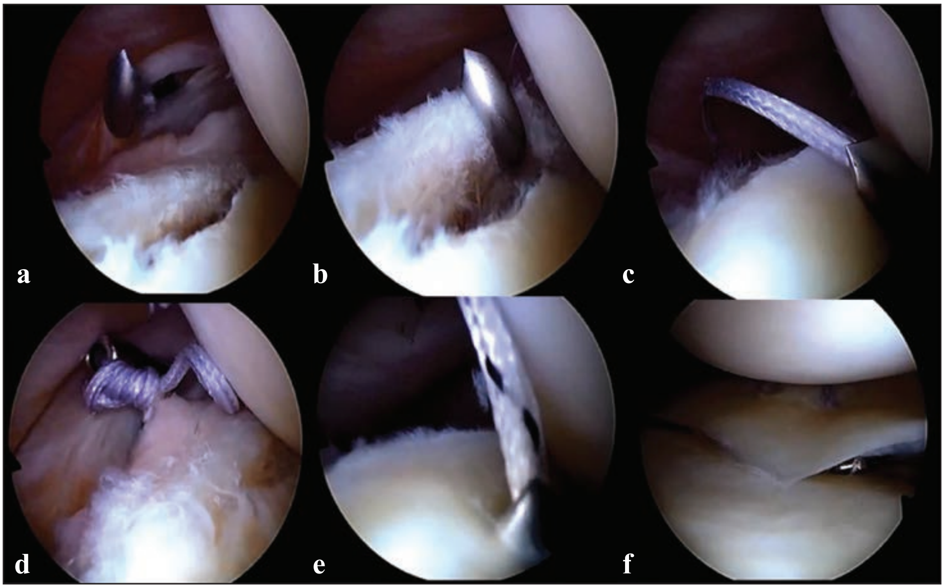


Fig. 2: ***Suture of the posterior segment of the medial meniscus of the right knee through a posteromedial portal with a suture hook device (25° suture lasso loaded with a N°2 fiberstick) (a, b) The sharp tip penetrated the peripheral wall of the medial meniscus from outside to inside. (c) Next, the suture hook is passed through the center (the inner portion) of the medial meniscus. (d) The first knot is tied with a knot pusher. (e) A second suture is performed 5mm more posterior to the first one with a tigerstick. (f) The final suture with non-absorbable suture from the anterior portal.***

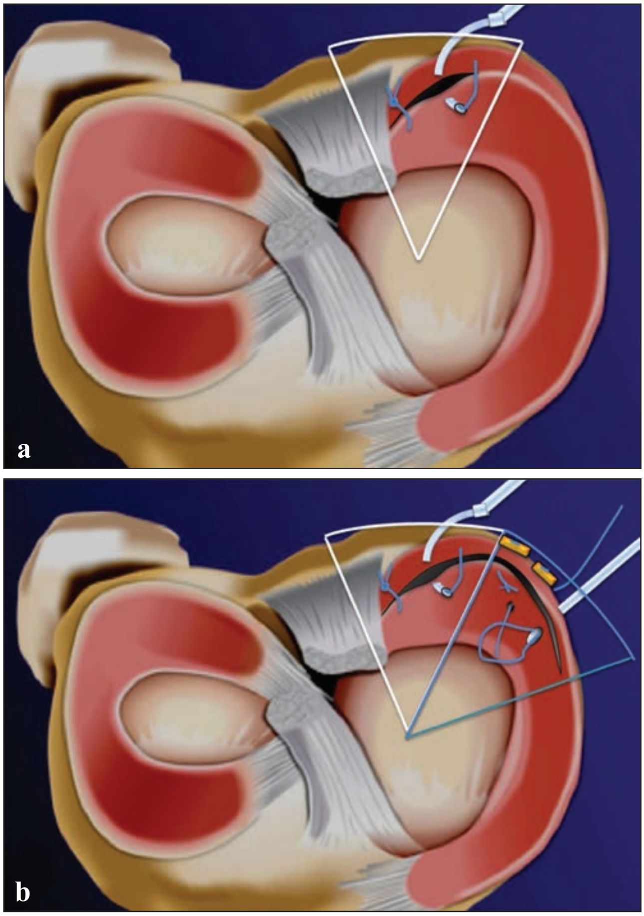


Fig. 3: a: ***The posterior suture is repeated as required depending on the length of the tear (one knot was inserted every 5mm for tears limited to the posterior segment ("limited tears").***
b: ***The posterior suture is completed with a repair through standard anterior portal with a meniscal suture anchor when the tear extends to the pars intermedia and/or by Outside-In sutures ("extended tears).***

Rehabilitation

Postoperatively, the active and passive range of motion is limited to 0-90° in the first six weeks and progression to full weight bearing by postoperative week 3. Jogging is permitted after week 12, pivot activity at 6 months, and full activity at 9 months for all patients.

Evaluation Methods

Follow-up assessments were made using both subjective and objective means. An experienced sports medicine fellow performed all the postoperative examinations. Patients were divided into two groups: those with a limited tear of the posterior segment (n=81) and those with a tear which extends to the midportion of the meniscus (n=51) that required an additional repair through standard anterior portal with meniscal suture anchor and/or an outside-in suture. Using Barrett's criteria [12] a repaired meniscus was considered healed if there was no joint-line tenderness or effusion, and a negative McMurray's test at the latest follow-up. Knee laxity was measured with the rolimeter Arthrometer (Aircast, Boca Raton, FL) postoperatively and knee function in activities of daily living and in recreational and competitive sports was assessed using the Tegner and subjective IKDC scores preoperatively and at last follow up [13].

Statistics

The Wilcoxon test was used for comparison of the preoperative and postoperative IKDC and Tegner scores. The Mann-Whitney test was used to compare the age of the patient, gender, number of devices used, tear zone, tear stability, and knee laxity between meniscal repair failures and nonfailures. Kaplan-Meier curves were used to visually illustrate differences in time to reoperation between groups. Significance was set at *P*<0.05.

Results

Population characteristics

We prospectively evaluated 132 consecutive patients in whom 132 medial menisci met the inclusion criteria and underwent a medial meniscus repair through a posteromedial portal in conjunction with ACL reconstruction. The average age was 26.4 years (12-57), the average BMI was 24.3 (16-34) with a male to female ratio of five to one. The surgery was performed in the right knee in 88 cases (66.7%). There were 106 cases of primary ACL reconstruction, 23 cases of revision ACL reconstructions and in 3 cases (2.3%) the procedure was a re-revision procedure. For reconstruction, a semitendinosus-gracilis tendon graft was used in 89 knees (67.4%), a patellar bone-tendon-bone graft was used in 41 knees (31.1%) and a quadriceps tendon graft was used in 2 knees (1.5%). The average side to side difference anterior knee laxity measured with the rolimeter (Aircast, Boca Raton, FL) preoperatively was 7mm (5-14mm). Preoperatively, the pivot shift test was normal in 7 cases, had a “glide” in 65 cases, a “clunk” in 23 cases and a gross pivot shift in 16 cases. It was not possible to test the pivot shift in 21 cases. Characteristics of the suture are summarized in table 1.

Objective and subjective evaluation

The mean follow-up period was 27 months (range 24-29 months). 3 patients refused to participate in the study and 6 patients had a new severe traumatic event postoperatively, resulting in 3 recurrent ACL tears, 2 contra-lateral ACL tears and 1 lateral meniscus tear. These 9 patients reported no complaints about the sutured meniscus but were excluded from subjective IKDC final evaluation. The average subjective IKDC rose from 63.8 ± 13.5 (range, 27-92) preoperatively to 85.7 ± 12 (range, 43-100) at last follow up (*P*<0,0001). The Tegner activity scale at the last follow-up (6.9 ± 1.72) was slightly lower than before surgery (7.2 ± 1.92) (*P*=0.0017). The rolimeter test decreased from a side to side difference in anterior knee laxity of 7mm (range, 5-14mm) to a mean value of 0.4mm (range: -3mm ± 5mm) at last follow up (*P*<0,0001). 82.2% of the patients returned to their premorbid level of activity.

Clinical failure

Unhealed tears

15 patients were found to be symptomatic according to Barret’s criteria. An MRI was performed in all cases. The tear appeared to be healed in 3 cases and unhealed in 12 cases.

12 patients were considered as clinical failures (positive Barret’s criteria and unhealed tear on MRI examination). Clinical failure rate was of 9%. It was of 4.9% in the sub-group “limited tear” and 15.7% in the sub-group “extended tear”. The extended lesions had an increased risk of clinical failure (*P*=0.036). 3 patients considered their symptoms were not so intense as to require revision surgery and only 9 patients underwent a revision surgery.

Need for revision surgery

The primary outcome in this study was the need for reoperation on the repaired meniscus. 9 patients (6.8%) had failure of the meniscal repair. 3.7% (3/81) occurred in the in the sub-group of “limited tears” and 11.7% (6/51) in the sub-group “extended tears” (fig. 3). With repeat surgical intervention involving resection or revision of the repair as the end-point, the

Table 1: ***Overall results in 132 menisci, by number and percentage.***

	Limited Tear			Extended Tear			Total
CHARACTERISTICS	Total	Sucess	Failures	Total	Sucess	Failures	
Patient	81	78	3	51	45	6	132
Male	67	82.1%	100%	43	82.2%	100%	110
Average age of surgery	28.2	28.1	30.3	27.9	27.9	27.6	28.1
Primary ACL	66	82.1%	66.7%	43	82.2%	100%	109
Lateral meniscal tear	29	37.2%	0%	16	31.1%	33.3%	45
Lateral meniscal repair	25	32.1%	0%	16	31.1%	33.3%	41
MEDIAL MENISCUS							
Bucket handle tear	1.2%	1.3%	0%	19.6%	17.8%	33.3%	8.3%
Unstable tear	51.9%	51.3%	66.7%	78.4%	75.6%	100%	62.1%
Ramp lesion	13.6%	12.8%	33.3%	3.9%	2.2%	16.7%	9.8%
Red Red tear	81.5%	82.1%	66.7%	78.4%	80%	66.7%	80.3%
Red White Tear	4.9%	5.1%	0%	17.6%	17.8%	16.7%	9.8%
MEDIAL MENISCUS REPAIR							
All inside posterior Lasso sutures							
Average no. ±SD	2.1±0,7	2.1±0,7	1.7±0,6	1.9±0,8	1.9±0,9	2±0.9	2±0.8
Median no. (range)	2 (1-4)	2 (1-4)	2 (1-2)	2 (1-4)	2 (1-4)	2 (1-3)	2 (1-4)
All inside Fast T Fix							
% of patient	0%	0%	0%	92.2%	93.0%	83.3%	35.6%
Average no. ±SD	0	0	0	1.3±0.5	1.2±0.4	1.6±0.9	0.5±0.7
Out in sutures							
% of patient	0%	0%	0%	15.7%	16.3%	16.7%	6.1%
Average no. ±SD	0	0	0	1.3±0.5	1.3±0.5	1	0.1±0.3
Average no. sutures ±SD	2.1±0.7	2.1±0.7	1.7±0.6	3.3±1.0	3.21±1.0	3.5±1.4	2.5±1.0

cumulative survival rate of all-inside suture repair of the medial meniscus through a posteromedial portal during ACL reconstruction was 93.2% (95% CI 0.887 to 0.974) at the final follow-up (fig. 2). The average time between the primary repair and the reoperation was 13.6 months (range, 5.3 to 19.7) months.

The cumulative survival rate in the subgroup limited tears (n=81) was 96.3% (95% CI 0.922 to 1.000) at the final follow-up. The average time between the primary repair and the reoperation was 15.8 months ± 2.37 (range, 13.1 to 17.8 months).

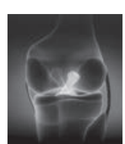
The cumulative survival rate in the subgroup extended tears (n=51) was 87.8% (95% CI 0.785 to 0.970) at the final follow-up. The average time between the primary repair and the reoperation was 12.6 months ± 6.2 (range, 5.3 to 19.6 months).

In the subgroup extended tears, the cumulative survival rate did not decrease significantly with the log rank test (p=0.069).

The relative risk of failure is 3.4 CI 95% [0.69-22.2] p=0,087 in the "extended" subgroup. The extended tears are not associated with a significant increased risk of revision of the medial meniscus.

The aspect of the recurrent tear was:

- Two flaps between the pars intermedia and the posterior portion of the meniscus. The initially sutured lesion was a bucket handle tear (n=2).



- Iterative ramp lesion (n=2).
- Newly tear located more anteriorly to the initial tear (white/white zone) with the initial tear healed when scope positioned deep in the notch (n=5) (fig. 4).

The data did not offer enough statistical evidence at alpha=0.05 to establish a difference in median age (success: 28.1 ± 9.3 versus failure: 28.5 ± 10.0, p=0.87), sex (success: 82.1% male versus failure: 100% male), (p=0.59), location of the meniscal tear (success: 8.9% ramp, 81.3% red/red, 9.8% red/white versus failure: 11.1% ramp, 77.8% red/red, 11.1% red/white) p=0.833, stability of the lesion (success: 60.2% unstable versus failure: 88.9% unstable: p=0.15), number of suture utilized for repair (success: 2.5 ± 1.0 sutures versus failure: 2.9 ± 1.5 sutures: p=0.51) or knee laxity at last follow up (success: 0.43 ± 1.38 mm versus failure: 0.67 ± 1.12mm: p=0.76) (Table 2).

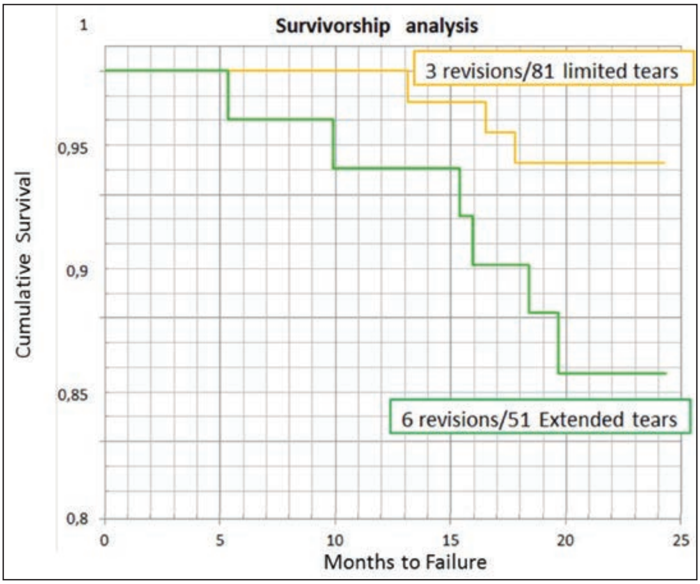


Fig. 4: ***Kaplan-Meier plot of medial meniscal survival between limited tears (tears limited to the posterior segment of the MM which required isolated all inside suture repair with the suture hook device) and extended tears (tears that extended to the pars intermedia that required hybrid repair either with all inside implants or outside in suture).***

Table 2: ***Effect of 6 factors on outcomes of meniscus repair.***

	Success	Failures	P Value
Male (%)	82.1	100	0.59
Median age (Years ±SD)	28.1±9.3	28.5±10	0.87
Location (%) . Ramp lesion/Red-Red/Red-White	8.9/81.3/9.8	11.1/77.8/11.1	0.83
Average no. of suture ±SD	2.5±1	2.9±1.5	0.51
Unstable tear (%)	60.2	88.9	0.15
Laxity at last FU (mm ±SD)	0.43±1.38	0.67±1.12	0.76

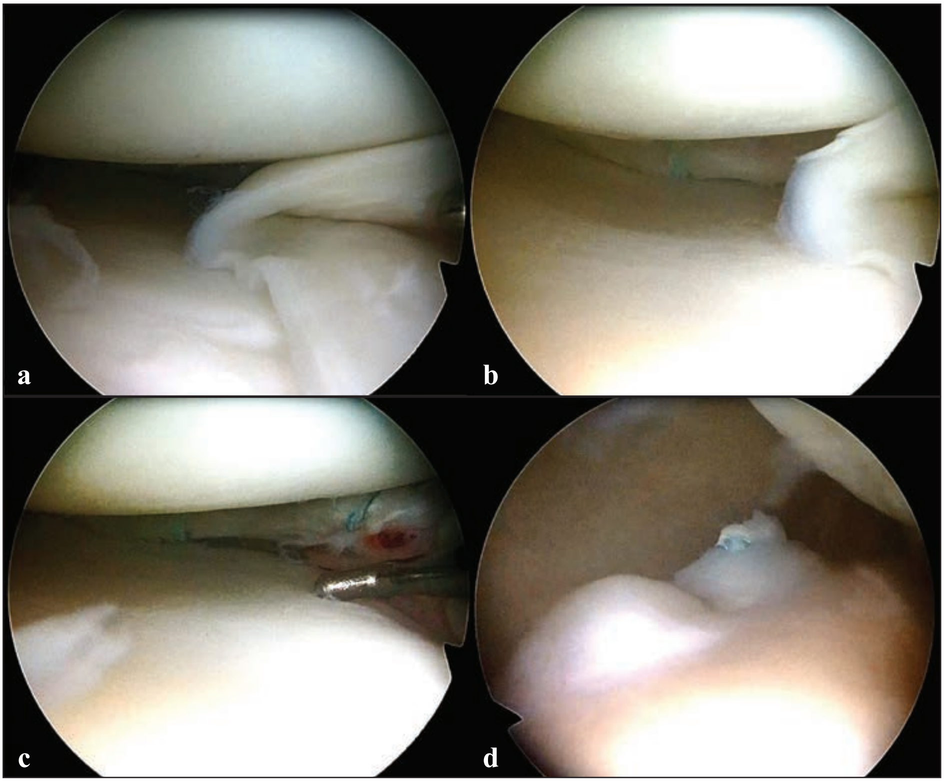


Fig. 5: ***Newly formed injury after the medial meniscal repair of the right knee. (a) A meniscal flap with an anterior pedicle located in the red/white zone is detached. (b) This newly formed injury is identified by a residual nonabsorbable suture material on the meniscus. (c) Aspect of the medial meniscus after economical subsequent meniscectomy of the unstable flap, the vertical suture from the primary repair are left alone. (d) View of the posterior segment with the scope placed deep in the notch: the original tear site is healed completely.***

Complications related to the posteromedial portal

Two patients sustained a hematoma which required an arthroscopy lavage during the first week after the index surgery. It was not possible to conclude that this complication was related to the puncture of the saphenous vein during the posteromedial approach. No patient had a neuroma located at the level of the posteromedial approach. It was difficult to precise the incidence of saphenous nerve lesions due to the posteromedial approach because the hamstring removal can cause sensibility change in different territories of the saphenous nerve (infrapatellar or sartorius branches).

DISCUSSION

The most important finding of this study is that vertical posterior sutures through an additional posteromedial approach during ACL reconstruction to repair peripheral tears of the posterior segment of the medial meniscus provided a high rate of meniscus healing and appeared to be safe and effective in this group of patients. These lesions are very frequently encountered with concomitant rupture of the anterior cruciate ligament. They are very rarely isolated and they certainly occurred during the ligament rupture mechanism. The only circumstances in which we meet similar lesions (vertically oriented tears of the posterior segment of the MM) outside a context of ligament rupture are the cases of isolated bucket handle medial meniscus tears. During the same period only four patients underwent suturing of the posterior segment of the medial meniscus without ACL reconstruction. We then decided to exclude this patient when deciding to publish the series in order to have a more homogeneous group of patient. These four patients had the same technique using a suture hook device through a posteromedial approach. Despite the development of new devices, the failure rate of the repair of medial meniscus posterior horn tears remains high [7, 14]. With classic anterior portals, a failure to visualize the posterior horn of the MM may result in insufficient debridement of the lesion, while hybrid suture anchor placement may be at risk becoming a blind procedure. Furthermore, with visualization from anterior portals alone, it is not always possible to be sure to achieve a complete closure of the lesion. The risk is to fail to flip the anchors in the gap between the central and peripheral zone of the injured meniscus and to leave the lesion open [15]. Without an excellent view of the lesion, meniscal repair devices may induce different complications like migration or breakage of the implant [15, 16] leading to iatrogenic cartilage damage [8]. Hence, a better healing rate of posterior horn MM lesions may be expected through a better visualization, allowing for an improved diagnosis [17], an improved quality of the debridement prior to the repair and the control of a complete closure of the lesion [18]. Better visualization also allows the placement of vertical sutures perpendicular to the deep fibers of the menisci, which are biomechanically more adapted. The reduction of the lesion is visualized during the procedure, which is not possible in the all inside implantation. The same hook device can be used to do more than one suture.

When we compare our healing rate to those previously reported using this method of suture, we found an abnormally high rate of recurrent meniscal lesions. However, our healing rate at the location of the initial tear was comparable to the rate of 96.4% reported by Ahn *et al.* in a recent study with a second look arthroscopy [19]. In the current study, the high rate of recurrent tear was explained by newly formed injuries which were confirmed on the surface of 5 menisci. It is conceivable that these injuries were attributable to a residual cleft left by the path of the suture lasso and maintained by the use of a strong N° 2 non absorbable suture. These clefts on the avascular meniscal substance may remain in situ without healing and would favor the recurrence of a more centrally located lesion in the white/white zone. We decided to change our suture from a strong non-resorbable suture to a PDS suture in order to reduce the risk of newly formed injury. From a biomechanical point of view, PDS 0 and PDS 1 sutures are recommended for meniscal sutures to guarantee a high primary stability, a small amount of gapping, and fewer partial tissue failure [20] and was used by Ahn *et al.* and they did not report any newly formed injury in their series of 140 knees who had a second look arthroscopy at a mean follow up of 37.7 months after an all inside suture of the posterior segment of the medial meniscus through a posteromedial portal [19]. However, in these 5 cases the amount of meniscectomy was decreased when compared with the initial lesion. We believe as advocated by Pujol *et al.* [21] that the meniscus can be partially saved and that a risk of a partial failure should be taken when possible.

The disadvantages of the all inside suture technique through a PM portal are that the second incision is necessary requiring more operative time. There is also a significant learning curve in placing and tying the sutures. There is also a potential risk for synovial fistula [22] but we did not encounter any in our series. The main risk of the posteromedial access is the saphenous nerve and vein injury. The popliteal artery, common fibular nerve, and tibial nerve are situated more laterally.

According to the anatomical studies, the portal is located at least 1.5cm from the saphenous nerve and vein. Morgan describes one case of transient hypoesthesia of the sartorius branch of the saphenous in one series of 70 cases probably due to an accessory access portal situated too anteriorly [10]. The clinical review of 179 patients who underwent posterior approaches did not show serious complications but included 3 cases (1.7%) of residual hypoesthesia in the saphenous nerve, and 2 cases of puncture of the saphenous vein [23]. The specific technique for passage of the arthroscope through the intercondylar notch is necessary to provide transillumination in order to avoid this complication.

Limitations

Our study has several weaknesses. We did not perform a systematic MRI or second-look arthroscopy and it is possible that some of the repaired menisci were healed incompletely. We acknowledge that a meniscal repair without symptoms postoperatively does not always reflect the true status of the meniscus and that only second-look arthroscopy can verify healing of the meniscus or not. It is also possible that longer follow-up would lead to poorer results. Further, this study was not a direct comparison with all inside repair with implants and in the extended meniscus tears, additional suture techniques were used which confound the results. Finally, all repairs were done during ACL reconstruction. We therefore cannot extrapolate these results to isolated meniscal repair with an ACL-intact knee. This study also includes several biases, including transfer bias (3 patients were lost to follow up), performance bias (multiple surgeons with different abilities), and selection bias because only peripheral longitudinal tears were repaired using this technique. Moreover, the transnotch vizualisation and the posteromedial approach allow diagnosing hidden lesion which could have been missed and not repaired using standard anterior portal and suture technique with all-inside meniscal implants [11].

CONCLUSION

Our results show that arthroscopic meniscal repair of ramp lesions during ACL reconstruction with a suture hook device through a posteromedial portal provided a high rate of meniscus healing at the level of the tear and appeared to be safe and effective in this group of patients.

LITERATURE

[1] AHLDÉN M, SAMUELSSON K, SERNERT N, FORSSBLAD M, KARLSSON J, KARTUS J. The Swedish National Anterior Cruciate Ligament Register: a report on baseline variables and outcomes of surgery for almost 18,000 patients. *Am J Sports Med 2012; 40(10): 2230-5.*

[2] GRANAN LP, INACIO MCS, MALETIS GB, FUNAHASHI TT, ENGEBRETSEN L. Intraoperative findings and procedures in culturally and geographically different patient and surgeon populations: an anterior cruciate ligament reconstruction registry comparison between Norway and the USA. *Acta Orthop 2012; 83(6): 577-82.*

[3] NOYES FR, CHEN RC, BARBER-WESTIN SD, POTTER HG. Greater than 10-year results of red-white longitudinal meniscal repairs in patients 20 years of age or younger. *Am J Sports Med 2011; 39(5): 1008-17.*

[4] STROBEL M. MENISCI. Manual of Arthroscopic Surgery. Fett HM, Flechtner P, Eds. *New-York, NY: Springer 1988; 171-8.*

[5] SEIL R, VANGIFFEN N, PAPE D. Thirty years of arthroscopic meniscal suture: What's left to be done? O*rthop Traumatol Surg Res 2009; 95(8 Suppl 1): S85*-S96.

[6] LIU X, FENG H, ZHANG H, HONG L, WANG XS, ZHANG J. Arthroscopic prevalence of ramp lesion in 868 patients with anterior cruciate ligament injury. *Am J Sports Med 2011; 39(4): 832-7.*

[7] KOTSOVOLOS ES, HANTES ME, MASTROKALOS DS, LORBACH O, PAESSLER HH. Results of all-inside meniscal repair with the FasT-Fix meniscal repair system. *J Arthrosc Relat Surg 2006; 22(1): 3-9.*

[8] SONNERY-COTTET B, MORTATI R, GADEA F, THAUNAT M, MOYERE F, CHOUTEAU J. Osteolysis of the tibial plateau after meniscal repair with hybrid suture anchor. *Knee Surg Sports Traumatol Arthrosc 2013; 21(9): 2137-40.*

[9] AŞÍK M, SENER N. Failure strength of repair devices versus meniscus suturing techniques. *Knee Surg Sports Traumatol Arthrosc 2002; 10(1): 25-9.*

[10] MORGAN CD. The "all-inside" meniscus repair. *J Arthrosc Relat Surg 1991; 7(1): 120-5.*

[11] SONNERY-COTTET B, CONTEDUCA J, THAUNAT M, GUNEPIN FX, SEIL R. Hidden lesions of the posterior horn of the medial meniscus: a systematic arthroscopic exploration of the concealed portion of the knee. *Am J Sports Med 2014; 42(4): 921-6.*

[12] BARRETT GR, FIELD MH, TREACY SH, RUFF CG. Clinical results of meniscus repair in patients 40 years and older. *Arthroscopy 1998; 14(8): 824-9.*

[13] IRRGANG JJ, ANDERSON AF, BOLAND AL, HARNER CD, KUROSAKA M, NEYRET P, *et al.* Development and validation of the international knee documentation committee subjective knee form. *Am J Sports Med 2001; 29(5): 600-13.*

[14] ELLERMANN A, SIEBOLD R, BUELOW JU, SOBAU C. Clinical evaluation of meniscus repair with a bioabsorbable arrow: a 2- to 3-year follow-up study. *Knee Surg Sports Traumatol Arthrosc 2002; 10(5): 289-93.*

[15] WALGRAVE S, CLAES S, BELLEMANS J. High incidence of intraoperative anchorage failure in FasT-fix all inside meniscal suturing device. *Acta Orthop Belg 2013; 79(6): 689-93.*

[16] CALDER SJ, MYERS PT. Broken arrow: a complication of meniscal repair. *J Arthrosc Relat Surg 1999; 15(6): 651-2.*

[17] PELTIER A, LORDING TD, LUSTIG S, SERVIEN E, MAUBISSON L, NEYRET P. Posteromedial Meniscal Tears May Be Missed During Anterior Cruciate Ligament Reconstruction. *Arthroscopy 2015 Feb 3. pii: S0749-8063(14)00979-7. doi: 10.1016/j.arthro.2014.12.003.*

[18] AHN JH, WANG JH, YOO JC. Arthroscopic all-inside suture repair of medial meniscus lesion in anterior cruciate ligament-deficient knees: results of second-look arthroscopies in 39 cases. *J Arthrosc Relat Surg 2004; 20(9): 936-45.*

[19] AHN JH, LEE YS, YOO JC, CHANG MJ, KOH KH, KIM MH. Clinical and second-look arthroscopic evaluation of repaired medial meniscus in anterior cruciate ligament-reconstructed knees. *Am J Sports Med 2010; 38(3): 472-7.*

[20] SEIL R, RUPP S, JURECKA C, REIN R, KOHN D. Effect of various suture strength factors on behavior of meniscus sutures in cyclic loading conditions. *Unfallchirurg 2001; 104(5): 392-8.*

[21] PUJOL N, BARBIER O, BOISRENOULT P, BEAUFILS P. Amount of meniscal resection after failed meniscal repair. *Am J Sports Med 2011; 39(8): 1648-52.*

[22] YIANNAKOPOULOS CK. Diagnosis and treatment of postarthroscopic synovial knee fistulae: a report of four cases and review of the literature. *J Knee Surg 2007; 20(1): 34-8.*

[23] OGILVIE-HARRIS DJ, WEISLEDER L. Arthroscopic synovectomy of the knee: is it helpful? *J Arthrosc Relat Surg 1995; 11(1): 91-5.*

SINGLE-BUNDLE ACL RECONSTRUCTION: HOW I DO IT

C.H. BROWN

PATIENT POSITIONING (fig. 1)

- Operating room table kept flat,
- Padded lateral thigh post,
- Padded lateral hip positioner,
- 2 padded L-shaped foot supports.

THREE PORTAL TECHNIQUE FOR ANATOMIC SINGLE-BUNDLE ACL RECONSTRUCTION

Anatomic ACL reconstruction (ACLR) has traditionally been performed using 2 arthroscopic portals, the anterolateral (AL) and the anteromedial (AM) portals. Limitations of the 2 portal approach include the following:

- The lateral wall of the intercondylar notch is viewed through the AL portal resulting in a tangential view of the ACL femoral attachment site which can potentially compromise the surgeon's ability to accurately place the ACL femoral tunnel within the native ACL femoral attachment site;
- Drilling the ACL femoral tunnel through the AM portal can result in shorter femoral tunnel lengths, limiting the length of the ACL graft that can be inserted into the ACL femoral tunnel when cortical suspensory fixation devices are used.

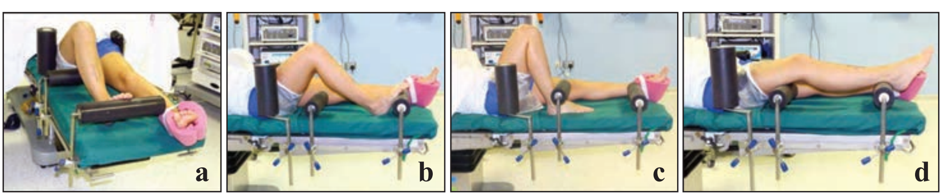


Fig. 1: ***Patient positioning. (a) Patient's pelvis and torso is stabilized on the operating room table by a padded lateral hip positioner and padded thigh post. (b) The distal foot support is secured to the side rail of the operating room table near the end of the table. The patient's torso is moved down the table until the knee is maintained at 90 degrees of knee flexion. (c) The proximal foot support is adjusted to maintain the knee in hyperflexion during drilling of the ACL femoral tunnel. (d) The height of the proximal and distal foot supports can be adjusted to maintain the desired degree of flexion during ACL graft tensioning and fixation.***

Anatomic ACLR is facilitated by using a 3 portal technique. The 3 portal technique is versatile and can be used when performing an anatomic ACL reconstruction with any type of ACL graft and most fixation methods. The 3 portal technique can be used for any primary, revision, single- or double-bundle ACL reconstruction. The technique is particularly useful in cases where only one of the two ACL bundles is torn or there is a large remnant of the native ACL present. In these situations, an augmentation or tissue preserving procedure can be performed. Augmentation and tissue preserving procedures cannot be performing using a transtibial or an all-inside technique.

In the 3 portal technique, the AL and AM portals are used as viewing portals and the ACL femoral tunnel is drilled through an accessory anteromedial (AAM) portal. There are several advantages of the 3 portal technique compared to the traditional 2 portal approach:

- The 3 portal technique allows the surgeon to interchange the working and viewing portals according to the specific task that is being performed;

- In the 3 portal technique, the lateral wall of the intercondylar notch can be viewed orthogonally through the AM portal while the AAM portal is used as a working portal for instrumentation. This approach allows the surgeon to look and work in the same direction, making it easier to achieve more consistent and accurate placement of the ACL femoral tunnel within the native ACL femoral attachment site;

- Viewing the lateral wall of the intercondylar notch through the AM portal also eliminates the need to perform a notchplasty for visualization purposes;

- Drilling the ACL femoral tunnel through the AAM portal increases the obliquity of the ACL femoral tunnel relative to lateral wall of the intercondylar notch, resulting in a longer femoral tunnel.

ARTHROSCOPIC PORTALS

- AL portal is created as close as possible to the lateral border of the patellar tendon at the height of the inferior pole of the patella;

- AM portal is created under arthroscopic control at the height or slightly higher than the inferior pole of the patella. An 18 gauge spinal needle is passed into the knee joint medial to the medial border of the patellar tendon and directed toward the roof of the intercondylar notch. The height of the spinal needle is adjusted such that the shaft of the spinal needle comes to lie parallel to the roof of the intercondylar notch. This step results in the external position of the spinal needle being located proximal to the inferior pole of the patella. Placing the AM portal at this location ensures adequate spatial separation between the viewing AM and the working AAM portal. Due to the curvature of the inferior pole of the patella, moving the AM portal more medially makes it is possible to achieve a higher AM portal position, creating greater separation between the AM and AAM portals (fig. 2).

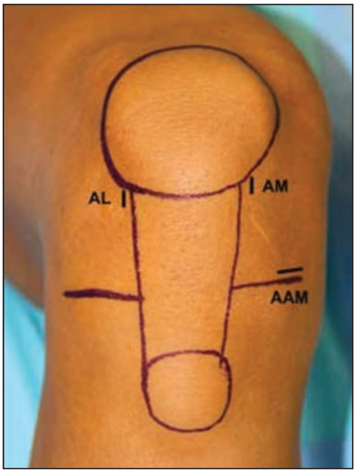


Fig. 2: ***Surface landmarks and arthroscopic portals: anterolateral portal (AL), anteromedial portal (AM), accessory anteromedial portal (AAM).***

Proper placement of the AAM portal is one of the most critical aspects of the technique. The location of the AAM portal is the major factor determining the length of the ACL femoral tunnel. When properly placed, drilling the ACL femoral tunnel through the AAM portal results in a longer ACL femoral tunnel compared to drilling through the AM portal. The preliminary location for the AAM portal is marked just proximal to the medial joint line. The final position for the AAM portal is created under arthroscopic visualization.

- A more medial placement of the AAM portal will result in a more perpendicular orientation of the drill with respect to the lateral wall of the notch, producing a more circular-shaped tunnel aperture and a shorter femoral tunnel (fig. 3).

- Moving the AAM portal more laterally orients the drill more obliquely with respect to the lateral wall of the notch and produces a more elliptically-shaped ACL femoral tunnel aperture and a longer femoral tunnel (fig. 4).

The location of the AAM portal is adjusted based on the ACL graft type and femoral fixation method. For example, if a bone-patellar tendon-bone ACL graft is used with interference screw fixation of the femoral bone block, a 25mm femoral tunnel length will allow the bone block to be fully seated in the femoral socket. In this situation, the AAM portal can be positioned more medially. For hamstring tendon grafts fixed with a femoral cortical suspensory fixation device, a longer femoral tunnel in the 35-45mm range is optimal. In this situation, the AAM portal is moved more lateral to achieve a longer femoral tunnel.

ANATOMIC ACL FEMORAL TUNNEL PLACEMENT

It is widely accepted that when performing an anatomic ACLR, the ACL femoral tunnel should be placed within the native ACL femoral attachment site. Anatomic ACL femoral tunnel placement is best achieved by identifying the

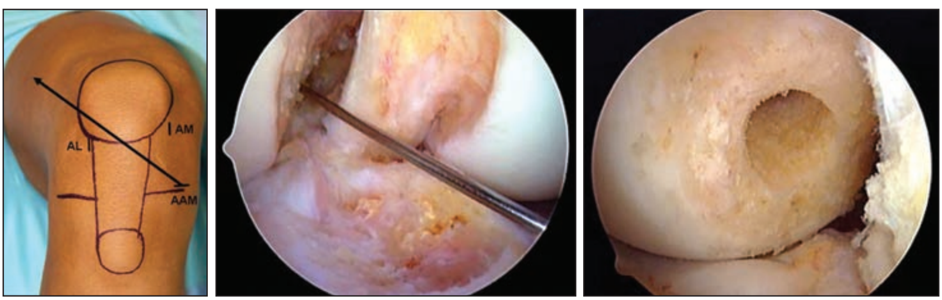


Fig. 3

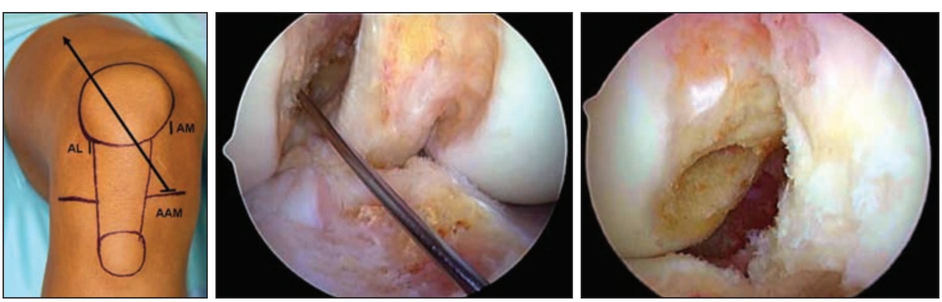


Fig. 4

center of the native ACL femoral attachment site. Using the center of the native ACL femoral attachment site as a defined anatomic reference point, the surgeon may choose to alter the location of the ACL femoral tunnel within the ACL femoral attachment site based on different philosophies.

- A central position within the native ACL femoral attachment site is favored by many surgeons based on biomechanical studies demonstrating that a single-bundle ACL graft positioned at the center of the native ACL femoral and tibial attachment sites best controls anterior tibial translation and tibial rotation during a simulated pivot shift test and more closely restores knee kinematics to that of the normal knee compared with other anatomic ACL graft placements (fig. 5).

- Moving the center of the ACL femoral tunnel towards the region of the center of the anteromedial (AM) bundle attachment site will result in an ACL graft that has smaller graft-length changes (isometric) and experiences lower and relatively constant *in situ* ACL graft forces. Lower *in situ* ACL graft forces may theoretically reduce the risk of ACL graft re-rupture compared to a centrally placed ACL graft which experiences higher *in situ* ACL graft forces. However, moving the center of the ACL femoral tunnel towards the center of the AM bundle attachment site often results in a more vertical orientation of the ACL graft that is not as well aligned as a centrally placed graft to control the pivot-shift phenomena (fig. 6).

- Moving the center of the ACL femoral tunnel towards the center of the posterolateral (PL) bundle attachment site results in an ACL graft that experiences larger graft-length changes and higher *in situ* ACL graft forces in extension. Although this femoral tunnel position results in a more horizontal ACL graft orientation that is better aligned to control the pivot shift, higher *in situ* ACL graft forces and greater ACL ligament strain could theoretically increase the risk of ACL graft re-rupture (fig. 7).

Recent studies have demonstrated that the ACL fibers in the region of the direct insertion contribute more restraining force to anterior tibial translation and the pivot shift phenomena. To restore more of these fibers, the ACL femoral tunnel is positioned higher in the attachment site closer to the lateral intercondylar ridge and midway between the center of the AM bundle and the center of the native attachment site (fig. 8).

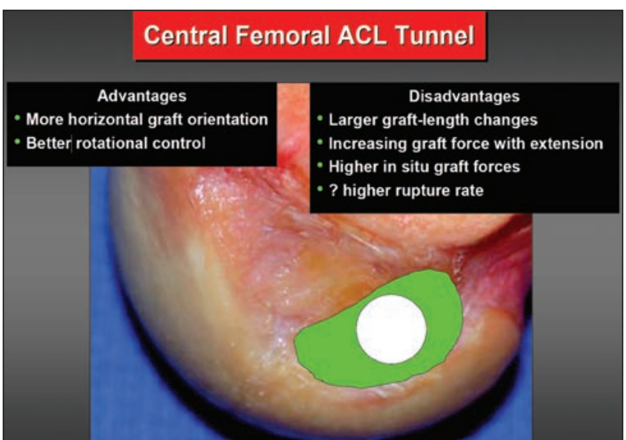


Fig. 5

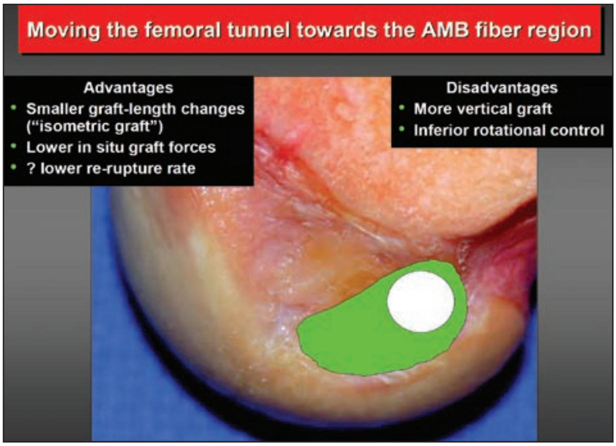


Fig. 6

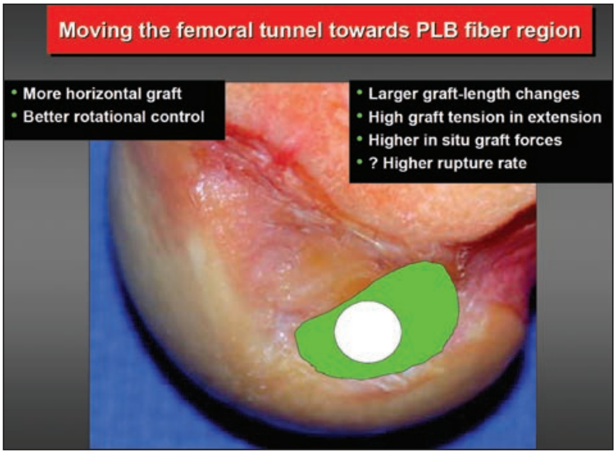


Fig. 7

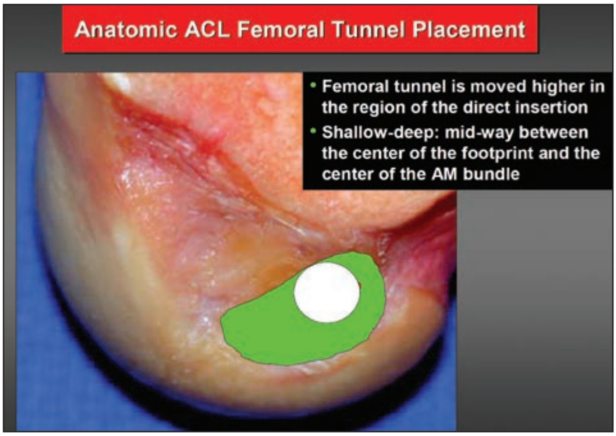


Fig.8

STRATEGIES TO FIND THE CENTER OF THE ACL FEMORAL ATTACHMENT SITE

- View the lateral wall of the notch through the AM portal;
- Place the knee in the figure-four position. This position opens up the lateral compartment by lifting the lateral femoral condyle away from the lateral meniscus, allowing better visualization of the deep (proximal) part of the ACL femoral attachment site and the low (posterior) part of the attachment site where the indirect ACL fibers (fan-like extension fibers) insert (fig. 9).
- Use the native ACL footprint if present (fig. 10).
- Bony ACL ridges (fig. 11).
- ACL ruler (fig. 12).
- Fluoroscopy (most reproducible and accurate method) ruler (fig. 13).

AL Portal View *AM Portal View* *Figure-Four: AM Portal View.*

Fig. 9

Fig. 10

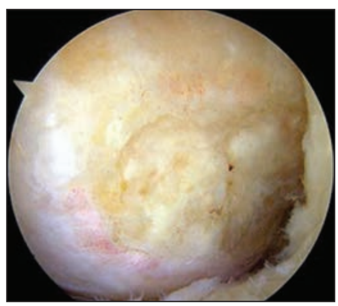


Fig. 11

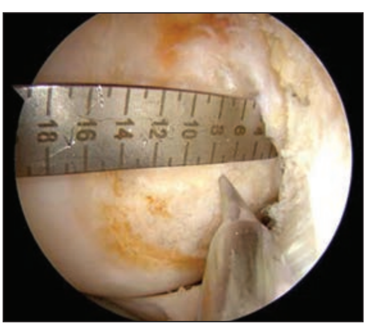


Fig. 12

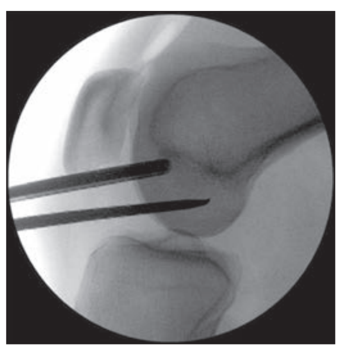


Fig. 13

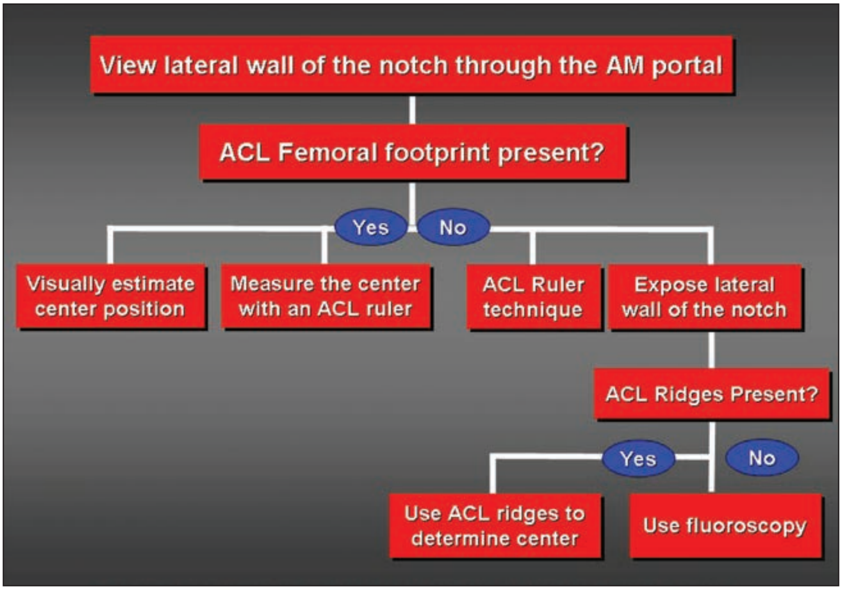


Fig. 14: ***Algorithm for ACL femoral tunnel placement.***

DRILLING THE ACL FEMORAL TUNNEL

- Desired femoral tunnel location marked with a microfracture awl;
- ACL femoral tunnel drilled in hyperflexion;
- More flexion = longer femoral tunnel;
- Angling the guide pin more laterally increases the obliquity of the tunnel and increases the femoral tunnel length.

DRILLING THE ACL TIBIAL TUNNEL

- View the ACL tibial attachment site through the AM portal. This approach positions the arthroscope directly over the ACL tibial attachment site resulting in an orthogonal view. This view allows for more accurate assessment of the guide pin location within the ACL tibial attachment site in both the anterior-posterior and medial-lateral directions.
- ACL tibial guide inserted through the AAM portal. This positions the arm of the aimer parallel to the joint line.
- Tibial guide pin positioned anterior to the posterior border of the lateral meniscus and as far medially in the footprint as possible.
- The tibial aimer bullet is marked with a surgical marker at the desired tibial tunnel length.
- The tibial aimer arm is raised or lowered until the marked position on the aimer bullet contacts the end of the aimer handle when the bullet is flush with the anterior cortex of the tibia.

- These steps allow a tibial tunnel of a known length to be drilled, allowing the issue of graft-tunnel length mismatch to be addressed.

- The tibial tunnel is initially drilled with a small diameter drill bit such as the 4.5 or 5mm fully fluted drill bit. The guide pin is repositioned eccentrically in the desired direction within the drilled tunnel using a small clamp inserted through the AL portal, and the tunnel is sequentially drilled by 1mm increments up to the final diameter of the tibial tunnel. These steps allow the tibial tunnel to be positioned as far medially in the tibial attachment site as possible.

GRAFT TENSIONING

At the present time, the optimal graft tension and knee flexion angle for a single-bundle ACL reconstruction are unknown. The usual graft excursion pattern for a femoral tunnel positioned near the center of the ACL attachment site results in the ACL graft tightening (pulling into the tibial tunnel) during the last 30 degrees of extension. In this situation, the graft is fixed at 20 degrees of flexion with a posterior force applied to the anterior tibia to hold the tibia in a reduced position. A spring-loaded tensioning device is used to tension the ACL graft. For 5-strand hamstring tendon grafts, a 60N load is applied. For 6-strand hamstring tendon grafts, a 70N load is applied.

GRAFT FIXATION

The graft is fixed with a tapered 7-9mm or 8-10mm, 30mm long bioabsorbable interference screw (fig. 15).

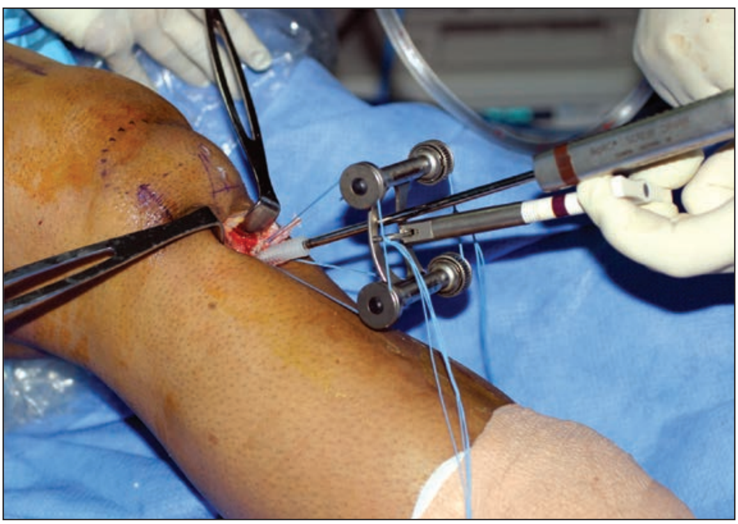


Fig. 15

LITERATURE

ARAUJO PH, VAN ECK CF, MACALENA JA, FU FH. Advances in the three-portal technique for single- or double-bundle ACL reconstruction. *Knee Surg Sports Traumatol Arthrosc 2011; 19: 1239-42.*

BIRD J, CARMONT M, DHILLON M, SMITH N, BROWN C, THOMPSON P, SPALDING T. Validation of a new technique to determine mid-bundle femoral tunnel position in anterior cruciate ligament reconstruction using 3D computed tomography analysis. *Arthroscopy 2011; 27: 1259-67.*

BROWN CH, SPALDING T, ROBB C. Medial portal technique for single-bundle anatomical anterior cruciate (ACL) reconstruction. *Int Ortho 2013; 37: 253-69.*

ERDEM M, GULABI D, ASIL K, ERDEM AC. Far medial versus anteromedial portal drilling of the femoral tunnel in ACL reconstruction: a computed tomographic analysis. *Arch Orthop Trauma Surg 2015; 135: 539-47.*

SPALDING T, ROBB C, BROWN CH. Femoral bone tunnel placement (arthroscopically and with fluoroscopy). In: Siebold R, Dejour D, Zaffagnini S, eds. Anterior Cruciate Ligament Reconstruction: A Practical Surgical Guide. *Heidelberg New York Dordrecht London: Springer, 2014; 159-79.*

ANTERIOR CRUCIATE LIGAMENT AUGMENTATION

M. OCHI, A. NAKAMAE, N. ADACHI

ACL AUGMENTATION AND ITS POTENTIAL ADVANTAGE

Anterior cruciate ligament (ACL) rupture is one of the most frequent orthopaedic sports-related injuries, and ACL reconstruction has become a common surgical treatment in the field of orthopaedic sports medicine. It is important to continue to develop new approaches to reconstruct the normal ACL from the biomechanical and biological point of view. Anatomic ACL reconstruction has attracted much attention because of its greater potential to restore knee kinematics. Over the past few years, an emerging body of evidence has shown the importance of anatomic ACL reconstruction. Restoration of normal bio-mechanical function is one of the essential factors for successful ACL reconstruction. However, early biological healing of the grafted tendon is also vital to obtaining satisfactory clinical results. Accelerated graft remodeling, ligamentization, and reinnervation of the grafted tendon are necessary in order to restore sufficient function and mechanical strength to the reconstructed ACL [1].

Arthroscopic examination for ACL re-construction occasionally demonstrates a relatively thick and abundant ACL remnant, maintaining a bridge between the tibia and the intercondylar notch. The femoral attachment of the ACL remnant is positioned abnormally in many cases. This represents a complete rupture of the ACL. However, a partial rupture of the ACL can be observed sometimes. In cases of partial ACL rupture, although complete rupture of the anteromedial (AM) or posterolateral (PL) bundle can be seen, the other bundle is preserved, if not normally, with an attachment of anatomical femoral origin. In standard single- or double-bundle ACL reconstruction, the ACL remnant is totally debrided. However, the ACL remnant has synovial tissue which contains many capillary blood vessels. An experimental animal study showed greater cellularity and angiogenesis in augmented grafts than in conventionally reconstructed grafts [2]. In addition, it is known that the ACL has an important proprioceptive function for the knee. Several studies have shown that human ACL remnants contain some types of mechanoreceptors [3]. Moreover, several studies have shown that the ACL remnant can contribute to biomechanical stability of the knee to some extent [4]. Therefore, ACL augmentation (remnant-preserving ACL re-construction) might have several advantages:

- Preservation of the ACL remnant may accelerate cellular proliferation, revascula-rization, and ligamentization of the grafted tendon;
- With respect to the proprioceptive function of the knee, the preserved mechanoreceptors in

the ACL remnant may have a positive effect on the proprioceptive ability of the knee;
- The ACL remnant may contribute to anteroposterior knee stability and guarantee mechanical strength in the early postoperative period.

Potential advantages of ACL augmentation are attractive in terms of early biological healing of the grafted tendon. In 1992, Ochi started performing ACL augmentation, when indicated, without sacrificing the ACL remnant by using an autogenous semitendinosus tendon under arthroscopy. In 2000, Adachi and Ochi *et al.* [5] reported that the knee stability and proprioceptive function of 40 patients who underwent ACL augmentation were superior to those of 40 patients who underwent standard single-bundle ACL reconstruction during the same period. However, the surgical procedure of ACL augmentation at this period required two incisions because the graft was passed through the over-the-top route on the femoral side. Therefore, in 1996 Ochi started performing ACL augmentation using the one-incision technique with EndoButton-CL [6, 7].

INDICATIONS FOR ACL AUGMENTATION

It is sometimes difficult to decide whether the remaining bundle of the ACL represents a partial rupture or a complete rupture. The decision is made after thorough consideration of clinical tests, laxity measurements, MRI, and arthroscopic findings [1, 4, 7]. Quantitative evaluation of anteroposterior knee joint laxity can aid in this decision. We consider patients as candidates for ACL augmentation when the side-to-side difference in the anterior displacement of the tibia is less than 5mm. MRI also provides important information to evaluate the condition of the ACL bundles. However, the final decision should be made after arthroscopic confirmation of the status of the injured ACL.

Partial rupture of the ACL is an ideal indication for ACL augmentation. However, in our previous studies, the frequency of partial ACL tear was only 10% during the study period between 2002 and 2005 [6], and 20% between 2006 and 2008 [4]. In 2008, we began performing ACL augmentation even for patients with continuity of the ACL remnant between the tibia and the femur after complete ACL rupture. In this complete rupture group, indication for the procedure comprises cases whose ACL remnant maintains a ligamentous bridge between the intercondylar notch and the tibia, and whose proximal ACL remnant diameter is greater than one-third of the original size. Anatomic central single-bundle or double-bundle [8] ACL reconstruction with the remnant preserving technique is performed for patients in the complete rupture group. Since 2006, ACL augmentation has attracted much attention in the field of ACL reconstruction. Several ACL augmentation techniques have been described, including selective AM or PL bundle reconstruction [7, 9], the remnant retensioning technique, anatomic single- or double-bundle ACL augmentation for complete rupture, and preservation of the ACL tibial remnant.

SURGICAL TECHNIQUE

In this section, a brief description of the surgical techniques of single-bundle ACL augmentation is provided. A quadrupled semitendinosus tendon or four-strand semitendinosus and gracilis tendon is desirable as the graft for the augmentation. The anterolateral, anteromedial and the far-anteromedial portals are used for the surgery.

Femoral bone tunnel

For femoral bone tunnel preparation, the far-anteromedial portal technique is used because this technique allows more flexibility in accurate anatomical positioning for femoral tunnel drilling than the transtibial technique. A delicate debridement and bone tunnel placement is important to preserve the ACL

remnant. Whilst it is true that the femoral attachment of the ACL is mainly on the resident's ridge, the grafted tendon is pulled and shifts to the anterodistal side of the femoral tunnel opening in the knee extension and mild flexion position. Therefore, our thinking at this point is that the center of the femoral tunnel opening should not be on the resident's ridge, but should be placed just behind the resident's ridge when using hamstring tendon for ACL reconstruction [1].

Partial rupture of the ACL is an ideal indication for ACL augmentation. In cases of partial rupture, single-bundle reconstruction of the ruptured bundle is desirable, to minimize damage to the ACL remnant. However, it may be true that the remaining AM or PL bundle is not completely intact and that the biomechanical function of the remaining bundle declines to some extent. Therefore, in cases of PL bundle rupture, the central portion of the femoral tunnel should not be the center of the femoral attachment of the PL bundle. It is recommended that approximately three-quarters of the femoral tunnel opening is occupied by the femoral attachment of the PL bundle and approximately one-quarter by the femoral attachment of the AM bundle. The same goes for AM bundle rupture. As for the patients with a thick ACL remnant between the intercondylar notch and the tibia after complete ACL rupture, the positions of the femoral tunnels is the same as used for standard anatomic single-bundle ACL reconstruction.

Tibial bone tunnel

A longitudinal slit is made at the center of the ACL remnant through the anteromedial portal. The ACL tibial guide, with the angle set at 60°, is used to pass a guide pin or Kirschner wire. The tip of the tibial drill guide is placed through the slit of the ACL remnant. In cases of PL bundle rupture, the tibial tunnel is positioned in the center of the tibial insertion of the whole ACL. In cases of AM bundle rupture and complete rupture, the tibial tunnel is located just posteriorly to the anterior margin of the footprint.

Graft passage and fixation

The graft composite is introduced from the tibial tunnel to the femoral tunnel. In cases of PL bundle rupture, if the graft passes above the ACL remnant, the positional relationship is anatomically incorrect. Therefore, in cases of PL bundle rupture (fig. 1) and complete rupture, the graft passes through the slit of the ACL remnant. However, in cases of AM bundle rupture, the graft passes above the ACL remnant (fig. 2). After passage of the graft composite, the proximal side of the graft is fixed to the lateral femoral cortex by flipping the Endobutton. Then, a tension force of 50 N is applied to the distal Endobutton tape connected to the graft, and the grafted tendon is fixed at 30° of knee flexion using two staples (double stapling technique). We also perform double-bundle reconstruction with the remnant-preserving technique (fig. 3).

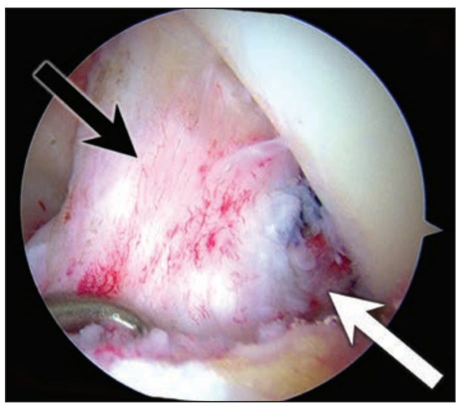


Fig. 1: ***Anteromedial (AM) bundle- preserving ACL augmentation for posterolateral (PL) bundle rupture (white arrow, grafted tendon; black arrow, preserved AM bundle).***

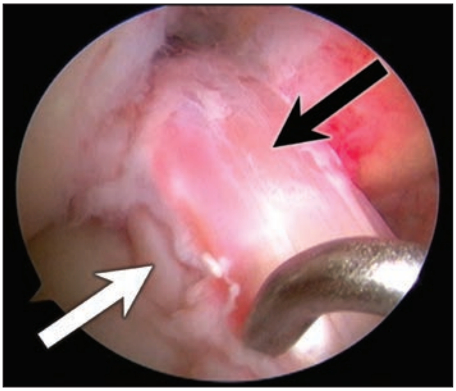


Fig. 2: ***Posterolateral (PL) bundle- preserving ACL augmentation for anteromedial (AM) bundle rupture (black arrow, grafted tendon; white arrow, preserved PL bundle).***

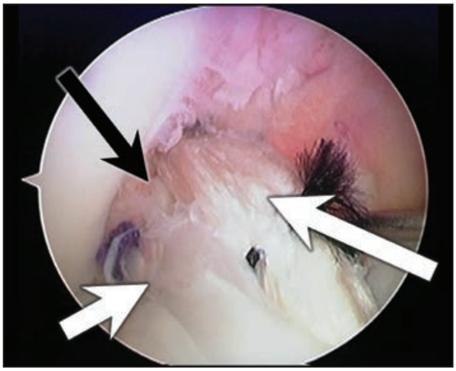


Fig. 3: ***Double-bundle reconstruction with the remnant-preserving technique (short white arrow, grafted PL bundle; long white arrow, grafted AM bundle; black arrow, preserved ACL remnant).***

SECOND-LOOK ARTHROSCOPIC EVALUATION AFTER ACL RECONSTRUCTION

Several studies have assessed graft conditions after ACL reconstruction by direct observation with use of second-look arthroscopy. Second-look arthroscopy after ACL reconstruction is one of the most reliable types of examination to provide valuable prognostic information on the graft, such as synovial coverage, tension, and damage of the graft, as well as on synovial coverage of the space between the opening of the femoral bone tunnel and the graft. Second-look arthroscopy shows that graft loosening or partial tear can occur even in clinically successful knees. Moreover, it is known that synovial coverage of the grafts differs substantially between cases. Good synovial coverage over the graft may accelerate revascularization and cellular proliferation of the grafted tendon. In addition, sufficient synovial coverage may improve proprioceptive ability of the knee after ACL reconstruction. Recently, we reported on the clinical outcomes and second-look arthroscopic findings of 216 patients who underwent ACL reconstruction (central anatomic single- or double-bundle ACL reconstruction) or ACL augmentation [10]. In 94 of the 216 patients, knee joint proprioceptive function was evaluated using the threshold to detect passive motion test (TTDPM) before and 12 months after surgery. Second-look arthroscopy showed significantly better synovial coverage over the graft in the ACL augmentation group (good, 82%; fair, 14%; poor, 4%) than in the other two groups. The mean side-to-side difference of anterior displacement of the tibia measured with a KT-2000 arthrometer was 0.4mm in the augmentation group, 0.9mm in the double-bundle group, and 1.3mm in the single-bundle group. Hence, the result differed significantly between the augmentation and single-bundle groups. No significant difference in the Lysholm knee score or pivot-shift test was observed between the three groups. In patients with good synovial coverage, three of the four measurements used revealed significant improvement in knee joint proprioceptive ability. In conclusion, patients in the ACL augmentation group exhibited better knee stability than those in the standard single-bundle reconstruction group and better synovial coverage over the graft upon second-look arthroscopy than those in the standard anatomic single- and double-bundle reconstruction groups. Improvement in knee proprioceptive ability was observed in patients with good synovial coverage of the graft. Therefore, ACL augmentation may be a reasonable treatment option for patients with favorable ACL remnants.

DAMAGE TO THE ARTICULAR CARTILAGE AND MENISCUS

It is well known that articular cartilage and meniscus injury often occurs in conjunction with ACL injury. The articular cartilage injury is typically described as the most important predictor of poor clinical outcomes after ACL reconstruction. In addition, the damage to the articular cartilage is also a significant predictor of failure to return to sports following ACL reconstruction. It is indisputable that proper anatomic ACL reconstruction is important to obtain normal knee stability and function. However, even when knee stability and function have been achieved using anatomic ACL reconstruction, the long-term clinical results are affected by the condition of the articular cartilage. We investigated the relationship between the progression of articular cartilage damage and meniscal surgery (normal, repair, or partial meniscectomy) in conjunction with anatomic ACL reconstruction or augmentation, using second-look arthroscopy. The results of our study indicated that although partial meniscectomy was strongly associated with progression of articular cartilage damage, meniscal repair was not associated with the progression (ongoing study). The surgical technique used for ACL reconstruction (central anatomic single- or double-bundle ACL reconstruction, or ACL augmentation) did not significantly influence the progression of cartilage damage. Although proper ACL reconstruction is extremely important, meniscal repair should be performed, where possible, to limit the progression of articular cartilage damage.

LITERATURE

[1] KAZUSA H, NAKAMAE A, OCHI M. Augmentation technique for anterior cruciate ligament injury. *Clin Sports Med 2013; 32: 127-40.*

[2] MIFUNE Y, OTA S, TAKAYAMA K, HOSHINO Y, MATSUMOTO T, KURODA R, KUROSAKA M, FU FH, HUARD J. Therapeutic advantage in selective ligament augmentation for partial tears of the anterior cruciate ligament: results in an animal model. *Am J Sports Med 2013; 41: 365-73.*

[3] ADACHI N, OCHI M, UCHIO Y, IWASA J, RYOKE K, KURIWAKA M. Mechanoreceptors in the anterior cruciate ligament contribute to the joint position sense. *Acta Orthop Scand 2002; 73: 330-4.*

[4] NAKAMAE A, OCHI M, DEIE M, ADACHI N, KANAYA A, NISHIMORI M, NAKASA T. Biomechanical function of anterior cruciate ligament remnants: how long do they contribute to knee stability after injury in patients with complete tears? *Arthroscopy 2010; 26: 1577-85.*

[5] ADACHI N, OCHI M, UCHIO Y, SUMEN Y. Anterior cruciate ligament augmentation under arthroscopy. A minimum 2-year follow-up in 40 patients. *Arch Orthop Trauma Surg 2000; 120: 128-33.*

[6] OCHI M, ADACHI N, DEIE M, KANAYA A. Anterior cruciate ligament augmentation procedure with a 1-incision technique: anteromedial bundle or posterolateral bundle reconstruction. *Arthroscopy 2006; 22: 463.e1-e5.*

[7] OCHI M, ADACHI N, UCHIO Y, DEIE M, KUMAHASHI N, ISHIKAWA M, SERA S. A minimum 2-year follow-up after selective anteromedial or posterolateral bundle anterior cruciate ligament reconstruction. *Arthroscopy 2009; 25: 117-22.*

[8] OCHI M, ABOUHEIF MM, KONGCHAROEN-SOMBAT W, NAKAMAE A, ADACHI N, DEIE M. Double bundle arthroscopic Anterior Cruciate Ligament reconstruction with remnant preserving technique using a hamstring autograft. *Sports Med Arthrosc Rehabil Ther Technol 2011; 3: 30.*

[9] SONNERY-COTTET B, LAVOIE F, OGASSAWARA R, SCUSSIATO RG, KIDDER JF, CHAMBAT P. Selective anteromedial bundle reconstruction in partial ACL tears: a series of 36 patients with mean 24 months follow-up. *Knee Surg Sports Traumatol Arthrosc 2010; 18:47-51.*

[10] NAKAMAE A, OCHI M, DEIE M, ADACHI N, SHIBUYA H, OHKAWA S, HIRATA K. Clinical outcomes of second-look arthroscopic evaluation after anterior cruciate ligament augmentation: comparison with single- and double-bundle reconstruction. *Bone Joint J 2014; 96-B: 1325-32.*

INTRINSIC RISK FACTORS OF ANTERIOR CRUCIATE LIGAMENT INJURY: REVIEW

G. ESTOUR, A. PINAROLI, L. BUISSON

INTRODUCTION

Anterior cruciate ligament (ACL) injury is one of the most severe injuries in sport. Three quarters of anterior cruciate ligament injuries are non contact injuries. Furthermore, Wright [1] described a controlateral ACL tear rate of 12%.

Surgical techniques have evolved dramatically in the past decade thanks to arthroscopic techniques, graft choices and bony fixation techniques.

Understanding the mechanism of failure is critical to otpimize prevention strategies.

Prevention programmes work on the risk factors of ACL injuries: They include intrinsic factors and extrinsic factors.

Intrinsic risk factors try to explain the mechanism of non contact ACL injury including anatomical factors (tibial slope and intercondylar notch stenosis), gender factors, gene factors, biomechanical factors (knee valgus, knee recurvatum, joint laxity) neuromuscular deficit.

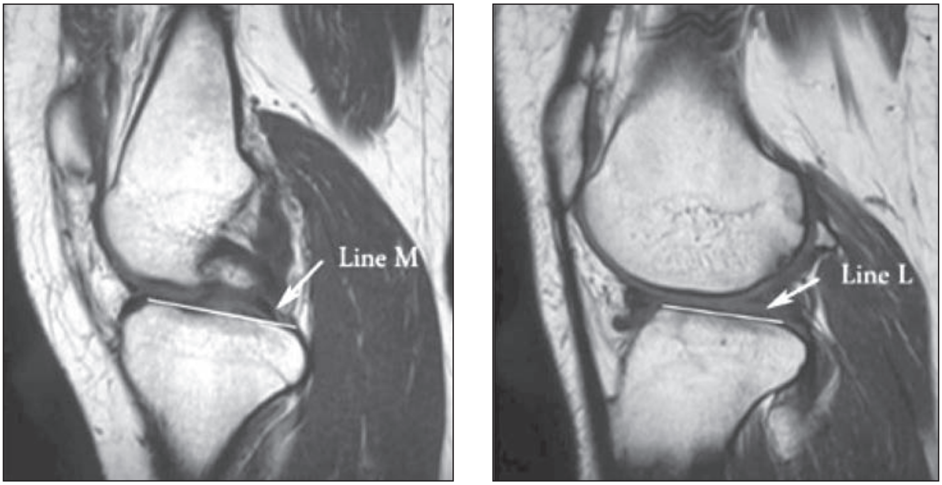
ANATOMICAL FACTORS

Tibial slope

Tibial plateau slope is one of the most often stated anatomic structures that could cause ACL injuries in the literature. Biomechanical studies have demonstrated that translation of the tibia resulted from the tibia plateau slope and created an anteriorly directly applied force. The tibial plateau must influence the *in situ* force of the ACL [2].

Tibial plateau slope is defined through several medical examinations either X-ray or in an MRI [3]. There is no significant difference between the radiographic methods and the MRI.

The most important findings of the meta-analysis [2] is that medial tibial plateau slope (MTPS) and lateral tibial plateau slope (LTPS) are risk factors for ACL [4]. In an X-ray, tibial slope is defined as the angle between a line on the surface of the plateau and a tibial anatomic reference. The angle is within the range of 5-7°.



From Haschimi et al. [5]

From this anatomic risk factor, several studies have described a revision of an ACL reconstruction, a tibial deflexion osteotomy to correct the tibial slope. It's suggested that correction is needed when the angle is over 12° and it can reduce the risk of recurrent failure. The technique is an anterior closing wedge tibial osteotomy with or without detachment of the patellar tendon [6].

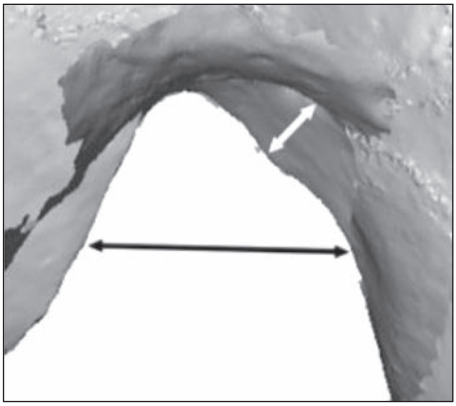
But literature is controversial. One point is the technique and the mesure of the intercondylar notch. The second point is the mechanism of failure. Most ACL injuries are known to occur with the knee in partial flexion. Most failures occur close to the femoral attachement site. An impingement mechanism would brake the ACL's need near the stenosis [7].

Intercondylar notch stenosis

The shape of the femoral notch at the anterior outlet has also been associated with ACL injury.

This intercondylar notch has been described by radiographics, MRI, arthroscopy and cadaveric studies. The U shape is not always identified by the same anatomic description. Stenosis is made by a bony ridge on the anteromedial notch or a narrow apex.

Notch width (black arrows) is measured halfway between the notch roof and floor; ridge thickness (white arrows) is measured perpendicular to the adjacent notch wall at its widest portion From Joshua S. Everhart [7].



Reconstruction of the notch

GENDER FACTOR

The fact is that females have 3 times greater a risk of ACL injury than males participating in the same sport. There are multiple studies indicating a contribution between hormonal factors and increased ligamentous laxity during the first half of a menstrual cycle [8]. Biomechanical explanation for the changes is most likely related to the increased levels of relaxin and oestrogen mediated reduction in pro collagen. Oral contraceptive and neuro-muscular training may increase dynamic knee stability and lessen the risk of ACL injury.

GENE FACTOR

Collagen is the most important component of ligaments. Type 1 collagen accounts for 85% of collagen and the rest is made up of types 3, 5, 6, 9. It has been previously demonstrated that individuals who have a family history of ACL tears show twice as high a risk of ACL rupture as another. There is an association between Col3 A1 and Col1 A1 and ACL ruptures [9]. This knowledge can help athletes with their training.

BIOMECHANICAL FACTOR

Valgus knee: The literature is controversial, numerous studies have shown that a valgus moment and valgus rotation are not associated with ACL injury. But some training programs for ACL injury have shown a reduction in trauma. Also valgus knee effects the axial compressive force on the lateral side of the knee and may contribute to an internal rotation [10].

Foot and Ankle: Boden *et al.* identified a safe and an injured position of the ankle associated with ACL injury. This can be associated with the lower ankle plantar flexion of athletes. When the ankle is not in appropriate extension, the tibia is in an unstable position and subluxation is easier than rolling. This ankle plantar flexion is one of the most crucial aspects for preventing ACL injury [10].

Torso and hip: Only 3 articles relate to torso and hip implication in ACL injury. After video analysis, authors concluded that patients who had ACL rupture had significantly higher hip flexion angles. From this data, prevention programs worked on torso stabilisation.

NEUROMUSCULAR

Just a few articles report information on neuromuscular risk factors of ACL injury [11].

Quadriceps: There is a postulat that the anterior vector of the quadriceps is the primary contributing force of ACL injury because the quadriceps are the biggest ones. But quadriceps force is full in extension and compressive force is larger than anterior force. On the MRI, bone bruising is more associated with compressive force than anterior translation.

Hamstring tendon: The Hamstring tendon has been proposed as a protective mechanism for the ACL. As the quadriceps, the hamstring tendon further determines a tibio-femoral joint compression force with minor posterior protective forces.

CONCLUSION

All these intrinsic factors must be known for several reasons. It can help with a training plan and prevent ACL injury. It can help also the surgeon performing ACL surgery strategy and revision of failed ACL reconstruction. However for the moment, the most important intrinsic factor is probably the tibial slope and must be known for the tibial deflexion slope osteotomy in revision ACL procedure.

The gender factor is more interesting for epidemiology. For the moment, evidence for biomechanical and neuromuscular risk factors are low. Neuromuscular and biomechanical aspects of the knee need further research and are included in the training and prevention program for ACL injury. It is also the main point of the post ACL reconstruction rehabilitation protocols. The new approach when returning to sporting activities after ACL reconstruction is focused on the resolution of neuromuscular deficits.

LITERATURE

[1] WRIGHT RW, MAGNUSSEN RA, DUNN WR, SPINDLER KP. Ipsilateral graft and contralateral ACL rupture at five years or more following ACL reconstruction: a systematic review. *J Bone Joint Surg Am 2011; 93(12): 1159-65.*

[2] ZENG C, CHENG L, WEI J, GAO SG, YANG TB, LUO W, LI YS, XU M, LEI GH. The influence of the tibial plateau slopes on injury of the anterior cruciate ligament: a metaanalysis. *Knee Surg Sports Traumatol Arthrosc 2014; 22(1): 53-65.*

[3] FEUCHT MJ, MAURO CS, BRUCKER PU, IMHOFF AB, HINTERWIMMER S. The role of the tibial slope in sustaining and treating anterior cruciate ligament injuries. *Knee Surg Sports Traumatol Arthrosc 2012.*

[4] LIPPS DB, WILSON AM, ASHTON-MILLER JA., WOJTYS EM. An evaluation of different methods for measuring lateral tibial slope using magnetic resonance imaging. *Am J Sports Med 2012; 40(12): 2731-6.*

[5] HASHEMI J, CHANDRASHEKAR N, MANSOURI H, GILL B, SLAUTERBECK JR, SCHUTT RC Jr, DABEZIES E, BEYNNON BD. Shallow medial tibial plateau and steep medial and lateral tibial slopes. *Am J Sports Med 2010; 38: 54-62.*

[6] DEJOUR D, SAFFARINI M, DEMEY G, BAVEREL L. *Knee Surg Sports Traumatol Arthrosc 2015; 23(10): 2846-52.*

[7] EVERHART JS, FLANIGAN DC, CHAUDHARI AMW Anteromedial ridging of the femoral intercondylar notch: an anatomic study of 170 archival skeletal specimens. *Knee Surg Sports Traumatol Arthrosc (2014) 22: 80-7.*

[8] POSTHUMUS M, COLLINS M, SEPTEMBER AV, SCHWELLNUS MP. The intrinsic risk factors for ACL ruptures: an evidence-based review. *Phys Sportsmed 2011; 39: 62-73.*

[9] STĘPIEN-SŁODKOWSKA M, FICEK K, EIDER J, LEOŃSKA-DUNIEC A, MACIEJEWSKA-KARŁOWSKA A, SAWCZUK M, ZARĘBSKA A, JASTRZĘBSKI Z, GRENDA A, KOTARSKA K, CIĘSZCZYK P. The +1245G/T polymorphismes in the collagen type 1 Alpha 1 (COL1A1) gene in polish skiers with anterior cruciate ligament injury. *Biinojl.uSryport 2013; 30: 57-60.*

[10] BODEN BP, SHEEHAN FT, TORG JS, HEWETT TE. Non-contact ACL Injuries: Mechanisms and Risk Factors. *J Am Acad Orthop Surg. 2010; 18(9): 520-7.*

[11] ALENTORN-GELI E, MENDIGUCH J, SAMUEL–SSON K, MUSAHL V, KARLSSON J, CUGAT R, MYER GD. Prevention of anterior cruciate ligament injuries in sports— Part I: Systematic review of risk factors in male athletes. *Knee Surg Sports Traumatol Arthrosc 2014; 22: 3-15.*

TIBIAL SLOPE AND ACL RUPTURE: MRI ASSESSMENT

S. LUSTIG, A. ELMANSORI, T. LORDING, E. SERVIEN, P. NEYRET

INTRODUCTION

The articular surfaces of the tibiofemoral joint in combination with the primary ligaments play an important role in controlling the biomechanical behavior of the joint. In particular, the geometry of the tibial plateau has a direct influence on the biomechanics of the joint in terms of translation, the location of instantaneous center of rotation, the screw-home mechanism, and the strain biomechanics of the knee ligaments such as the anterior cruciate ligament (ACL) [1].

It is probable that the cruciate, collateral ligaments and the menisci are functional members that act in concert to align the opposing knee joint surfaces to afford congruent contact and normal kinematic articulating motion [2].

ACL injury occurs predominantly via noncontact mechanisms. Because of a high incidence of long-term sequelae to ACL injury including pain, instability, and early development of osteoarthritis, identification of risk factors for ACL injury is an important step in the development of injury prevention [3].

Recently in the literature, there has been a great focus on anatomic risk factors [4].

Posterior Tibial slope (PTS) is commonly defined as the angle between a line fit to the posterior-inferior surface of the tibial plateau and a tibial anatomic reference line [5, 6, 7, 8, 9, 10, 11].

Biomechanically, a higher tibial slope in the presence of a compressive load will generate a higher anterior shear component of the tibio-femoral reaction force, resulting in increased anterior motion of the tibia relative to the femur. Because the ACL is the primary restraint against this type of motion in the knee, it logically follows that an increase in posterior tibial slope will generate an increased load in the ACL. This hypothesis was first by Butler *et al.* in the year 1980 [3].

Reliable clinical measurements of posterior tibial slope are important for understanding ACL injury mechanisms. It's widely mentioned in the literature that ACL-injured individuals have a greater posterior tibial slope than healthy controls [12].

It remains unclear whether the risk of noncontact ACL injury could be increased in those with increased slope in one or both compartments and individual analysis of the compartments separately could be essential to understand the functional consequences of tibial slope [13].

The medial and lateral PTS are not necessarily identical in one given knee and differences of as much as 27° have been reported in cadaveric studies [14]. An increased lateral tibial slope relative to the medial tibial slope can influence dynamic landing biomechanics by coupling knee abduction with internal tibial rotation [12].

Various models for PTS measurement on conventional lateral radiographs have been described, however it is still imprecise. As a consequence of superimposition, the lateral tibial plateau is difficult to identify and separate assessment of the plateaus is not reliably possible on lateral radiographs [14].

Previous studies have validated different radiographic methods for measuring posterior tibial slope [12]. No significant difference exists between radiographs, computed tomography, and magnetic resonance imaging (MRI); recent work has focused on MRI [12].

Although lateral radiographs are better to assess the medial PTS, they are inadequate for reliable and separate PTS and MS assessment. Therefore, it's recommended to use conventional MRI scans of the knee, because they allow simple assessment of each plateau separately and provide the possibility to assess the MS reliably [6] and methods using three-dimensional computed reconstructions are time-consuming and complex [15].

One of the greatest strengths of using MRI for this application is the ability to visualize the surface geometry of the articular cartilage. Because this represents the functional point of tibiofemoral articulation and is not visible on radiographs, it permits visualization and measurement of the separate compartments and their associated tissue structures [13].

The effects of patient demographics, such as gender and age, on tibial slope have not been fully elucidated. Females are at greater risk of noncontact ACL injury and a steeper tibial slope has been observed in females [13]. Multiple studies showed that women have a greater propensity for ACL injury compared to their male counterparts [3, 4, 6, 20, 21]. It has been suggested that a possible risk factor for this observation is that women have a narrower notch than men and even smaller ACLs.

Gender-and age-specific assessments of the STS and BS could be important and may explain the difference in the incidence of anterior cruciate ligament rupture between individuals, as well as differences in function following high tibial osteotomies [13].

The soft tissues (e.g. cartilage and meniscus) may influence tibial slope and consequently play a role in antero-posterior stability of the knee joint. The posterior horn of the menisci is thicker than the anterior one, and this could decrease the postero-distal slope [16].

The aims of this study were to evaluate the correlation between the tibial slope and the non contact ACL – injury using MRI, as well as to determine the effects the menisci on tibial slope. It was hypothesized that the meniscus would reduce the differences in slope between the medial and lateral compartments of the same knee. In addition, it was hypothesized that the presence of meniscus would correct the bony inclination of the tibial slope towards the horizontal.

SUBJECTS AND METHOD

A large group from the Croix-Rousse Hospital in Lyon city was followed from January 2012 to December 2015. The patients were accepted for knee interventions; none were diagnosed with gonarthrosis. Two groups of patients were established. The examined group consisted of 100 patients (67 male & 33 female) with isolated complete or partial ruptures of the ACL injury with age group 18-63 (Mean ± SD, 33.76 ± 10.81). The control group consisted of 100 patients whose major complaint was patella-femoral pain and their MRIs reveled intact ACL (52 male & 48 female) and their ages were ranged from 18-86 (Mean ± SD, 43.65 ± 15.96).

Approval was obtained from the ethics committee of the medical institution at which the patients were treated.

All measurements of the tibial bony slopes and meniscal slopes angles were carried out by using the annotation tools on the digital Picture Archiving and Communication System (PACS) provided by the hospital. For a given measurement, the maximum deviation from the actual value does not exceed 0.5°. Proton density sagittal sections of the MRIs were selected to measure the angles.

All the MRIs were obtained from a single 1.5-T MRI scanner (manufacturer-supplied quadrature head coil, Philips Medical Systems). We chose three sagittal images from the corresponding axial cuts at the joint line for 3 different cut regions: the mid-sagittal cut (fig. 1, 2), the mid-medial tibial plateau cut (MTP) (fig. 3, 4, 5) and the mid-lateral tibial plateau cut (LTP) (fig. 6, 7, 8).

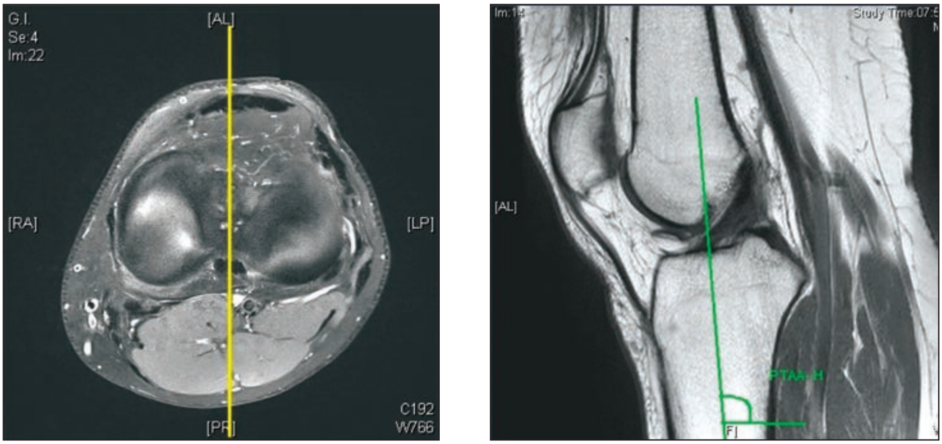


Fig. 1, 2: ***The sagittal image was chosen from the axial cut at the joint line in midsagittal cut. The PTTA was calculated by a line bisecting the midpoint distances between the two tibial cortices at the level of tibial tuberosity and 5cm below. The angle between the PTAA and the horizontal was also calculated PTAA-H.***

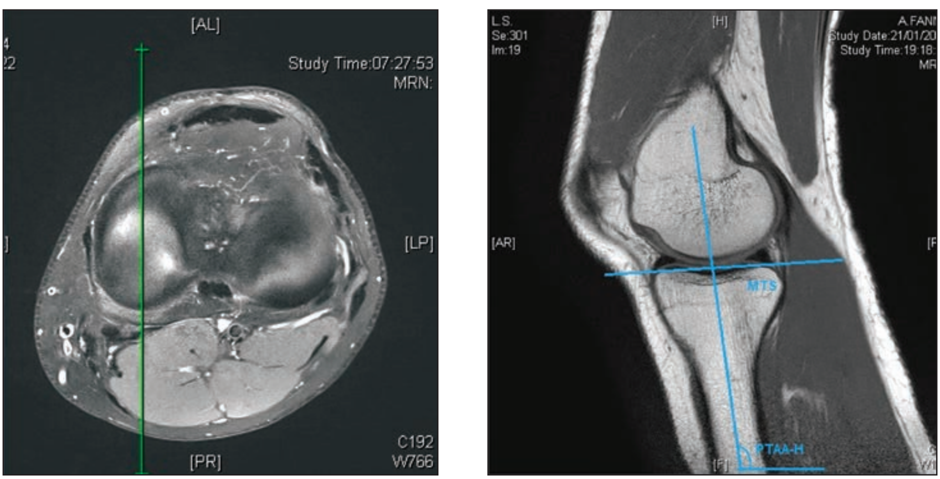


Fig. 3, 4: ***The sagittal image was chosen from the axial cut at the joint line in mid-medial cut and the PTAA was superimposed on the selected image by means of the PTAA-H angle. The MTS was calculated as the angle between tangent line to the high points of anterior & posterior region of the medial tibial plateau and a perpendicular line to the tibial axis.***

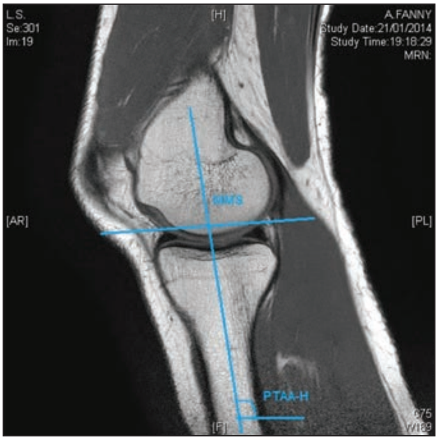


Fig. 5: ***After superimposition of the PTTA by means of the PTAA-H, the MMS was calculated as the angle between tangent line to the highest points in the anterior and posterior region of the medial meniscus and perpendicular line to the tibial axis.***

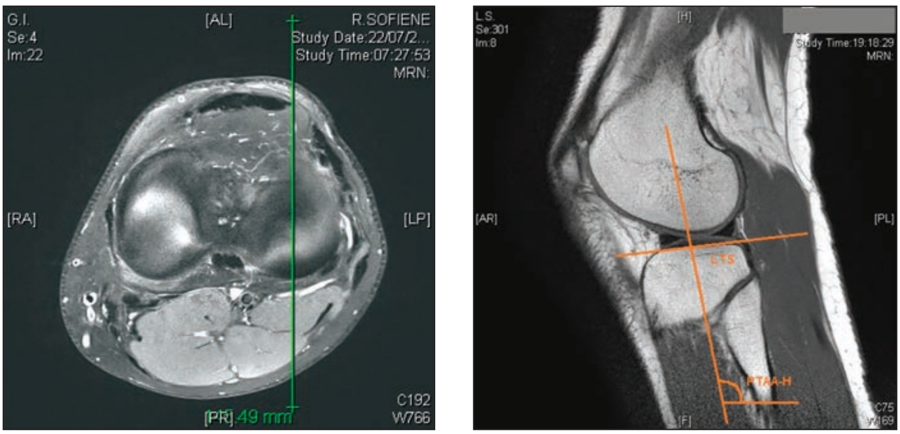


Fig. 6, 7: ***The sagittal image was chosen from the axial cut at the joint line in mid-lateral cut and the PTAA was superimposed on the selected image by means of the PTAA-H angle. The LTS was calculated as the angle between tangent line to the high points of anterior & posterior region of the lateral tibial plateau and a perpendicular line to the tibial axis.***

Fig. 8: ***After superimposition of the PTTA by means of the PTAA-H, the LMS was calculated as the angle between tangent line to the highest points in the anterior and posterior region of the lateral meniscus and perpendicular line to the tibial axis.***

Two independent reviewers calculated the angles on each MRI using a modified Hashemi method which published previously by Lustig *et al.* [5].

According to the procedure described by those authors, to establish the tibial slope, we used the proximal tibial anatomic axis (PTAA), which demonstrates the best correlation with the tibial shaft anatomic axis (TSAA) [17]. The PTAA is calculated on the mi-sagittal cut by a line joining the midpoint between the anterior and posterior tibial cortices at the level of tibial tuberosity and at another level 5cm below it. The angle subtended between the tibial axis to the horizontal was calculated (Angle TA-H).

The MTP and LTP cuts were used to measure the medial and lateral tibial slope (MTS, LTS) respectively.

The PTAA was superimposed on these cuts by means of TA-H angle. The tibial slope in each compartment was measured as the angle between a tangent line connecting the highest points in the anterior & posterior parts of the tibial and the perpendicular to the PTTA.

All measurements were positioned as an overlay and remained in a fixed position on the complete image series. The meniscal slope (MS) was defined in the same manner as the PTS. A tangent to the superior edge of the meniscosynovial border of the anterior and posterior meniscus on the sagittal plane was chosen instead of the tibial plateau cortices.

A posterior inclination to the horizontal was assigned a positive value, while an anterior inclination was assigned a negative value. The measurements were done by two observers and repeated again after interval of two weeks.

The average PTS and MS angles are reported as mean angles with standard deviation.The data was statistically analyzed and the differences between the bony and soft tissue slope were compared between the two groups using independent *t*-test.

RESULTS

The average PTS and MS angles are reported as mean angles with standard deviation.The data were initially analyzed for each reviewer and then the parameters were compared between the two groups. The maximum and minimum values for each parameter were also reported.

Statistical Analysis

The assumption of normality was assessed with Kolmogorov-Smirnov tests which revealed that all the measured parameters of both groups were within normal distribution ($p<0.0001$).

Inter-observer reliability:

Repeated measures analysis of variance and 95% confidence limits were used to establish whether the mean slope was altered between reviewers by means of Intra class Correlation Coefficient (ICC) and the results showed high ICC for all the variants which reveal strong agreement between the observers for all measurements (table 1).

Table 1: ***Inter-observer reliability of the bony and soft tissue slope for ACL and control (CNT) groups.***

VARIANT	ICC (95 % CI)
LTS ACL Group	0.9349
MTS ACL Group	0.9148
MMS ACL Group	0.9252
LMS ACL Group	0.9713
LTS CNT Group	0.8841
MTS CNT Group	0.9186
MMS CNT Group	0.8857
LMS CNT Group	0.9159

The means and standard deviations (**SD**) for the repeated measurements of lateral tibial slope (**LTS**), lateral tibial slope (**MTS**), the medial meniscal slope (**MMS**), and lateral meniscal slope (**LMS**) for the examined group are shown in the table 2, and those for the control group are shown in table 2.

Table 2: ***Measurements of the ACL injury group n=100.***

VALUE	LTS	MTS	MMS	LMS
MEAN	10.48	9.47	6.06	4.76
SD	3.15	3.34	3.49	4.74
MAX	15.85	16	14.5	13.85
MIN	1.9	1.4	-2.25	-5.65
LTS: Lateral tibial slope, **MTS:** Medial tibial slope, **MMS:** Medial meniscal slope, **LMS:** Lateral meniscal slope.				

For the ACL injury group the LTS ranged from 15.85° to 4.1° and the MTS ranged from 16° to 1.4° while the MMS ranged from 14.5° to -2.25° and the LMS ranged from 13.85° to -5.65°. Similarly, for the control group the LTS ranged from 15.45° to 0°, and the MTS ranged from 15.05° to -0.6° while the MMS ranged from 11.55° to -4.25° and the LMS ranged from 12.65° to -12.5°.

Table 3: ***Measurements of control group n=100.***

VALUE	LTS	MTS	MMS	LMS
MEAN	7.33	7.05	3.72	0.91
SD	3.45	3.72	3.68	4.85
MAX	15.45	15.05	11.55	12.65
MIN	0	-0.6	-4.25	-12.5
LTS: Lateral tibial slope, **MTS:** Medial tibial slope, **MMS:** Medial meniscal slope, **LMS:** Lateral meniscal slope.				

In the analysis of the ACL injury group the LTS was larger than the MTS but the LMS was smaller than MMS. In the control group, the LTS was also larger than the MTS and the LMS was smaller than MMS (Chart 1).

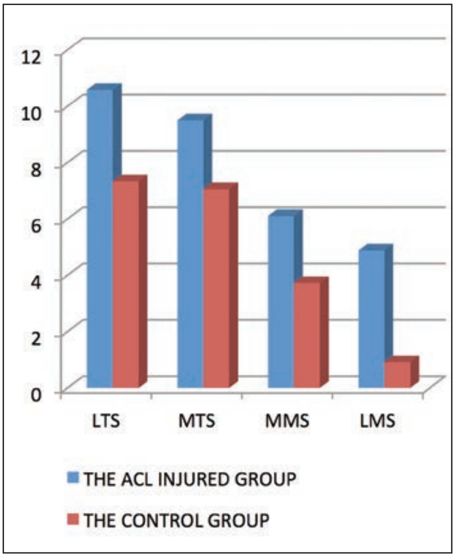


Chart 1: ***Comparison of the means different parameters between the ACL group and the control group, measurements are in millimeter.*** **LTS*****: Lateral tibial slope,*** **MTS*****: Medial tibial slope,*** **MMS*****: Medial meniscal slope,*** **LMS*****: Lateral meniscal slope.***

Comparison of the variants between examined and control groups

Independent *t*-test was used to compare the four variants between the two groups, where the difference is judged to be statistically significant when p=0.05 or less.

By direct comparison between the two groups using independent *t*-test, the MTS & LTS were significantly larger in the ACL injury group than the control ($p \leq 0.0001$). Similarly, the MMS & LMS were significantly greater in the ACL injury group than the control ($p \leq 0.0001$) (table 4).

Table 4: ***Represents the result of comparison of the variants between examined and control groups using independent student t-test:***

Variants	*t*-test	SD	DOF	*P* Value
LTS	6.76	3.30	198	0.0001
MTS	4.85	3.53	198	0.0001
LMS	5.67	4.80	198	0.0001
MMS	4.61	3.59	198	0.0001

SD: standard deviation, **DOF:** degree of freedom, ***p*:** probability

DISCUSSION

Some studies found that the measurement of posterior slope using lateral radiographs and the measurement of meniscal insertion using sagittal MRI images were both reproducible and reliable [12], in contrast Han *et al.* [17] declare that tibial slopes obtained from conventional plain X-rays are of limited value because they have poor reproducibility, caused by tibial rotation in lateral view. The problem inherent to the measurement of the tibial slope on the short sagittal MRI sections of the knee is the impossibility to adequately determine the PTAA. To determine the PTAA, a section covering a minimum of 150mm below the joint gap of the knee is necessary [12].

The true tibial slope should be based on measurements made at the center of the articular regions of the medial and lateral compartments of the tibial plateau.

The most important finding of the present study was that the soft tissue tibial slope can be measured reliably using an MRI-based method where our results showed high ICC for all the variants which reveal strong agreement between the observers for all measurements.

It was hypothesized that patients with ACL injury have larger tibial slope than normal people and within the injured group, the lateral tibial slope is larger than the medial one. The results supported this hypothesis. Our results are somehow similar to those observed by Matsuda *et al.* [18], who reported a range of 5° to 15.5° for medial tibial slope and a range of 0° to 14.5° for lateral tibial slope in their study of subjects with normal knees.

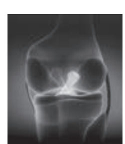
Our results agreed with Brandon *et al.* [13] who found that ACL-insufficient patients had a significantly greater PTS than their negative controls. In a resemble Studies, Todd *et al.* [19] found that subjects in the noncontact ACL group had significantly greater slope angles than did control subjects. Stijak *et al.* [21] found that the tibial slope on the lateral plateau had a significantly higher value in the ACL group than in the control group. The anterior tibial translation during flexion was greater on the lateral tibial plateau. This can explain why the additional increase in the tibial slope imparted stress on the ACL that could result in its rupture.

The axial compression of a knee with a higher LTS compared with MTS may cause greater anterior motion of the lateral compartment of the tibia compared with the medial one, creating a net internal rotation of the tibia with respect to the femur, which may increase loading on the ACL [21]. Dejour and Bonnin [24] demonstrated a mean 6mm increase in anterior tibial translation (ATT) for each 10° increase in posterior tibial slope in ACL-deficient patients and healthy controls.

The effect of the posterior slope on knee kinematics may be altered by the menisci. Thus, the STS may reflect the true relationship between the femoral & tibial condyles.

It was hypothesized that the soft tissues would influence the slope in both compartments.

In contrast to the similar study of Lustig *et al.* [13] who declared that the menisci shift the tibial slope towards the horizontal and the soft tissue slope is more horizontal in the lateral compartment of the knee compared to the medial one, we found that the meniscal slope was large in the injured group than the normal and the soft tissue slope is more horizontal in the lateral compartment of the knee compared to the medial one.



Our study confirms the previous MRI study which done by Hudek *et al.* [6] who found that a greater lateral MS in the patients with ACL injuries, which leads to the suggestion that a greater lateral MS is associated with a greater risk for noncontact ACL injury, they found also uninjured women had a greater PTS and MS than men (Table 5). Therefore, in ACL surgery it may be beneficial to preserve particularly the lateral meniscus or to reconstruct it to improve sagittal stability and prevent the progression of osteoarthritis.

Table 5: ***Review of the different MRI studies comparing tibial and meniscal slopes of ACL injured groups.***

STUDY	YEAR	N° OF SUBJECTS	LTS	MTS	MMS	LMS	COMMENT
Stijak *et al.* [21]	2008	33 injury *vs.* 33 control	Exam: 7.52 ± 3.39° Cnt: 4.36 ± 2.26°	Exam: 5.24 ± 3.60° Cnt: 6.58 ± 3.21°	-	-	The ACL group has greater LTS while the intact ACL has greater MTS
Khan *et al.* [9]	2011	73 injury *vs.* 51 control	Exam: 4.6 ± 3.04° Cnt: 2.65 ± 2.48°	Exam: 5.06 ± 2.46° Cnt: 4.81± 3.55°	-	-	LTS was steeper in the injured compared with the control group
Hudek *et al.* [6]	2011	55 injury *vs.* 55 control	Exam: 5.6° Cnt: 4.9°	Exam: 4.7° Cnt: 4.7°	Exam: 1.3° Cnt: 0.1°	Exam: 1.8° Cnt: -1.7°	Both the PTS & MS are larger in ACL group than control
Hohmann *et al.* [8]	2011	272 injury vs. 272 control		Exam: 5.8 ± 3.5° Cnt: 5.6 ± 3.2°	-	-	ACL group have larger PTS than control
Hashemi *et al.* [20]	2010	49 injury *vs.* 55 control	Exam Male 7.22 ± 2.7° Female 8.44 ± 2.8° Cnt: Male 5.4 ± 2.7° Female 7.03 ± 3.0°	Exam Male 5.95 ± 2.7° Female 6.85 ± 3.6° Cnt: Male 3.68 ± 3.1° Female 5.91 ± 2.9°	-	-	The ACL group have greater LTS & MTS than the control
Lustig *et al.* [13]	2013	101 ACL injury	5.5 ± 4.7°	5.1 ± 4.1°	1.8 ± 4.3°	-0.1 ± 5.7°	In ACL injury the LTS larger than MTS. The soft tissue is more horizontal in lateral compartment
Our study	2016	100 injury *vs.* 100 control	Exam: 10.48 ± 3.15° Cnt: 7.33 ± 3.45°	Exam: 9.47 ± 3.34° Cnt: 7.05 ± 3.72°	Exam: 6.06 ± 3.49° Cnt: 3.72 ± 3.68°	Exam: 4.76 ± 4.74° Cnt: 0.91 ± 4.85°	Both the bony & soft tissue slops are larger in ACL group than control

LTS: Lateral tibial slope, **MTS:** Medial tibial slope, **MMS:** Medial meniscal slope, **LMS:** Lateral meniscal slope, **PTS:** posterior tibial slope. **Exam:** examined group, **Cnt:** control group

Under normal loading conditions, patients with a greater lateral PTS may have greater internal rotations of the lower leg. The resulting internal rotation stresses the ACL and may increase the injury risk [15]. Inconsistency was reported by Hashemi *et al.* [20] in which the male's medial PTS was associated with injury but not the females. They also observed an increased medial tibial plateau depth in conjunction with an increased PTS in patients with noncontact ACL injuries.

The anterior tibial translation increased significantly after an ACL rupture [25, 26]. It suggested that the ACL served as the main knee stabilizer in tibiofemoral translation, with specific tension being produced in the course of internal rotation [15]. When an anterior force is applied to the tibia of the knee with intact ligaments, the internal rotation that occurs imparts considerable stress on the ACL [26].

Tibial slope on lateral tibial plateau undertakes an important role during extension motion because it favors internal rotation, which, in turn, imparts considerable stress on the extended ACL [25].

The PTS plays an important role in knee replacement, after total knee arthroplasty (TKA); the posterior tibial slope affects anteroposterior stability, range of motion, and contact pressure within the tibiofemoral joint [28]. Moreover, an inappropriate cutting angle of the posterior tibial slope results in polyethylene wear, component loosening and posterior cruciate ligament strain [29].

During early weight bearing after ACL reconstruction, a steep tibial slope might place increased load on the healing graft and fixation material and potentially increase the risk of early elongation or acute failure. Improved knowledge about the effect of the tibial slope on the graft after ACL reconstruction might serve as a basis for individually adapted postoperative rehabilitation programmes [15].

A small increase in tibial slope, which may occur inadvertently during medial opening-wedge HTOs, would not adversely affect overall A-P knee stability or the in situ forces in the cruciate ligaments. However, the changes observed in the resting position with osteotomies in the sagittal plane may be important in the treatment of cruciate ligament-deficient knees [30].

Inconsistencies within and between tibial slope measurement methodologies have precluded repeatable demonstration of an "at ACL injury risk" range of tibial slope values.

Identification of new risk factors is paramount to prevention. While trends in the current literature indicate a potential relationship between ACL injury and PTS, standardized techniques and more consistent and repeatable data are required to definitively link the two [25].

The future goal of the research relating tibial plateau slope to ACL injury risk should be to establish not only the extent of the role of tibial slope in injury risk but also the extent to which that risk can be decreased by prophylactic interventions such as neuromuscular training.

Such methodologies will also enhance the objectivity of tibial slope as a factor in the assessment of post-injury stability and long-term sequelae [25].

Subjects with an increased tibial slope who are participating in high-risk activities should perhaps consider prophylactic precautions. This could include education on the increased risk for ACL rupture, as well as injury prevention training [5].

One of the limitations of the present study is that we did not have access to the height and weight of the subjects, and consequently we did not explore correlations that may exist with the measured slopes. These parameters should be tested in future. Secondly, it is important to note that the MRI voxel resolution, the access to a sufficient length of the tibia and the ability to identify landmarks precisely all could have an impact on the slope measurements. However, although these factors may influence the results, they will not influence the large inter individual differences or the large range of slope values.

CONCLUSION

Our results demonstrate that the tibial bony & soft tissue slopes can be measured reliably using an MRI-based method and both tibial & meniscal slope were significantly larger in the ACL injury group compared to the control. Furthermore, the soft tissue slope is more markedly higher in the medial compartment of the knee compared to the lateral compartment in the both group. Although this study demonstrates how soft tissue alters the traditional measurement of the bony tibial slope, the implications of differences in slope between medial and lateral compartments on knee function require further research.

These geometric differences may be important to consider when assessing the risk of knee injury and the susceptibility to osteoarthritis.

LITERATURE

[1] HASHEMI J, CHANDRASHEKAR N, GILL B, BEYNNON BD, SLAUTERBECK JR, SCHUTT RC Jr, MANSOURI H, DABEZIES E. The geometry of the tibial plateau and its influence on the biomechanics of the tibiofemoral joint. *J Bone Joint Surg Am 2008 Dec; 90(12): 2724-34.*

[2] TORZILLI PA, DENG X, WARREN RF. The Effect of Joint-Compressive Load and Quadriceps Muscle Force on Knee Motion in the Intact and Anterior Cruciate Ligament-Sectioned Knee. *Am J Sports Med 1994 Jan-Feb; 22(1): 105-12.*

[3] WORDEMAN SC, QUATMAN CE, KAEDING CC, HEWETT TE. In Vivo Evidence for Tibial Plateau Slope as a Risk Factor for Anterior Cruciate Ligament Injury: A Systematic Review and Meta-analysis. *Am J Sports Med 2012 July; 40(7): 1673-81.*

[4] GRIFFIN LY, ALBOHM MJ, ARENDT EA, BAHR R, BEYNNON BD, DEMAIO M, DICK RW, ENGEBRETSEN L, GARRETT WE Jr, HANNAFIN JA, HEWETT TE, HUSTON LJ, IRELAND ML. Understanding and Preventing Noncontact Anterior Cruciate Ligament Injuries. *Am J Sports Med 2006 Sep; 34(9): 1512-32.*

[5] VYAS S, VAN ECK CF, VYAS N, FU FH, OTSUKA NY. Increased medial tibial slope in teenage pediatric population with open physes and anterior cruciate ligament injuries. *Knee Surg Sports Traumatol Arthrosc 2011 Mar; 19(3): 372-7.*

[6] HUDEK R, FUCHS B, REGENFELDER F, KOCH PP. Is Noncontact ACL Injury Associated with the Posterior Tibial and Meniscal Slope? *Clin Orthop Relat Res 2011; 469: 2377-84.*

[7] WHITESIDE LA, AMADOR DD. The effect of posterior tibial slope on knee stability after Ortholoc total knee arthroplasty. *J Arthroplasty 19883 Suppl: S51-7.*

[8] HOHMANN E, BRYANT A, REABURN P, TETSWORTH K. Is there a correlation between posterior tibial slope and non-contact anterior cruciate ligament injuries? *Knee Surg Sports Traumatol Arthrosc 2011, 19 (Suppl 1):S109-14.*

[9] KHAN MS, SEON JK, SONG EK. Risk factors for anterior cruciate ligament injury: assessment of tibial plateau anatomic variables on conventional MRI using a new combined method. *Int Orthop 2011 Aug; 35(8): 1251-6.*

[10] KOSTOGIANNIS I, SWÄRD P, NEUMAN P, FRIDÉN T, ROOS H. The influence of posterior-inferior tibial slope in ACL injury. *Knee Surg Sports Traumatol Arthrosc 2011, 19, 592-97.*

[11] SIMON RA, EVERHART JS, NAGARAJA HN, CHAUDHARI AM. A case-control study of anterior cruciate ligament volume, tibial plateau slopes and intercondylar notch dimensions in ACL-injured knees. *J Biomech 2010 Jun 18; 43(9): 1702-7.*

[12] LIPPS DB, WILSON AM, ASHTON-MILLER JA, WOJTYS EM. An Evaluation of Different Methods for Measuring Lateral tibial slope using magnetic resonance Imaging. *Am J Sports Med 2012 December; 40(12): 2731-36.*

[13] LUSTIG S, SCHOLES CJ, LEO SP, COOLICAN M, PARKER DA. Influence of soft tissues on the proximal bony tibial slope measured with two-dimensional MRI. *Knee Surg Sports Traumatol Arthrosc (2013) 21: 372-9.*

[14] HUDEK R, SCHMUTZ S, REGENFELDER F, FUCHS B, KOCH PP. Novel Measurement Technique of the Tibial Slope on Conventional MRI. *Clin Orthop Relat Res 2009; 467: 2066-72.*

[15] HAN HS, CHANG CB, SEONG SC, LEE S, LEE MC. Evaluation of anatomic references for tibial sagittal alignment in total knee arthroplasty. *Knee Surg Sports Traumatol Arthrosc 2008; 16: 373-7.*

[16] LEE YS, KIM JG, LIM HC, PARK JH, PARK JW, KIM JG. The relationship between tibial slope and meniscal insertion. *Knee Surg Sports Traumatol Arthrosc 2009; 17: 1416-20.*

[17] BRAZIER J, MIGAUD H, GOUGEON F, COTTEN A, FONTAINE C, DUQUENNOY A. Evaluation des méthodes de mesure radiographique de la pente tibiale. *Rev Chir Orthop Reparatrice Appar Mot 1996; 82(3): 195-200.*

[18] MATSUDA S, MIURA H, NAGAMINE R, URABE K, IKENOUE T, OKAZAKI K, IWAMOTO Y. Posterior tibial slope in the normal and varus knee. *Am J Knee Surg 1999; 12: 165-8.*

[19] TODD MS, LALLISS S, GARCIA E, DEBERARDINO TM, CAMERON KL. The relationship between posterior tibial slope and anterior cruciate ligament injuries. *Am J Sports Med 2010; Jan; 38(1): 63-7.*

[290] HASHEMI J, CHANDRASHEKAR N, MANSOURI H, GILL B, SLAUTERBECK JR, SCHUTT RC Jr, DABEZIES E, BEYNNON BD. Shallow medial tibial plateau and steep medial and lateral tibial slopes: new risk factors for anterior cruciate ligament injuries. *Am J Sports Med 2010 Jan; 38(1): 54-62.*

[21] STIJAK L, HERZOG RF, SCHAI P. Is there an influence of the tibial slope of the lateral condyle on the ACL lesion? A case-control study. *Knee Surg Sports Traumatol Arthrosc 2008 Feb; 16(2): 112-7.*

[22] DEJOUR H, BONNIN M. Tibial translation after anterior cruciate ligament rupture. *J Bone Joint Surg Br 1994 Sep; 76(5): 745-9.*

[23] WORDEMAN SC, QUATMAN CE, KAEDING CC, HEWETT TE. *In vivo* evidence for tibial plateau slope as a risk factor for anterior cruciate ligament injury: a systematic review and meta-analysis. *Am J Sports Med 2012 Jul; 40(7): 1673-81.*

[24] BONNIN M, CARRET JP, DIMNET J, DEJOUR H. The weight-bearing knee after anterior cruciate ligament rupture. An in vitro biomechanical study. *Knee Surg Sports Traumatol Arthrosc 1996; 3(4): 245-51.*

[25] FEUCHT MJ, MAURO CS, BRUCKER PU, IMHOFF AB, HINTERWIMMER S. The role of the tibial slope in sustaining and treating anterior cruciate ligament injuries. *Knee Surg Sports Traumatol Arthrosc 2013 Jan; 21(1): 134-45.*

[26] BAI B, BAEZ J, TESTA N, KUMMER FJ. Effect of posterior cut angle on tibial component loading. *J Arthroplasty 2000 Oct; 15(7): 916-20.*

[27] GIFFIN JR, VOGRIN TM, ZANTOP T, WOO SL, HARNER CD. Effects of increasing tibial slope on the biomechanics of the knee. *Am J Sports Med 2004 Mar; 32(2): 376-82.*

WHAT ARE THE INTRINSIC FACTORS IN ACL FAILURE?

M. VALOROSO, G. LA BARBERA, G. DEMEY, D. DEJOUR

INTRODUCTION

The revision surgery of anterior cruciate ligament (ACL) reconstruction is always challenging for the surgeon and the results are dependent upon the ability to understand and to treat the causes of the graft failure. Its incidence varies between 4,5-20% [1]. The outcome of revision ACL procedure remains poor compared to primary ACL reconstruction. The definition of failure is not universally accepted. Several authors consider that the surgery is failed in case of subjective and/or objective knee instability, persistent pain, stiffness, extensor mechanism dysfunction or infection. Despite the improvements in the surgical techniques, the risks of re-rupture are still high [2].

In literature several intrinsic factors leading to ACL reconstruction failure are described such as narrow notch width, increased tibial slope, high anterior tibial translation, rotatory laxity, gender, hyper-laxity with recurvatum and genetic factors. The extrinsic factors are represented by technical errors (mainly femoral tunnel malposition), sports, neuromuscular aspects, rehabilitation and physical preparation. It is mandatory to identify and to address all the modifiable risk factors in order to limit the re-rupture rate [3, 4].

NOTCH WIDTH

The narrow intercondylar notch was described by Palmer in 1936 as an anatomical risk factor for ACL injury, providing less space for the ligament to function correctly especially in full extension [4] (fig. 1).

In literature the association between dimension measurements of the femoral notch and increased risk of ACL ruptures is well described. Femoral notch measurements include the notch width (distance between the femoral condyles at the anterior outlet), the notch width index (the ratio of the notch width to the total condylar width), and the presence of a bony crest on the anteromedial aspect of the femoral intercondylar notch that may predispose individuals to ACL rupture [4]. Zeng *& al.* [5], in a meta-analysis, report that the narrow intercondylar notch dimensions are associated with the risk of ACL injury. Besides the width of the intercondylar notch, its shape may also play a role in ACL ruptures. Narrow notches are frequently A- or wave-shaped while wider notches are more rounded or reverse U-shaped. A broader and rounded notch can provide more space for the ACL when the knee is near or in full extension 4. Sonnery-Cottet *& al.* [6] confirm that patients

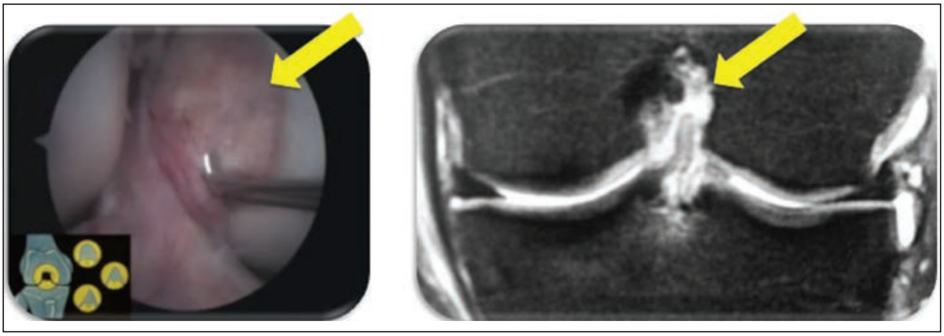


Fig. 1: ***Narrow intercondylar notch is a modifiable intrinsic factor affecting the correct ligament kinematic. Narrow notches are frequently A- or wave shaped while wider notches are more rounded or reverse U-shaped.***

with ACL lesion have a statistically significant increased posterior tibial slope (PTS) and a narrow intercondylar notch compared to the control group. They report that 80% of patients present at least one of these two risk factors, but both are present only in 24% of the cases.

TIBIAL SLOPE

A significant association between increased PTS and anterior tibial translation is observed, suggesting that increased tibial slope is a predisposing risk factor to ACL ruptures [4]. Normal values for PTS range from 5° to 7º [7].

In a radiological analysis performed using lateral monopodal stance tests, Dejour and Bonnin [7] observe that every 10º increase in the PTS is associated with 6mm increase of the anterior tibial translation in normal and ACL insufficient knees. The forces on the knee during weight-bearing can be resolved into a vertically directed compression component and a horizontally directed shear component: the latter varies with the PTS. An excessive slope induces the anterior tibial translation tensioning the ACL and predisposing the ligament to fatigue and injury (fig. 2). As well as for first-time ACL ruptures, tibial slope can be considered an important risk factor leading to ACL graft failure. In revision ACL surgery, the

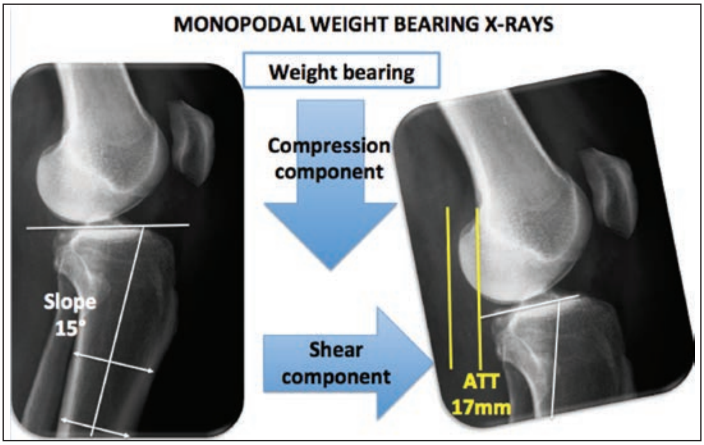


Fig. 2: ***During weight bearing, the forces on the knee can be resolved into a vertically directed compression component and a horizontally directed shear component: the latter varies with the PTS. An excessive PTS induces the anterior tibial translation (ATT), tensioning the ACL and predisposing the ligament to fatigue and injury.***

slope correction should be taken into consideration and performed when values superior to 12° are measured [8]. PTS inclination is influenced also by the presence of the menisci that shift the tibial slope towards the horizontal as described by Lustig *& al.* [9]. In this context, meniscal lesions or a previous meniscectomy may theoretically increase PTS. The treatment of the meniscal tears (repair or replacement) seems to be recommended not only to reduce the incidence of osteoarthritis, but also to protect the ACL graft.

ANTERIOR TIBIAL TRANSLATION AND ROTATORY LAXITY

The anterior knee laxity is an important factor in predicting ACL status both in ACL-ruptured and ACL-intact patients [4]. Several devices are available to quantify the knee laxity in pre-operative and post-operative ACL reconstruction assessment. However, a lot of them are examiner dependent and a potential overestimation of the laxity can occur. Therefore, a careful interpretation of their results is required. The most popular tools to measure the knee laxity are: KT-1000™ and KT- 2000™ Knee Ligament Arthrometer (KT-1000™, KT-2000™; MEDmetric Corp, San Diego, California), the Rolimeter™ (Aircast Europa, Neubeuern, Germany), and the stress radiography Telos™ device (Telos GmbH, Laubscher, Holstein, Switzerland). Uhorchak *& al.* [10], in a prospective study, observe that the relative risk for sustaining an ACL rupture is increased by 2,7 times in female subjects who have increased knee laxity measured by KT-2000™ [4]. In a prospective study comparing Telos™ to Rolimeter™ in patients with ACL lesion, Panisset *& al.* [11] observe that the association of the side to side difference (SSD) >5mm with Telos™ and positive pivot-shift test has a sensitivity of 88% and a specificity of 94,6% (P<0.01) for complete ACL rupture. Instead the combination of SSD >5 mm with Rolimeter™ and positive pivot-shift test has a sensitivity of 72,7% and a specificity of 92,4% (P<0.01) in case of complete ACL tears [11] (fig. 3).

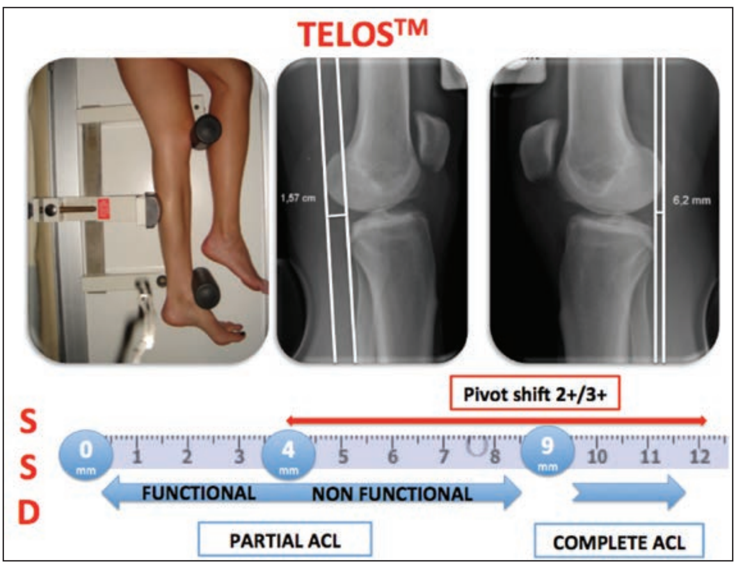


Fig. 3: ***Correlation between SSD with TelosTM, pivot-shift test and arthroscopic ACL injury pattern:***
< 4 mm: partial tear - functional remnant - pivot shift test 0/1+
4-9 mm: partial tear - non functional remnant - pivot shift test 2+/3+
> 9 mm: complete tear - pivot shift test 2+/3+

ACL rupture leads to antero-posterior and rotatory instability. The last one, described by patients as “knee giving away”, is clinically demonstrated by the pivot-shift (PS) test. However, it is difficult to find a gold standard method for its quantification. The devices used to quantify this test are usually complex and bulky. Recently, the accelerometer KIRA™ shows promising and reliable results. The limit of this system is that a learning curve to perform properly the PS is required. The objective evaluation of PS allows the surgeon to confirm the clinical diagnosis in case of ACL rupture and to verify the ACL status after the reconstruction [12].

GENDER AND HYPER-LAXITY

ACL injury occurs with a 4- to 6-fold greater incidence in female athletes compared to male athletes playing the same landing and cutting sports. The mechanism responsible for the gender disparity in ACL injury risk is multifactorial and it is related both to extrinsic (neuromuscular and sport activities) and intrinsic factors (anatomical and hormonal differences between genders) [13].

During the menstrual cycle phase, several authors observe that estrogen reduces the rate of fibroblast proliferation and type I procollagen synthesis, while progesterone has an opposite effect [14]. ACL biomechanical properties may be influenced by fluctuations in estrogen and progesterone concentrations, increasing the risk of ACL rupture during the pre-ovulatory phase [4].

In literature, the Beighton score is frequently used to quantify the whole body joint laxity. In a military cadet prospective cohort study, it is reported that an increased generalized joint laxity is a significant predictor of ACL ruptures in both males and females. More specifically, cadets with a Beighton score >5 are 2,8 times more likely to sustain an ACL rupture [10]. Moreover, increased knee hyperextension (genu recurvatum) of 10° and hamstring flexibility are significantly associated with risk of ACL lesion [4].

GENETIC RISK FACTORS

Familial predisposition and specific genetic variants are described as other possible risk factors for ACL lesion. Retrospective studies report a familial predisposition to ACL tears. Patients with bilateral ACL ruptures show a highly significant incidence of ACL injury in the family members compared to control healthy subjects (35% versus 4% respectively). Moreover, patients with an ACL lesion are more likely to have a relative with an ACL rupture compared with individuals without any history of ACL tear. The risk is slightly increased when only first-degree relatives are considered. The familial predisposition of ACL injury may probably due to the role of specific genetic variants within genes (COL1A1, COL5A1, and COL12A1) encoding for the extracellular matrix and predisposing to ACL fragility [4].

TREATMENT

During ACL reconstruction, the surgeon has to consider all the modifiable intrinsic risk factors such as narrow notch, increased PTS, postero-medial meniscal lesion and a significant rotatory instability. Several authors suggest that the notchplasty is a possible solution for graft impingement and it is particularly advised in case of revision surgery. The menisci have to be preserved during the surgery not only to prevent the chondral degeneration but also to improve the anterior and rotational stability. We suppose that the posterior horn of the medial meniscus acts like a “wedge” reducing the anterior tibial translation.

The anterolateral plasty should be used as an associated procedure both in primary and revision ACL surgery for patients that demonstrate an excessive anterolateral rotatory laxity (fig. 4). In a recent systematic review,

Song *& al.* [15] conclude that the combination of anterolateral plasty and ACL reconstruction is effective in eliminating the PS phenomenon. We propose that the association of SSD >9 mm (Telos™) with PS test 2+ or 3+ may require an additional anterolateral plasty (modified Lemaire). In a biomechanical study, Kittl *& al.* [16] demonstrate the surgical rationale of this technique showing that a graft fixed proximally to the lateral femoral epicondyle and running under the lateral collateral ligament provides the desirable graft behavior, without excessive slackening or tightening of the plasty during knee motion.

Deflexion osteotomy has to be considered especially after the failure of two or more consecutive ACL procedures, when PTS is higher than 12° and in case of meniscal lesions or previous meniscectomy, which could exacerbate the effects of a high PTS [8] (fig. 5). Dejour *& al.* [8] report a mean PTS reduction from 13,2°±2,6° pre-operatively to 4,4°±2,4° post-operatively and a mean SSD decrease from 11,7±5,2mm pre-operatively to 4,3±2,5mm post-operatively. However, the authors conclude that the correction of excessive PTS should be considered also in the first revision ACL reconstruction as this can reduce the risks of failure.

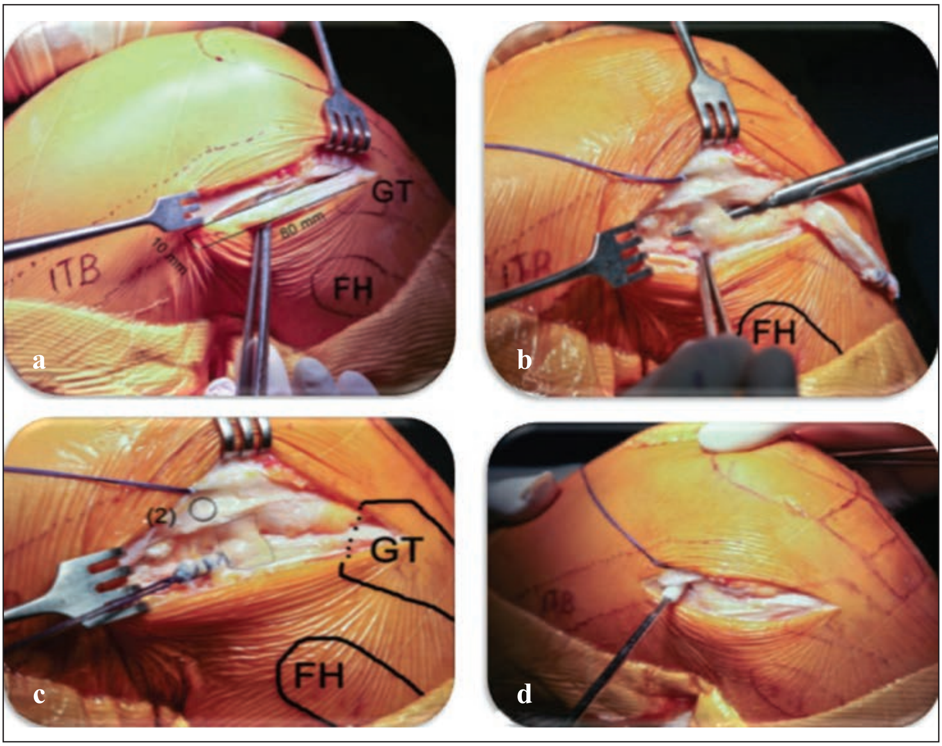


Fig. 4: ***In case of pivot shift 2+/3+ and SSD > 9 mm (Telos™), an anterolateral plasty (modified Lemaire) can be associated to the ACL reconstruction. (a) A strip of Ileotibial band (ITB) is harvested keeping intact its distal insertion. (b) The lateral collateral ligament (LCL) is identified and two mini-arthrotomies (posterior and anterior to LCL) are performed. (c) The strip of ITB is pulled under the LCL. (d) An half tunnel is drilled proximally to the lateral femoral epicondyle and the fixation is achieved with an interference bioabsorbable screw.***

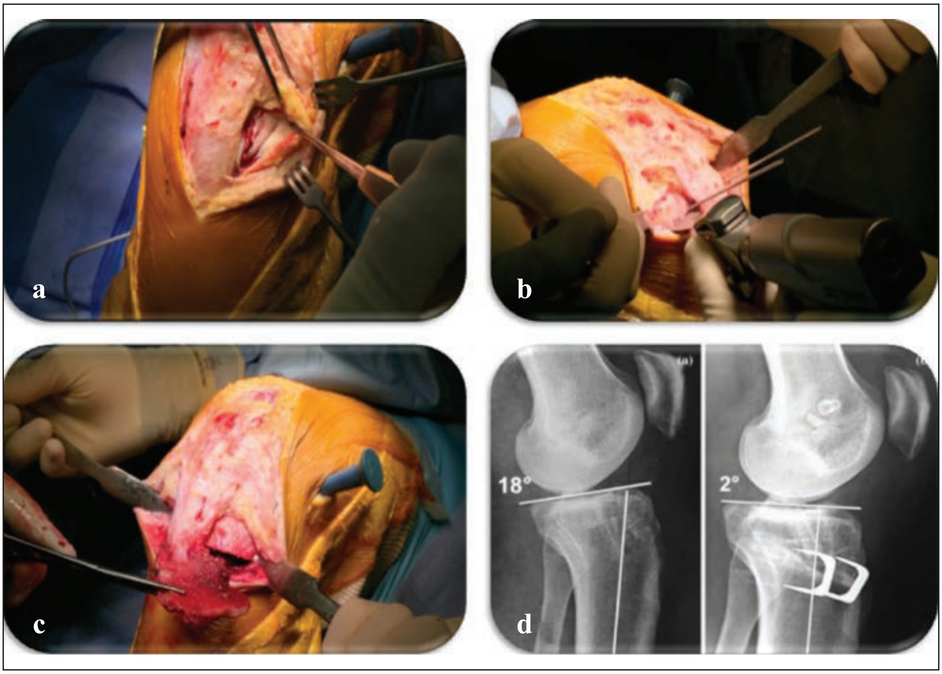


Fig. 5: ***Deflexion osteotomy is performed in order to correct the PTS, reducing the ATT effect leading to the ACL graft fatigue and injury. After ACL revision, (a) the proximal tibia is exposed and (b) the osteotomy is performed under fluoroscopic control. (c) The bone fragment is removed and the osteotomy is fixed with two staples. Tibial tunnel is manually re-drilled and ACL graft passage and fixation are achieved. (d) Pre-operative and post-ostoperative X-ray showing PTS correction.***

CONCLUSION

ACL rupture is one of the most catastrophic events affecting the quality of life of an active patient. The identification of the predisposing risk factors leading to ACL failure has to be performed both in primary and in revision surgery. It is mandatory to address all the modifiable risk factors to limit the re-rupture rate improving the clinical results and patient satisfaction.

LITERATURE

[1] WEBSTER KE, FELLER JA, LEIGH WB, RICHMOND AK. Younger Patients Are at Increased Risk for Graft Rupture and Contralateral Injury After Anterior Cruciate Ligament Reconstruction. *Am J Sports Med 2014; 42(3): 641-7.*

[2] KAMATH GV, REDFERN JC, GREIS PE, BURKS RT. Revision Anterior Cruciate Ligament Reconstruction. *Am J Sports Med 2011; 39(1): 199-217.*

[3] WETTERS N, WEBER AE, WUERZ TH, SCHUB DL, MANDELBAUM BR. Mechanism of Injury and Risk Factors for Anterior Cruciate Ligament Injury. *Oper Tech Sports Med 2016; 24(1): 2-6.*

[4] POSTHUMUS M, COLLINS M, SEPTEMBER A V., SCHWELLNUS MP. The Intrinsic Risk Factors for ACL Ruptures: An Evidence-Based Review. *Phys Sportsmed 2011; 39: 62-73.*

[5] ZENG C, GAO S, WEI J, *& al.* The influence of the intercondylar notch dimensions on injury of the anterior cruciate ligament: a meta-analysis. *Knee Surgery, Sport Traumatol Arthrosc 2013; 21(4): 804-15.*

[6] SONNERY-COTTET B, ARCHBOLD P, CUCURULO T. The influence of the tibial slope and the size of the intercondylar notch on rupture of the anterior cruciate ligament. *J Bone Jt. 2011; 93(11): 1475-8.*

[7] DEJOUR H, BONNIN M. Tibial translation after anterior cruciate ligament rupture. Two radiological tests compared. *J Bone Joint Surg Br 1994; 76(5): 745-9.*

[8] DEJOUR D, SAFFARINI M, DEMEY G, BAVEREL L. Tibial slope correction combined with second revision ACL produces good knee stability and prevents graft rupture. *Knee Surgery, Sport Traumatol Arthrosc 2015; 23(10)2846-52.*

[9] LUSTIG S, SCHOLES CJ, LEO SPM, COOLICAN M, PARKER DA. Influence of soft tissues on the proximal bony tibial slope measured with two-dimensional MRI. *Knee Surgery, Sport Traumatol Arthrosc 2013; 21(2): 372-9.*

[10] UHORCHAK JM, SCOVILLE CR, WILLIAMS GN, ARCIERO RA, ST-PIERRE P, TAYLOR DC. Risk factors associated with noncontact injury of the anterior cruciate ligament: a prospective four-year evaluation of 859 West Point cadets. *Am J Sports Med. 2003; 31(6): 831-42.*

[11] PANISSET JC, NTAGIOPOULOS PG, SAGGIN PR, DEJOUR D. A comparison of Telos™ stress radiography versus Rolimeter™ in the diagnosis of different patterns of anterior cruciate ligament tears. *Orthop Traumatol Surg Res 2012; 98(7): 751-8.*

[12] BERRUTO M, UBOLDI F, GALA L, MARELLI B, ALBISETTI W. Is triaxial accelerometer reliable in the evaluation and grading of knee pivot-shift phenomenon? *Knee Surgery, Sport Traumatol Arthrosc 2013; 21(4): 981-5.*

[13] HEWETT TE, MYER GD, FORD KR. Anterior Cruciate Ligament Injuries in Female Athletes: Part 1, Mechanisms and Risk Factors. *Am J Sports Med 2006; 34(2): 299-311.*

[14] YU WD, PANOSSIAN V, HATCH JD, LIU SH, FINERMAN GA. Combined effects of estrogen and progesterone on the anterior cruciate ligament. *Clin Orthop Relat Res 2001;(383): 268-81.*

[15] SONG G-Y, HONG L, ZHANG H, ZHANG J, LI Y, FENG H. Clinical Outcomes of Combined Lateral Extra-articular Tenodesis and Intra-articular Anterior Cruciate Ligament Reconstruction in Addressing High-Grade Pivot-Shift Phenomenon. *Arthroscopy 2015; 32(5): 898-905.*

[16] KITTL C, HALEWOOD C, STEPHEN JM, *& al.* Length Change Patterns in the Lateral Extra-articular Structures of the Knee and Related Reconstructions. *Am J Sports Med. 2015; 43(2): 354-62.*

NOTCH PLASTY IN ACL RECONSTRUCTION

L. BUISSON, G. ESTOUR, A. PINAROLI

PURPOSE AND INTRODUCTION OF THE STUDY

Several ACL rupture occur without any exterior factor. This can happen through a mechanism of tiredness by a repeated twisting and tension on the ACL, or by conflict with the lateral femoral condyle when the knee twists. These are intrinsic factors.

Two of the most frequent cases are: a high tibial slope, exceeding 10° [10], which is describe as a mechanical factor of anterior translation and also an intercondylar notch stenosis which is responsible for stress on the ACL in tibial rotation [1].

The purpose of this study is to analyse the benefits of a notch plasty while the ACL is being repaired by arthroscopy in order to prevent ACL rupture recurrence in the narrow intercondylar notch.

AUTHORS ANALYSIS

Some authors have witnessed a significant difference in the intercondylar notch size index compared to the ACL rupture. They have found a correlation in the prevalence of non contact ACL rupture with a narrow intercondylar notch which creates an impingement between ACL and the lateral condyle of the femur.

The non contact ACL injury supposes that there is a stenosis of inter-condylar notch. The case of an ACL rupture is different between a slow traumatic injured knee in external rotation and an highly impacted injury of the knee. Those slow traumatic injured ACLs are not associated with a medial collateral ligament injuried.

We have used the Souryal index in this study [1]. Usually a 22% index is considered as a limit between the normal width notch and the narrow width notch. This index is usefull even in CT Scan (Anderson) or in MRI (Herzog) and the size or sexe of the patient is not taken into consideration. An index over 26% is considered as large.

The purpose of the narrow width notch is to consider that it is a intrinsic factor of ACL rupture in slow mecanism. But this analysis is not accepted by all the authors [2-4-5-8].

This index based on a 902 ACl study group showed a significant difference between ACL injury and a narrow inter-condylar index. But others studies have shown a non significant correlation of narrow notch in the bilateral cases.

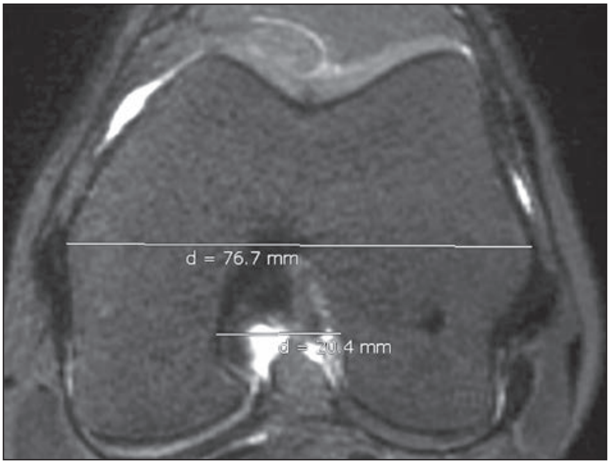


Fig. 1: ***Inter-condylar Notch index.***

THE MEDIPOLE CLINIC STUDY

Our study is based upon 200 cases of repaired ACLs (group A) with eleven re-repaired cases receiving a follow up over 2 years with an MRI ; and a control group (group B) of 200 cases with intact ACL analysed with an MRI. The arthroscopic shape and the width index of the indercondylar notch was analysed in these two groups.

- ***Group A*** contains 43 females for 157 males with 56% of right knees and a average age of 36 years old (15 to 56).

- ***Group B*** contains 92 females for 108 males with 52% of right knees and a average age of 31 years old (20 to 40).

In group A, the ACL tear mainly came from a Valgus flexion external rotation of the knee (80% of cases) and from sports like handball (7%), football (30%), basketball (4%), rugby (3%), skiing (40%) and snow board (1%) and other axis sport.

We found 5 types of inter-condylar notch: large, normal, larger lateral condyle, narrow and very narrow inter-condylar notch (ICN) with triangular aspect.

We found 37 cases of narrow and very narrow ICN (18,5%) with 30/157 (19%) males and 7/43 females (16%). The bilateral cases do not have specifically narrow ICN (only 15%).

But we found in these cases that most often, they had an external flexion traumatic injury.

No difference can be found in the comparison of both groups' narrow ICN and normal ICN in the bilateral cases. Those groups have the same percentage of cases : 14% *versus* 11%.

This result does not confirm the Shelbourne analysis [10] which finds a signifiant différence in the 714 ICN measured cases analysis in which 6% of bilateral cases where the ICN is narrow for only 1% of cases if the ICN is normal. However, this analysis considers large ICN over 16 mm which does not have the same point of view as in other studies showing 22 mm for normal ICN and more than 26 mm for large ICN. That means that the index has a more objective criteria than the real value in millimeters.

In our study we have noted that the possibility of an ACL tear in full extension (22 cases: 11%) does not concern the narrow notch with triangular aspect but most frequently a normal ICN. The tear depends on the extent of the

traumatic injury and not the shape of the top of the inter-condylar notch.

What we consider important is the percentage of narrow notch in the second ACL reconstruction: 54% higher than in the first cases: 16%.

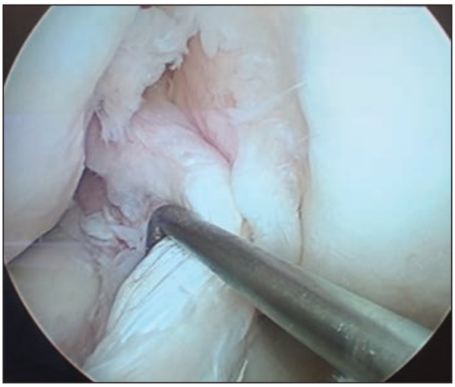


Fig. 2: ***Release ACL in narrow intercondylar notch.***

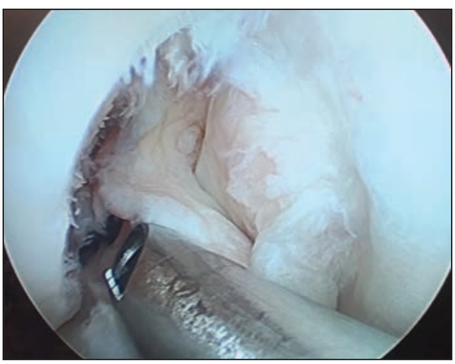


Fig. 3: ***View after plasty.***

CONCLUSION

The results presented in this study have found 18,5% of narrow inter-condylar notches in ACL reconstruction on a group of 200 cases.

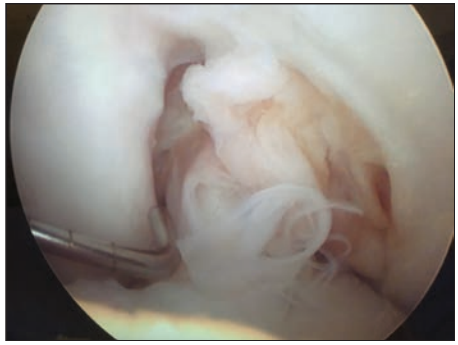


Fig. 4: ***Intercondylar notch shows a small lateral osteophytis after one year ACL surgery (DT4) for a meniscectomy arthroscopy.***

We didn't find any difference in the cases of ICN concerning bilateral cases, but we did find a significant increase in cases of narrow ICN for the second ACL reparation for whom a notch plasty had been made.

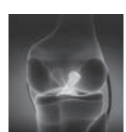
Furthermore, we also didn't find any difference in the ICN index between the two groups A (0,247) and B (0,245). Our population finds itself in the middle of statistical values but with little difference in the two groups.

So we have to consider, as the Doctor Beaufil wrote in his paper, that Notch plasty must only restore the anatomy if the notch is narrow, but the plasty should not be made to correct an anterior position of the ACL graft which is too significant.

We think that notch plasty could create an osseous conflict with possible threatening complications to the graft and it has to remain reserved for particular indications.

With these indications of narrow inter-condylar notch aside, the plasty should not be done.

When we have to do it, we should respect the primary anatomy.



LITERATURE

[1] SOURYAL TO, FREEMAN TR. Intercondylar notch size and anterior cruciate ligament injuries in athletes. *AJSM 1993; Vol 21: N° 4, 535-9.*

[2] SHELBOURNE KD, DAVIS TJ, KLOOTWYK TE. The relation ship between intercondylar notch width of the femur and the incidence of anterior cruciate ligament tears: a prospective study. *AJSM 1998; Vol 26: N° 3, 402-8.*

[3] CHARLTON WPH, ST-JOHN TA, CICCOTTI MG, HARRISSON N, SCHWEITZER M. Differences in femoral notch anatomy between men and women: a magnetic resonnance imaging study. *AJSM 2002; Vol 30: N° 1, 329-33.*

[4] SHELBOURNE KD, TIONKER-GRAY MA. Intercondylar notch width measurement differences between african american and white men and women with intact anterior cruciate ligament knees. *AJSM 2007; Vol 35: N° 8, 1304-7.*

[5] LOMBARDO S, SETHI PM, STARKEY C. Intercondylar notch stenosis is not a risk factor for anterior cruciate ligament tears in professional male basketball players: an 11 year prospective study. *AJSM 2005; Vol 33: N° 1, 29-34.*

[6] KOUVALCHOUK JF, HASSAN E, SADDIER P. Plastie de l'échancrure inter-condylienne. *J Traumatologie sport, 1995; vol 12; N° 3: P 162-6.*

[7] HERZOG RJ, SILLIMAN JF, HUTTON K, RODKEY WG, STEADMAN JR. Measurements of the intercondylar notch by plain film radiography and magnetic resonance imaging. *Am J Sports Med. 1994; 22: 204-10.*

[8] NAWAL A MOOSAWI, PARAG MAHAJAN, YUSRA S. AL NAHEDH. MRI evaluation of femoral intercondylar notch width index in cases with and without anterior cruciate ligament injuries. A retrospective study. *The Kuwait medical journal 2010; 42 (4): 286.*

[9] SHELBOURNE KD, DAVIS TJ, KLOOTWYK TE. The relation ship between intercondylar notch width of the femur and the incidence of anterior cruciate ligament tears: a prospective study. *AJSM 1998; Vol 26: N° 3, 402-8.*

[10] DEJOUR H, BONNIN M. Tibial translation after anterior cruciate ligament rupture. Two radiological test compared. *JBJS-Br- 1994; 76 (5): 745-9.*

IMPACT OF PATIENT FACTORS ON OUTCOMES OF ACL RECONSTRUCTION:
Data from the MOON Cohort

R.A. MAGNUSSEN

INTRODUCTION

Many factors influence outcomes following anterior cruciate ligament (ACL) reconstruction. While much time and effort has been spent evaluating the influence of modifiable surgical factors such as graft choice, tunnel locations, and surgical technique; patient factors continue to play a large role in determining outcomes following surgery. Important outcomes following ACL reconstruction include graft failure risk (or as report in many studies, revision risk) and patient-reported outcomes.

Age and activity level are well known at this point to influence failure risk following ACL reconstruction, with younger patients and those with higher activity levels (particularly cutting and pivoting sports) demonstrating higher failure risk [1]. Other intrinsic patient factors including posterior tibial slope, associated meniscus tears (particularly medially), and smoking may influence failure risk.

Many patient factors including articular cartilage and meniscus status, body mass index, tobacco use, and activity level may effect patients reported outcomes following ACL reconstruction [4].

The goal of this study is to identify and describe the influence of patient factors on outcomes of ACL reconstruction in the MOON cohort.

PATIENT FACTORS AFFECTING RISK OF GRAFT FAILURE

Patient Age

Age has long been noted to be among the strongest predictors of graft failure risk. Analysis of 2683 primary ACL reconstructions from the MOON cohort with 6 year follow-up demonstrated a 9% decrease in the odds of ACL graft failure for every 1 year increase in patient age at the time of ACL reconstruction [2].

Activity Level

While activity level and age are related in that activity level tends to decrease with increasing age, activity level (as defined with a Marc activity score) has also been shown in the MOON cohort to be an independent predictor of failure risk, controlling for age. The odds of graft failure were demonstrated in this same cohort to increase by 11% for every 1 point increase in the Marx activity score [2].

Increased Pre-Reconstruction Knee Laxity

Another recent MOON cohort study utilized a group of 2333 patients who underwent primary isolated ACL reconstruction without collateral or posterior cruciate ligament injury to assess the impact of high-grade pre-reconstruction knee laxity on risk of subsequent revision ACL reconstruction at 2 years follow-up [3]. Patients with a Lachman or anterior drawer examination greater than 10mm different from the contralateral side, or a 3+ pivot-shift were classified as having a high-grade laxity. High-grade pre-operative laxity was noted in 743 patients (31.9%). The presence of high-grade pre-reconstruction laxity was associated with significantly increased odds of ACL graft revision (OR=1.87, 95% CI: 1.19-2.95, p=0.007), controlling for patient age, sex, Marx activity level, level of competition, and graft type.

Other Potential Predictors

In the analysis of 2683 ACL reconstructions with 6-year follow-up, numerous other factors were evaluated as potential predictors of graft failure risk [2]. The risk of revision ACL reconstruction was not significantly associated with patient sex, smoking status, sport, or meniscus status.

PATIENT FACTORS AFFECTING PATIENT-REPORTED OUTCOMES

Knee injury and Osteoarthritis Outcome Score (KOOS) and International Knee Documentation Committee (IKDC) Scores

The MOON group reported 6 year outcomes on 378 (84%) of 448 unilateral ACL reconstructions [5]. The specifically reported factors that predicted IKDC score and two KOOS subscales: Knee-related quality of life and sport/recreation function. Pre-operative scores and prior ipsilateral ACL surgery (that is to say that patient was undergoing a revision ACL reconstruction) were noted to be strong predictors of all three scores at 6 year follow-up was the (All p<0.01). BMI at the time of surgery was a significant predictor of the IKDC and KOOS sports/rec at 6 years of follow-up, with increased BMI associated with decreased scores. Smoking at the time of reconstruction was predictive of poorer IKDC at 6 years follow-up. Increased ago was associated with slightly higher IKDC scores at 6 years follow-up. Patient ethnicity, sex, and marital status had no impact on patient-reported outcomes.

High-grade pre-reconstruction laxity as described above was not noted to be a predictor of patient-reported outcomes 2 years following ACL reconstruction [3].

The presence of a lateral meniscus tear that was treated with observation was also associated with better scores at 6 years follow-up on all three scales. No effect of medial meniscus status, articular cartilage status, or collateral ligament status at reconstruction was noted in any of the scores.

Marx Activity Score

In the previously reported publication of 6 year outcomes on 378 (84%) of 448 unilateral ACL reconstructions [5]. Marx activity score prior to injury was the strongest predictor of Marx activity level 6 years post-operative. Marx activity level was also lower at follow-up in females and those whose index surgery in the study was a revision ACL reconstruction. Patient ethnicity, age, and marital status had no impact on patient-reported outcomes. Patients who underwent a lateral meniscus repair were noted to have lower activity level 6 years post-operative, while medial meniscus, collateral ligament, and articular cartilage status did not significantly affect activity level 6 years post-operative.

CONCLUSIONS

Patient factors are important predictors of ACL graft tear risk and patient-reported outcomes 6 years following ACL reconstruction. The strongest patient factors related to graft failure risk and age and activity level. Smoking status and body mass index, along with meniscus status are strong predictors of patient-reported outcomes.

LITERATURE

[1] ANDERNORD D, DESAI N, BJORNSSON H, YLANDER M, KARLSSON J, SAMUELSSON K. Patient predictors of early revision surgery after anterior cruciate ligament reconstruction: a cohort study of 16,930 patients with 2-year follow-up. *Am J Sports Med Jan 2015; 43(1):121-7. PMID: 25325560.*

[2] KAEDING CC, PEDROZA AD, REINKE EK, HUSTON LJ, SPINDLER KP. Risk Factors and Predictors of Subsequent ACL Injury in Either Knee After ACL Reconstruction: Prospective Analysis of 2488 Primary ACL Reconstructions From the MOON Cohort. *Am J Sports Med Jul 2015; 43(7): 1583-90. PMID: 25899429.*

[3] MAGNUSSEN RA, REINKE EK, HUSTON LJ, MOON, HEWETT TE, SPINDLER KP. Effect of High-Grade Pre-operative Knee Laxity on Outcomes of ACL Reconstruction. *41st Annual Meeting of the American Orthopaedic Society for Sports Medicine. Orlando, FL; 2015.*

[4] MAGNUSSEN RA, SPINDLER KP. The effect of patient and injury factors on long-term outcome after anterior cruciate ligament reconstruction. *Current Orthop Practice 2011; 22(2): 211-8. PMID.*

[5] SPINDLER KP, HUSTON LJ, WRIGHT RW, *et al.* The prognosis and predictors of sports function and activity at minimum 6 years after anterior cruciate ligament reconstruction: a population cohort study. *Am J Sports Med Feb 2011; 39(2): 348-59. PMID: 21084660.*

THE EVOLUTION OF ACL RECONSTRUCTION OVER THE LAST 50 YEARS

P. CHAMBAT, C.A. GUIER, J.M. FAYARD, M. THAUNAT, B. SONNERY-COTTET

INTRODUCTION

By the mid 19th century [1], anatomists and surgeons showed interest in the pathology of the Anterior Cruciate Ligament (ACL) and provided clinical descriptions.

Appearing in the literature at the beginning of the 20th century [1], were proposals for ACL repair by suture or reconstruction.

It is only since the late 60's, that support for ACL injuries truly began. It seemed interesting to us to make a point regarding the evolution of its surgical concepts. It encompasses a vision Lyonnaise, of which this city's School of Knee Surgery is implicated, under the direction of Albert Trillat, in this pathology for several decades as evidenced by the organization of its *"Journées Lyonnaises du Genou",* held since 1970.

LATE 60's, EARLY 70's

During this period, making the diagnosis of ACL tear was not obvious. Clinically, the insufficiency was diagnosed by looking for the anterior drawer at 90° of flexion, the foot being positioned in internal rotation, external rotation and neutral positions.

The treatment therefore then logically proposed as its goal, a reduction of this drawer at 90° of flexion and aimed at restoring tension in the medial capsuloligamentous structures in accordance with the techniques described by O'Donoghue [2], Nicholas [3] and Hughston [4]. The surgical procedure was followed by a period of cast immobilization and an often laborious period of rehabilitation.

1970's

The real turning point corresponded to English language journal publications of clinical tests which afforded clinicians a means of making the diagnosis of ACL insufficiency.

The first was the "Pivot Shift" (Mac Intosh) described by Galway [5], then the "Lachman test" described by Torg [6], corresponding to the anterior translation of the tibia relative to the femur. The surgeons' acquisition of these tests allowed for the making of a diagnosis of ACL tear.

Previously in 1967, Lemaire [7] had described a dynamic test in internal rotation which had the same significance as the "Pivot Shift", as did Noulis [8] in 1875, when he described anterior translation in extension. Numerous

subsequent publications described dynamic tests executed in different ways that, in an index knee, were also effective in showing lateral condyle subluxation or reduction from a subluxed position on the lateral tibial plateau.

These tests were helpful to the clinician and patient to the extent that they afforded different ways to clinically reproduce a sensation similar to the one the patient felt when their knee gave way. It also aided in a better understanding of the role the ACL plays.

It became evident in cases of ACL deficiency, that subluxation occurred with the knee closer to extension than 90° of flexion. Any surgery being proposed therefore had, as its goal, a method for opposing the sliding of the lateral condyle at a position near extension.

In 1967, Lemaire [7, 9] described an anterolateral tenodesis using the fascia lata which limited the gliding. Such an operation had previously been proposed by Matti [10, 11, 12]. Other surgeons subsequently proposed similar techniques [13, 14, 15, 16, 17, 18].

It was Marcel Lemaire's technique of lateral tenodesis that we adopted in Lyon. At first¸ we combined it with a posteromedial imbrication followed by cast immobilization. This resulted in poor outcomes. It was then performed as an isolated procedure. If at first, this anterolateral reconstruction gave quite good results, we soon noticed a clinical deterioration in outcome. This evolution was later confirmed by Dodds [19] who, in 2011, wrote: the technique (extra articular reconstruction) has not gained favor due to the residual instability and the subsequent development of degenerative changes.

With peripheral reconstructions not affording long term stability to the knee, it became evident that attention needed to be directed to reconstructing the ACL. Albert Trillat began this journey based on the technique described by Jones [20], using the patellar tendon (PT) with some modifications (drilling a tibial and femoral tunnel from outside to inside), with the technique subsequently modified by using the medial third of the patellar tendon as described by Erikson [21], in a manner of where it was left attached distally. This technique was similar to that described by Brüchner [22], known only by German surgeons, who in 1966 also proposed to use the medial third of the patellar tendon. In our practice these techniques were all cast immobilized post operatively. Rehabilitation was difficult, with postoperative stiffness due to immobilization and incorrect positioning of the graft.

During this same period, perhaps because of the difficulties encountered using the PT, surgeons offered other techniques using fascia lata (FL) or the extensor mechanism. The former was described in operations by Insall [23] and MacIntosh (MacIntosh II) [24]. Insall's operation consisted of harvesting a band of FL and freed at its distal attachment with a bone block. This was passed "over the top" and secured with a screw to the anterior tibial plateau. The MacIntosh II operation freed a strip of FL proximally and passed it "over the top" to then assume the path of the ACL and insert into a tibial tunnel. The first description using the extensor mechanism was also attributable to MacIntosh (MacIntosh III) [24] who harvested a continuous strip of PT, pre patellar fascia throughout its pre patellar surface and a tubularized strip of quadriceps tendon. The proximal portion was passed through a tibial tunnel, "over the top" and then fixed to the femur. Marshall then suggested adding a synthetic ligament to the pre patellar portion (weak point of the previous operation) to strengthen it.

This technique, known most commonly as the "Marshall MacIntosh", was most popular in the late 70's, some surgeons enhancing the technique by tenodesing the proximal end of the quadriceps tendon to reinforce the antero lateral corner.

YEARS 1980-2000

A free patellar tendon graft

Regarding the use of patellar tendon, its use seemed again possible after hearing Franke's

presentation in Lyon for the first meeting of the International Society of Knee in 1978, which revisited his 1976 publication [25]. The novelty consisted of harvesting the middle third of the patellar tendon and uses it as a free graft, hence affording a perfect anatomical position. This option had previously been proposed by Brückner [22] in 1966 to reconstruct the ACL when the ipsilateral patellar tendon was injured. Brückner then recommended the use of the contralateral tendon.

This operation became increasingly popular, the patellar tendon becoming the "gold standard" for ACL grafts. Some authors proposed maintaining some continuity between the patellar tendon and Hoffa's ligament in order to improve its vascularization. Others proposed associating this intra-articular plasty with a lateral tenodesis [26, 27] to protect the graft during the process of "ligamentization", with an effort to better control internal rotation stresses to the neo-ligament. During this period, the femoral tunnel was drilled from outside to inside. Fixation of the graft was initially done with wires and extra-articular screws and subsequently greatly improved by the use of interference screws. The original idea goes to Lambert [28] who proposed AO screws, Kurosaka [29] then developing a more specific screw design.

As these techniques improved and gained in reliability, the indication for antero lateral tenodesis became progressively less necessary. They increased the surgical burden to the knee and rendered rehabilitation more difficult without a proven functional benefit. The indication for lateral tenodesis persists for some surgeons in cases of significant laxity or a proven antero lateral ligament injury.

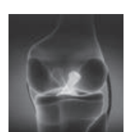
The introduction of the arthroscope in the late 70's for meniscal lesions began playing a role in ACL surgery in the 80's. Dandy [30] was the first to use it to reconstruct the ACL using a synthetic ligament. Since the mid 1980's we used the arthroscope to assist, at first only to drill the tibial tunnel under anterior portal visualization, the femoral tunnel being drilled through a postero lateral arthrotomy using a "rear entry guide". With the development of specific femoral guides, we were then able to create the femoral tunnel from outside to inside [31] under arthroscopic control. The goal was to reproduce the anterior portion of the ACL, namely the antero medial bundle. Its femoral insertional position is located on the axial wall of the lateral femoral condyle behind the "pseudo" femoral isometric point of the ACL. This gives the neo-ligament a "favorable non isometry" (relaxed in flexion, taught in extension), and addressed the parameters in which the ACL deficient knee seemed to cause the greatest sense of instability.

The problems posed by the passage of PT bone blocks into the femoral tunnel drilled from "outside-in" brought some medical companies to propose new guides that facilitated drilling the femoral tunnel "inside-out". This option facilitated the passage of the transplant. This also introduced new concepts and understandings of the insertional anatomy of the ACL as it relates to arthroscopy. The "inside-out" techniques remain in use today but, in our opinion, do not offer an ideal anatomic position with a real bone (and not a mixed fibrous and bone) tunnel.

Hamstrings grafts

The use of the PT graft posed problems not only encountered during passage of the bone block portions of the graft. In addition, risks of patellar fracture and secondary problems of patellar tendinitis, residual flexion contracture and anterior knee pain were discovered.

The use of the hamstring was thought to be a solution to all these problems. Before becoming a now widely used technique, many surgeons had previously used this graft. The first descriptions are attributable to [32, 33, 34], all using the semitendinosus or gracilis tendon, freed proximally to reconstruct the ACL. J.C. Puddu [35] used the same technique with the semitendinosus but the tibial tunnel had an extra articular orifice positioned quite medially, in a manner to preserve the internal rotational action of the semitendinosus.



The first publication describing a technique using both the semitendinosus and gracilis was that of Libscomb B. [36] in 1982. The principle, with a number of variations relating to the graft being free or attached at its distal end, be it single (2 strands) or double (4 strands) bundled, along with a multitude of proposed graft fixation techniques [37], wound be adopted by all surgeons utilizing this graft. Subsequently techniques developed using the semitendinosus in triplicate. Marcacci [38] meanwhile proposed using one of the strands of the graft to perform an antero lateral tenodesis.

The two choices, patellar tendon or hamstring graft, are popular today with no real modifications except for different fixation techniques for the hamstrings. Meta-analysis [39, 40, 41, 42] comparing both graft choices showed better control of laxity using the patellar tendon yet no difference in functional outcome. There were less patellar, loss of extension and pain with kneeling problems in the hamstring grafts and in one study, more recurrent ruptures with hamstrings.

YEARS 2000-2010

Double Bundle

Even though the results of conventional reconstructions (PT or Hamstring) were satisfactory and reliable over time, a positive "Pivot Shift" test of varying grades and proportions up to 25% persisted during clinical examination [43]. This lack of rotational control possibly responsible for secondary meniscal or cartilaginous problems, led surgeons to reconsider the anatomy and biomechanics of the ACL. The importance of the postero lateral bundle, whose action is effective for control of recurvatum, of the anterior drawer between 0° and 20° and of internal rotation was until now, ignored. An awareness of the importance for an anatomical reconstruction of the ACL with two bundles became elementary. Many techniques had been proposed in the 70's, 80's and 90's, but all had the inconvenience of only having one tunnel in the tibia or the femur to mirror the anatomy. Munetta [44] in 1999 was the first to publish a preliminary series of patients operated on using these techniques, but it was Yasuda's article [45] in 2004 that allowed for a perfect definition of what anatomical zones needed to be chosen for an anatomical positioning. The realization of this double bundle theory and procedure raised certain technical problems. We remain committed to drilling the femoral tunnel from "outside-in" and have developed a specific guide for the postero lateral bundle [46].

A meta-analysis [47] published by R. Meredick and based on 4 randomized studies, noted an improvement in arthrometer differentials of 0.52 mm without a statistical difference in normal or subjectively normal (pivot glide) rotary subluxation. Yasuda's 2010 publication [48], reviewed 10 randomized trials comparing the single and double bundle reconstruction and showed a 7 fold significantly better result in anterior laxity for the double bundle technique. Statistically, it was 8 times better for dynamic tests that were positive (variability of 5 to 20%). One study noted a better IKDC objective outcome. Two authors reported a higher percentage of reruptures in the single bundle reconstructions.

This interesting technique has a long and difficult learning curve. It doubles the possibility of committing an error in positioning. Medium and long term complications, especially those regarding lytic lesions of bone, are not well arrested and a longer follow-up is necessary to judge its superiority over conventional techniques.

PARTIAL RECONSTRUCTIONS

Arthroscopic double bundle reconstruction has allowed us to progress on anatomy and also reflect on partial tears of the ACL. Called to mind on MRI and suspected on clinical examination, this diagnosis should be confirmed peri-operatively. The greater the time between the trauma and the surgery, the more the evaluation becomes difficult because of the evolution of healing of these ACL lesions

that leads to a retraction of the remnants. It is also very difficult to say that the supposed healthy bundle doesn't have a lesion, at a minimum, intra ligamentously or at its insertion. The percentage of these lesions confirmed in the operating room after a thorough arthroscopic examination varies according to the literature and represents 10-15% of the anatomical lesions of the ACL [49, 50, 51]. The techniques used to reconstruct the affected bundle is variable but we remain confident that the "outside-in" techniques can preserve as much of the supposed healthy bundle as possible.

The results of patients operated on according to this view are, in the literature, very satisfactory with a significant improvement in anterior translation of the tibia relative to the preoperative measurement and a differential laxity measured at 1 mm [52, 53]. One must note in these patients, a very small percentage of positive dynamic tests (5%) [52, 53] and a significant improvement in knee's proprioceptive qualities compared to a knee undergoing a conventional intervention.

Surgically speaking, the interest to preserve the intact bundle is beneficial for several reasons all described in the literature [54]:

- Improvement in the postoperative mechanical quality, with a mechanically solid bundle protecting the graft and its fixation and allowing a more aggressive rehabilitation.
- Preservation of the vascularity at the level of the synovial envelope required for healing of the graft [55].
- Preservation of existing mechanoreceptors in the intact bundle. This improves the proprioceptive qualities of the knee, therefore its ability to resume physical activity [56].

Technically it is an intervention requiring a lot of attention, with a delicate balance between too much resection which may damage the supposed healthy bundle and not enough which can lead to impingement at the notch.

RECONSTRUCTION WITH PRESERVATION OF LIGAMENT TISSUE

The benefits associated with conservation of an assumed intact bundle in partial ruptures, has led surgeons to consider the possibility of preserving as much as possible ligamentous tissue, even when ruptures are complete.

The possibility of such a surgical option can be first eluded to on MRI if there is a high avulsion, but it is the arthroscopic exploration that will decide that (high avulsion without retraction). This is possible only if the intervention is performed relatively acutely.

The femoral tunnel is drilled from outside-in with a prudent release of the posterior portion of the axial wall of the lateral femoral condyle. The drilling of the tibial tunnel is even more delicate [57]. The tibial guide is positioned for emergence of the guide pin in the center of the tibial insertion and the tunnel is drilled with drill bits of increasing diameter. The perforation must stop as soon as the intra-articular bone is crossed and the drill bits must remain strictly within the base of the ACL. This way, the entire residual tissue is preserved. A "shaver" is passed through the tibial tunnel and into the foot of the ACL and used to progressively skewer and emerge in the upper part of the residual ligament, permitting a piercing of the remnant ACL and creating a passage for the future transplant. The transplant (semi-tendinosus) harvest may remain attached distally. It can be passed intra-particularly in double or triple, from distal to proximal. At the completion of the procedure the transplant itself is not visible, covered in its entirety by the preserved ACL tissue [58].

During our experience in 2009, this technique represented 10% of operated patients. Our short-term review showed no significant differences compared with conventional techniques for range of motion, Lachman test, the "Pivot Shift" and the differential. We performed subsequent MRI studies which at

3 months showed that the transplant had low signal intensity and was clearly distinguishable from the remnant ACL which showed a hyper signal. At 6 months the signal intensity of the transplant increased, approaching that of the residual ACL, perhaps signifying an advanced maturation.

The interest in this technique is in some respects, similar to those of partial reconstruction, with a vascularization and proprioception advantage to which must be added:

- Conservation at the tibial attachment of the ACL with a flare shaped filling of the anterior part of the intercondylar notch in extension contributing to stability.

- A recovering of the neo-ligament by well-organized tissue which puts to rest any anarchic and exuberant healing that might lead to a Cyclops lesion.

This technique does not enhance the mechanical properties of the initial transplant and does not allow for an accelerated rehabilitation program. The weak point remains the upper part of the graft which is not covered by the remnant ACL.

AFTER 2010

After Steven Claes's publication in 2013, substantial media buzz has put in light a "new" anatomical structure, the anterolateral ligament of the knee (ALL) [59]. Since this date, orthopedic surgeons have demonstrated a renewed interest in the anterolateral structures of the knee. More than 85 articles have been published on this ALL since 2013. Despite this extensive research effort, there is no consensus on ALL; on contrary, the ALL is a highly controversial subject. For some authors; this anatomical structure does not exist or/and has no function in knee stability [60-63]. For others authors, its macroscopic existence has been demonstrated in all knees, as well as its histologic appearance being analogous to a ligamentous structure [64-67]. Moreover, the ALL appears to be involved in the rotational control of the knee [68, 69]. This controversy is mainly due to the difficulty to isolate the ALL using different dissection protocol and to identify this structure by imaging including MRI.

However, the ALL could be the anatomical missing link justifying the historical "lateral extra articular tenodesis (Lemaire procedure)" for rotatory instability in ACL deficient knee. Despite promising clinical results, the ALL reconstruction procedure is still in its early phase of development and it is too soon to know if this procedure will be largely diffused or not.

CONCLUSIONS

ACL surgery has evolved considerably over the past 50 years. At first, this involved an awareness of the inadequacy of extra articular procedures and the need to reconstruct the ACL. The use of PT is at first difficult and reconstruction using fascia lata or extensor mechanisms becomes popular. The use of a free PT graft disrupts the hierarchy and becomes the "gold standard". For reasons relating to frequent secondary pain problems, some surgeons gradually move towards the hamstrings. The transition to a double bundle technique is an evolution linked to a better understanding of ACL anatomy. All this evolution is based on the biomechanics of the ACL. Beginning in 2000, a biological and mechanical concept emerges. It is on track for being evaluated and under an interesting evolutionary path that will provide food for thought for young surgeons for many years to come. We must today also evaluate the addition of an anatomical antero lateral tenodesis.

LITERATURE

[1] SCHINDER OS. Surgery for anterior cruciate deficiency: a historical perspective. *Knee Surg Sports Traumatol Arthrosc.*

[2] O'DONOGHUE DH. Reconstruction for medial instability of the knee: techniques and results in sixty cases. *J Bone Jt Sur 1973; 55-A: 941-54.*

[3] NICHOLAS JA. The five one reconstruction for antero medial instability of the knee. *J Bone Jt Surg 1973; 55-A: 899-922.*

[4] HUGHSTON JC, EILERS AF. The role of the posterior oblique ligament in repaires of acute medial ligament tear of the knee. *J Bone Jt Surg 55-A: 923-40.*

[5] GALWAY RD, BEAUPRÉ A, MAC INTOSH DL. A clinical sign of symptomatic cruciate insufficiency. *J Bone Jt Surg 1972; 54-B: 763-4.*

[6] TORG JS, CONRAD W KALEN V. Clinical diagnosis of anterior cruciate ligament instability in athlete. *Am J Sports Med 1976; 4: 84-93.*

[7] LEMAIRE M. Ruptures anciennes du ligament croisé antérieur. Fréquence-clinique-traitement. *J Chir 1967; 93: 311-20.*

[8] NOULIS G. Entorse du genou. *Thèse N° 142, 1875; Fac Med Paris 1-53.*

[9] LEMAIRE M. Instabilité chronique du genou. Techniques et résultat des plasties ligamentaires en traumatologie sportive. *J Chir 1975; 110: 281-94.*

[10] MATTI H. Ersatz des gerissenen vorderen kreuzbandes durch. *Schr 1918; 17: 451-2.*

[11] BENNET GE. The use of fascia lata for the reinforcementof relaxed joints. *Arch Surg 1926; 13: 655-66.*

[12] BOSWORTH DM, BOSWORTH BM. Use of fascia latato stabilize the knee in case of ruptured crucial ligament. *J Bone Jt Surg 1936; 18: 178-9.*

[13] MACINTOSH DL, DARBY CA. Lateral substitution reconstruction. *J Bone Jt Surg 1076; 58 B: 142.*

[14] JÄGER M, WIRTH CJ. Kapselband läsion: Biomecanik, Diagnostik und therapies Thieme Stuttgart.

[15] LOSEE RE, JOHNSON TR, SOUTHWICK WO. Anterior subluxation of the lateral tibial plateau: a diagnostic test and operative repair. *J Bone Jt Surg 1978; 60-A: 1015-30.*

[16] ELLISON AE. Distal iliotibial transfer for antero lateral rotatory instability of the knee. *J Bone Jt Surg 1979; 61-A: 330-7.*

[17] MÜLLER W. In The Knee. *Springer Berlin 1983.*

[18] ANDREWS JR, SANDERS RA. A "mini reconstruction" technique in treating antero lateral rotatory instability. *Clin Orthop Relar Res 1983; 172: 93696.*

[19] DODDS AL, GUPTE CM, NEYRET P, WILLIAMS AM, AMIS AA. Extra articular techniques in anterior cruciate ligament reconstruction. *J Bone Jt Surg 2011; 93-B: 1440-8.*

[20] JOHNES KG. Reconstruction of the anterior cruciate ligament. *J Bone Jt Surg 1963; 45-A: 925-32.*

[21] ERIKSON E. Reconstruction of the anterior cruciate ligament. *Orthop Clin N Am 1976; 7: 167-79.*

[22] BÜCKNER H. Eine neue method der krezbandplastik. *Chirurg 1966; 37: 413-4.*

[23] INSALL J, JOSEPH D, AGLIETTI P, CAMPBELL R. Bone block illio tibial band transfer for anterior cruciate insufficiency. *J Bone Jt Surg 1981; 63-A: 560-9.*

[24] MAC CULLOCH P, LATTERMANN C, BOLAND AL, BACH BR. An illustrated history of anterior cruciate ligament surgery. *The Journal of Knee Surgery 2007; 20:95-104.*

[25] FRANKE K. Clinical experience in 130 cruciate ligament reconstruction. *Orthop Cli N Am 1976; 7: 191-3.*

[26] CLANCY WG, NELSON DA, REIDER B, NARECHANIA RG. Anterior cruciate ligament reconstruction using one third of the patellar ligament augmented by extra articular tendon transfers. *J Bone Jt Surg. 1982; 64-A: 252-9.*

[27] DEJOUR H, DEJOUR D, AÏT SI SELMI T. Laxité chronique du genou traité par une greffe de tendon rotulien libre et une plastie extra-articulaire anterolatérale. 10 ans de recul. 148 cas. *Rev Chir Orthop Réparatrice App Mot 1999; 85: 777-89.*

[28] LAMBERT KL Vascularized patellar tendon graft with rigid internal fixation for anterior cruciate ligament insufficiency. *Clin Orthop Relat Res 1983; 172: 85-9.*

[29] KUROSAKA M, YOSHIYA S, ANDRISH JT. A biomechanical comparison of different techniques of graft fixation in anterior cruciate ligament reconstruction. *Am J Sports Med 1987; 15: 225-9.*

[30] DANDY DJ, FLANAGAN JP, STEENMEYER V. Arthroscopy and the management of the ruptured anterior cruciate ligament. *Clin Orthop Relat Res 1982; 167: 43-9.*

[31] CHAMBAT P, VERDOT FX. Reconstruction du ligament croisé antérieur avec un tunnel fémoral de dehors en dedans. In: Franck A, Dorfmann H. *éd. Arthroscopie, 2e édition. Elsevier 2006; 139-42.*

[32] GALEAZZI R. La recostituzione dei ligamenti crociati del ginocchio. *Atti e Memorie della Societa lombarda di Chirurgica 1934; 13: 302-17.*

[33] MACEY HB. A new operative procedure for the repair of ruptured cruciate ligament of the knee joint. *Surg Gynecol Obstet 1939; 69: 108-9.*

[34] CHO KO. Reconstruction of the anterior cruciate ligament by semitendinosus tenodesis. *J Bone Jt Surg 1975; 57-A: 608-12.*

[35] PUDDU JC. Method for reconstruction of the anterior cruciate ligament using semitendinosus tendon. *Am J Sports Med 8: 402-4.*

[36] LIPSCOMB AB, JONHSTON RK, SYNDER RB, WARBURTON MJ, GILBERT PP. Evaluation of hamstring strength following use of semitendinosus and gracilis tendons to reconstruct the anterior cruciate ligament. *Am J Sports Med 1982; 10: 340-2.*

[37] MARTIN SD, MARTIN TL, BROWN CH. Anterior cruciate ligament fixation. *Orthop Clin N Am 2002; 33: 685-96.*

[38] MARCACCI M, ZAFFAGNINI S, IACONO F, NERI MP, LORETI I, PETITTO A. Arthoscopic intra and extra articular anterior cruciate ligament reconstruction with

gracilis and semi tendinosus tendons. *Knee Surg Sports Traumatol Arthrosc 1998; 6: 68-75.*

[39] YUNES M, RICHMOND JC, ENGELS EA, PINCZEWSKI LA. Patellar versus hamstring tendons in anterior cruciate ligament reconstruction: a meta-analysis. *Arthroscopy 2001; 17: 248-57.*

[40] FREEDMAN KB, D'AMATO MJ, NEDEFF DD, KAZ A, BACH BR. Arthroscopic anterior cruciate ligament reconstruction: a meta-analysis comparing patellar tendon and hamstring tendon autografts. *Am J Sports Med 2003; 31: 2-11.*

[41] GOLDBLATT JP, FITZSIMMONS SE, BALK E, RICHMOND JC Reconstruction of the anterior cruciate ligament: meta-analysis of patellar tendon versus hamstring tendon autograft. *Arthroscopy 2005; 21: 791-803.*

[42] BIAU DJ, KATSAHIAN S, KARTUS J, HARILAINEN A, FELLER JA, SAJOVIC M, EJERHED L,ZAFFAGNINI S, RÖPKE M, NIZARD R. Patellar tendon versus hamstring tendon autograft for reconstructing the anterior cruciate ligament: a meta-analysis based on individual patient data. *Am J Sports Med 2009; 37: 2470-7.*

[43] CHAMBAT P, VARGAS R, FAYARD JM, LEMAIRE B, SONNERY-COTTET B. Résultat des reconstructions du ligament croisé antérieur sous contrôle arthroscopique avec un recul supérieur à 15 ans. In: Chambat P, Neyret P., éd. Le genou et le sport du ligament à la prothèse. *Sauramps Médical; 2008; 147-52.*

[44] MUNETA T, SEKIYA I, YAGISHITA,K, PGUICHI T, YAMAMOTO H, SHINOMIYA K. Two bundles reconstruction of the anterior cruciate ligament using semitendinosis tendon with endo buttons: operative technique and preliminary results. *Arthroscopy 1999; 15: 618-24.*

[45] YASUDA K, KONDO E, ICHIYAMA H, KITAMURA N, TANABE Y, TOHYAMA H, MINAMI A. Anatomic reconstruction of the anteromedial and posterolateral bundles of the anterior cruciate ligament using hamstring tendon grafts. *Arthroscopy 2010; 26(9 Suppl 1): S21-S34.*

[46] SONNERY-COTTET B, CHAMBAT P. Anatomic double bundle: a new concept in anterior cruciate ligament reconstruction using quadriceps tendon. *Arthroscopy 2006; 22: 1949-52.*

[47] MEREDICK RB, VANCE KJ, APPLEBY D, LUBOWITZ JH. Outcome of single versus double bundle reconstruction of the anterior cruciate ligament reconstruction: A meta-analysis. *Am J Sports Med 2009; 38: 25-34.*

[48] YASUDA K, TANABE Y, KONDO E, KITUMARA N, TOHYAMA H. Anatomic double bundle anterior cruciate ligament reconstruction. *Arthroscopy 2010; 26(9 Suppl 1) : S21-S34.*

[49] OCHI M, ADACHI N, DEIE M, KANAYA A. Anterior cruciate ligament augmentation procedure with a 1 incision technique: antero medial bundle or postero lateral bundle reconstruction. *Arthroscopy 2006; 22: 463-8.*

[50] SIEBOLD R, FU F. Assessment and augmentation of symptomatic anteromedial or postero lateral bundle tears of the anterior cruciate ligament. *Arthroscopy 2008; 24: 1289-98.*

[51] LÖCHERBACH C, ZAYANI R, CHAMBAT P, SONNERY-COTTET B. Biologically enhanced ACL reconstruction. *Orthopedics & Traumatology: Surgery & research 2010; 96(7): 810-5.*

[52] OCHI M, ADACHI N, UCHIO Y, DEIE M, KUMAHASHI N, ISHIKAWA M, SERA S. A minimum 2 years follow-up after selective anteromedial or posterolateral anterior cruciate ligament reconstruction. *Arthroscopy 2009; 25(2): 117-22.*

[53] SONNERY-COTTET B, LAVOIE F, OGASSAWARA R *et al.* Selective anteromédial bundle reconstruction in partial ACL tears: a series of 36 patients with mean 24 months follow-up. *Knee Surg Sports Traumatol Arthrosc 2010; 18: 47-51.*

[54] BORBON CA, MOUZOPOULOS G, SIEBOLD R. Why perform an ACL augmentation? *Knee Surg Sports Traumatol Arthrosc 2012; 20(2) 2455-51.*

[55] ARNOCZKI SP, TAVIN GB, MARSHALL JL. Anterior cruciate replacement using patellar tendon. An evaluation of graft revascularization in the dog. *J Bone Joint Surg Am 1982; 64: 217-24.*

[56] OCHI M, ISAWA J, UCHIO Y, ADACHI N, SUMEN Y. The regeneration of sensory neurons in the reconstruction of the anterior cruciate ligament. *J Bone Joint Surg Br 1999; 81: 902-6.*

[57] LÖCHERBACH C, ZAYANI R, CHAMBAT P, SONNERY-COTTET B. Biologically enhanced ACL reconstruction. *Orthopedics & Traumatology: Surgery & research 2010; 96(7): 810-5.*

[58] SONNERY-COTTET B, FREYCHET B, MURPHY CG, PUPIM BH, THAUNAT M. Anterior Cruciate Ligament Reconstruction and Preservation: The Single-Anteromedial Bundle Biological Augmentation (SAMBBA) Technique. *Arthrosc Tech. 2014; 3(6): e689-93.*

[59] CLAES S, VEREECKE E, MAES M, VICTOR J, VERDONK P, BELLEMANS J. Anatomy of the anterolateral ligament of the knee. *J Anat 2013; 223(4): 321-8.*

[60] INGHAM SJ, DE CARVALHO RT, MARTINS CA, LERTWANICH P, ABDALLA RJ, SMOLINSKI P, LOVEJOY CO, FU FH. Anterolateral Ligament anatomy: a comparative anatomical study. *Knee Surg Traumatol Arthrosc 2015; (Epub ahead of print) PMID: 26713325.*

[61] MUSAHL V, RAHNEMAI-AZAR AA, VANECK CF, GUENTHER D, FU FH. Anterolateral ligament of the knee, fact or fiction? *Knee Surg Traumatol Arthrosc 2016; 24: 2-3.*

[62] SAIEGH YA, SUERO EM, GUENTHER D, HAWI N, DECKER S, KRETTEK C, CITAK M, OMAR M. Sectioning the anterolateral ligament did not increase tibiofemoral translation or rotation in an ACL-deficient cadaveric model. *Knee Surg Traumatol Arthrosc 2015; (Epub ahead of print) PMID: 26377096.*

[63] KITTL C, EL-DAOU H, ATHWAL KK, GUPTE CM, WEILER A, WILLIAMS A, AMIS AA. The Role of the Anterolateral Structures and the ACL in Controlling Laxity of the Intact and ACL-Deficient Knee. *Am J Sports Med. 2016; 44(2): 345-54. doi: 10.1177/0363546515614312. Epub 2015 Dec 10.*

[64] DAGGETT M, OCKULY AC, CULLEN M, BUSCH K, LUTZ C, IMBERT P, SONNERY-COTTET B. Femoral Origin of the Anterolateral Ligament: An Anatomic Analysis. *Arthroscopy. 2015; pii: S0749-8063(15)00833-6. doi: 10.1016/j.arthro.2015.10.006. [Epub ahead of print].*

[65] VINCENT JP, MAGNUSSEN RA, GESMEZ F, UQUEN A, JACOBI M, WEPPE F, AL SAATI MF, LUSTIQ S, DEMEY G, SERVIEN E, NEYRET P. The anterolateral

ligament of the human knee: an anatomic and histologic study. *Knee Surg Traumatol Arthrosc 2012; (1): 147-52.*

[66] HELITO CP, DEMANGE MK, BONADIO MB, TIRICO LE, GOBBI RG, PÉCORA JR, CAMANHO GL. Anatomy and histology of the Knee Anterolateral Ligament. *Orthop J Sports Med 2013; 1,7.*

[67] CATERINE S, LITCHFIELD R, JOHNSON M, CHRONIK B, GETGOOD A. A cadaveric study of the anterolateral ligament: re-introducing the lateral capsular ligament. *Knee Surg Traumatol Arthrosc 2015; 23: 3186-95.*

[68] RASMUSSEN MT, NITRI M, WILLIAMS BT, MOULTON SG, CRUZ RS, DORNAN GJ, GOLD-SMITH MT, LAPRADE RF. An *In Vitro* Robotic Assessment of the Anterolateral Ligament, Part 1: Secondary Role of the Anterolateral Ligament in the Setting of an Anterior Cruciate Ligament Injury. *Am J Sports Med 2016; 44(3): 585-92. doi: 10.1177/0363546515618387. Epub 2015 Dec 18.*

[69] SONNERY-COTTET B, LUTZ C, DAGGETT M, DALMAY F, FREYCHET B, NIGLIS L, IMBERT P. The Involvement of the Anterolateral Ligament in Rotational Control of the Knee. *Am J Sports Med 2016; pii: 0363546515625282. [Epub ahead of print].*

[70] SONNERY-COTTET B, THAUNAT M, FREYCHET B, PUPIM BH, MURPHY CG, CLAES S. Outcome of a Combined Anterior Cruciate Ligament and Anterolateral Ligament Reconstruction Technique With a Minimum 2-Year Follow-up. *Am J Sports Med 2015; 43(7): 1598-605.*

MANAGEMENT OF DAY CASE ANTERIOR CRUCIATE LIGAMENT RECONSTRUCTION

T. CUCURULO, E. SERVIEN
& la Société Francophone d'Arthroscopie

The current rate of day case anterior cruciate ligament reconstruction (ACLR) in France remains low. Reasons for inpatient procedure include pain control, prolonged recovery time, and surgeon's fear of compromise to safety and reduction in patient satisfaction [1, 2]. The feasability of outpatient surgery for ACL reconstruction is well known, and many US studies have shown favourable results for the last twenty years, including low rates of readmissions in the post-operative period and similar pain control and satisfaction rates between ambulatory and inpatient groups [3, 4]. Cost containment issues have had major impact on the increasing number of daycase procedures in orthopaedic departments over the world [6]. The SFA *(Société Francophone d'Arthroscopie)* led a symposium in 2015 to define the specific pathway for day case ACL reconstruction.

Between January 2014 and March 2015, ten different french orthopaedic departments included prospectively 1076 patients who underwent primary arthroscopic ACL reconstructions with all surgical arthroscopic techniques and autograft used in France (hamstring, short graft with semi tendinosous tendon, patellar tendon and fascia lata). Two groups were compared: an outpatient group (OG) including 680 patients who underwent ambulatory surgery and a hospitalization group (HG) including 396 patients who underwent inpatient procedure, with a post-operative stay ranging from 1 to 4 days. The two groups were comparable at inclusion in terms of gender, age, sport activity, IKDC score and Lysholm score. Three types of anaesthesia were realised in both groups: general anaesthesia (60%), spinal anaesthesia (33%) or four regional nerve blocks anaesthesia (7%, combined femoral, sciatic subgluteal, obturator and lateral femoral cutaneous nerve blocks). Four types of local anesthetic injections were also performed in both groups, except for patients who underwent procedure under only regional blocks anesthesia: single injection blocks, continuous femoral nerve blocks with catheter, intraarticular local anesthesia injection and hamstring donor-site block.

The main evaluation criterion was postoperative pain on D0 to D5 assessed on a Visual Analog Scale (VAS - 0 no pain to 10 maximum pain) between the outpatient group and the hospitalization group.

The secondary evaluation criteria were the influences of surgical technique, anaesthesia modality and type of analgesic procedures in the pitfalls of ambulatory surgery, the comparison of complications in both groups, and the patient satisfaction on the admission modality on D5.

All the self-evaluation criteria were entered by the patient using the websurvey.fr software which enabled us to have independent responses with an online link to the electronic version of the questionnaires.

RESULTS

Pain

The global analysis of pain score didn't show any significant difference between the out-patient group and the hospitalized group from the evening of the procedure to D5.

The follow-up of the evolution of the pain in the days after surgery showed there is an increase of pain scores between D0 an D1 in both groups only for patients who had no controlled pain just after the procedure. In fact, patients who had low pain in the evening after surgery remained pain free the following days.

Multifactorial analysis of the postoperative pain in both groups showed differences according to the age, the preoperative pain scale and the procedure time, but no difference was found between the outpatient group and the inpatient group. We noticed that there was no influence of surgical technique (type of autograft, treatment of chondral or meniscal lesions) on postoperative pain. The multi-factorial analysis of the postoperative pain in the outpatient group permitted to make up a kind of composite image of the typical painful outpatient (pain score >7) who is a young girl (age between 15 and 18), with a preoperative pain >3 and who underwent a surgery with tourniquet used more longer than 50 minutes.

There were no differences in the analysis of VAS regarding to the three modalities of anesthesia (general, spinal or four nerve blocks anesthesia).

The analysis of modalities of analgesia by local anaesthetic (single or continuous nerve block, intraarticular or donor site injection) demonstrated a decrease in pain score and postoperative opioids requirements for patients who underwent hamstring donorsite injection. There were no influence in control pain regarding intraarticular anesthetic injections. Our results didn't show a better control of pain with single or continuous femoral or saphene nerve blocks compared to periarticular local anesthetic infiltrations.

Moreover, systemic nonsteroidal anti-inflammatory drugs (NSAIDs) have proved in our study to be valuable in the management of postoperative pain between D0 and D5. The use of systemic glucocorticoids (i.v. dexa-methasone) during the procedure didn't improve VAS pain but decreased side effects such as nausea and vomiting.

Patient satisfaction

Patient satisfaction assessed on D5 was comparable in the two groups (93% satisfied patients in the hospitalized group, 94% satisfied in the outpatient group).

There were no differences in patient satisfaction regarding the type of graft.

Insufficent control of pain and lack of preoperative information were the most frequent causes of unsatisfaction in the out-patient group (4,8% unsatisfied outpatients).

Whereas 23% of the hospitalized patients declared they would choose a day case surgery for a future similar intervention, only 10% in the outpatient group would request conventional hospitalization.

Ambulatory failure

We considered as a failure of daycase ligamentoplasty an outpatient who had to stay at last one further day of hospitalisation. This study found 3,4% of day case failure (23 patients/680), with a great variability between private centers (2% failure) and Public Teaching Hospitals (12% failure). The major

cause of ambulatory failure (52%) was symptoms related to anesthesia (e.g. nausea and dizziness). Five patients (22%) were unable to be discharged due to excessive pain, and five patients (22%) because of bleeding or longer surgery. Finally, one patient (4%) had to stay in hospital because of administrative problem.

Multifactorial analysis of ambulatory failure showed differences according to sex, duration of tourniquet, NSAID delivery and side effects of opioids but no difference was found whatever the anesthaesia technique used. We noticed that there was no influence of surgical technique (type of autograft, treatment of chondral or meniscal lesions) on daycase failure, except the presence of drain. The multifactorial analysis of ambulatory failure permitted to draw up a kind of composite image of the outpatient who could be unable to be discharged: a woman (relative risk (RR)= 3.6) who underwent a surgery with tourniquet used longer than 50 minutes (RR= 3/ RR= 9,8 if tourniquet duration > 80 minutes), with an intraarticular drain (RR= 3,3), who didn't have NSAID delivered (RR= 4,2) and who took morphin at D0 (RR= 5,5) with opioid side effects (RR= 3,6).

Side effects and complications

In the global serie including OG and HG, 70% patients didn't have any side effects in D0 evening. The most important side effects were symptoms related to anesthesia or opioids side effects: dizziness and discomfort (12%), digestive disorders (9%), anxiety (3%) and other side effects (4%).

The rate of adverse effects in D0 evening decreases significantly with the use of local anaethetics (locoregional blocks or injection in hamstring donor-site), except with intra articular injections.

The administration of dexamethason and NSAID decreases the rate of side effects at D0, but both increase abdominal pain in the evening and in the night after the procedure.

No difference was found between the two groups (OG and HG) regarding early complications, except dizziness and anxiety which were more frequent in the OG.

There were no significant differences found between the rate of secondary surgery because of complications in both outpatient (1%) and hospitalized groups (0,5%).

Regarding complications of anesthesia, there were no differences between the OG and the HG.

We found specific complications secondary to spinal anesthesia: one sciatic pain, two post-lumbar puncture headaches, two urinary retentions.

Continuous femoral nerve blocks with catheters are responsible for more complications (1 infection on catheter, 12 painful patients because of problem of battery or obstructed catheter, 3 falls secondary to weakness of quadriceps).

CONCLUSION

This study is not a study of feasibility of outpatient surgery in ACL reconstruction, which was already done in the USA twenty years ago and more recently in a French prospective study [5].

If most of our outpatients were satisfied [8], the analysis of our failures showed the importance of a specialised patient pathway to avoid pitfalls in day case surgery [13].

The management of outpatients needs clear preoperative information and the postoperative period has to be anticipated with standard operating procedures (SOPs) [13].

If the surgeon and the anesthetist don't have to change their surgical [7] and anesthetic techniques [9, 10], they must work together especially to detect preoperative risk factors of day case failure [1, 2]. The management of pain is based on multimodal analgesia which concerns both the anaesthetist and the surgeon [11, 12]. However intraarticular anesthetic injections and continuous femoral nerve blocks with catheter are currently not recommanded in pain management.

With specific pathways involving the surgeon, the anesthesiologist, the nurse and the physiotherapist, the day case ACL reconstruction can be safely proposed in specific ambulatory services with a high level of satisfaction for the patient [8, 13].

LITERATURE

[1] ANDRÉS-CANO P, GODINO M, VIDES M, GUERADO E. Postoperative complications of anterior cruciate ligament reconstruction after ambulatory surgery. *Rev Esp Cir Ortop Traumatol 2015; 59(3): 157-64.*

[2] MATTILA K, TOIVONEN J, JANHUNEN L, ROSENBERG PH, HYNYNEN M. Postdischarge symptoms after ambulatory surgery: first-week incidence, intensity, and risk factors. *Anesth Analg 2005; 10: 1643-50.*

[3] KAO JT, GIANGARRA CE, SINGER G, MARTIN S. A comparison of outpatient and inpatient anterior cruciate ligament reconstruction surgery. *Arthroscopy 1995; 11: 151-6.*

[4] TIERNEY GS, WRIGHT RW, SMITH JP, FISCHER DA. Anterior cruciate ligament reconstruction as an outpatient procedure. *Am J Sports Med 1995; (6): 755-6.*

[5] LEFEVRE N, BOHU Y, DE PAMPHILIS O, KLOUCHE S, DEVAUX C, HERMAN S. Outpatient surgery feasibility in anterior cruciate ligament reconstruction: a prospective comparative assessment. *Orthop Traumatol Surg Res 2014; 100: 521-6.*

[6] HEATH P, OGG T, HALL C. The cost of day surgery. *Health Trends 1990; 22: 109-11.*

[7] BAVEREL L, DEMEY G, ODRI G.-A, LEROY P, SAFFARINI M, DEJOUR D. Do outcomes of outpatient ACL reconstruction vary with graft type? *Orthop Traumatol Surg Res. 2015; 101(7): 803-6.*

[8] KRYWULAK SA, MOHTADI NG, RUSSELL ML, SASYNIUK TM. Patient satisfaction with inpatient versus outpatient reconstruction of the anterior cruciate ligament: a randomized clinical trial. *Can J Surg 2005; 48: 201-6.*

[9] WULF H, LOWE J, GNUTZMANN KH, STEINFELDT T. Femoral nerve block with ropivacaine or bupivacaine in day case anterior crucial ligament reconstruction. *Acta anaesthesiologica Scandinavica 2010; 54: 414-20.*

[10] MALL NA, WRIGHT RW. Femoral nerve block use in anterior cruciate ligament reconstruction surgery. Arthroscopy: the journal of arthroscopic & related surgery: official publication of the Arthroscopy Association of North America and the *International Arthroscopy Association 2010; 26: 404-16.*

[11] VALKERING KP, VANBERGEN CJ, BUIJZE GA, NAGEL PH, TUINEBREIJER WE, BREEDERVELD RS. Pain experience and functional outcome of inpatient versus outpatient anterior cruciate ligament reconstruction, an equivalence randomized controlled trial with 12 months follow-up. *Knee 2015; 22: 111-6.*

[12] SECRIST ES, FREEDMAN KB, CICCOTTI MG, MAZUR DW, HAMMOUD S. Pain Management After Outpatient Anterior Cruciate Ligament Reconstruction: A Systematic Review of Randomized Controlled Trials. *The American journal of sports medicine 2015.*

[13] KHAN T, JACKSON WF, BEARD DJ, MARFIN A, AHMAD M, SPACIE R, JONES R, HOWES S, BARKER K, PRICE AJ. The use of standard operating procedures in day case anterior cruciate ligament reconstruction. *Knee 2012; 19(4): 464-8.*

KEY POINTS OF REHABILITATION OF THE ANTERIOR CRUCIATE LIGAMENT

O. RACHET, B. QUELARD

The different steps of the post-surgery rehabilitation of the anterior cruciate ligament each meet fixed recovery goals based on the post surgery period, on the type of transplant used, associated actions. It should be noted that for the last 5 years, ACL reconstructions with hamstring (DIDT) superseded ACL transplants on the patellar tendon, previously considered as the "gold standard".

Schematically there are 3 following steps:

- *D1-D45:* Rehabilitation mainly based on analytics exercises,
- *D45-D90:* Rehabilitation mainly based on functional exercises,
- *D90-D150:* Begin controlled physical activity,

Beyond D150 begin normal physical and sports activities.

It is important to note that:

- Recovering extension takes priority over recovering flexion;
- Working on dynamic weight bearing must always be prepared first with working on static weight bearing;
- Effectively removing the crutches implies a perfect quadriceps control of 0° of extension in full weight bearing, without flexum, pain or limping;
- CCF work (closed kinetic chain exercises) must remain the basis to strengthen the quadriceps muscle until 16 weeks after surgery. After that period, it can be associated with a more analytical CCO work (open kinetic chain exercises) allowing a better and more optimal recovery of the quadriceps (Mikkelsen, Shaw, Fitzgerald);
- Recovering hamstrings must be paid special attention for two reasons: as protectors of the reconstruction graft and because of their deficiency when the transplant is taken at their expense.

The first rehabilitation period (D1-D45) is the most important as it determines the functional future of the operated knee. During this period, 4 goals must be reached:

- Wakening the quadriceps,
- Recovering the complete passive extension,
- Restoring a normal walking pattern,
- Wakening the hamstrings, then strengthening them even in the last degrees of flexion.

Those four goals are the four key points of rehabilitation.

KEY POINT N° 1: WAKENING THE QUADRICEPS

Wakening the quadriceps, which inhibition is extremely frequent whatever the type of transplant, will allow to recover the active locking of the knee. This muscular awakening is based on learning.

- Rapid voluntary contractions, called "flash" of vastus medialis and vastus lateralis (1 contraction/sec for 10 seconds then rest for 10 seconds), knee extended, patient in sitting position to put the rectus femoris in impaired functions.

- Static contractions maintained with maximal and below pain intensity during the whole duration of the contraction (contraction lasting 10 sec then resting for 10 sec).

Contractions are done in the right way if the vastus medialis can be seen, the patella pulls up and the patellar tendon is stretched. Alleviating the heel on the floor (fig. 1a, 1b) shows the efficiency of the contractions.

Fig. 1a: ***Resting position.***

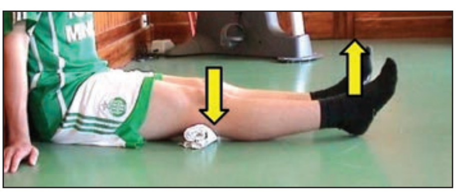


Fig. 1b: ***Contraction of the quadriceps: marking the poplieal fossa go down and at the same time the pression of the heel on the floor decrease.***

KEY POINT N° 2: RECOVERING THE COMPLETE PASSIVE EXTENSION

During the days following surgery, to live the knee in full extension is painful leading to a reflex defense of the hamstrings and an antalgic flexum can appear, and if he stay a long time, may be responsible for the foun'dation of a cyclope. Loosening the posterior muscular chain affects then the recovery of the 0° passive extension. This loosening is gotten by putting a rolled towel under the popliteal fossa (fig. 2a) which towel is slowly smaller and smaller. Combined with passive knee mobilizations towards extension, soft and below pain, with "flash" contractions of the vastus medialis and lateralis, this towel will allow lto slowly recover the full extension and is taken away as soon as possible (fig. 2b).

Fig. 2a

Fig. 2b

KEY POINT N° 3: RESTORING A NORMAL WALKING PATTERN

From the day of surgery, walking exercises should be performed with relieved and progressive weight bearing with the help 2 crutches in parallel position. The full weight-bearing in static is recovered step by step by

translating the body on operated leg. During the dynamic phase of the walking, the weight of the body is partial, with quadriceps contraction locking the knee in extension in phase of support, alternating with quadriceps slackness and flexion of the knee in swing phase.

Getting a normal walking pattern, without flexum, without limping, without pain, with an actively locked knee in full extension during propulsion in the support phase, is an absolute necessity to remove permanently the crutches.

KEY POINT N° 4: WAKENING THE HAMSTRINGS, THEN STRENGTHENING, THEM EVEN IN THE LAST DEGREES OF FLEXION

The inhibition of medial hamstrings is almost constant during grafts of ACL by semi-tendinosus and gracilis. It is clearly noticed on a patient laying in procubitus, knees bending between 100 to 120 degrees, asking him to resist to one traction toward extension, made by examiner (fig. 3).

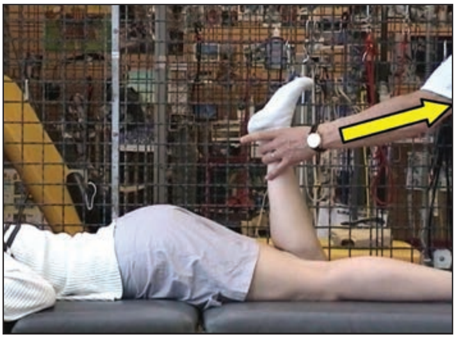


Fig. 3: ***Work of the hamstringts in eccentric.***

This position is also a position of exercises where the therapist can visualy control the presence of semi-tendinosus and gracilis muscles in maximal flexion of the knee (120°).

The awekening with Swiss-ball in decubitus dorsal position also allows to make them work, and later, to strengthen them, associating different types of contractions (static, concentric, eccentric) in the same range of motion (fig. 4a, 4b).

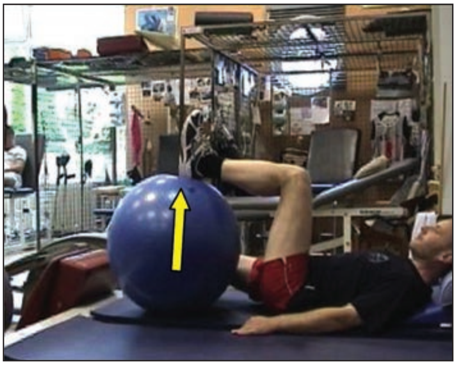


Fig. 4a: ***Relaxing slowly the pressure of the heel corresponds to an eccenteric work of hamstrings.***

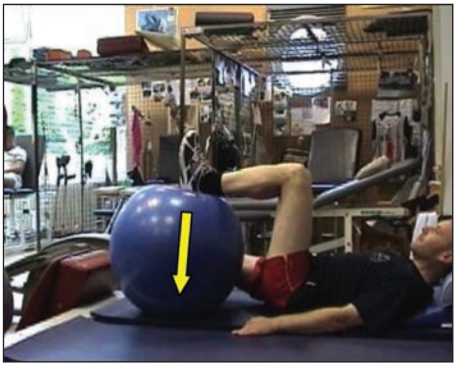


Fig. 4b: ***Pulling down the hell corresponds to a concentric contraction of the hamstrings.***

Strengthening the hamstrings, usually well-made in the first 100 degrees of flexion, is often negleted beyond this range of motion, knowing that weakness and a delay of pre-activation of this muscular group is a well-know recurrence factor.

IN CONCLUSION

Obtaining those four key points allows to ensure the future with serenity during the next steps of rehabilitation and avoid some secondary complications such as stiffness in extension, anterior pain, low patella, muscular weakness and some tendinopathies.

This learning will be of as much quicker when the patient gets the benefit of rehabilitation sessions during the pre-surgery, targeted on this 4 key points.

LITERATURE

ZEBIS MK, ANDERSEN LL, BRANDT M *et al.* Effects of evidence-based prevention training on neuromuscular and biomechanical risk factors for ACL injury. A randomised trial. *Br J Sports Med 2015; 0:1-7.*

QUELARD B, RACHET O, SONNERY COTTET B, CHAMBAT P. Rééducation postopératoire des greffes du ligament croisé antérieur. Encyclopédie médico-chirurgicale. *Elsevier Masson 2010; 26:240-C-10.*

RETURN TO SPORT AND PREVENTION: COMPLICATIONS - LITERATURE

A. PINAROLI, L. BUISSON, G. ESTOUR

Anterior Cruciate Ligament reconstruction is a safe surgical procedure and postoperative complications are very rare.

Infection and deep veinous thrombosis are well known and won't be detailed here.

Despite the fact that early outcomes after ACL reconstruction are very good and are not influenced by the type of graft [2], delayed complications can occur during a rehabilitation period and when returning to sporting activities.

Specific complications are related to the harvesting site, tunnels and fixation material.

Delayed general complications may concern anterior persistant knee pain, muscle weakness, knee stiffness, secondary cartilage damage and meniscal tears, and of course graft rupture.

SPECIFIC COMPLICATIONS ON HARVESTING SITE

A way to avoid donor site morbidity is to use an allograft. However the majority of surgeons use tendinous autograft from hamstrings or bone-tendon-bone graft from the patellar tendon, each harvesting technique having its own specific risks.

Harvesting btb graft can weaken the patella and lead to a fracture during early rehabilitation period [8]. Tibial tubercule fracture [1] and patellar tendon avulsion are very rare and authors described patello femoral instability due to iatrogenic sagittal patella fracture [22].

Patellar tendonitis is common and healing is the rule with an adapted rehabilitation program, chronical evolution with patellar tendon ossification is very exceptional [7] (fig. 1).

Fig. 1

Harvesting hamstring tendons seems to be less risky but tendon strain is very common during the first postoperative month and healing is the rule when respecting a rest period during rehabilitation. Chronical evolution with painful fibrosis and persistant weakness is very rare [25].

SPECIFIC COMPLICATIONS DUE TO TUNNELS AND MATERIALS

Most of them can be prevented peroperatively. Efficient lavage and fluid aspiration after reaming prevents heterotopic ossifications at the femoral tunnel exit with a bone-tendon-bone graft [4], controlling the correct femoral button deployement in the same location also prevents lateral knee pain [19]. Good positionning of femoral tunnels, use of progressive diameter reamers, especially in double bundle ACL reconstruction, can avoid the occurrence of femoral condyle fractures [13].

Lately, tibial tunnel enlargment caused by bioarbsorbable screw resorbtion can explain extra-articular cyst formation (fig. 2) and facilitate a proximal tibial fracture [21].

Fig. 2

PERSISTANT ANTERIOR KNEE PAIN

Tear of infrapatellar nerve when harvesting median third of patellar tendon is well known and can probably explain superior prevalence of anterior knee pain and discomfort while kneeling in btb graft than in the hamstring.

Though, a mini invasive double incision [3] and the use of PRGF in donor site [17] can reduce this risk.

MUSCLE WEAKNESS

The underlying neuro-physiologic mechanisms remain unclear, but asymmetry in quadriceps strength, activation, and cortical excitability persist in individuals with ACL reconstruction. It can help to understand long-term reduction in sporting activity and increase the rate of subsequent joint injury in otherwise healthy, active individuals after ACL reconstruction [14].

STIFFNESS AND ARTHROFIBROSIS

Influence of the notch for cyclop syndrome is also well known [11], as well as anterior positionning of the graft can also explain the occurrence of this complication.

Major stiffness is very rare and surgical treatment is difficult [20].

Well conducted rehabilitation is necessary to avoid stiffness and patient participation is mandatory. Day-to-day variations in negative mood and stress may contribute to adherence when prescribed home exercises [5].

CARTILAGE DAMAGE AND SECONDARY MENISCAL TEARS

Patello-femoral arthritis, especially with btb graft, can be prevented by adapted rehabilitation and can also reduce poor results 3 years after ACL reconstruction [9].

Early damaging chondrolysis has been described after postop intraarticular continuous pump catheter infusion of bupivacain and epinephrin [6].

Pseudogout is a very rare complication [24].

Secondary meniscal tears are clearly correlated to the amount of residual laxity after surgery.

GRAFT RUPTURE

Literature is controversial about the influence of grafts on rerupture rate. Some authors suggest that graft rupture is higher with hamstrings [16], others find no difference when comparing to btb graft [15], but they agree on the fact that there is a higher rate of rereuptures with allografts [15].

A higher rate of rerupture is also correlated with preop grade 3 pivot shift [18], this is influenced by hip rotation restriction (non contact rerupture) [10] and especially concerns young patients [16, 23].

Young patients and females are also higher at risk to have a controlateral ACL rupture [16, 23].

Patient adapted rehabilitation protocols are therefore important to prevent these complications and can also help to decrease fear of reinjury [12].

LITERATURE

[1] ACTON KJ, DOWD GS. Fracture of the tibial tubercle following anterior cruciate ligament reconstruction. *Knee 2002; 9(2): 157-9.*

[2] BAVEREL L, DEMEY G, ODRI GA, LEROY P, SAFFARINI M, DEJOUR D. Do outcomes of outpatient ACL reconstruction vary with graft type? *Orthop Traumatol Surg Res 2015; 101(7): 803-6.*

[3] BEAUFILS P, GAUDOT F, DRAIN O, BOISRENOULT P, PUJOL N. Mini-invasive technique for bone patellar tendon bone harvesting: its superiority in reducing anterior knee pain following ACL reconstruction. *Curr Rev Musculoskelet Med 2011; 4(2): 45-51.*

[4] BHANDARY B, SHETTY S, BANGERA VV, R Y, KASSIM MS, ALVA K, BHANDARY S. To study the incidence of heterotopic ossification after anterior cruciate ligament reconstruction. *J Clin Diagn Res 2013; 7(5): 888-91.*

[5] BREWER BW, CORNELIUS AE, VAN RAALTE JL, TENNEN H, ARMELI S. Predictors of adherence to home rehabilitation exercises following anterior cruciate ligament reconstruction. *Rehabil Psychol 2013; 58(1): 64-72.*

[6] BUCHKO JZ, GURNEY-DUNLOP T, SHIN JJ Knee chondrolysis by infusion of bupivacaine with epinephrine through an intra-articular pain pump catheter after arthroscopic ACL reconstruction. *Am J Sports Med 2015; 43(2): 337-44.*

[7] CAMILLIERI G, DI SANZO V, FERRETTI M, CALDERARO C, CALVISI V. Patellar tendon ossification after anterior cruciate ligament reconstruction using bone-patellar tendon-bone autograft. *BMC Musculoskelet Disord 2013; 14:164.*

[8] CHOUTEAU J, LAPTOIU D, LERAT JL, MOYEN B. Patellar fracture after anterior cruciate ligament reconstruction using a bone patellar tendon bone transplant: a comparative study of two harvesting techniques. *Rev Chir Orthop Reparatrice Appar Mot 2008; 94(6): 561-5.*

[9] CULVENOR AG, LAI CC, GABBE BJ, MAKDISSI M, COLLINS NJ, VICENZINO B, MORRIS HG, CROSSLEY KM. Patellofemoral osteoarthritis is prevalent and associated with worse symptoms and function after hamstring tendon autograft ACL reconstruction. *Br J Sports Med 2014; 48(6): 435-9.*

[10] E GOMES JL, PALMA HM, RUTHNER R. Influence of hip restriction on noncontact ACL rerupture. *Knee Surg Sports Traumatol Arthrosc 2014; 22(1): 188-91.*

[11] FUJII M, FURUMATSU T, MIYAZAWA S, OKADA Y, TANAKA T, OZAKI T, ABE N. Intercondylar notch size influences cyclops formation after anterior cruciate ligament reconstruction. *Knee Surg Sports Traumatol Arthrosc 2015; 23(4): 1092-9.*

[12] GIGNAC MA, CAO X, RAMANATHAN S, WHITE LM, HURTIG M, KUNZ M, MARKS PH Perceived personal importance of exercise and fears of re-injury: a longitudinal study of psychological factors related to activity after anterior cruciate ligament reconstruction. *BMC Sports Sci Med Rehabil 2015; 7:4.*

[13] HAN Y, SARDAR Z, McGRAIL S, STEFFEN T, MARTINEAU PA Peri-anterior cruciate ligament reconstruction femur fracture: a biomechanical analysis of the femoral tunnel as a stress riser. *Knee Surg Sports Traumatol Arthrosc Suppl 2011; 19 Suppl 1: S77-85.*

[14] KUENZE CM, HERTEL J, WELTMAN A, DIDUCH D, SALIBA SA, HART JM Persistent neuromuscular and corticomotor quadriceps asymmetry after anterior cruciate ligament reconstruction. *J Athl Train 2015; 50(3): 303-12.*

[15] MARS GROUP. Effect of graft choice on the outcome of revision anterior cruciate ligament reconstruction in the Multicenter ACL Revision Study (MARS) Cohort. *Am J Sports Med 2014; 42(10): 2301-10.*

[16] MOHTADI N, CHAN D, BARBER R, PAOLUCCI EO Reruptures, Reinjuries, and Revisions at a Minimum 2-Year Follow-up: A Randomized Clinical Trial Comparing 3 Graft Types for ACL Reconstruction. *Clin J Sport Med 2016; 26(2): 96-107.*

[17] SEIJAS R, CUSCO X, SALLENT A, SERRA I, ARES O, CUGAT R Pain in donor site after BTB-ACL reconstruction with PRGF: a randomized trial. *Arch Orthop Trauma Surg 2016; 26(2): 829-35.*

[18] SONG GY, ZHANG H, WANG QQ, ZHANG J, LI Y, FENG H Risk Factors Associated With Grade 3 Pivot Shift After Acute Anterior Cruciate Ligament Injuries. *Am J Sports Med 2016; 44(2): 362-9.*

[19] SONNERY-COTTET B, REZENDE FC, MARTINS NETO A, FAYARD JM, THAUNAT M, KADER DF Arthroscopically confirmed femoral button deployment. *Arthrosc Tech 2014; 3(3): e309-12.*

[20] TARDY N, THAUNAT M, SONNERY-COTTET B, MURPHY C, CHAMBAT P, FAYARD JM Extension deficit after ACL reconstruction: Is open posterior release a safe and efficient procedure? *Knee 2016.*

[21] THAUNAT M, NOURISSAT G, GAUDIN P, BEAUFILS P Tibial plateau fracture after anterior cruciate ligament reconstruction: Role of the interference screw resorption in the stress riser effect. *Knee 2006; 13(13):241-3.*

[22] VIDAL C, GUINGAND O, DE THOMASSON E, CONSO C, TERRACHER R, BALABAUD L, MAZEL C Painful patellofemoral instability secondary to peroperative patellar fracture during bone-patellar tendon-bone autograft harvesting for anterior cruciate ligament reconstruction. *Orthop Traumatol Surg Res 2012; 98(6): 733-5.*

[23] WEBSTER KE, FELLER JA, LEIGH WB, RICHMOND AK Younger patients are at increased risk for graft rupture and contralateral injury after anterior cruciate ligament reconstruction. *Am J Sports Med 2014; 42(3): 641-7.*

[24] ZAMAN M, SABIR N, MILLS SP, CHARALAMBOUS CP Pseudogout: A Rare Cause of Acute Arthritis Following Arthroscopic Anterior Cruciate Ligament Reconstruction. *Knee Surg Relat Res 2015; 27(3): 194-6.*

[25] JORVINEN TL, JORVINEN TA, PENTTILO T, HARILAINEN A, SANDELIN J, PAAKKALA T. Failed regrowth of the harvested semitendinosus tendon: a rare complication of tendon harvest after anterior cruciate ligament reconstruction. *Arthroscopy 2003; 19(4): E31.*

EXTENSION DEFICIT AFTER ACL RECONSTRUCTION: Is Open Posterior Release a Safe and Efficient Procedure?

N. TARDY, M. THAUNAT, B. SONNERY-COTTET, C.G. MURPHY, P. CHAMBAT, J.M. FAYARD

INTRODUCTION

Arthrofibrosis after anterior cruciate ligament reconstruction (ACLR) is a challenging complication. A recent epidemiological study by Werner *et al*. [1] reported an incidence of 0.49% of surgical lysis of adhesions after isolated ACLR by 6 months post-operatively and 0.91% when associated with a meniscal repair.

Flexion deficit is usually better tolerated than an extension deficit, even 5 degrees, which causes difficulties with walking and anterior knee pain [2].

Most post-operative extension deficits result from localized mechanical causes and can be treated by isolated anterior arthroscopic release [3]. In rare cases, a chronic flexion contracture with generalized arthrofibrosis requires an additional posterior release.

Even though open posterior release is the gold standard procedure for treating chronic extension deficit, only a few studies have reported the results of this procedure. Moreover, the four studies investigating posterior open release outcomes used a single posterior approach [4-8]. To our knowledge, no study analysing the results of both posteromedial and posterolateral approaches has been performed so far.

The purpose of this study was [1] to analyse the midterm outcome and complications of a combined procedure – anterior arthroscopic debridement and posterior open capsulotomy – for the treatment of chronic extension deficits after ACLR, and [2] to describe the surgical technique of posterior open release with both posteromedial and posterolateral approaches.

MATERIAL AND METHODS

Subjects

Between 2005 and 2012, 14 patients were secondarily referred to our institution for knee range of motion (ROM) deficit following ACLR. All patients had knee arthrolysis performed by two senior orthopaedic surgeons from our institution.

Inclusion criteria included the following: ***1)*** flexion contracture of 10° or more following ACLR; ***2)*** chronic flexion contracture persisting for 6 months or longer; ***3)*** failure of conservative treatment or isolated anterior arthroscopic release. A minimum 6 months' follow-up after arthrolysis was requested. Patients had no history of knee trauma or surgery of the contralateral knee. Patients who had undergone prosthetic knee surgery were excluded from the study.

Surgical technique

Our surgical management was based on a systematic operative strategy. The first surgical step was an anterior arthroscopic release.

The subquadricipital pouch and both the medial and lateral gutters were released using anteromedial and anterolateral portals, with two superomedial and superolateral portals if necessary. Next, the anterior interval was inspected and released if adhesions were present. The intercondylar notch was debrided of scar tissue. The knee was then mobilized in flexion.

The intercondylar notch was then analysed in extension to treat potential causes of an extension deficit, such as a localized arthrofibrosis [9, 10] ("Cyclops" lesion [11]), an impingement of the ACL graft with the roof of the notch in extension [12] called the "cyclopoïde" aspect [13] or a technical error such as protrusion of an interference screw. A notchplasty was systematically performed when an anterior impingement was present. If the impingement persisted after the notchplasty because of ACL graft malposition, we were sometimes obliged to debride the graft.

Knee motion was then assessed. If full extension could not be achieved, a posterior open procedure with a posterolateral and a posteromedial approach was used. With the knee flexed at 90° to take away the popliteal neurovascular bundle, a posterolateral 10cm skin incision was made. Proximally, the incision started at the posterior part of the femoral shaft and ran distally to the lateral epicondyle and was curved towards Gerdy's tubercle. The incision continued on the posterior third of the iliotibial band, allowing the biceps femoris to be retracted backward and the vastus lateralis forward. The capsulotomy was performed between the lateral collateral ligament and the lateral gastrocnemius, taking care not to injure the popliteus tendon. So the posterolateral recess was progressively open. This supra-meniscal posterior release was continued subperiostally until the posterior cruciate ligament was reached.

For the posteromedial approach, a 7-8cm longitudinal incision was made starting at the top from the soft point between the medial epicondyle and the adductor tubercle and running parallel to the axis of the tibia as described by Lobenhoffer *et al.* [6] (fig. 1a). The retinaculum was also incised and the sartorius muscle displaced posteriorly protecting the saphenous nerve and vein. The retroligamentous capsulotomy was performed behind the medial collateral ligament fibres at the junction with the posterior oblique ligament, exposing the medial condyle and the posterior horn of the medial meniscus. In arthrofibrotic knees, dense scar tissue was seen instead of the normal thin synovial layer. This fibrotic tissue was released subperiostally to enter the posteromedial recess of the knee.

Using the two retroligamentous approaches, the posterior cruciate ligament and its synovial fold were visualized. The posterior cruciate ligament fold was carefully divided from the posterior capsule using scissors to create a posterior space behind the femoral condyles connecting both posterolateral and posteromedial recesses. The scissors should cross this posterior space and be visible from both sides of the femur in both incisions (fig. 1b). All adhesions in the posterior recess were then released. A complete posterior subperiosteal capsular release was performed, detaching the capsule and the head of the gastrocnemius muscles from the posterior femoral condyles and shaft, a technique described as the "femoral peel" by Windsor and Insall in the context of total knee arthroplasty revision [14] (fig. 1b). The release was mainly focused on the femoral capsular attachment to preserve the posterior horn of medial and lateral menisci. On the tibial side, the dissection stopped above the meniscal limit, unlike Millett *et al.* [15], who performed the tibial dissection behind the posterolateral part of the tibia with an occasional release of the semimembranosus tendon.

Passive extension was regularly tested and the subperiosteal dissection was continued until full extension could be achieved. At the end of the procedure, the ACL graft was checked because mobilization to regain extension can lead to graft rupture. After deflating the tourniquet, meticulous haemostasis was performed. One suction drain was inserted in the posterolateral portal and left in place for 24 hours in order to avoid post-operative haematoma. The arthrotomy was left open. The iliotibial band, the medial retinaculum, the subcutaneous tissues and the skin were sutured at the end of the procedure.

Postoperative rehabilitation

Patients were placed in an extension brace for the first post-operative night only. A continuous passive motion (CPM) machine was not used. Intensive physiotherapy with several sessions a day began on the first post-operative day with special emphasis on quadriceps awakening. It included manual mobilization, full passive and active-assisted ROM exercises and patellar

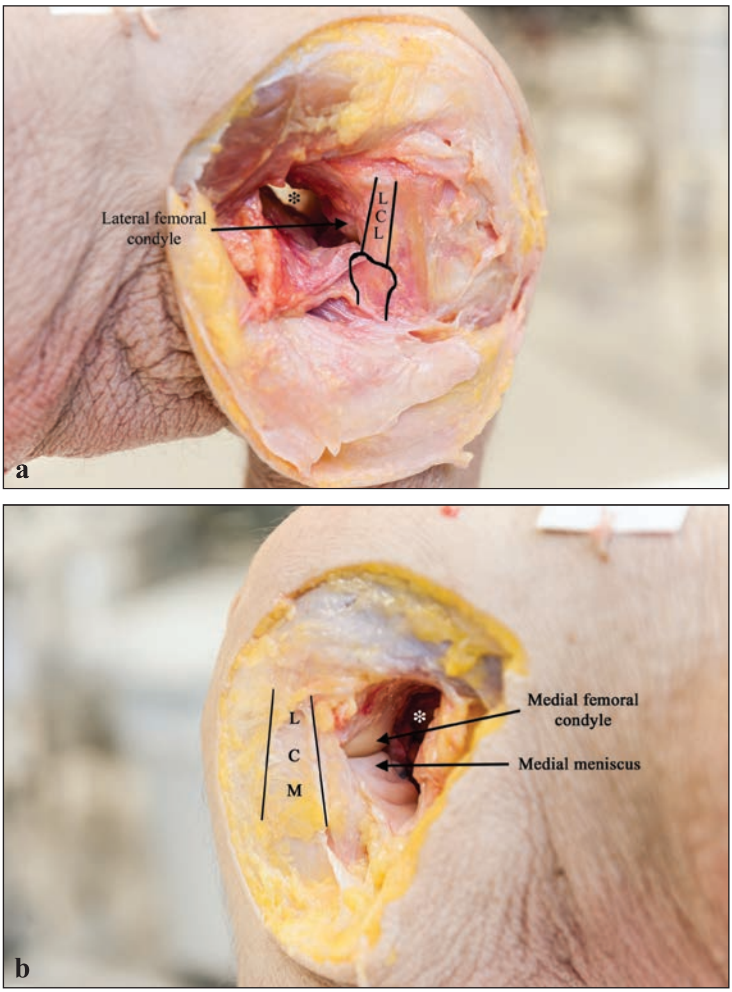


Fig. 1: ***Cadaveric dissection of a right knee:***
a: ***Lateral view: retroligamentous approach showing the posterior space behind the femoral condyles (LCL: lateral collateral ligament; * posterolateral recess).***
b: ***Medial view: "femoral peeling" by the posteromedial retroligamentous approach (MCL: medial collateral ligament; * posteromedial recess).***

mobility exercises. Extension postures had to be maintained for long periods of time (1 hour every 4 hours). Complete weight-bearing was authorized as tolerated. Patients walked with crutches until extension and quadriceps contraction during the stance phase were achieved. All patients were systematically addressed to a rehabilitation centre for 3 weeks.

Clinical Evaluation

At final follow-up, objective and subjective International Knee Documentation Committee (IKDC) forms, KOOS score and activity level were recorded. The range of motion (ROM) was measured preoperatively and at follow-up with a goniometer and compared to the contralateral healthy knee both for extension and flexion.

All patients gave their informed consent before they were included in the study, and the study protocol was reviewed and approved by the institutional review board.

Statistical Analysis

The Wilcoxon-Mann-Whitney test was conducted using the GNU GSPP v.3 free software. A *p*-value <0.05 was considered significant.

RESULTS

At median follow-up of 38 months (range 6-90 months) after arthrolysis, a total of 12 patients were reviewed (5 women, 7 men). Two patients were lost to follow-up. The median age at final follow-up was 36 years (range 20-56 years).

Knee stiffness was secondary to primary bone-to-bone ACLR in all 12 patients and associated with medial menisectomy in 4 cases (Table 1). All primary surgeries to regain ROM had been performed in other institutions and all patients were referred secondarily to our service. Seven patients had sustained surgery to treat knee stiffness prior to presenting to our service (Table 1).

The median time between the primary operation and the secondary surgical release was 17 months (range 6-84). Surgical findings during the arthrolysis are summarized in Table 1. The mean operation time was 54min (range 40-78min).

Preoperatively, all patients had more than 10° of extension loss (Table 2). Ten patients presented a global form of arthrofibrosis with a combined extension and flexion deficit. Two patients had more than 10° extension loss with a flexion loss of less than 15° ("isolated" extension loss; patients 7 and 8 - Table 2).

At follow-up, all patients except one (93%) achieved complete extension (Table 2). Only 1 patient (patient 11) (7%) had a residual post-operative flexion deformity of 5°. Extension and flexion improvements were highly significant after arthrolysis ($p<0.001$).

Analysis of mean ROM of the operated knee before arthrolysis showed 96° ± 14.3°. The ROM improved significantly after arthrolysis to 143° ± 7° ($p<0.001$).

Intra-operative findings during arthrolysis are summarized in Table 1.

No post-operative complications were recorded. No patients required further open debridement. No neurovascular deficits were noted after the posterior release.

Pre- and post-operative objective IKDC scores as well as post-operative subjective IKDC scores are shown in Table 2.

The post-operative KOOS distribution was as follows: pain 93.8 ± 5; symptoms 88 ± 8.6; ADL 96.8 ± 3.7; sports activities 83.6 ± 12.3; and quality of life 82.9 ± 8.8.

With regard to the activity level, at follow-up, all patients (100%) had returned to sport, or daily living activities for the 2 patients who did

Table 1: ***Demographic datas and surgical management of the twelve patients (*ACL*: anterior cruciate ligament;* BTB*: bone-to-bone;* ROM*: range of motion;* MUA*: manipulation under anesthesia).***

Patients	Age	Surgery after injury	Time between injury and initial ACL reconstruction (months)	Initial ROM deficit management	Time between initial ACL reconstruction and arthrolysis	Surgical findings during arthrolysis	Specific surgical step during arthrolysis
1	27	ACL reconstruction (BTB with patellar tendon)	2,5	Only standard rehabilitation	6	Cyclop syndrome	
2	29	ACL reconstruction (BTB with patellar tendon)	2	Only standard rehabilitation	10	Cyclop syndrome	
3	56	ACL reconstruction (BTB with patellar tendon) + medial menisectomy	78	Only standard rehabilitation	84	Cyclop syndrome	
4	37	ACL reconstruction (BTB with patellar tendon)	47	Only standard rehabilitation	9	Subquadricipital pouch with localized fibrosis	
5	47	ACL reconstruction (BTB with patellar tendon)	4	MUA at 3 months	24	Cyclop syndrome	
6	19	ACL reconstruction (BTB with patellar tendon)	2	Only standard rehabilitation	10	- Cyclop syndrome - ACL graft malposition (too vertical)	
7	29	ACL reconstruction (BTB with patellar tendon)	2,5	Tibial screw removed (too long)	10	ACL graft malposition with impingement	Complete ACL shaving
8	26	ACL reconstruction (BTB with patellar tendon) + medial menisectomy	1	MUA at 3 months	10	ACL graft malposition with impingement	Complete ACL shaving
9	31	ACL reconstruction (BTB with patellar tendon) with early postoperative septic arthritis	3	Arthroscopic synovectomy at 20 days postoperatively for septic arthritis	7	- Subquadricipital pouch with localized fibrosis - ACL graft malposition	Complete ACL shaving
10	35	ACL reconstruction (BTB with patellar tendon) + medial menisectomy	2	MUA at 2 months	6	Subquadricipital pouch with localized fibrosis and calcifications in the intercondylar notch	
11	45	ACL reconstruction (BTB with patellar tendon)	3	Tibial screw and metallic wire removed at 7 months	14	ACL graft malposition with impingement	Partial ACL shaving
12	52	ACL reconstruction (BTB with patellar tendon) + medial menisectomy	2	Isolated anterior arthroscopic debridement at 9 months for cyclop syndrom	17	ACL graft malposition with impingement	

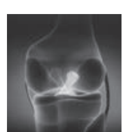


Table 2: ***Postoperative clinical outcomes.***
****Class I: jumping, pivoting, hard cutting, soccer. Class II: heavy manual work, skiing and tennis. Class III: light manual work, jogging and running. Class IV: sedentary work and activities of daily living.***

Patients	Follow-up after arthrolysis (months)	Extension		Flexion		Objective IKDC		Subjective IKDC	Activity level*		Patient satisfaction (scale of 10)
		Pre-operative	Post-operative	Pre-operative	Post-operative	Pre-operative	Post-operative	Post-operative	Pre-injury	At follow up	At follow up
1	33	-10	0	110	140	C	B	92	I	I	10
2	22	-10	0	100	140	C	A	95	I	I	9
3	22	-20	0	120	140	C	B	79	IV	IV	10
4	90	-15	0	110	140	D	A	87	IV	IV	9
5	28	-30	0	110	130	D	A	82	I	I	9
6	35	-20	0	120	140	C	A	99	II	II	9
7	14	-15	0	130	130	D	B	98	II	II	10
8	9	-15	0	130	130	D	B	70	I	III	9
9	40	-15	0	80	125	C	B	80	II	II	9
10	65	-15	0	110	140	D	A	98	II	II	10
11	86	-10	5	120	140	D	B	78	II	II	8
12	6	-20	0	110	130	D	B	79	II	IV	9
Average (range) ± SD	38 (6-90)	-16.25° ± 5.7	0.4° ± 1.4	112.5° ±13.6	135.4° ± 5.8			86.4 ± 9.7			9,25 ± 0,6

not practise sports (patients 3 and 4 – Table 2). Two patients decreased in activity level because of residual knee pain (patients 8 and 12) but follow-up was only at 6 and 9 months, respectively.Functional outcomes were not statistically influenced by age, time between index surgery and arthrolysis, or associated surgical procedures such as menisectomy or ACL graft shaving during arthrolysis.

One patient (patient 7) complained of knee instability 6 months after arthrolysis. In this case, the ACL graft had to be resected in order to obtain full extension at the end of the procedure, and ACL revision using hamstring

tendons was necessary 6 months after arthrolysis. The three other patients who had ACL graft resections during the arthrolysis did not complain of knee instability.

DISCUSSION

The most important finding of the present study was that open posterior release is a safe and efficient additional procedure for treating persistent flexion contracture after anterior arthroscopic release. Indeed, all the patients except one (93%) had a complete post-operative extension and all patients were satisfied. Subjective functional results after posterior release were close to outcomes seen from primary ACLR [16].

Loss of range of motion remains a problematic complication after ACLR [17]. Strum *et al.* [18] reported 35% of ROM loss after acute ACLR two decades ago. However, with a better understanding of risk factors, surgical timing, improved surgical technique and advanced rehabilitation protocols, this ROM loss had markedly decreased to 0.49 to 11% [1, 11, 19, 20].

The aetiology of motion loss after ACLR is variable. As opposed to just the timing of surgery [21, 22], other factors should be analysed closely preoperatively, including the severity of the initial soft-tissue or bony injury, MRI documented bone bruising [23] and ROM. Other causes can lead to loss of motion after ACLR such as delayed rehabilitation, technical errors [24, 25], Cyclops lesions [11, 26], patellar entrapment or infrapatellar contracture syndrome (IPCS) [27], infection, complex regional pain syndrome and genetic factors [28].

Despite these preventative strategies, a few patients do develop ROM loss after knee surgery. In most cases, conservative treatment with enhanced rehabilitation or manipulation under anaesthesia should suffice to solve the deficit. On rare occasions, a surgical debridement is necessary to obtain complete extension. It remains difficult to know when to intervene surgically. It is fundamental to identify the cause of knee stiffness as soon as possible. At the beginning of the third month following the index operation, should there be no gain in ROM despite intensive rehabilitation, a surgical solution should be envisioned. In cases where an obvious cause is idenfied, such as a “Cyclops” lesion or an intra-articular screw, then a surgical solution should be executed rapidly. Where the pathology is more of a global deficit with associated inflammatory syndrome, the decision is more difficult. Paulos *et al.* [29] recommended avoiding surgery until the inflammatory state has become quiescent. Occasionally, a vicious cycle is present: intensive rehabilitation causes pain and inflammation, which in turn cause knee stiffness. In these cases, anti-inflammatories and restriction of painful rehabilitation is useful, and at 6 months, surgical intervention should be considered [30].

The structured release procedure for treating ROM deficit has always included a systematic anterior arthroscopic release [3, 31-33]. Sometimes, when the initial ACL graft is malpositioned and conflicts with the intercondylar notch, it has to be removed to obtain full extension. In these cases, the patient should be informed that an iterative ACLR could be necessary in the case of knee instability. No extension deficit, even a few degrees, should be tolerated at the end of the arthroscopic step. If there is still a residual flexion contracture, a second open posterior step must be performed [34].

Various studies have reported post-operative outcomes following knee stiffness treatment procedures [9, 19, 35-37]. Nonetheless, these series were heterogeneous with a large variety of different treatments, with a systematic anterior release associated in a few cases to a posterior release. None of these studies detailed separately the specific outcomes of the posterior open release because of the rarity of this procedure.

Only four studies specifically report their posterior open release results but none include a systematic posteromedial and posterolateral approach (Table 3).

Table 3: ***Literature review of the posterior open and arthroscopic debridement series.***

Authors	Patients (n)	Mean age (years)	Arthrobibrosis aetiology	Interval from index procedure to arthrolysis (months)
Benum *& al.* **(1982) [4]**	4	42 (35-52)	Ligament procedures, menisectomies	19.3 (12-36)
Millet *& al.* **(1999) [8]**	8	29 (19-43)	4 Acute ACLR 1 Acute PCLR 1 Acute ACLR/PCLR 1 septic arthritis 1 ORIF + MCL/LCL and PCLR	12.3 (6-9)
Lobenhoffer *& al.* **(1996) [6, 7]**	21	28	Ligament procedures Infection Prolonged immobilization for fractures	6 months to 7 years
Freiling *& al.* **(2009) [5]**	86	N/D	Various causes	N/D
Our Serie	12	36 (20-56)	8 isolated ACLR 8 ACLR + medial menisectomies	17 (6-84)
Tröger *& al.* **(2014) [40]**	16	45	9 ACLR 7 fractures or osteotomies	N/D
Mariani *& al.* **(2010) [39]**	18	34 (23-63)	14 femoral or tibial fractures 4 septic arthritis f ollowing surgery	15 (4-22)
Laprade *& al.* **(2008) [38]**	15	32 (15-53)	8 isolated ACLR 3 arthroscopic debridements 1 lateral menisectomy 1 drilling for OCD 2 multiligament reconstructions	18.5 (3-52)

MM: ***medial menisectomy,*** **MCL:** ***medial collateral ligament,*** **LCL:** ***lateral collateral ligament,*** **ORIF:** ***open reduction and internal fixation,*** **ACLR:** ***anterior cruciate ligament reconstruction,*** **PCLR:** ***posterior cruciate ligament reconstruction;*** **OCD:** ***osteochondritis dissecans;*** **N/D:** ***non documented. The solid line separates the open and arthroscopic series.***

Table 3: ***Literature review of the posterior open and arthroscopic debridement series.***

Follow up	Treatment	ROM Results	Clinical results	complications
17 months (4-38)	Medial parapatellar anterior extensile approach	Extension 8° (-15 to 5°) to 4° (-15 to 5) Flexion 69°(30-90) to 136°(125-145)	No	1 additional mob under anesthesia at 10 days
57 months (9-13)	Medial parapatellar anterior extensile approach	ROM gain: 62° Flexion gain: 81° (40-130) to 125° (110 -145) Extension loss: 18.8° (15-20) to 1.25° (0-5) All improvement significant p<0.01	Mean improvement Lysholm: 35.5 points (p<0.05)	3 subsequent procedures: 1 manipulation under anesthesia, 1 arthroscopic debridement and one ACLR/PCLR for knee instability at 9 months after open debridement.
18 months (6-38)	Arthroscopic arthrolysis + posteromedial open capsulotomy	Extension gain: 15° Preop: extension deficit 17° (10°-30°) Follow up: ext deficit 2°	Lysholm: 62 preop and 88 postop. Tegner score: 2.2 to 4 after arthrolysis	1 haematoma in the posterior wound (aspiration) No neurovascular complication
4.6 years (1-10)	Combined open approach: anteromedial + posteromedial	Extension gain: 17° No patient with more than 5° of flexion contracture	Lysholm: 84 Tegner activity scale: 1.9 to 4	2 synovial fistulas 1 haematoma
38 months (6-90)	Double posteromedial and posterolateral approaches	ROM: 96° ±14,3 to 143° ±7 Extension: -16.25° ± 5.7 to 0.4° ± 1.4 Flexion: 112.5° ± 13.6 to 135.4° ± 5.8	Postop. subjective IKDC: 86.4 ±9.7 Postop. Objective IKDC: 5A, 7B.	No
2.9 months (0-20)	Arthroscopic posterior arthrolysis with single posteromedial portal	Extension loss: 13.6° (0-40) to 3° (0-10) Flexion gain: 91.6 ° (35-125) to 117.8 ° (95-140)	N/D	N/D
12 months	Arthroscopic posterior arthrolysis with both posteromedial and posterolateral portals	Extension loss: 34° (12-44) to 3° (0-5) Flexion gain: 85° (65-110) to 100° (85-110)	N/D	Synovial fistula at the posteromedial portal. No neurovascular deficits
24.1 months (12.760.5)	Arthroscopic posterior arthrolysis with single posteromedial portal	Extension loss: 14.7° (7-28) to 0.7° (0-15) Flexion gain: 116.3° (76-135) to 130.1° (120-135)	N/D	No

MM: ***medial menisectomy,*** **MCL:** ***medial collateral ligament,*** **LCL:** ***lateral collateral ligament,*** **ORIF:** ***open reduction and internal fixation,*** **ACLR:** ***anterior cruciate ligament reconstruction,*** **PCLR:** ***posterior cruciate ligament reconstruction;*** **OCD:** ***osteochondritis dissecans;*** **N/D:** ***non documented. The solid line separates the open and arthroscopic series.***

Benum *et al.* [4] reported their results for 7 patients that underwent open extensive capsulotomy to treat knee loss of motion. They used a single medial parapatellar anterior approach to treat mainly flexion deficit. In all 7 patients, a posteromedial capsular release was carried out while only 4 of the 7 patients had an associated posterolateral release. The mean preoperative extension deficit was only 4 degrees and 3 of the 7 patients (43%) retained a post-operative extension deficit. Similarly, Millett *et al.* [8] reported a series of 8 patients who experienced flexion contracture, and were treated by anterior and posterior release using a single anterior extensile approach. This open procedure permitted a 62° ROM gain with good subjective outcomes but two patients retained an extension deficit (25%) and 3 patients required subsequent procedures (Table 3).

Treating a posterior flexion contracture using an isolated anterior approach seems to us technically difficult and needs an extensive and invasive approach.

In a series of 21 patients with chronic flexion contracture, Lobenhoffer *et al.* [6, 7] reported their outcome at a mean of 18 months' follow-up (range 6-36 months). They also performed an anterior arthroscopic release, followed by a posterior open release. In their series the capsulotomy was performed using a single posteromedial approach. The mean extension deficit of 17° improved to a mean of 2° but 6 patients (29%) retained an extension deficit, albeit moderate. In a similar cohort, Freiling *et al.* [5] reported their series of 86 patients who underwent a single posteromedial open release. With a mean follow-up of 4.6 years, the mean extension increased by 17° following the posterior debridement but several patients had a residual extension deficit (Table 3). Post-operative ROM was not precisely reported. Three patients required revision surgery (1 for haematoma, 2 for synovial fistulas).

Unlike Lobenhoffer *et al.* [6] and Freiling *et al.* [5], who insisted on the importance of a single posteromedial approach to avoid a peroneal nerve injury, we prefer a dual posteromedial and posterolateral approach as it allows good visual and tactile access to both posterior recesses to fully and safely release the contracted posterior capsule, with no complications experienced in our series.

Recently, several authors have described arthroscopic posterior release [3, 38-40] for treating extension deficit of the knee. The results of the three posterior arthroscopic release series are presented in Table 3. Although it seems attractive to use modern arthroscopic techniques to perform posterior release of the knee, we still prefer the open procedure, which permits a more extensive release and a more thorough haemostasis than arthroscopic treatment. Indeed, posterior arthroscopic dissection of the scar tissue or adhesion is technically demanding, especially when posterior recesses are almost completely obliterated. Even in the most experienced hands, it's a difficult and time-consuming procedure. Moreover, the arthroscopic treatment may fail because it is unable to remove all fibrotic tissue in the posterior compartments. Indeed, Laprade *et al.* [38] and Tröger *et al.* [40] only performed a posteromedial portal without a posterolateral portal. It seems difficult to completely release both posteromedial and posterolateral compartments byusing a single posterior portal. Finally, the clinical outcomes of these arthroscopic series are not completely satisfying as extension deficit persists at follow-up. Four of the 15 patients (27%) in the series of Laprade *et al.* [38] had an extension deficit after the procedure including one of 15°. Mean extension loss is still 3 degrees in the series of Mariani *et al.* [39] and Tröger *et al.* [40] after the posterior arthroscopic procedure.

The main limitations of this study are its retrospective design and the small sample size, which did not allow us to statistically underscore pejorative factors for functional results. However, open posterior release is a salvage procedure for treating rare cases of chronic ROM deficit, so the overall study patient number is considered acceptable. Further follow-up is also warranted, especially to study degenerative changes after this

procedure. Another limitation is the absence of a control group.

CONCLUSION

In conclusion, the procedure involving anterior arthroscopic arthrolysis and posterior open release gives good ROM gain and functional scores without complications in this series. Prevention of extension contracture after ACLR is essential, through a better understanding of surgical timing, an improved surgical technique and non-aggressive early rehabilitation. Nonetheless, open posterior release should be safely performed only for rare cases of refractory extension deficit with significant ROM improvements and patients' satisfaction.

LITERATURE

[1] WERNER BC, CANCIENNE J, MILLER MD, GWATHMEY FW. Incidence of manipulation under anesthesia or lysis of adhesions after arthroscopic knee surgery. *Am J Sports Med 2015; 43: 1656-61.*

[2] IRRGANG JJ, HARNER CD. Loss of motion following knee ligament reconstruction. *Sports Med 1995; 19: 150-9.*

[3] MAYR HO, STÖHR A. Arthroscopic treatment of arthrofibrosis after ACL reconstruction. Local and generalized arthrofibrosis. *Oper Orthop Traumatol 2014; 26: 7-18.*

[4] BENUM P. Operative mobilization of stiff knees after surgical treatment of knee injuries and posttraumatic conditions. *Acta Orthop Scand 1982; 53: 625-31.*

[5] FREILING D, LOBENHOFFER P. The surgical treatment of chronic extension deficits of the knee. *Oper Orthop Traumatol 2009; 21: 545-56.*

[6] LOBENHOFFER HP, BOSCH U, GERICH TG. Role of posterior capsulotomy for the treatment of extension deficits of the knee. *Knee Surg Sports Traumatol Arthrosc 1996; 4: 237-41.*

[7] LOBENHOFFER P, GERICH T, HERNANDEZ R. Therapy of extension deficits of the knee joint by arthroscopic arthrolysis and dorsal capsulotomy. *Unfallchirurg 1996; 99: 487-91.*

[8] MILLETT PJ, WILLIAMS RJ 3rd, WICKIEWICZ TL. Open debridement and soft tissue release as a salvage procedure for the severely arthrofibrotic knee. *Am J Sports Med 1999; 27: 552-61.*

[9] COSGAREA A, DE HAVEN K, LOVELOCK J. The surgical treatment of arthrofibrosis of the knee. *Am J Sports Med 1994; 22: 184-91.*

[10] DANDY D, EDWARDS D. Problems in regaining full extension of the knee after anterior cruciate ligament reconstruction: does arthrofibrosis exist? *Knee Surg Sports Traumatol Arthrosc 1994; 2: 76-9.*

[11] JACKSON D, SCHAEFFER R. Cyclops syndrome: loss of extension following intra-articular anterior cruciate ligament reconstruction. *Arthroscopy 1990; 6: 171-8.*

[12] HOWELL S, CLARK J, FARLEY T. A rationale for predicting anterior cruciate graft impingement by the intercondylar roof. A magnetic resonance imaging study. *Am J Sports Med 1991; 19: 276-82.*

[13] MUELLNER T, KDOLSKY R, GROOSSCHMIDT K, SCHABUS R, KWASNY O, PLENK H. Cyclops and cyclopoid formation after anterior cruciate ligament reconstruction: clinical and histomorphological differences. *Knee Surg Sports Traumatol Arthrosc 1999; 7: 284-9.*

[14] WINDSOR R, INSALL J. Exposure in revision total knee arthroplasty: The femoral peel. *Tech Orthop 1988; 3: 1-4.*

[15] MILLETT PJ, WICKIEWICZ TL, WARREN RF. Motion loss after ligament injuries to the knee. Part II: prevention and treatment. *Am J Sports Med. 2001; 29: 822-8.*

[16] LIND M, MENHERT F, PEDERSEN AB. The first results from the Danish ACL reconstruction registry: epidemiologic and 2 year follow-up results from 5,818 knee ligament reconstructions. *Knee Surg Sports Traumatol Arthrosc 2009; 17: 117-24.*

[17] MAYR HO, WEIG TG, PLITZ W. Arthrofibrosis following ACL reconstruction-reasons and outcome. *Arch Orthop Trauma Surg 2004; 124: 518-22.*

[18] STRUM GM, FRIEDMAN MJ, FOX JM, FERKEL RD, DOREY FH, DEL PIZZO W, *et al.* Acute anterior cruciate ligament reconstruction. Analysis of complications. *Clin Orthop 1990; 253: 184-9.*

[19] HARNER CD, IRRGANG JJ, PAUL J, DEARWATER S, FU FH. Loss of motion after anterior cruciate ligament reconstruction. *Am J Sports Med 1992; 20: 499-506.*

[20] SHELBOURNE KD, PATEL DV, MARTINI DJ. Classification and Management of Arthrofibrosis of the Knee after Anterior Cruciate Ligament Reconstruction. *Am J Sports Med 1996; 24: 857-62.*

[21] EVANS S, SHAGINAW J, BARTOLOZZI A. ACL reconstruction - it's all about timing. *Int J Sports Phys Ther 2014; 9: 268-73.*

[22] KWOK CS, HARRISON T, SERVANT C. The optimal timing for anterior cruciate ligament reconstruction with respect to the risk of postoperative stiffness. *Arthroscopy 2013; 29: 556-65.*

[23] QUELARD B, SONNERY-COTTET B, ZAYNI R, OGASSAWARA R, PROST T, CHAMBAT P. Preoperative factors correlating with prolonged range of motion deficit after anterior cruciate ligament reconstruction. *Am J Sports Med 2010; 38: 2034-9.*

[24] PETSCHE TS, HUTCHINSON MR. Loss of extension after reconstruction of the anterior cruciate ligament. *J Am Acad Orthop Surg 1999; 7: 119-27.*

[25] YARU NC, DANIEL DM, PENNER D. The effect of tibial attachment site on graft impingement in an anterior cruciate ligament reconstruction. *Am J Sports Med 1992; 20: 217-20.*

[26] MILLETT PJ, WICKIEWICZ TL, WARREN RF. Motion loss after ligament injuries to the knee. Part I: causes. *Am J Sports Med 2001; 29: 664-75*.

[27] PAULOS LE, WNOROWSKI DC, GREENWALD AE. Infrapatellar contracture syndrome. Diagnosis, treatment, and long-term followup. *Am J Sports Med 1994; 22: 440-9.*

[28] SKUTEK M, ELSNER HA, SLATEVA K, MAYR HO, WEIG TG, VAN GRIENSVEN M, *et al.* Screening for arthrofibrosis after anterior cruciate ligament reconstruction: analysis of association with human leukocyte antigen. *Arthroscopy 2004; 20: 469-73.*

[29] PAULOS LE, ROSENBERG TD, DRAWBERT J, MANNING J, ABBOTT P. Infrapatellar contracture syndrome. An unrecognized cause of knee stiffness with patella entrapment and patella infera. *Am J Sports Med 1987; 15: 331-41.*

[30] CHAMBAT P, GUIER C, FAYARD JM, SONNERY-COTTET B. Limitation of Joint Range of Motion After Surgery of the Anterior Cruciate Ligament. In: Sanchis-Alfonso V, Monllau JC, editors. *The ACL-Deficient Knee 2013; p 373-81.*

[31] PUJOL N, BOISRENOULT P, BEAUFILS P. Post-traumatic knee stiffness: Surgical techniques. *Orthop Traumatol Surg Res 2015; 101: S179-86.*

[32] REIDER B, BELNIAK RM, PREISKORN D. Arthroscopic arthrolysis for flexion contracture following intraarticular reconstruction of the anterior cruciate ligament. *Arthrosc J Arthrosc Relat Surg 1996; 12: 165-73.*

[33] ROBERTSON GA, COLEMAN SG, KEATING JF. The surgical treatment of knee stiffness following anterior cruciate ligament reconstruction. *Scott Med J 2011; 56: 156-60.*

[34] BEHREND H, HERTEL P. Results of the surgical treatment of arthro-fibrosis of the knee. *Unfallchirurg 2003; 106: 483-91.*

[35] AGLIETTI P, BUZZI R, DE FELICE R, PAOLINI G, ZACCHEROTTI G. Results of surgical treatment of arthrofibrosis after ACL reconstruction. *Knee Surg Sports Traumatol Arthrosc 1995; 3: 83-8.*

[36] NOYES FR, MANGINE RE, BARBER SD. The early treatment of motion complications after reconstruction of the anterior cruciate ligament. Clin Orthop 1992; 277: 217-28.

[37] STEADMAN J, BURNS T, PELOZA J, SILLIMAN J, FULSTONE H. Surgical treatment of arthrofibrosis of the knee. *J Orthop Tech 1993; 1: 119-27.*

[38] LAPRADE RF, PEDTKE AC, ROETHLE ST. Arthroscopic posteromedial capsular release for knee flexion contractures. *Knee Surg Sports Traumatol Arthrosc 2008; 16: 469-75.*

[39] MARIANI PP. Arthroscopic release of the posterior compartments in the treatment of extension deficit of knee. *Knee Surg Sports Traumatol Arthrosc 2010; 18: 736-41.*

[40] TRÖGER M, HOLSCHEN M. Arthroscopic arthrolysis for the treatment of movement disorders of the knee. *Oper Orthop Traumatol 2014; 26: 361-8.*

RETURN TO PLAY AFTER ACL RUPTURE

P. LANDREAU

After an anterior cruciate ligament (ACL) rupture, the aim of the treatment (whatever the treatment, conservative or surgical) is to allow the patient to return to previous physical activity. If the patient is sedentary, the conservative treatment usually allows a safe return to normal daily life. If the patient is an athlete, the surgical treatment must be considered especially if the practiced sport is a pivot-sport. The aim of the surgical treatment must be pointed out, mainly to provide a stable knee in order to return to sport activity. There is currently no evidence that surgery could prevent osteoarthritis in comparison to conservative treatment.

There is a consensus on clearance to return to sport should occur at around 6 months after the surgery, between 4 to 9 months for moderate sports and at a range from 4 to 18 months in case of strenuous sports [1]. However, there is no real scientific evidence to define an accurate time to return to sport.

The objective of this paper is to provide a return to play guidelines after ACL re-construction, based on our experience and supported by the current literature.

INTRODUCTION

One of the main and first question that an athlete asks to his surgeon after an ACL rupture is *"When can I go back to play?"* It is usually observed in professional athlete population as well the pressure from the club. The competition calendar and the financial issues are prominent, but it can be asked by a recreational athlete, like some "weekend warriors" as the sport is an important part of their life, physical and psychological balance. The surgeon should take in consideration these factors before making any surgical decision and informing the patient about the objective and the timeframe of the surgery along with re-habilitation procedures accordingly, in order to fit the patient's expectation. Therefore, patient's information is crucial to avoid any disappointment and any mistake in the postoperative evolution.

The main questions for the surgeon are: When is it safe to stress the graft according to the bone integration and graft healing process? When do patients have sufficient muscle strength and neuromuscular control to cope with the physical load of their sport? The two previous questions generate this one: When will the risk of re-injury be at the lower possible level in order to authorize the player to return to sport?

WHAT DOES IT MEAN "RETURN TO PLAY" AND WHAT IS THE ACTUAL RATE?

In their meta-analysis, Arden *et al.* (Forty-eight studies evaluating 5770 participants at a mean follow-up of 41.5 months were included for review) demonstrated that while 82% of patients returned to some form of sports participation following ACL reconstruction surgery, only 63% of patients were able to return to their pre-injury level and only about half of patients returned to competitive sport after ACL reconstruction surgery [2].

In another study, the same group showed that while two-thirds of patients had attempted some form of sport by 12 months following their surgery, only one-third had returned to their pre-injury level of competitive sport participation [3].

In a more selected population, including motivated professional athletes, it is probable that the rate of return to same level and competition should be better but the patient must be informed about the actual rate in order to fit his/her expectations.

WHICH FACTORS SHOULD BE TAKEN INTO CONSIDE-RATION TO CONDUCT THE CUSTOMIZED RETURN TO PLAY PROCESS?

Different factors must be taken into account to allow the patient to move from one step to another during his rehabilitation and return to play: the biology (fixation, integration and maturation of the graft according to the type of graft) the neuromuscular control and the psychological factors.

The biology

The fixation and the maturation of the graft should be considered.

Even if there are some controversies in literature, it seems that there is no evidence that one graft should be superior to another concerning return to sport and risk of re-rupture [4].

However, the consolidation of the bone plugs in the tunnels has been shown to be faster than the tendon tunnel integration. Therefore, prudence is advised especially after hamstrings reconstruction.

The development of the fixation systems have facilitated the modern rehabilitation protocols allowing immediate weight bearing, less knee immobilization, early and unrestricted range of motion, early recovery of neuromuscular function and therefore, early return to physical activity. The bone integration is different according to bone-tendon-bone graft or tendon grafts. It can take up to 4-6 months before complete bone integration; then a minimum of 4-6 months should be respected before to return to play only according to the bone integration.

The maturation of the graft has been studied on animals. The three phases of healing and their approximate timelines in animal models are remodeling (first 4 weeks postoperatively), maturation (weeks 4-12), and ligamentization (from 12 weeks). It has been demonstrated that there are substantially reduced mechanical properties of the graft in the first 8-12 weeks. This notion has not been demonstrated in human population and appears to contradict the successful clinical outcomes reported after accelerated rehabilitation programs. Additionally, there are some controversy concerning the properties of the tendon graft in human population. This graft could undergo a process of adaptation rather than a ligamentization or restoration of native ACL [5]. We miss further research to accurately

assess the properties of human ACL graft. However, the animal studies should lead to at least some prudence during the intermediate phase between physiotherapy and return to play (4 to 6 months).

Strength and neuromuscular control

Many guidelines have been proposed regarding the criteria that the patient must meet before to return safely to play but there is currently no evidence to support one protocol or another one (fig. 1).

For that reason, at Aspetar, we have conducted a study to evaluate whether strength or functional tests, which are frequently used as return to sport criteria, are risk factors for an ACL graft rupture in a group of male professional athletes [6]. 158 male professional athletes who underwent an ACL reconstruction and returned to their previous professional level of sport were included. Before players returned to sport, they underwent a battery of discharge tests (isokinetic strength testing at 60°, 180° and 300°/s, a running T test, single hop, triple hop and triple crossover hop tests). Athletes were monitored for ACL re-ruptures once they returned to sport (median follow-up 646 days, range 1-2060). Out of the 158 athletes, 26 (16.5%) sustained an ACL graft rupture with an average of 105 days after return to sport. Two factors were associated with increased risk of ACL graft rupture:

1) not meeting all six of the discharge criteria before returning to team training; and **2)** decreased hamstring to quadriceps ratio of the involved leg at 60°/s.

We concluded that athletes who did not meet the discharge criteria before returning to professional sport had four times greater risk on sustaining an ACL graft rupture compared with those who met all six RTS criteria. In addition, hamstring to quadriceps strength ratio deficits were associated with an increased risk of an ACL graft rupture.

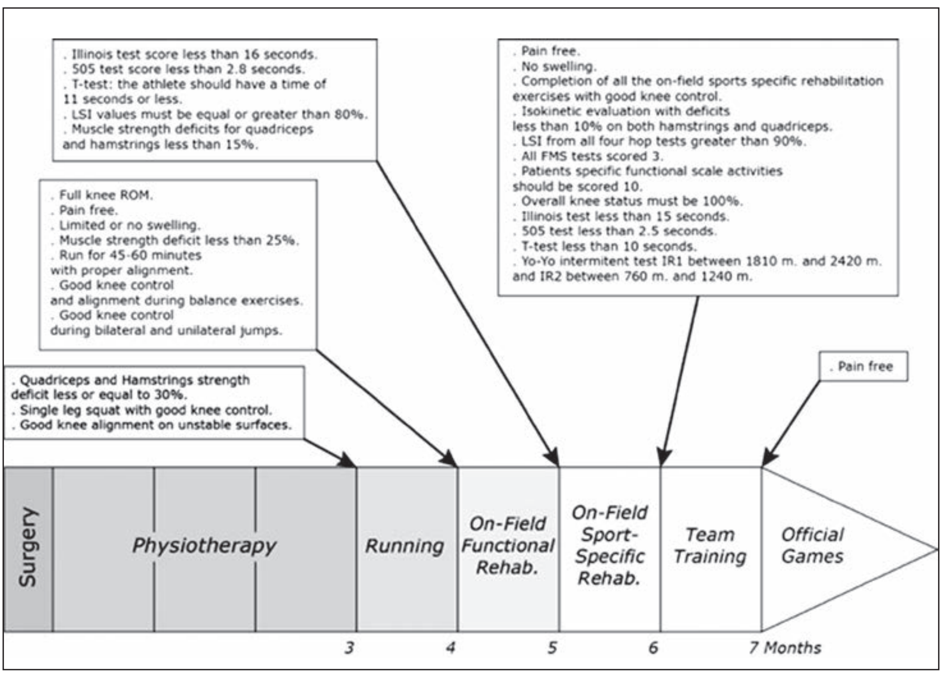
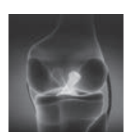


Fig. 1: ***Return to sport after ACL recontruction. Aspetar guidelines.*** *(E. Witvrouw, P. Kyritsis, P. Landreau).*



In the literature, it is notable that there is no relationship can be found between the rate of returning to the pre-injury level of sports participation and knee function, as measurements were conducted by the *International Knee Documentation Committee* (IKDC) knee evaluation form. [3].

Psychological factors

Some authors have suggested that psychological factors may also contribute to the return-to-sport outcomes, as fear and motivation [7]. Other factors can influence the return to play and its quality, like family situation and work involvement.

RISK OF NEW INJURY (GRAFT RUPTURE AND CONTRALATERAL ACL INJURY)

After RTS the risk of re-injury (graft rupture) ranges in the literature from 6% to 25% whereas the risk of contralateral ACL injury ranges from 2 to 20.5%.

Wright *et al.* [8] conducted a systematic review of six level I or II prospective studies that evaluated the graft rupture and contralateral ACL injury rates in patients at least 5 years following ACL reconstruction surgery, using either a patellar tendon or hamstring tendon autograft. The results demonstrated that, the ipsilateral ACL graft rupture rate ranged from 1.8 to 10.4%, with a pooled percentage of 5.8%. The contralateral injury rate ranged from 8.2 to 16.0%, with a pooled percentage of 11.8%. They concluded that the risk of ACL tear in the contralateral knee (11.8%) was double the risk of ACL graft rupture in the ipsilateral knee (5.8%). However, most studies do not clearly separate graft rupture and graft deficiency that may have been present from the early postoperative period. This may in turn influence the factors that are identified as predictors of graft rupture as opposed to failure.

Young age is a factor of re-injury. Shelbourne *et al.* [9] demonstrated that young patients (<18 years) had the highest risk of graft rupture and they have also been shown to be up to seven times more likely to sustain a contralateral ACL injury than patients aged greater than 18 years.

Wiggins *et al.* [10] in a systematic review, showed that athletes younger than 25 years who returned to sport have a secondary ACL injury rate of 23%. This systematic review and meta-analysis demonstrates that younger age and a return to high level of activity are predominant factors associated with secondary ACL injury. These combined data indicate that nearly 1 in 4 young athletic patients who sustain an ACL injury and return to high-risk sport will go on to sustain another ACL injury at some point in their career, and they will likely sustain it early in the return-to-play period. Andernord *et al.* [11] in a cohort study of 16,930 patients with 2-year follow-up, demonstrated that soccer players and adolescents are predictors for a high risk of revision surgery.

CONCLUSION

Most athletes can return to sport after an ACL reconstruction but the rate of return to previous sports level and competition can be more disappointing. The time to return to sport in practice goes from 4 months to 18 months.

The elements which influence the time and quality of return to play are multifactorial and the return-to-sport decision should be individualized and objective (goal), rather than based on time.

The maturation of the human ACL graft should not be the only factor to be considered. Meeting specific objective discharge criteria can reduce the relative risk of sustaining an ACL graft rupture. Nevertheless, careful attention to athletes achieving an appropriate hamstring to quadriceps strength ratio before discharge after ACL reconstruction, may help to reduce the likelihood of ACL graft rupture.

The young age and high level of sports must make return to sport discharge even more prudent.

LITERATURE

[1] HARNER CD, FU FH, IRRGANG JJ, *et al.* Anterior and posterior cruciate ligament reconstruction in the new millennium: a global perspective. *Knee Surg Sports Traumatol Arthrosc 2001; 9: 330-6.*

[2] ARDERN CL, WEBSTER KE, TAYLOR NF, *et al.* Return to sport following anterior cruciate ligament reconstruction surgery: a systematic review and meta-analysis of the state of play. *Br J Sports Med 2011; 45: 596-606.*

[3] ARDERN CL, WEBSTER KE, TAYLOR NF, *et al.* Return to the preinjury level of competitive sport after anterior cruciate ligament reconstruction surgery. Two-thirds of patients have not returned by 12 months after surgery. *Am J Sports Med 2011; 39: 538-43.*

[4] POOLMAN RW, ABOUALI JAK, CONTER HJ, BHANDARI M. Overlapping systematic reviews of anterior cruciate ligament reconstruction comparing hamstring autograft with bone-patellar tendon-bone autograft: Why are they different? *J Bone Joint Surg Am 2007; 89: 1542-52.*

[5] CLAES S, VERDONK P, FORSYTH R *et al.* The "ligamentization" process in anterior cruciate ligament reconstruction: what happens to the human graft? A systematic review of the literature. *Am J Sports Med 2011; 39: 2476-83.*

[6] KYRITSIS P, BAHR R, LANDREAU P, MILADI R, WITVROUW E. Likelihood of ACL graft rupture: not meeting six clinical discharge criteria before return to sport is associated with a four times greater risk of rupture. *Br J Sports Med 2016.*

[7] WEBSTER KE, FELLER JA, LAMBROS C. Development and preliminary validation of a scale to measure the psychological impact of returning to sport following anterior cruciate ligament reconstruction surgery. *Phys Ther Sport 2008; 9: 9-15.*

[8] WRIGHT RW, MAGNUSSEN RA, DUNN WR, *et al.* Ipsilateral graft and contralateral ACL rupture at five years or more following ACL reconstruction. A systematic review. *J Bone Joint Surg Am 2011; 93(12): 1159-65.*

[9] SHELBOURNE KD, GRAY T, HARO M. Incidence of subsequent injury to either knee within 5 years after anterior cruciate ligament reconstruction with patellar tendon autograft. *Am J Sports Med 2009; 37: 246-51.*

[10] WIGGINS AJ, GRANDHI RK, SCHNEIDER DK, STANFIELD D, WEBSTER KE, MYER GD. Risk of Secondary Injury in Younger Athletes After Anterior Cruciate Ligament Reconstruction: A Systematic Review and Meta-analysis. *Am J Sports Med 2016.*

[11] ANDERNORD D, DESAI N, BJÖRNSSON H, YLANDER M, KARLSSON J, SAMUELSSON K. Patient predictors of early revision surgery after anterior cruciate ligament reconstruction: a cohort study of 16,930 patients with 2-year follow-up. *Am J Sports Med 2015; 43(1): 121-7.*

CONSERVATIVE TREATMENT AFTER PARTIAL ACL TEAR: IS RETURN TO SPORT POSSIBLE?

J.M. FAYARD, G. DUBOIS DE MONT-MARIN,
B. SONNERY-COTTET, M. THAUNAT

INTRODUCTION

Anterior cruciate ligament (ACL) is composed of two bundles, the anteromedial (AM) bundle and the posterolateral bundle (PL). These two bundles are tight in extension, the AM band tightens between 45 and 90° of knee flexion and seems to be mainly involved in anterior tibia translation control, whereas PL band is tighten at 30° of flexion and controls the rotational stability [1, 2, 3]. Isolated injuries of the ACL account for nearly half of all knee ligament injuries [4] and primarily affect young and active patients. Partial tears of ACL, namely just one bundle injured, are observed in 10 to 28% of isolated ACL lesions [5, 6]. Functional consequences are moderate and clinical relevance is usually poor. Patients present a firm and delayed stop at the Lachman test, a moderate anterior laxity and a weak or no pivot shift [5]. MRI is not sensible to distinguish partial from total ACL lesions. For Van Dyck *& al.*, the sensibility is between 25% and 53% [1]. The diagnosis of partial tears is based on a combination of clinical and paraclinical factors [1, 5, 6, 7]. Functional treatment may be proposed in the absence of meniscal or cartilaginous lesion.

The aim of this study was to analyse the level of the return to sport after partial ACL rupture, the rate of progression to a complete rupture and of development of cartilaginous and meniscal lesions in young and athletics patients.

MATERIAL AND METHODS

A consecutive series of 41 patients presenting a partial ACL tear between 2008 and 2014 is reported.

Inclusion criteria were patients under the age of 30 years old presenting a partial ACL tear. Exclusion criteria were associated meniscal or chondral lesions, previous surgical history on the index knee and contralateral ACL rupture.

The diagnosis of partial ACL tear was based on a delayed firm stop at the Lachman test and a differential laxity measured with the Rolimeter® less or equal to 5 mm and/or a weak or no pivot shift. An MRI was done to assess the type of ACL tear and the cartilage and meniscal status.

Non-surgical treatment was proposed and based on a rehabilitation protocol including quadriceps and hamstring strengthening, neuromuscular rehabilitation. The absence of pain and instability was regularly assessed.

The time between the ACL tear and the first consultation, the type and the level of sport at the time of the rupture were recorded.

The functional evaluation of the knee before the trauma was done using IKDC subjective score and the level of sport was evaluated with the Tegner score.

All patients were systematically examined at one year follow-up after the injury. The anterior and the rotatory stability were analysed using the Lachman test, an instrumented evaluation of the anterior drawing with the Rolimeter® and the jerk test.

Furthermore, all patients were contacted to know if they were stable and if they presented a complete ACL tear. The Tegner and IKDC subjective scores were also recorded. The ACL-RSI score was done to analyse psychological impact of the tear on the return to sport.

RESULTS

Forty one patients, 24 men (59%) and 17 women (41%) were included. The mean age at the time of the ACL tear was 21 years (range, 15 to 29).

The mean time between injury and the first consultation was 61 days (range, 2 to 271). All the patients presented ACL tear during pivoting sports. Ski (29%) and soccer (20%) were the more frequently reported activities.

Initially, all the patients presented a firm and delayed stop at the Lachmann test. The mean differential anterior laxity was 2.6 mm (range, 0 to 5). Pivot shift was absent in 34 patients (83%), noted as glide in 2 (5%) and marked in 4 patients (10%). The pivot shift could be evaluated in one patient. On the initial MRI, the ACL lesion was considered as partial in 89% and complete in 11%. All the patients did not present any meniscal or cartilage lesion. The mean Tegner score before the ACL tear was 7±1 (range, 5 to 10) and the mean IKDC subjective score was 96.4±4 (range, 84 to 100).

At mean 8.4 months follow-up (range, 1 to 33), 100% of the patients still presented an early or delayed firm stop at the Lachman test. The mean differential anterior laxity was 1.9 mm (range, 0 to 5). Pivot shift was absent in 89%, noted as glide in 4% and marked in 7%.

The mean Tegner score was 6.2±2 (range, 3 to 9) and the mean IKDC subjective score was 83±12 (range, 54 to 100). We found a significant decrease for both score ($p<0.05$). The mean ACL-RSI score was 68.8±18 (range, 38 to 100).

All the patients were contacted at a mean 3.4 years (range, 2 to 8) follow-up from the partial rupture.

Twenty six patients still presented a partial tear and did not progress to a total rupture. The mean IKDC subjective score and Tegner score in this population were respectively 83.6±10 (range, 68 to 100) and 5.8±1.6 (range 3 to 8). The ACL-RSI score in this population was 69±18 (range, 43 to 98). Fifteen patients progressed to a complete rupture (36.6%). The mean IKDC subjective score and Tegner score in this population before the complete ACL rupture were respectively 80.5±17 (range: 54 to 100) and 7.5±1.2 (range: 6 to 9).The ACL-RSI score in this population was 67±21 (range: 38 to 100).

The mean time between partial and total tear was 23.4 months (range: 5 to 43). The complete ACL rupture occurred in a sport trauma in 12 cases (80%) and without any trauma in 3 cases (20%).

A progression of meniscal lesions was found in 8 patients (53%). We did not have this information for one patient. No chondral lesions were recorded.

Tegner score after partial ACL tear was significantly higher in patients who progress to a complete lesion (7.5±1.2) than the others (5.8±1.6) ($p=0.03$). Only 50% of the patients returned to sport at the same level and 45% of them progressed to a total tear (Table 1).

There were no significant difference concerning gender, anterior laxity, pivot shift test, IKDC and ACL RSI score between the two groups at the first examination and at 1 year follow-up.

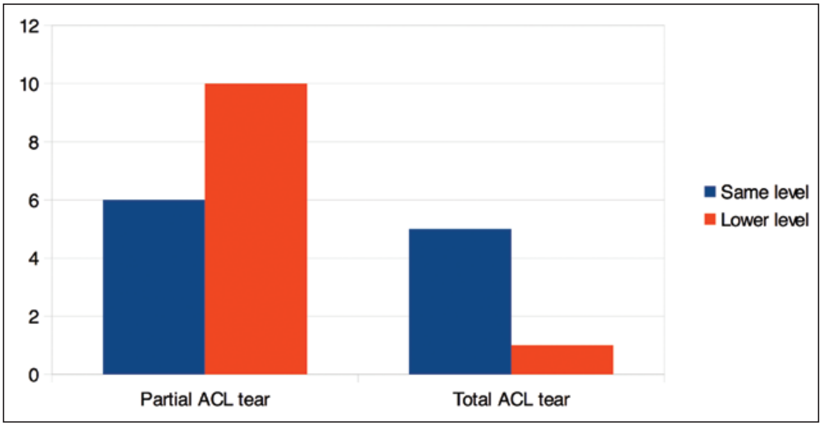


Table 1: Tegner score related to the progression or not to a total ACL tear

Because of the small sample number, statistical tests were not utilized to evaluate normality. Instead, the assessment was performed with non-parametric equivalents. The relationship between the variables was studied with the chi² test, Fisher's exact test, or Mann Whitney test, depending on what corresponded. The inference in continuous variables was calculated with the paired-samples *T*-test and their results are presented with their 95% confidence interval (95% CI). The level of significance was set at 5% (α=0.05), bilateral approximation.

DISCUSSION

Partial tears of the ACL are reported to represent up to quarter of all ACL ruptures. Diagnosis may frequently be difficult because of poor functional consequences and clinical relevance. MRI accuracy is also known to be insufficient.

Our approach was to appreciate if a conservative management for partial ACL tear can reasonably be proposed to the most exposed population, where the functional requirement is the most important. Considering this point, the ability to return to sport, the rate of progression to a complete ACL rupture and the rate of associated lesions were evaluated.

Conservative treatment was initially proposed as the gold standard in case of partial tears. Odensten *& al.* followed 21 patients presenting partial ACL tears conservatively treated at a mean 6 years follow-up. All patients had good or excellent results. The mean Lysholm score was 93±6 points. Three were considered as unstable at final follow-up [8]. Sommerlath *& al.* evaluated 19 patients with partial ACL tears at 15 years follow-up. Knee function was rated as good with a mean Lysholm score of 93 points. None of the patients complained of instability [9]. The authors considered conservative treatment as effective only if the patients decrease their activity level. These studies evaluated a heterogeneous population of patients in term of age and meniscal status. Even if associated lesions were found in more than half of the knees presenting a partial ACL tear, the authors considered that non-operative management can be established. Our study analysed a homogenous population presenting a partial ACL tear. All of the patients were active and aged less than 30 years. Initially, none of them had cartilage or meniscal lesions.

The aim of most patients presenting an ACL lesion is return to the same sport and ideally at the same level. Noyes *& al.* did not find any correlation between the Tegner score before and after injury and the progression to a complete ligament deficiency [10].

In our study, the most exposed activities were pivoting sport especially ski and soccer. We reported a significant decrease of the Tegner score after the partial ACL lesion. Functional management allowed a return to sport at the level before injury only in half of the patients and 45% of them had progressed to a complete rupture.

Noyes *& al.* evaluated 32 patients presenting a partial ACL tear at a mean 7.3 years follow-up. The rate of return to sport at the same level was only 12.5%. No patient progressed to a complete rupture [10]. Barrack *& al.* found 40% of 35 patients with partial ACL tears who were able to return to their pre-injury level at a mean 41 months follow-up. Age at the time of the injury ranged from 15 to 45 years and the level of sport was not advised [11]. Bak *& al.* evaluated 56 patients presenting a partial ACL tear without associated meniscal or chondral lesions at a mean 5.3 years follow-up. Sixty-two percent had good or excellent knee function with a Lysholm score between 84 and 100. Only 30% patients resumed their preinjury activities. If we consider patients under 30 years old, only 5 patients on 16 (31%) were able to return to their preinjury level. The authors concluded that the prognosis for knee function is good if pivoting sports are stopped [12]. We noted a significant decrease of the IKDC subjective score at the last follow-up after the partial rupture. However, our patients had an acceptable knee function at 3.4 years follow up with a mean IKCD subjective score over 80%.

ACL-RSI score is described to analyse the psychological impact of a ACL tear on return to sport. In our study, we observed a mean ACL-RSI score of 69/100 after partial ACL tears. Even though IKDC subjective score was good, we noted a decrease of the Tegner score. This could be explained by an apprehension to return to sport. We did not find a significant relationship between the ACL-RSI score and progression to a complete rupture.

We observed an important rate of progression to a complete rupture (36.6%) at the last follow-up. Noyes *& al.* found a progression to a complete tear in 38% with 7.3 years of follow up. The authors described 3 levels of partial ACL lesions according to the amount of tear: 25, 50 and 75%. According to the authors, the progression to a complete ACL tear was related to the initial extent of the partial tear. This evaluation was done by arthroscopy [10]. Actually, there is no place for arthroscopy in the diagnosis of ACL lesions. Clinical examination and MRI do not allow an evaluation of the amount of the ACL damage. Treatment is based on knee stability during clinical examination and diagnosis of partial tear on the IRM.

Fritschy *& al.* found 42% of complete rupture at 6.5 years follow-up in a non-homogeneous population. The mean age at the ACL partial tear was 31 years (range 16 to 57 years) and most of the patients had associated lesions. The ruptures were arthroscopically graded in two groups according to the amount of the ACL tear : 25-50% and 50-75% of ligament rupture. The authors concluded that it was impossible to estimate the quality of the remnant ACL fibres [13].

In their study, Bak *& al.* reported only 11% of progression to a total tear on 56 patients. This lower rate can be explained by an older population (age between 17 and 48 years) and a reduction of pivoting activities [12].

We observed an important rate of progression to a complete rupture (36.6%) with a shorter follow-up than what was published in the literature. In our study, progression from a partial to a complete ACL tears occurred at a mean 23.4 months follow-up. It might be explained by the population we studied. Younger patients, playing pivoting sport may present a greater risk to progress to a complete tear.

Most of the authors who studied the outcomes of partial ACL tears reported associated initial meniscal and cartilage lesions. Noyes *& al.* found meniscal tears in 17 of 32 knees (53%) presenting partial ACL tears [10]. In their study, Fritschy *& al.* reported 25 of 43 patients (58%) with initial associated lesions. Five cartilage lesions were recorded [13]. These authors did not evaluated associated lesions at the last follow-up and the progression of these lesions after complete tears.

In order to analyse the development of meniscal tears, we studied a homogeneous population without any associated lesion. Fifty seven percents of the patients who progressed to a complete tear presented associated meniscal lesions. We didn't report any cartilage lesion but our follow-up was short. Young patients presenting meniscal and/or cartilage lesion have a greater risk to develop early osteo-arthritis. Considering this point of view, patients presenting a risk to progress to a total tear should be initially identified and a surgical treatment should be proposed. Conservative treatment including rehabilitation and progressive return to sport can be proposed for the less active patients.

CONCLUSION

Non operative treatment for partial ACL tears can be carefully proposed to young and active patients. A lower level of sport than before the partial tear is usually reported.

Patient motivation to return to sport should be precisely analysed. Identifying patients' risk for progression to anterior cruciate ligament deficiency is a critical step in developing the treatment strategy. Surgical treatment should be proposed to patients who desire to return to pivoting sports at the same level. If a conservative treatment is decided, return to sport should be progressive and patients should be informed of the risk of progression to a complete rupture and the development of associated meniscal lesions.

A longer follow-up is mandatory to analyse the development of meniscal and chondral lesions in the group which did not progress to a total tear.

LITERATURE

[1] VAN DYCK P, DE SMET E, VERYSER J, LAMBRECHT V, GIELEN JL, VANHOENACKER FM, *& al.* Partial tear of the anterior cruciate ligament of the knee: injury patterns on MR imaging. *Knee Surg Sports Traumatol Arthrosc Off J ESSKA 2012; 20(2): 256-61.*

[2] ABAT F, GELBER PE, ERQUICIA JI, PELFORT X, TEY M, MONLLAU JC. Promising short-term results following selective bundle reconstruction in partial anterior cruciate ligament tears. *The Knee 2013; 20(5): 332-8.*

[3] AMIS AA, DAWKINS GP. Functional anatomy of the anterior cruciate ligament. Fibre bundle actions related to ligament replacements and injuries. *J Bone Joint Surg Br 1991; 73(2): 260-7.*

[4] DEFRANCO MJ, BACH BR. A comprehensive review of partial anterior cruciate ligament tears. *J Bone Joint Surg Am 2009; 91(1): 198-208.*

[5] TEMPONI EF, DE CARVALHO JÚNIOR LH, SONNERY-COTTET B, CHAMBAT P. Partial tearing of the anterior cruciate ligament: diagnosis and treatment. *Rev Bras Ortop 2015; 50(1): 9-15.*

[6] COLOMBET P, DEJOUR D, PANISSET JC, SIEBOLD R, French Arthroscopy Society. Current concept of partial anterior cruciate ligament ruptures. *Orthop Traumatol Surg Res OTSR 2010; 96(8 Suppl): S109-18.*

[7] DEJOUR D, NTAGIOPOULOS PG, SAGGIN PR, PANISSET JC. The diagnostic value of clinical tests, magnetic resonance imaging, and instrumented laxity in the differentiation of complete versus partial anterior cruciate ligament tears. *Arthrosc J Arthrosc Relat Surg Off Publ Arthrosc Assoc N Am Int Arthrosc Assoc 2013; 29(3): 491-9.*

[8] ODENSTEN M, LYSHOLM J, GILLQUIST J. The course of partial anterior cruciate ligament ruptures. *Am J Sports Med 1985; 13(3): 183-6.*

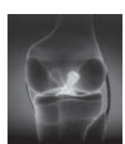
[9] SOMMERLATH K, ODENSTEN M, LYSHOLM J. The late course of acute partial anterior cruciate ligament tears. A nine to 15-year follow-up evaluation. *Clin Orthop 1992; (281): 152-8.*

[10] NOYES FR, MOOAR LA, MOORMAN CT, McGINNISS GH. Partial tears of the anterior cruciate ligament. Progression to complete ligament deficiency. *J Bone Joint Surg Br 1989; 71(5): 825-33.*

[11] BARRACK RL, BUCKLEY SL, BRUCKNER JD, KNEISL JS, ALEXANDER AH. Partial versus complete acute anterior cruciate ligament tears. The results of nonoperative treatment. *J Bone Joint Surg Br 1990; 72(4): 622-4.*

[12] BAK K, SCAVENIUS M, HANSEN S, NØRRING K, JENSEN KH, JØRGENSEN U. Isolated partial rupture of the anterior cruciate ligament. Long-term follow-up of 56 cases. *Knee Surg Sports Traumatol Arthrosc Off J ESSKA 1997; 5(2): 66-71.*

[13] FRITSCHY D, PANOUSSOPOULOS A, WALLENSTEN R, PETER R. Can we predict the outcome of a partial rupture of the anterior cruciate ligament? A prospective study of 43 cases. *Knee Surg Sports Traumatol Arthrosc Off J ESSKA 1997; 5(1): 2-5.*



PSYCHOLOGICAL FACTORS AND ANTERIOR CRUCIATE LIGAMENT RECONSTRUCTION

J.A. FELLER, K.E. WEBSTER

INTRODUCTION

Following anterior cruciate ligament (ACL) reconstruction, there are many factors that influence an individual's ability, desire and decision whether to return to sport and at what level. It is recognised that there is a poor correlation between objective knee function and return to sport following ACL reconstruction [5]. This suggests that there are other factors that may play a role and these may include lifestyle, occupational concerns and psychological factors.

Negative psychological responses have been associated with sports injury and may persist following surgery and rehabilitation. They may continue to be present even when an athlete receives clearance to return to sports. Such negative responses include tension, low self-esteem, depression and anxiety. The athlete's ability to cope with stress may also influence their recovery and rehabilitation.

FEAR OF RE-INJURY

Fear of re-injury may affect an athlete's ability to return to their previous sports and may also affect the quality of their performance when participating in sport. Using the Tampa Scale of Kinesiophobia, Kvist *et al.* identified fear of re-injury as a significant factor in patients who did not return to their pre-injury activity level compared to those who did [7]. Exactly what constitutes fear of re-injury is unclear. It may be the fear of the pain of injury itself, fear of the subsequent surgery, fear of the rehabilitation process and time out of sport, fear of the implications for time off work and income, or a combination of the above.

Ardern *et al.* [1] investigated whether fear of re-injury was still a consideration in athletes who made a successful return to their sport. A cohort of 209 athletes answered a series of questions regarding the behavioural manifestations of fear, such as playing with hesitation and being wary of injury provoking situations. Overall, the results showed that athletes who had successfully returned to their pre-injury sport generally participated without fear of re-injury. Males who had earlier surgery (<3 months after injury) were found to participate in their pre-injury sport with the least amount of fear. This was consistent with previous work which showed that during rehabilitation males report being more influenced by powerful others, such as trained professionals (doctors, physiotherapists) and team-mates compared with females. This may be protective against any negative psychological impact associated with returning to sport after this surgery [11].

SYSTEMATIC REVIEW

A systematic review found that the literature about the psychological response of athletes returning to sport following injury and/or surgery was relatively sparse and that there was a high risk of bias for the included studies [2]. Nonetheless, the review found that as athletes progress through the rehabilitation phase towards a return to sport, there is a reduction of the negative emotions which are associated with the initial injury (such as depression, anger and anxiety), and a shift towards more positive emotions (such as confidence and readiness to return to sport), providing the period of rehabilitation has progressed as anticipated.

ACL-RSI SCALE: DEVELOPMENT

Given the apparent impact of psychological factors on athletes returning to sport following injury or surgery, it may be helpful to be able to quantify some of these factors and also to determine whether they have a predictive value. The Anterior Cruciate Ligament Return to Sport after Injury (ACL-RSI) scale was designed to address these issues, given the paucity of psychological measures specific to sports injury rehabilitation [10]. The aim was to develop a tool to specifically measure psychological readiness to return to sport after ACL reconstruction.

Items developed for the scale were centred on three categories of psychological responses identified in the literature as being associated with returning to sport: **emotions, confidence and risk appraisal** (see Table 1). For the emotions category, an extensive search of the literature identified fear of re-injury, frustration, nervousness and tension as commonly reported emotions experienced by athletes during rehabilitation and the commencement of sport. Five items (items 1-5) were therefore developed to measure these emotions.

In the sports setting, confidence typically refers to the amount of confidence the athlete has in their ability to perform well at their sport. However, in the case of ACL reconstruction, it may also relate to the level of confidence the athlete has in the function of their operated knee. Five items (items 6-10) were therefore generated to cover these two aspects of sport confidence. Three (items 6-8) were developed to target the athlete's confidence in their knee function and two (items 9, 10) were developed to measure the athlete's confidence in their overall ability to perform well at their sport.

Finally, two items (items 11, 12) were included to investigate the cognitive risk appraisal of the athlete to re-injury. The second of these, item 12, was suggested by a patient group during pilot testing of the scale for relevance.

The ACL-RSI scale was initially completed by 220 athletes who had undergone ACL reconstruction between 8 and 22 months (mean = 12 months) previously. The scale was found to have high internal consistency (Cronbach's alpha = 0.96) and principal components analysis confirmed the presence of one underlying factor that accounted for 67.8% of the total variance. It is important to note that although the scale was designed around three constructs, these constructs were all highly related and a single score between 0-100 is calculated for the scale where higher values indicate a more positive psychological response (see Table 1).

To validate the scale, the athletes were divided in the following groups; ***1)*** athletes who had returned to full completion, ***2)*** athletes who had returned to training only, ***3)*** athletes who had not yet returned but planning to return to sport, and ***4)*** athletes who given up sport. Athletes who had returned to full competition scored significantly higher than the other three groups and athletes who had given up sport scored significantly lower [10].

Table 1: ***ACL-RSI items***

Scale Item	Order in Scale
Emotions:	
1. Are you nervous about playing your sport?	3
2. Do you find it frustrating to have to consider your knee with respect to your sport?*	6
3. Do you feel relaxed about playing your sport? **#**	12
4. Are you fearful of re-injuring your knee by playing your sport?	7
5. Are you afraid of accidentally injuring your knee by playing your sport?	9
Confidence in performance:	
6. Are you confident that your knee will not give way by playing your sport?	4
7. Are you confident that you could play your sport without concern for your knee?	5
8. Are your confident about your knee holding up under pressure?	8
9. Are you confident that you can perform at your previous level of sport participation?	1
10. Are you confident about your ability to perform well at your sport?	11
Risk appraisal:	
11. Do you think you are likely to re-injure your knee by participating in your sport?	2
12. Do thoughts of having to go through surgery and rehabilitation again prevent you from playing your sport?	10

* Item 2 was from the Quality of Life Outcome Measure for Chronic ACL Deficiency (ACL-QOL) scale 9.

\# Item 3 measures “tension” with the positive antonym relaxed used to get a balance between positive and negatively worded items.

Each item is scored on a 0-100 scale and scores from the 12 items are summed and averaged to obtain a single score (0-100). Higher scores indicate a more positive psychological response.

ACL-RSI SCALE: PREDICTIVE VALUE

Given the potential effect of psychological factors on athletes during rehabilitation from ACL reconstruction, it may be helpful to be able to predict which athletes could benefit from psychological counselling or intervention to ensure that psychological recovery occurs in parallel with physical recovery. It is therefore relevant to know whether the psychological responses athletes experience during the rehabilitation period are related to subsequent return to sport.

Two large scale studies have been conducted which have shown that the ACL-RSI scale can in fact be used to predict return to sport outcomes. The first enrolled 100 athletes who completed the ACL-RSI at 3, 6 and 12 months

after undergoing ACL reconstruction surgery [8]. At 12 months half of the athletes had returned to competitive sports. Scores on the ACL-RSI at 6 months were significantly lower in the athletes who did not successfully return to their competition sport at 12 months compared to the athletes who did. Thus, an athlete's readiness to return to sport at 6 months after ACL reconstruction surgery was related to whether or not they actually returned to sport at 12 months. This result suggested that it may be possible during rehabilitation to identify athletes at risk of not returning to competitive sport due to psychological.

The second and larger study of 187 patients administered a battery of psychological assessments, including the ACL-RSI scale, before ACL reconstruction surgery, as well as at 4 and 12 months after surgery [3]. At 12 months only 56 athletes (31%) had returned to their previous level of sports participation, despite scoring well on standard outcome measures. Three variables; psychological readiness to return to sport, the participant's estimate of the number of months it would take to return to sport, and locus of control predicted returning to sport by 12 months after surgery. Psychological readiness, as measured by the ACL-RSI, was the only variable to be predictive of return to sport both preoperatively and at four month postoperatively. Therefore this study showed that even before the participants underwent surgery, their psychological responses were associated with their chances of returning to the pre-injury level 12 months later. Furthermore, the results of this study suggested that a score of less than 56 points on the ACL-RSI may indicate an increased risk of not returning to the pre-injury level and may therefore help clinicians to identify at-risk athletes.

The patient cohort of the second study was subsequently followed up at two years to specifically see whether those who had not returned by 12 month made a later return [4]. The group included 122 competitive and recreational level athletes who had not attempted sport at 12 months. Ninety-one per cent of athletes reported having returned to some form of sport. At 2 years after surgery 66% were still playing sport, with 41% playing at their previous level and 25% playing at a lower level. Thus, most of the athletes who were not playing sport at 1 year had returned to some form of sport within 2 years.

Nonetheless, only 41% of athletes were still playing their pre-injury sport at 2 years post-operatively. When sport participation data was categorised by the type of sport, basketball had the highest rate of return with 50% of athletes playing at 2 years, followed by netball (41%), Australian Rules (37%), and soccer (26%). It appears that the sustained participation rates for those athletes who do not return within the first 12 months postoperatively are low. Once again, a more positive psychological response was associated with participation in the pre-injury sport at 2 years.

Overall, the ACL-RSI scale appears to be a useful tool for screening and identifying athletes who may have difficulty resuming sport after ACL reconstruction due to psychological reasons. The scale is currently available in English, Swedish, French [6] and German versions, with other translations currently underway.

CONCLUSION

Knee injuries are associated with negative psychological responses which may persist following surgery such as ACL reconstruction, and which may influence rehabilitation and an athlete's decision whether or not to return to sport. Fear of re-injury is one such factor and has been reported to be a relatively common reason for patients choosing not to return to sport following ACL reconstruction. The ACL-RSI scale was developed as a tool to assess an athlete's psychological readiness to return to sport following ACL reconstruction. It has been shown to be a significant predictor of whether an athlete will return to sport, not only in the 4 to 6 month period following surgery, but also pre-operatively. Whether negative psychological factors can be addressed during rehabilitation remains to be determined.

LITERATURE

[1] ARDERN CL, TAYLOR NF, FELLER JA, WEBSTER KE. Fear of re-injury in people who have returned to sport following anterior cruciate ligament reconstruction surgery. *J Sci Med Sport 2012; 15(6): 488-95.*

[2] ARDERN CL, TAYLOR NF, FELLER JA, WEBSTER KE. A systematic review of the psychological factors associated with returning to sport following injury. *Br J Sports Med 2013; 47(17): 1120-6.*

[3] ARDERN CL, TAYLOR NF, FELLER JA, WHITEHEAD TS, WEBSTER KE. Psychological responses matter in returning to preinjury level of sport after anterior cruciate ligament reconstruction surgery. *Am J Sports Med 2013; 41(7): 1549-58.*

[4] ARDERN CL, TAYLOR NF, FELLER JA, WHITEHEAD TS, WEBSTER KE. Sports participation 2 years after anterior cruciate ligament reconstruction in athletes who had not returned to sport at 1 year: a prospective follow-up of physical function and psychological factors in 122 athletes. *Am J Sports Med 2015; 43(4): 848-56.*

[5] ARDERN CL, WEBSTER KE, TAYLOR NF, FELLER JA. Return to sport following anterior cruciate ligament reconstruction surgery: a systematic review and meta-analysis of the state of play. *Br J Sports Med 2011; 45(7): 596-606.*

[6] BOHU Y, KLOUCHE S, LEFEVRE N, WEBSTER K, HERMAN S. Translation, cross-cultural adaptation and validation of the French version of the Anterior Cruciate Ligament-Return to Sport after Injury (ACL-RSI) scale. *Knee Surg Sports Traumatol Arthrosc 2015; 23(4): 1192-6.*

[7] KVIST J, EK A, SPORRSTEDT K, GOOD L. Fear of re-injury: a hindrance for returning to sports after anterior cruciate ligament reconstruction. *Knee Surg Sports Traumatol Arthrosc 2005; 13(5): 393-7.*

[8] LANGFORD JL, WEBSTER KE, FELLER JA. A prospective longitudinal study to assess psychological changes following anterior cruciate ligament reconstruction surgery. *Br J Sports Med 2009; 43(5): 377-81.*

[9] MOHTADI N. Development and validation of the quality of life outcome measure (questionnaire) for chronic anterior cruciate ligament deficiency. *Am J Sports Med 1998; 26(3): 350-9.*

[10] WEBSTER KE, FELLER JA, LAMBROS C. Development and preliminary validation of a scale to measure the psychological impact of returning to sport following anterior cruciate ligament reconstruction surgery. *Phys Ther Sport 2008; 9(1): 9-15.*

[11] WEBSTER KE, LANGFORD J, FELLER JA. Psychological impact of anterior cruciate ligament reconstruction: an examination of gender differences. Paper presented at: Promoting Health and Performance for Life. *Proceedings of the 11th World Congress of Sport Psychology 2005; Sydney.*

RETURN TO HIGH LEVEL PLAY AFTER ACL RECONSTRUCTION

A. WILLIAMS

INTRODUCTION

Having undertaken a good operation there has to be a decision made as to when it is safe to return to play. A premature return to play prior to restoration of satisfactory neuromuscular control to a limb will put the good surgery at risk of failure with graft re-rupture. I think it is correct to say that most surgeons involved in dealing with elite athletes, such as myself, try to extend the recovery time to return to play to be longer and longer! Most graft re-ruptures in elite sport occur with return to play around 6-7 months post surgery. It is likely that the "knee" matures for around 18 months following ACL reconstruction. As a result it is illogical to return all players to play at the same point in time as each is ready at a different time. Apart from insisting on minimum safe times, using a time-dependent return to play is risky. Although the biological healing of a graft may have completed prior to 18 months, the fine-tuning of neuromuscular control takes a very long time; in truth it is probably never entirely normal. Nevertheless, with structured rehabilitation and maintenance drills, safe function is to be expected as long as certain criteria are met.

Nowadays when I meet an athlete for the first time who has an uncomplicated ACL rupture I explain that my aim for them is to return to play between six and nine months from surgery. I go on to tell them that when I was younger I would say to my players confidently: "you will be back in six months" - but with experience I have learnt it often needs to be longer than that, and some individuals take as long as a year. Obviously if there are other factors such as significant chondral lesions and other ligament tears etc. the recovery should be expected to be slower. Generally, I don't use allograft, but it would seem logical that these grafts need far longer to mature than autograft. Also there would be logic (but no proof) that hamstring grafts may need longer than patellar tendon grafts. Some individuals are prone to ACL rupture and therefore also re-rupture of ACL grafts due to factors such as malalignment, a strong family history, being skeletally immature, or being abnormally lax. It is important to identify these patients and insist on a longer return to play. In elite sport this is rarely a concern in senior established players as the process of "natural selection" means that an ACL tear in this group is actually a relatively rare injury. However in the young age group it is a real issue.

I support the "traffic light" concept, popularised by "Isokinetic", to govern progress in rehabilitation. A player cannot move on to the next level of rehabilitation if they are not safely, and without difficulty, completing tasks

of the lower level. In this way those athletes who are capable of a rapid safe return to play can do so and avoid any unnecessary delay, and will be separated from those who must need a longer period to avoid a risky return too early.

Unfortunately despite much study in the area, the decision as to when a player can return to play remains uncomfortably inexact. I have learned to customise my decision making according to the patient, key milestones and the graft choice. Due to the lack of consensus and objective firm criteria a team approach combining opinions of physios, team physicians, and the surgeon is important.

"NEED TO KNOW" FACTS

1 -The graft is dying or dead before healing and rejuvenation.

2 -The ACL cannot be as good as the natural one, although statistically patients are more likely to rupture the contralateral ACL than re-tear the ipsilateral graft. Nevertheless if they have torn their natural ACL, don't forget they can certainly tear their "new" one!

3 -Knee joint proprioception will never be the same again hence problems with mal-alignment, or a suboptimal ACL reconstruction.

MY DECISION MAKING STRATEGY

When I am at the point of considering a return to full training, and subsequent play, I use the following factors to determine a return to play time once a player has successfully completed their rehabilitation period, and at a minimum of 6 months after surgery:

Factor One: Player Confidence

It seems logical that a player should not compete until they are totally confident. There is a problem with this criterion-many athletes have achieved much in their careers by having an abnormally positive attitude to play, even despite "carrying" injuries. I therefore cannot be persuaded by player confidence alone! Alternatively, if a player lacks confidence this usually reflects a significant deficit in their readiness to play, and I take that very seriously.

Factor Two: The Dry Knee

An effusion is a reflection of either a problem or that the knee is not ready for loading. Naturally after any injury, and this includes surgery, there will be an inflammatory response and fluid will accumulate in the joint. In the longer term fluid may persist if there is subtle instability in the joint, chondral damage or mechanical issues such as meniscal tears. It is essential to take an effusion seriously since trying to continue with activity whilst the knee is swollen can cause permanent damage. The fluid is thin rather than naturally occurring thick synovial fluid and is therefore a poor lubricant and shock absorber, plus it contains chemicals from the inflammatory response that perpetuates the inflammatory response and swelling. I also suspect the inflammatory mediators soften the articular cartilage. It is not uncommon for a player working through an effusion to develop subsequent chondral damage, such as in the trochlear groove, related to the loading of rehabilitation exercises. These situations are very regrettable. A collaboration between Fortius Clinic and The Kennedy Institute at Oxford University has recently shown a correlation following knee injury between increased levels of various markers, especially IL6, with low KOOS4 scores and improving KOOS4 over time as the IL6 falls [1].

If effusions persist past three months into the recovery I obtain an MRI scan and will often undertake an arthroscopy if there is any suspicion of a mechanical problem such as a meniscal tear. If the chondral surface looks healthy and there is no sign of meniscal pathology then aspiration of the joint and injection of PRP, or viscosupplement and some

steroid is appropriate. Steroid must not be used to progress a player towards play however and is simply rather used to calm the knee down to allow resolution of effusion for a period of relatively low loading to regain muscle strength and neuromuscular control before proceeding again some weeks later.

In my career cases in which all seemed to be well apart from an effusion have been associated with premature graft re-rupture. Swelling has to be respected.

Factor Three: Aerobic Fitness

It seems obvious that allowing athletes who are aerobically unfit to play is a risk. They will fatigue quickly and lose neuromuscular control, which will put them at risk of graft re-rupture. Aerobic fitness is easily measured with functional testing and tests such as a VO_2 Max.

Factor Four: The Concept of Limb Symmetry

This concept embodies the theory that normal neuromuscular control in the limb will protect ACL graft.

Some athletes will have jump/land mechanics that are putting them at risk of ACL injury. These need to be corrected during the rehab process of course. This is particularly true of female athletes who have a tendency to land with valgus and external rotation, even in the uninjured limb.

I explain to the players that they should have limbs with sufficient muscular symmetry that I find it hard to judge which was the knee that was operated upon. They can have their muscle strength tested with isokinetic testing and have functional testing such as hop heights, hop distance and star excursion measured. Prior to return to play I aim for a deficit of less than 5% side to side. I also explain that none of the tests we do are perfect since they cannot replicate true on-field play. Nevertheless they, of course, provide helpful evidence to justify return to play.

Factor Five: Timing

Whilst anecdotally I have had many players return ahead of schedule I realise this is not something that should be encouraged since the majority of players will be at risk if they do this.

Factor Six: Graft Maturation

The reality is that we have no firm understanding of the biology of graft healing. It would be logical to suggest that the fastest healing within the bone tunnel would be to blocks of a quadriceps tendon or patellar tendon. It is likely that the quality of soft tissue healing in these grafts is also better as they have a natural attachment to their bone blocks. It would also be logical to think that the slowest healing of all would be with Allograft. The truth is that the proof of this is lacking. We can only really guess at the various stages of healing presuming an initial graft degradation followed by revascularization and subsequent ligamentisation with the laying down of collagen. The only judge of the healing process is clinical examination, the presence or absence of an effusion, instrumented laxity testing, stress radiographs, or MRI appearance. MRI scans report the signal of the graft with a dark black appearance indicating good healing and a pale appearance indication oedema in the graft. Unfortunately we do not have firm data as to how this can guide is with regards to timing of return to play. Perhaps a pale graft should delay return to play and reduce loading durng the rehabilitation period. When a loose ACL is obvious by clinical examination, it is too late to make any adjustments to the graft itself. Adding a lateral tenodesis in some cases could be justified, but practically it would be best to encourage an athlete to accept a slower return to play hoping that better neuromuscular control after a longer rehabilitation period could allow the player to cope dynamically with their ACL laxity.

CONTINUING SAFEGUARDING AFTER RETURN TO PLAY

When they are back on the pitch – they think it is all over – it's not! With the knowledge that the knee will mature for 18 months and will never be normal it is important that the 1st season has altered training and playing schedules including recovery and consolidation periods and graded exposure to match play. To avoid re-rupture preventative maintenance strengthening and conditioning programmes must be used career long. The basis of these can be the FIFA 11+ and PEP programmes.

LITERATURE

[1] WATT FE, PATERSON E, FREIDIN A, KENNY M, JUDGE A, SAKLATVALA J, WILLIAMS A, VINCENT TL. Acute Molecular Changes in Synovial Fluid Following Human Knee Injury Are Associated With Early Clinical Outcomes. *Arthritis Rheumatol. 2016; 18 (epub ahead of print).*

ANTERIOR CRUCIATE LIGAMENT

17èmes Journées Lyonnaises de Chirurgie du Genou

The ACL is THE ligament that entertains many surgeons in the orthopaedic world. While this ligament is cut with confidence in 100% of total knee arthroplasty procedures, we are still struggling to reconstruct it in a perfect way. Indeed we have an unfortunately large number of failures - many of which are due to surgical mistakes. A critical and often overlooked part of performing an ACL reconstruction is to analyze all of the associated structures:
What is the role and importance of the so-called anterolateral ligament or the anterolateral complex? How much do surgical technique, graft choice, tunnel location, and fixation methods influence outcomes? What is the role of biology and the menisci in restoring stability? Finally, what impact do rehabilitation, proprioception, muscular control and strength, and neurologic control have on return to sport following ACL reconstruction?
We will develop and try to understand all of these aspects of ACL reconstruction.

Elvire SERVIEN,
President of Lyon School of Knee Surgery

Lyon School of Knee Surgery's Team:
Tarik AIT SI SELMI
Roger BADET
Johannes BARTH
Nicolas BONIN
Michel BONNIN
Laurent BUISSON
Christophe BUSSIERE
Pierre CHAMBAT
Christophe CHOL
David DEJOUR
Guillaume DEMEY
Philippe DEROCHE
Gérard DESCHAMPS
Jean-Marie FAYARD
Sébastien LUSTIG
Philippe NEYRET
Jean-Claude PANISSET
Alban PINAROLI
Elvire SERVIEN
Bertrand SONNERY-COTTET
Mathieu THAUNAT
Franck TROUILLET

Past Presidents:
Albert TRILLAT
Henri DEJOUR
Pierre CHAMBAT
Philippe NEYRET
David DEJOUR
Michel BONNIN