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II.4 Isometric Reconstruction of the Anterior Cruciate Ligament: Femoral and Tibial Tunnel Placement

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Introduction

Study of our anterior cruciate ligament (ACL) plasties shows that more than one-fourth of failures are due to technical faults. This is true for all types of repair and especially for those involving the use of artificial ligaments, which are less tolerant than autogenous ligaments. These observations have led us to propose a set of rules, the first of which being the respect of isometry. Isometry has two components: "extrinsic" isometry depends on the choice of the femoral and tibial insertions, and "intrinsic" isometry depends on the ligament architecture.

This chapter presents the development and clinical implementation of isometric surgical insertion for an ACL replacement. Definitions of both extrinsic and intrinsic isometry are first provided. Methodology and results of experimental data used to determine isometric surgical placement are presented, followed by a description of the corresponding clinical implementation of the proposed technique.

"Extrinsic" Isometry

Determination of the Femoral Isometric Point

The results of this anatomic and radiological study have previously been published [5]. As a whole, the ACL is not isometric. It is taut in complete extension and relaxed for a 90° knee flexion. However, some transitional fibers are close to isometry, as has been shown by many authors, notably Daniel et al. [6], Abbink [1], and Bradley et al. [4].

The femoral isometric point F, i.e., femoral attachment of these fibers, is the center of a 140° circular arc formed by the posterior border of the lateral condyle (Fig. 1). The radius of this circle varies between 17 and 26 mm depending on the subject. Saragaglia et al. [17] and more recently Elias et al. [8] arrive at the same conclusion. On average, point F is located at 59% of the anteroposterior length of the condyle, measured on a line parallel to the Blumensaat line and starting from the top of the posterior condyle. It is re markable that this circular arc of 140° has the same numerical value as the knee's normal range of motion. Moreover, the center of the arc is the only

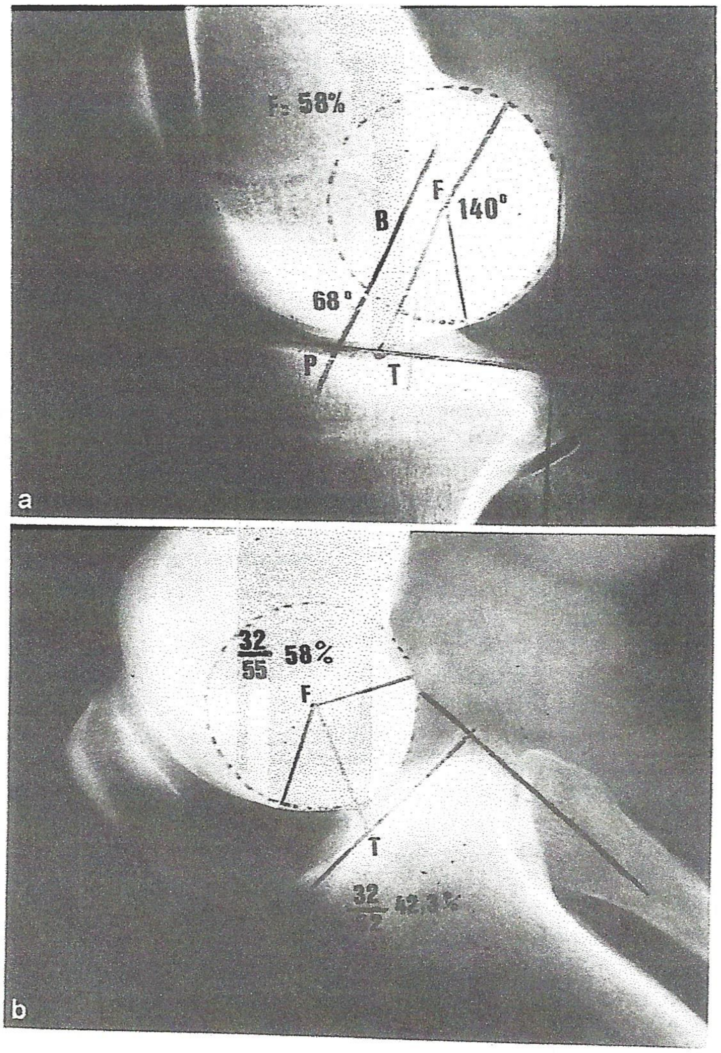

Fig. 1. a The isometric point F is situated at the center of a 140° circular arc and corresponds for this case to 58% of the anteroposterior length of the condyle (i.e., 55 mm for the example shown). The angle formed between the Blumensaat line and the tibial plateau is 68° in maximum extension. Note how the increased condylar radius in a (and hence increase in distance FT) explains the loading of the ACL with respect to the knee in flexion seen in b. b Same knee in flexion, the isometric tibial point T, center of the tibial plateau along its longest length, is at 42.3% of the length (52 mm) of the superior face of the internal tibial plateau. The FT distance is practically constant between flexion and extension (32–31 mm) since there is little to no hyperextension in this knee

geometrical shape possibly compatible with the definition of isometry during complete flexion-extension of the knee.

Determination of the Tibial Isometric Point

The stabilization by the ACL can be considered as a geometric system. The tibial plateau appears as a tangent to the circle formed by the posterior border of the lateral condyle. The contact point moves from front to back when knee flexion varies from 0° to 140°. Since the medial tibial plateau is relatively immobile when ACL is normal (unlike the lateral tibial plateau), and the ACL inserts near the axial border of the medial tibial plateau, this insertion is also relatively immobile in the anteroposterior direction. Our choice of the center of the tibial tunnel is based on three considerations: (a) anatomic and radiological study of the center of the tibial insertion of the ACL, (b) the absolute necessity of the absence of conflict between the plasty and the roof of the intercondylar notch in complete extension, and (c) perioperative clinical measurements of length variations in the plasty.

"Intrinsic" Isometry

One should in fact speak of "limited anisometry." The anterior fibers relax during extension. The posterior fibers relax during the flexion. The ligament, as a whole, is taut during complete extension. During the movement from extension to complete flexion, the most posterior and proximal femoral insertions become anterior and distal, and roll around the anterior fibers. The main axis of the ACL femoral insertion rotates 140°. This movement is clockwise for the right knee and counterclockwise for the left knee. This movement partially compensates for the decrease in the distance between the tibial and femoral insertion points so that the individual fibers remain relatively isometric (Fig. 2). The natural elasticity of the ligament or the autogenous transplant compensates for these movements without fiber stress.

The drawback of artificial fibers, which is their lack of elasticity, must be compensated by the ligament's architecture. This architecture must have two principal anterior and posterior bundles. These two bundles are made up of longitudinal fibers without transversal structures because transversal fibers would limit the winding around of longitudinal fibers during torsion in the intraarticular part of the ligament (Fig. 3).

With the ligament being placed for practical reasons in the flexed knee, the two bundles must be pretwisted around one another in a clockwise direction for the right knee and a counterclockwise direction for the left knee. This implies different ligaments for left and right knees. When the knee moves from complete flexion to extension, the twist disappears. In complete extension all fibers are parallel and longitudinal, thus at their maximum length. The reproduction of this architecture allows the physiological mechanism of progressive fiber recruitment.

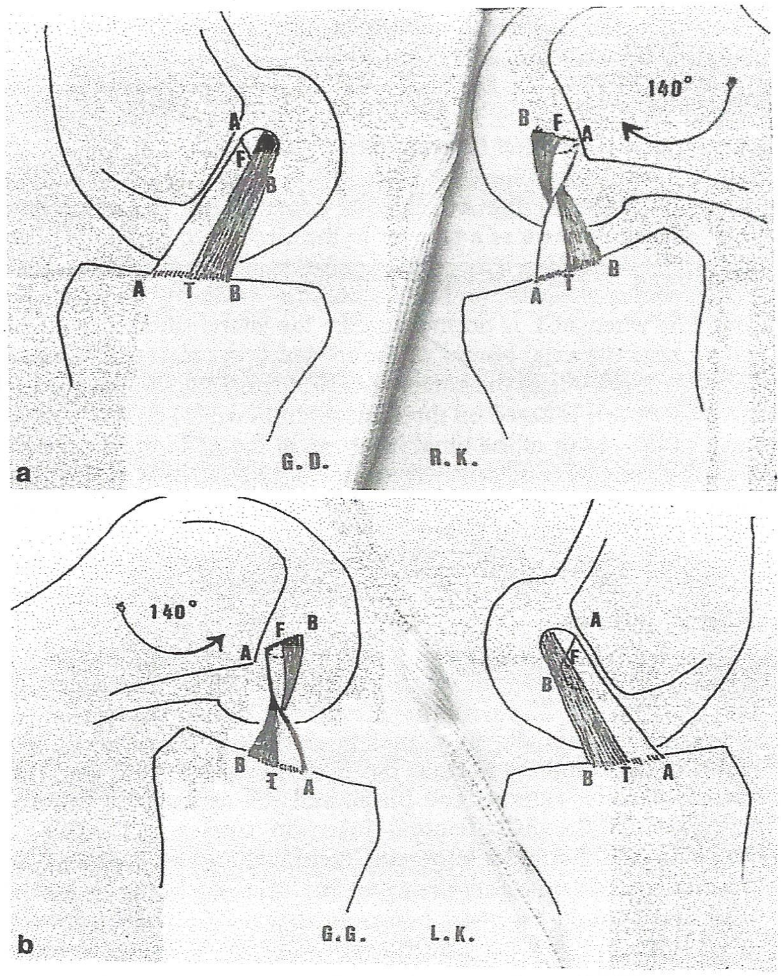

Fig. 2. a Right knee. In extension the ACL fibers are taught, longitudinal, and parallel. In flexion at 140° the line AB has turned by the same number of degrees, which invokes clockwise torsion in the ligament fibers. The artificial ligament must during manufacturing be pretwisted in the same direction as the torsion to sustain it without damage. b Left knee. The torsion here is counterclockwise and requires a specific ligament

Methodology and Results

Anatomic and Radiological Study of Tibial ACL Insertion

Materials and Method

This study was performed on 25 knees operated by open surgery for total or unicompartmental prostheses, and having a normal ACL (14 men, 11 women).

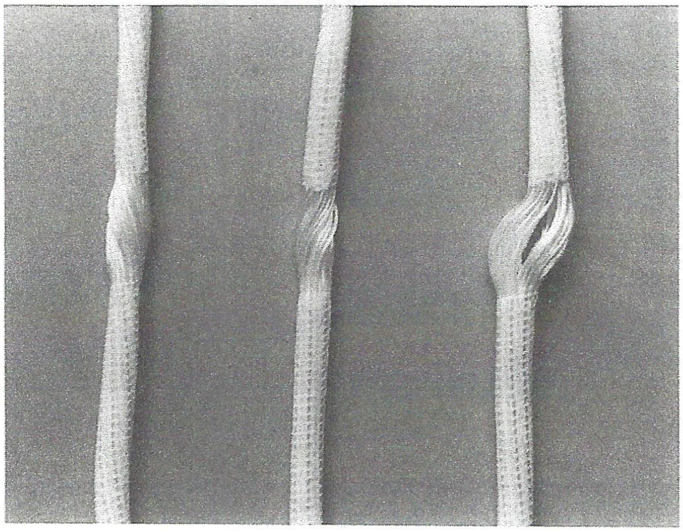

Fig. 3. *From left to right:* LARS ligament for left ACL (counterclockwise) as inserted at 90° knee flexion; right ligament (clockwise) the two anterior and posterior bands which form the ligament. The free central fibers correspond to the intraarticular zone. In the intraosseus zone the longitudinal fibers are united by a special knitting procedure

Metallic landmarks were fixed in the cartilage at the anterior and posterior boundaries of the ACL insertion. The spacing between the landmarks was measured and marked with an electrical bistoury on the adjacent cartilage of the medial tibial plateau. A lateral X-ray was taken. The center between anterior and posterior marks was determined on the X-ray. The resected bone pieces and the ACL insertion were then measured (Fig. 4).

Results

The ACL insertion is large: from 16 to 21 mm (mean 19 mm). Its center is located near the middle of the projection of the largest anteroposterior length of the tibial plateau. The length ranged from 45 to 65 mm (mean 54.4 mm; Figs. 1, 5). The distance between the center of the tibial ACL insertion and the most anterior border of the plateau was 22–33 mm (mean 26.92 mm), that is, 49.6% of the total length measured from the anterior border. Measurements were also performed relative to the medial tibial plateau (MTP). Its longest length was 39–56 mm (mean 46.6 mm). The center of the ACL insertion relative to the anterior border of the MTP was 17–23 mm (mean 19.8 mm), that is 42.5% of the total length measured from the anterior border.

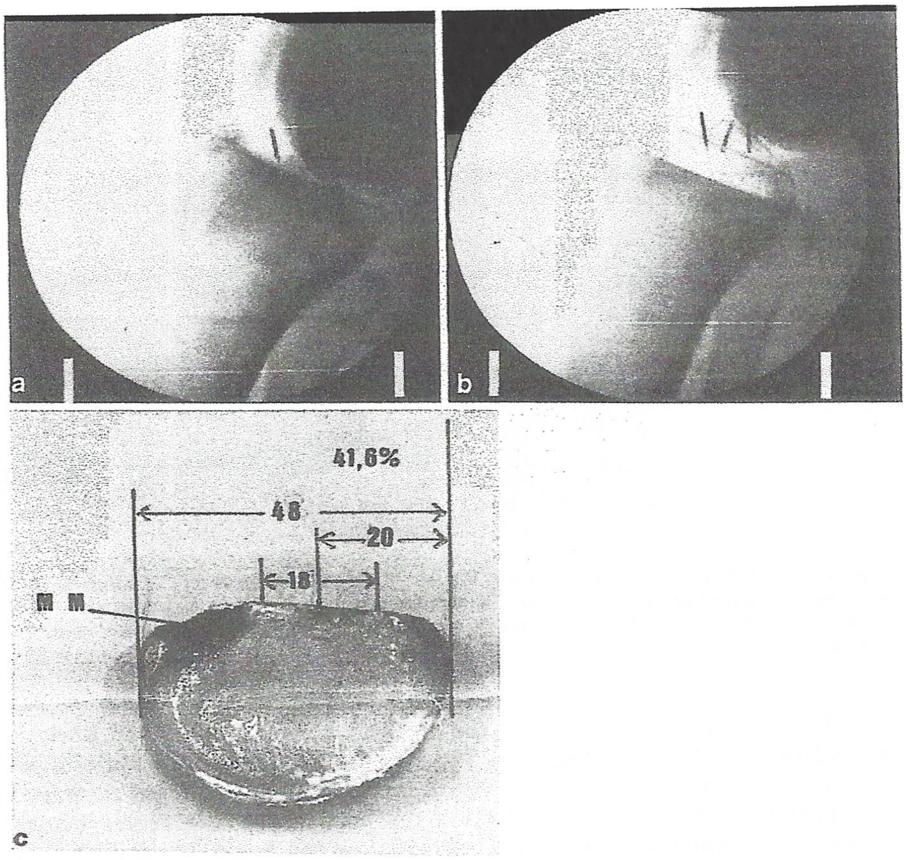

Fig. 4a–c. Locating the ACL insertion for a unicompartimental prosthesis. a View before resection. b View after resection of the internal tibial plateau. The median landmark is dead center of the plateau and corresponds to the apex of the spine. c The measurements are taken on a resected plateau. The ACL insertion is 18 mm, and its center is at 20 mm, or 41.6% of the total length 46 mm. Note that the posterior insertion of the medial meniscus is flush with the most posterior fibers of the ACL

Absence of Conflict with the Intercondylar Roof

The conflict which seems to be the cause of technical faults has led us to study the relationship between the intercondylar roof and the tibial plateau

Materials and Method

Fifty patients without pathology or previous traumatism on at least one knee, were recruited: 29 men and 21 women aged 18–36 years. A lateral X-ray of the

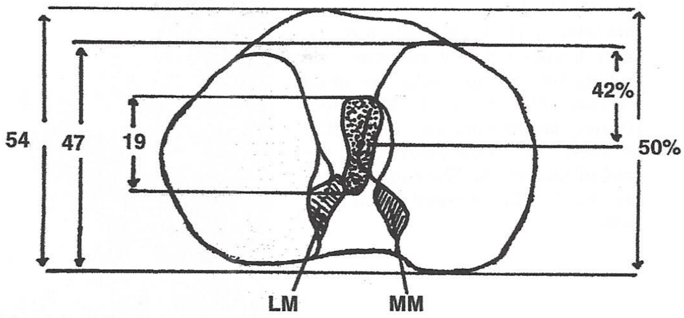

Fig. 5. Schematic view of tibial plateau and average measurements reported in millimeters. Note the close relationship between the ACL and the posterior horn of the lateral meniscus (*LM*)

knee of a standing subject at maximum extension was taken while ensuring superposition of the condyles. The source-plate distance was 1.50 m to prevent any magnification and control penetration to permit proper visualization of the Blumensaat line. On this X-ray we measured: (a) the posterior angle formed between the Blumensaat line and the tibial plateau, and (b) the space between the intersection of these lines and the middle of the tibial plateau (i.e., between the most anterior projection and the posterior border of the internal tibial plateau; the presumed center of the ACL insertion).

Results

The B-TP angle (Blumensaat line, tibial plateau) varied between 82° and 45°, with a mean of 65.0° (64.9°±8.3° in men and 65.1°±7° in women). Of the 50 patients 35 (70%) had an angle in between 60° and 70° (65°±5°) The value of this B-TP angle depends on two factors: (a) the angle between the intercondylar roof and the femoral axis; (b) the degree of added hyperextension. The distance between the Blumensaat line and the center of the tibial plateau was 14 –3 mm, with a mean of 9.5 mm (9.8±1.9 mm in men and 9.3±2 mm in women; Fig. 6). This intersection appears always anterior to the tibial plateau center for all knees studied. The larger the B-TP angle, the closer the intersection was to this center. In 2 of 50 knees (4%) the distance was 3 and 4 mm.

Perioperative Clinical Study

Materials and Method

We measured the movement of the artificial ligament at the tibial tunnel for 50 operated patients according to the following procedure. Only the femoral extremity of the ligament was fixed with an interference screw. The ligament was

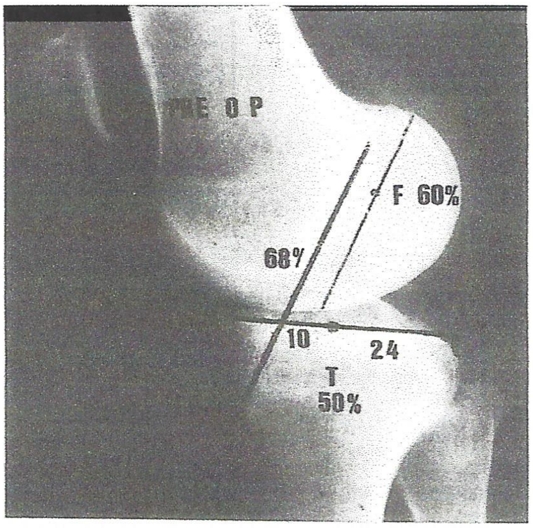

Fig. 6. The lateral X-ray in hyperextension permits calculation of the angle between the Blumensaat line and its intersection with the tibial plateau. The distance PT (here 10 mm) ensures absence of conflict between the future plasty and the roof of the notch. The intervention can be totally planned from this view

held manually in tension, marked by a thin needle at the tibial tunnel exit first at 100° knee flexion and then at the complete extension. Then the distance between the landmarks was measured.

Results

In 10 cases the two landmarks were superimposed, and in 16 they were in contact with one another. We accepted an error of 0.5 mm in these cases. In 16 cases the distance was 1 mm, in 6 it was 2 mm, and in 2 it was 3 mm. The mean movement was 0.84 mm.

Clinical Application

Principles and Techniques

The isometric femoral point can be determined from an exact preoperative lateral X-ray projection, with superposition of the two condyles and the plate-source distance at 1.5 m to avoid any magnification. We used a transparent template to determine the circle and its center more easily.

The position of the center F can then be determined with respect to anatomical reference points. These reference points can be the circumference of the circle, the anterior border of the intercondylar notch roof or its posterior border which corresponds to the "over-the-top" point, that is at the posterior edge of the Blumensaat line on the X-ray (point O). The distance between points F and O can be measured on the X-ray. It varies from 6 to 12 mm depending on the subject. (Fig. 7).

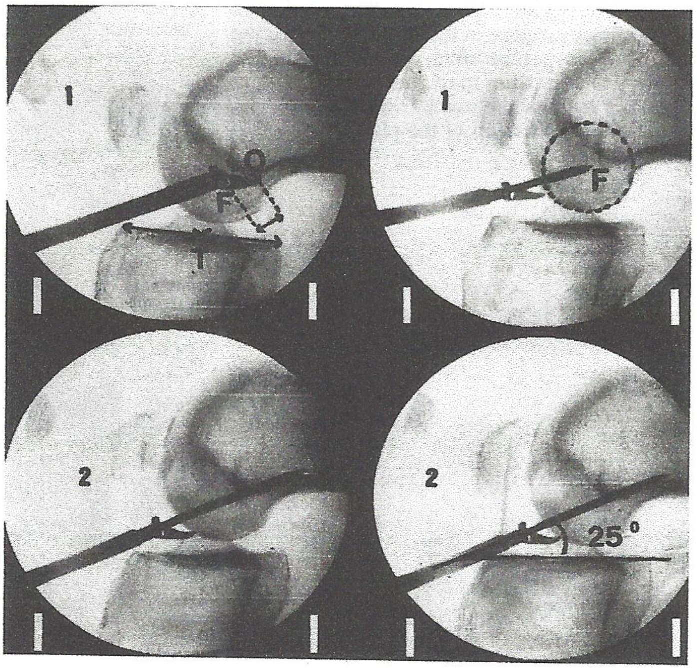

Fig. 7. Perioperative view under fluoroscopy. *1*, The isometric guide is opened to the FO spacing which allows placement of the K-wire guide at the center of the circle. The extremity of the guide arches around the posterior border of the roof of the notch and is oriented at 10 o'clock or 2 o'clock depending on whether it is a right or left knee. *2*, The K-wire is penetrated into the condyle with an approximate angle of 25° with respect to the tibial plateau

The femoral guide FAC (Ligament Advanced Reinforcement System, LARS), the end hook of which attaches onto the point O, is adjustable. The length between the tip of the hook and the drill guide, which passes through the handle of the instrument, represents the distance between the points F and O and can be adjusted thanks to a graduated wheel (Fig. 8).

The body of the instrument represents the future plasty and must be oriented in the notch to avoid contact with its walls, therefore guaranteeing the absence of friction between the neo-ACL and the surrounding bone. This body of the instrument crosses the anterior face of the posterior cruciate, which allows visualization of the future relationship between the two ligaments after the ACL reconstruction, a relationship which guarantees the stability of the knee.

Use of the guide permits accurate placement of the K-wire which serves as a guide for a cannulated drill bit.

In the absence of a preoperative X-ray, the center of the circle, and adjustment of the guide can be determined using fluoroscopy. Open or arthroscopic surgery can be performed. In the latter case the guide with the hook in closed position is introduced by a microincision at the intersection of the

Fig. 8. The LARS FAC guide. The graduated wheel allows variance in the K-wirehook spacing according to preoperative measurements. The intraarticular portion must remain at a distance from the walls of the notch, which ensures absence of later abrasion of the plasty

medial border of the patellar tendon and the anterior border of the tibial plateau. The knee is flexed at 90°–100°. The guide penetrates into the middle of the notch, somewhat closer to the anterior border of the medial condyle than to the lateral condyle, yet keeping a certain distance. The hook is then opened to the desired spacing and fixed at the "over-the-top" position, at 10 o'clock or at 2 o'clock, depending on whether it is a right or left knee. The body of the instrument is directed obliquely upwards and out with about a 25° angle with respect to the tibial plateau and a 20° outwards angle with respect to the sagital plane. This orientation actually represents that of the normal ACL with a knee flexed at 90°.

The 3 mm rigid K-wire is motor-driven through the guide. When penetrated by a few centimeters, the guide is retracted. The K-wire can then penetrate totally. It passes by, at a distance, the posterior methaphysal cortical bone and exits quite high on the anterolateral femur and out through the skin. The choice of the center of the tibial plateau as the center of the tibial tunnel corresponds to the anatomy and guarantees the absence of conflict between the plastie and the roof of the notch in the majority of cases. Nonetheless, in the rare cases where there is coexistence of a vertical roof and a hyperextension, a conflict between the plasty and the roof is not eliminated if the roof-center distance is inferior to the radius of the tunnel.

We cannot move the insertion back since this would risk making the plasty vertical, which would deprive it of its mechanical efficiency. In these rare cases a plasty of the roof of the notch must be performed. These cases must be

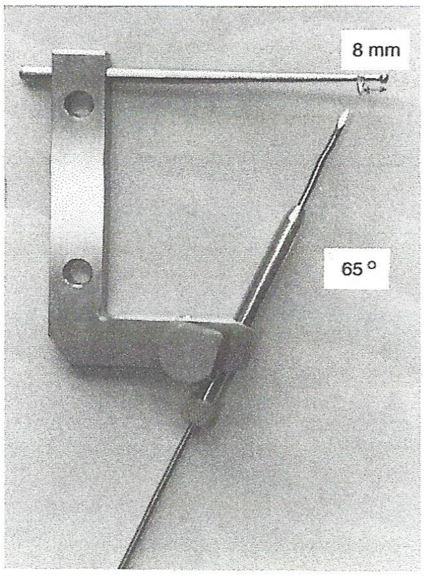

Fig. 9. The LARS TAC guide. The rounded extremity of the intraarticular rod touches the anterior aspect of the PCL. The tibial K-wire, which must be oriented at 65°, penetrates into the articulation, 8 mm in front of the PCL, i.e., at the center of the plateau

detected clinically, by looking for hyperextension, and radiologically. The lateral X-ray in maximal extension must be part of a preoperative assessment and permit planification of the surgical intervention (Fig. 6).

The difficulty in arthroscopy is determining the field of depth. The LARS tibial guide has a ball on its extremity which one applies on the anterior face of the PCL and it provides a 65° angle with respect to the tibial plateau (Fig. 9).

In this situation the point pierced into the cartilage of the tibial spine is situated 8 mm more forwards, which is on average 42% of the MTP length. This corresponds to the intraarticular emergence of the K-wire put into place from the middle of the medial face of the metaphysis, just above the tendons of the Pes Anserinus. Another method to position the K-wire is based on a geometrical relationship (Fig. 10). The femoral drill guide was inserted in the external condyle from the center of the posterior circle as indicated above. This K-wire exits at the skin. With the driller placed at the femoral side the K-wire is retracted upwards and outwards from the notch until it is flush with the axial aspect of the condyle. The knee until now flexed at 90° is flexed at 50°. The femoral K-wire then forms a 65° incline with respect to the tibial plateau. The K-wire is then moved downwards into the tibia, which it enters at the center of the anatomical insertion and exits through the skin on the medial face of the tibial metaphysis. This K-wire serves as a guide for a cannulated bit.

In addition to its simplicity, this method has the advantage of assuring a perfectly rectilinear alignment of the tibial and femoral tunnel for a knee near its functional position. This absence of angulation during loading is important for all plasties, as suggested by Djian et al. [7]. It is fundamental for artificial ligaments to prevent ovalisation of the osseous tunnels or the rupture of the implant.

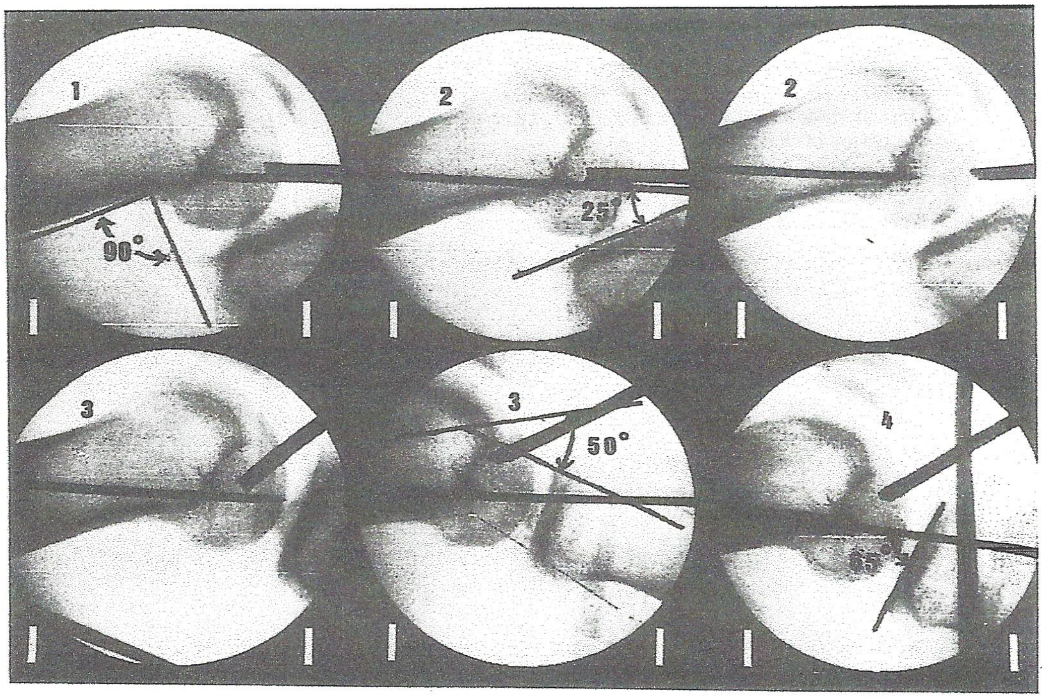

Fig. 10. The four phases in an arthroscopic intervention. *1*, The drill guide, which is placed with the FAC guide or under direct visual control on the fluoroscopic screen, at the center of the circle, penetrates the lateral condyle, the knee at 90°. *2*, The K-wire is penetrated with an upwards sloping angle of 25° and is retracted by its femoral extremity exiting at the skin until its distal point is flush with the wall of the notch. *3*, The knee is placed in 50° flexion. The K-wire then forms a 65° incline with respect to the tibial plateau (25° ± 40°). *4*, The K-wire is penetrated from the top to the bottom of the tibia and serves as a guide for the femoral and tibial drill bits. The two tunnels are drilled one after another to avoid damage of the remaining ACL

Results

Mechanical

The above technique has been used for the past 5 years. Among 126 patients who exhibited a acute ACL lesion reconstructed with sutures reinforced by artificial ligament, 107 have been seen again, with an average follow-up of 30 months (12–54 months). The mechanical tests were carried out according to the criteria described by Bercovy [3] with radiolaximetry using the TELOS under 100, 150, and 250 N (Fig. 11)

Under 250 N, 92 (86%) had a differential Lachman equal to or less than 3 mm, 6 (5.6%) between 3 and 5 mm, and 9 (8.4%) greater than 5 mm. On the Jerk test 91 (85%) had a negative result, 10 an uncertain result, and 6 a positive result.

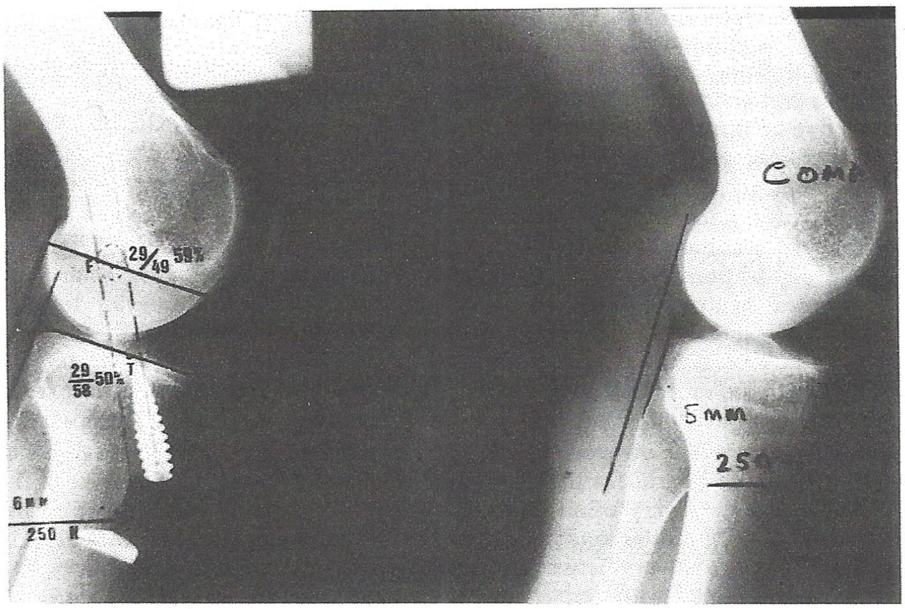

Fig. 11. Comparative radiolaximetry at 32 months postoperatively under 250 N. Differential Lachman 1 mm. The good mechanical result corresponds to a proper technique: F at 59%, T at 50% of the total length of the plateau, tunnels perfectly aligned in the functional position

Functional (for Mobility)

No patient exhibited a deficit in extension. Of the 107 patients 11 (10%) had a flexion deficit always less than 15°. These results are more better than those in a similar series of 100 patients reported previously [13, 14]. In this study, although the femoral tunnel was the same, its placement and orientation in the tibia and the relation with the intercondylar roof was not precisely defined. In this series, the differential Lachman effect was higher than 5 mm for 30% of cases and an extension deficit for 8% of cases.

Discussion

The results of our measurements on the placement of the ACL and the slope of the intercondylar notch [5], lead to a more posterior tibial tunnel and more anterior femoral tunnel than classic techniques. Almekinders et al. [2], in a study on the postoperative problems encountered on a series of 70 ACL reconstructions by patellar tendon, ideally placed the center of their tibial tunnel on a cadaveric knee at 34% of the anteroposterior length of the tibial plateau. They found this to be 29% on their operated patients. The authors consider biological factors to be more important than mechanical factors in explaining failures of replacements. Our experience with artificial ligaments, where the "biology" is eliminated, led us to think differently.

A multicenter series of 575 ACL reconstructions, regrouping Kenneth-Jones plasties and artificial ligament plasties was reviewed by Bercovy et al. [19]. The objective of this study was to determine the cause of failures. Of the 18% of patients with poor mechanical results, even when the functional results were acceptable, a technical positioning error was found in half of these cases as a factor in the slackening of the plasty. These errors occurred equally with artificial and Kenneth-Jones plasties, and gave identical consequences (Fig. 12).

A study by Stauebli et al. [18] on the magnetic resonance images located the anatomical center of the fibers insertion at 43% from the anterior border, which corresponds almost exactly to the results in the present study (42.5%), when the medial tibial plateau was used as a reference. Morgan et al. [15] presented similar results and further illustrated that the center of the tibial insertion is consistently 7–8 mm in front of the anterior aspect of the posterior cruciate ligament. However, we only partially agree with their femoral placement. Their landmarks for the femoral K-wire does not vary with the size of the condyle and may very often be too posterior. In a recent study relating the orientation of the intercondylar notch roof to knee flexion Howell et al. [10] found this slope to vary between 26° and 46° with a mean of 35°. However, this slope is calculated with respect to the femoral axis. In the present study we investigated the real maximal slope, i.e., that which considers the knee in hyperextension. Taking into account this hyperextension, the authors found a variance in the center of the tunnel to be between 26% and 55% of the length

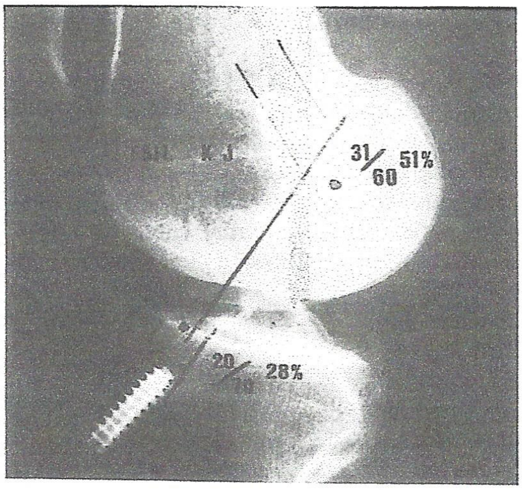

Fig. 12. Failure by error in KJ technique; reproduction of the laxity after an initial period with deficit in extension. The tibial tunnel is partially in front of the Blumensaat line (at 28%). The femoral tunnel is too anterior (at 51%). The revision required obstruction of the previous tunnels with bone grafts and drilling of new tunnels

along the tibial plateau. The safest position we located at 42% of the medial tibial plateau or 50% of the largest length coincides with their results.

The slope of the intercondylar roof, which we found to be on average 65°, establishes not only the central position of the tibial tunnel but also its sagittal plane angle with respect to the tibial plateau. This angle must also approach 65° to avoid bending in the plasty at the intraarticular tunnel exit. Morgan et al. [15] advocate an ideal angle of 68°, which is very similar to the present study.

Regarding the femoral tunnel, our choice is more anterior than classical descriptions. Good et al. [9] place the tunnel at 66% of the anteroposterior length of the femoral condyle, along a line parallel to the Blumensaat line, starting from the edge of the posterior condyle. In our study this percentage was 59%. On an average condyle, this corresponds to 3 or 4 mm, i.e., at the most anterior fibers of the natural ACL which are the most isometric. Furthermore, Good et al. [9] found a mean length of 2.9 mm in their plasty (2.7–3.3 mm) between 0° and 90° knee flexion. We hope to be more strict in the use of artificial ligaments. They concluded that the transplant must be fixed in a knee position which maximizes its length. This is in accordance with our opinion when perfect isometry is not obtained. Following the condition of isometry and avoidance of contact with the intercondylar roof, the absence of tension should be the golden rule when using an artificial ligament.

Dijan et al. [7] in a retrospective study of 36 ACL reconstructions reinforced with artificial ligaments placed their tibial tunnel on average at 34% of the anteroposterior length of the internal tibial plateau with an angle of 74° and a femoral tunnel at 72% of the condylar length. With these landmarks they obtained a 6/36 ratio, that is, a 16% deficit in extension, 8/36 (22%) deficit in flexion, and 5/36 (13%) of differential Lachman effect greater than 5 mm at 89 N, force for which the test has little sensitivity. For Bercovy et al. [3] only the test results at higher than 180 N are sufficiently reliable and eliminate the false negatives.

The deficit in extension appeared to us to be significantly correlated with an overly posterior femoral tunnel and with a tibial tunnel located in front of the Blumensaat line. Contrary to our deductions and those of Howell et al. [11, 12], we did not find a correlation between residual laxity and the position of the transplant. It is logical to think that an overly anterior placed tunnel, leading to a mechanical deterioration of the transplant, would result in a poor mechanical result. Romano et al. [16] also insisted on the influence of the choice of insertions on mobility and laxity of the knee.

It is certain that our choice of more posteriorly placed tunnels on the tibia and more anteriorly placed tunnels on the femur theoretically make the plasty less efficient for controlling anterior drawer. However, the anterior aspect of the plasty consequently buts up against the roof of the notch, along its entire length, in extension which opposes backwards movement of the femur. The ligament's action is no longer restricted to the tibial insertion. As well illustrated by Bercovy [3], respecting the rigidity curve of the knee is more important to consider than its laxity at low applied force values. We prefer the risk of a slight residual laxity to a potentially more damaging risk of a deficit in extension or flexion which in any case would imply a more or less premature degeneration of the ligament by repetitive microtrauma and thus a poor mechanical result.

Conclusion

The use of the artificial ligaments, which are more sensitive than autogenous plasties, led us to a strict surgical technique which allows better definition of the compromise to which all ACL reconstructions are subjected. This compromise is necessary until the exact reproduction of the natural ACL is obtained. The ligament must ensure mechanical efficiency while limiting stresses, permitting normal function, and minimizing social and economical consequences of the accident.

The respect of isometry, absence of conflict with bony surfaces, absence of tension, and alignment of the tunnel at 50° of flexion are the fundamental rules. To these four rules we must add the proprioceptivity aspect, which requires a nontraumatic arthroscopic surgery and the preservation of the recently ruptured cruciate ligament, which possesses indispensable mechanoreceptors. It is certainly the strict adherence to these rules, and use of the most studied ligaments, which presently allows us to obtain competitive results more simply and quickly for the patient.

References

1. Abbink EP (1988) Clinical experience in correction of chronic anterior cruciate ligament defiency with bovine xenograft: a 5 years study. In: Friedman M, Ferkel RD (eds) Prothetic ligament reconstruction of the knee. Saunders, Philadelphia, pp 101–111
2. Almekinders LC, Moore T, Freedman D, Taft TN (1995) Post-operative problem following anterior cruciate reconstruction. Knee Surg Sports Traumatol Arthroscopy 3:78–82
3. Bercovy M, Weber E (1995) Evaluation de la laxite, de la rigidite et de la compliance du genou normal et pathologique. application a la courbe de survie des ligamentoplasties. Rev Chir Orthop 81:114–127
4. Bradley J, Fitzpatrick D, Daniel D, Shercliff T, O'Connor J (1988) Orientation of the cruciate ligament in the sagital plane. J Bone Joint Surg Br 70B:94–99
5. Cazenave A, Laboureau JP (1990) Reconstruction isometrique du ligament croise anterieur. Determination pre et post-operatoire du point femoral. Rev Chir Orthop 76:288–292
6. Daniel DM, Penner DA, Burks RT (1988) Anterior cruciate ligament graft isometry and tensioning. In: Friedman MJ, Ferkel RD (eds) Prosthetic ligament reconstruction. Saunders, Philadelphia, pp 17–21
7. Djian P, Christel P, Roger B, Witvoet J (1994) Evaluation radiologique et IRM des ligamentoplasties intra-articulaires utilisant le tendon rotulien. Rev Chir Orthop 80:403–412
8. Elias SG, Frieman MAR, Gokcay EL (1990) A correlation study of the geometry and anatomy of the distal femur. Clin Orthop 260:98–103
9. Good L, Odensten M, Gillquist J (1994) Sagittal knee stability after anterior cruciate ligament reconstruction with a patellar tendon stip. A two year follow-up study. Am J Sports Med 22(4):518–523

10. Howell SM, Barad SJ (1995) Knee extension and its relationship to the slope of the intercondylar roof. Am J Sports Med 23(3):288–294
11. Howell SM, Berns G, Farley TE (1991) Unimpinged and impinged anterior cruciate ligament grafts: MR signal intensity measurement. Radiology 179:639–643
12. Howell SM, Taylor MA (1993) Failure of reconstruction of the anterior cruciate ligament due to impingement by the intercondylar roof. J Bone Joint Surg Am 75:1044–1055
13. Laboureau JP, Cazenave A (1991) Rupture fraiche du ligament croise anterieur. Technique de renfort par ligament artificiel. Resultats apres 5 ans d'experience. Rev Chir Orthop 77:92–102
14. Laboureau JP, Cazenave A, Dericks GH (1991) The acute rupture of the anterior cruciate ligament. Reconstruction by suture on a synthetic reinforcement evaluated by arthroscopy. Arthroscopy 1:13–22
15. Morgan CD, Kalman VR, Grawl DM (1995) Definitive landmarks for reproductible tibial tunnel placement in anterior cruciate ligament reconstruction. Arthroscopy 11:275–288
16. Romano VM, Grof BK, Keene JS, Lange RH (1993) Anterior cruciate ligament reconstruction. The effect of tibia tunnel placement on range of motion. Am J Sports Med 21:415–418
17. Saragaglia D, Dayez J, Borot E, Butel J (1988) De l'utilisation de Kennedy LAD dans le renforcement des plasties du ligament croise anterieur selon MacIntosh–Imbert. A propos de 100 observations. J Traumatol Sport 5:83–91
18. Stauebli HU, Rauschming W (1994) Tibial attachment area of the anterior cruciate ligament in the extended knee position. Anatomy and cryosections in vitro completed by magnetic resonance arthrography in vivo. Knee Surg Sport Traumatol Arthroscopy 2:138–146
19. Bercovy M, Laboureau JP, Dericks GH (1993) Reasons for failure in the surgical treatment of anterior cruciate instability. European Congress of Orthopaedics, European Federation of National Associations of Orthopaedics and Traumatology, Paris, 21–23 April