REVIEW ARTICLE

Current concept of partial anterior cruciate ligament ruptures

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Summary
A partial tear of the anterior cruciate ligament is a frequent pattern of ACL injury, observed in 10 to 27% of isolated ACL lesions. There are three reasons to preserve these remnants: biomechanical, vascular and proprioceptive advantages for the patient. Good quality fibers work as graft protection during the healing process. Periligamentous and endoligamentous vessels present into the native ACL tissue may enhance the vascularization of the ACL augmentation. Mechanoreceptors still remaining in the residual ACL fibers may have proprioceptive function. Definition is controversial, based on anatomy, on clinical examination, on instrumental laxity assessment or on MRI findings. Continuous remnant ACL fibers bridging the femur and tibia, from native femoral ACL footprint to native tibial ACL footprint seem to be a good definition. Diagnostic is suspected by accumulation of arguments brought by a thorough clinical examination, precise MRI analysis and examination under anesthesia. But the final diagnostic needs an arthroscopic evaluation to confirm the presence of fibers in good position and to validate its good mechanical properties. The treatment of ACL partial tear is a demanding surgery; difficulties to visualize the graft insertion site, especially on the femoral side, require a perfect knowledge of the normal anatomy of the native ACL footprint. Adapted portals, perfect controls of the tunnel drilling process, intercondylar notch space management are the keys of success. The pivot shift test under anesthesia, a hard stop Lachman test, MRI findings, level and type of sport, arthroscopic aspects of the remnants and its mechanical properties, allow the surgeon decide between non operative treatment, ACL augmentation or standard ACL reconstruction.

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Introduction

Anterior cruciate ligament (ACL) injury is common traumaism during sport activity and isolated injuries account for nearly half of the knee ligament injuries [1]. If the complete tear is usually a clinical diagnosis, partial tear is mostly missed by a standard clinical examination. The clinical diagnosis might be suspected by the accumulation of arguments but supported by the MRI and the arthroscopic evaluation of the ACL. The better knowledge of the natural history of the partial ACL tear has led to change the treatment plan. However, many different aspects of this lesion remain controversial issues. First of all, the definition is not consensual. For Noyes et al. and Hong et al. [2,3] it is based on the percentage of remnant fibers, for Crain et al. and Sonnery-Cottet et al. [4,5] on the arthroscopic evaluation, for the American Medical association [6] on the clinical assessment and for DeFranco and Bach [1] multifactorial. The evaluation of the biomechanical quality of the residual fibers is another issue. It is questionable if it is it a partial ACL rupture or a partial healing of a complete rupture? [5], and which bundle is injured to which degree?

The purpose of this review is to clarify the definition, clinical assessment, and strategies for treatment of partial tears of the anterior cruciate ligament.

Basic anatomy or current ACL anatomy update

It is now generally recognized that the native ACL does not behave as a simple band of fibers with constant tension. The separation of this ligament into AM and PL fiber bundles has now been widely accepted as a basis of understanding of ACL function [7,8]. Different effects of each bundle on tibial rotation and translation were described with different tensioning patterns throughout the full range of knee flexion. The AM bundle better restrains anterior tibia translation at greater than 45° of knee flexion [9,10], whereas the PL bundle has been shown to be less isometric and a more important restraint toward full extension [11]. This biomechanical behavior could be the explanation for partial ACL ruptures depending on the position of the knee (flexion, rotation, and adduction/abduction) and the energy transfer to the knee during the traumatism.

Definition

There is great controversy regarding the definition of a partial tear. Different definitions are based on anatomy, arthroscopic findings or on clinical symptoms.

ACL anatomy has been described by Weber et al. in 1836 and confirmed by many other studies. Even Norwood and Cross described the ACL as having three distinct anatomic and functional bundles: posterolateral, anteromedial and intermediate. Each bundle contributes separately to knee function and can be torn separately, leading to partial tears. For Noyes et al. [3], definition of partial tear was based on the percentage of ACL fibers torn. Partial tears that involved one half or three fourths of the ligament diameter had a great probability to develop an ACL deficiency. For Hong et al. [2], partial tear definition was less than 50% of ligament fibers torn.

Nevertheless, is it possible to estimate with accuracy the percentage of ligament fibers torn? A potential cause of controversy is that isolated ruptures of anteromedial bundle and posterolateral bundle are difficult to diagnose during arthroscopy. During arthroscopic ACL examination, an isolated posterolateral bundle rupture can easily be missed when viewing from standard anterolateral portal. In such cases, the anteromedial bundle overlies the posterolateral bundle, and the posterolateral bundle can only be seen by retraction of the anteromedial bundle with a probe. The posterolateral bundle is more easily identified when the knee is placed in Cabot’s position (figure of four position) [12] (Fig. 1). Anatomic and arthroscopic definitions have the same approach. The aim is to determine the intact and functional ACL remaining fibers. Crain et al. [5] examined variations in the ACL scar pattern and the relationship with the anterior laxity in 48 patients. They were divided into four categories according to ACL remnant morphology: group 1 ACL remnant scarring to PCL (38%), group 2 ACL remnant scarring to the roof of the notch (8%), group 3 ACL remnant scarring to the lateral femoral condyle (12%), and group 4 no identifiable ligament tissue remaining (42%). This description is close to our description presented at the SFA symposium in 2007 [8]. We have listed these different aspects of the ACL tears and studied the correlations between these different anatomic aspects and the data from the clinical, radiological and MRI examination. We reported a prospective multicentric study, on a continuous series of 418 patients. The ACL remnant in the intercondy lar notch has been analyzed at the precise moment of the surgery and characterized by its visual and palpation aspect and by its mechanical quality. Four categories of remnants were described: “Totally disappeared ACL” 50%, “posterolateral bundle conservation” 16% (Fig. 2), ”healing on PCL” 23% and “anteromedial bundle conservation” 11% (Fig. 3). There is a good correspondence with the study of Crain et al., even if he did not identify clearly the scarring remnant. Sonnery-Cottet et al. [4] identified clearly tears of posterolateral or anteromedial bundle. In our injured patient’s population, the quality has been considered as good only for 17% of the remnants and bad for 83%. Preser-
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DeFranco and Bach [1] proposed a multifactorial definition with asymmetric Lachman test, negative pivot shift, differential KT 1000 laxity measurement equal or less than 3 mm, and arthroscopic examination. We support this definition; however a clear anatomical definition is needed.

In summary, the partial ACL tear is a combination of factors: It is often a young patient, who practices a lot of sports, with a knee injury, and poor symptoms in the follow up, sometimes pain and swelling and rarely instability and especially a short delay injury-surgery. We proposed a new arthroscopic definition of ACL partial tear, as continuous fibers from native tibial ACL footprint to native femoral ACL footprint. Assessment of mechanical properties of ACL remnant remains an issue. Palpation in Cabot’s position is a best way to evaluate these properties.

Diagnosis

The diagnosis of a partial ACL tear remains a difficult challenge. It is based on clinical examination, radiological and MRI data, but the real diagnostic is supported by arthroscopic findings.

The clinical examination

In the SFA study [13], the clinical laxity was totally different (P < 0.00001) between a population with complete disappearance of the ACL (98% of soft end point Lachman test [LT] and 80% of clunk or gross pivot shift test [PS]) and the population of partial tear or partial healing (30% to 64% of firm and point delayed LT and 57 to 73% of equal or glide PS). It is in the healing on the notch group (or conservation of the antero-medial bundle) that existed the highest number of hard stop LT (64%). A high link existed also between the pivot shift test and the ACL aspect, a difference was found between the ‘‘totally disappeared’’ and ‘‘posterolateral conservation’’ groups (P < 0.00001). So a soft end point LT was a high predictive value for a complete ACL rupture and hard stop delayed PS corresponded in 94% of cases to a tear or partial healing but could not specify its type more accurately (conservation of posterolateral bundle, healing on PCL of healing on notch). Many cadaver studies have shown that it is difficult to know the percentage of injured fibers only with a Lachman test or an anterior drawer [14]. For Fritschy et al. [15], it is common to have a negativity of the Lachman test, with a partial tear. The pivot-shift is more sensitive than the anterior drawer or the Lachman test. A positive test (glide or clunk) defines an insufficiency of the ACL. For several authors, a partial ACL tear is defined by a pivot shift grade 1 (glide) 4 and we agree with this interpretation in our study.

Laximetry

Many different devices are available to measure the laxity; mostly addressed to antero-posterior laxity KT 1000®, Rolimeter® and Telos®. More recently, Robert et al. [16] reported specific measurement using the GNRB® system with...
80% of sensitivity and 87% of specificity for the diagnostic of an isolated AM bundle tear.

The radiological examination

The radiological examination and arthrometric testing: the analysis of side-to-side differential radiological measurements of both medial and lateral compartments under anterior stress, showed a high correlation with the ACL aspects \( P < 0.0001 \). The group “totally disappeared” had the highest differential laxity on both compartments whereas the groups “posterolateral conservation” and “healing on notch” were the less lax. It was the group “healing on notch”, which presented the lowest laxity on the lateral compartment. Mechanical quality of remnant, assessed under arthroscopy, had a significant relation with the differential laxity of the medial compartment. The laxity was lower when the quality of the remaining bundle was assessed “good” compared to a “bad” quality of remnant. The radiological examination with Telos® device was able to make the difference between a complete tear and a partial tear, without determining the exact nature of this tear. Instrumental laxity measurement using KT 1000® was unable to show a significant difference. In the literature, we found a threshold of 3 mm anterior laxity to define a partial tear. Noyes et al. [3] indicated that an anterior laxity up to 5 mm had a bad prognosis. We can conclude that Telos measurements and arthrometric assessments give the same information about partial tears.

MRI findings

It is difficult today to make an ACL partial tear diagnosis with no doubt. The MRI may only suggest a partial tear without any certitude. In the French study [13], 195 files with a complete MRI were collected for analysis. On sagittal sections, we described three types of ACL fibers lesions: “disorganized fibers” when the fibers had no structural aspect any more or had been disappeared, “straight fibers” when fibers had longitudinal orientation parallel to the Blumensaat’s line (Fig. 4), the third type was “lying down fibers” when the remaining fibers were lying down in the intercondylar notch close to the PCL. Specific views are needed to make the difference between a complete tear and a partial tear. Roychowdhury et al. [18] proposed axial or perpendicular views to be more accurate on the MRI diagnosis. MRI was considered in our study as an adjunct for diagnosis of partial ACL tear.

Arthroscopy data

Arthroscopic examination was proposed by authors [14] to diagnose a partial tear. In our experience, we do not propose systematically an arthroscopy to make the diagnosis. The arthroscopy allows determining the type of partial tear and according to the other assessments (clinical and radiological) we decided the type of reconstruction.

A new classification of these lesions was proposed according to the arthroscopic, clinical and radiological aspects

The complete ACL rupture, 50% of injured patients, it was characterized by a large majority of soft end LT, clunk and gross PS, high instrumental side to side differential laxity value (mean 7.9 mm) long delay injury-surgery (mean 22 months), and a high rate of medial meniscus tear (42%). “Posterolateral bundle conservation” and “antero-medial bundle conservation” respectively 16% and 11%, they presented similar features. We found a similar differential laxity (4.97 and 4.49 mm), and a moderate rate of medial meniscus lesion. Similar findings were reported by Adachi et al. [19] who described 40 cases of isolated lesions of the antero-medial bundle (conservation of the posterolateral bundle) with a laxity of 5.3 mm measured at KT2000. In these two groups, the delay “injury-surgery” was short (5 and 5.07 months). Ochi et al. [20] reported in a 169 injured patients study, 10% of ACL partial tears with a majority of postero-lateral bundle conservation.

Healing on PCL 23%, characterized by 70% of soft end point LT, 42% of clunk or gross PS, a higher laxity than in the two other precedent groups (5.08 mm), a higher delay injury-surgery (11.8 months) and 37% of lesions of the medial meniscus. Crain et al. [5] showed in an ACL scar pattern variation study that healing on PCL had no effect on anterior laxity.

Treatment

Why a specific treatment saving remnant fibers is required?

Saving ACL remnants during ACL reconstruction may have some biomechanical, vascular and proprioceptive advan-
The current concept of partial ACL ruptures highlights the excellent knee function and a significant decline in activity compared with the uninjured knee. The largest side-to-side difference was 4.5 mm. However, only 62% had a good or excellent knee function, and 27% had a +1 or +2 positive Lachman test. Instrumental laxity was investigated in various ways, such as the joint position sense test and latency of reflex hamstring contraction. Beard et al. [31] reported that the extremities of ACL have a greater vascular density and the proximal part has greater vascularity compared to the distal part.

The importance of ACL remnants was reconfirmed by Crain et al. [5]. In the majority of cases, its femoral attachment is the posterior cruciate ligament (PCL), but in some cases, the ACL remnant bridges the femur and tibia, although its diameter is attenuated and its femoral attachment positions are slightly different from the normal anatomical origin. To some extent, this type of ACL remnant helps to prevent anterior knee laxity. In contrast, the ACL remnant attached to the PCL does not contribute to stabilization of the ACL-deficient knee. The authors examined the anterior laxity before and after ACL remnant debridement using a KT-1000 arthrometer in 48 patients and found that ACL remnants scared to the roof of the notch (8%) or to the lateral wall of the notch or the medial aspect of the lateral femoral condyle (12%, or 20% of their series) contributed to the prevention of tibial anterior laxity. They concluded that ACL remnants may act like a biomechanical restraint against anterior translation.

The importance of the ACL remnants was reconfirmed by a modeling study of partial ACL injury with simulated KT-2000 tests by Liu et al. in 2002 [21]. A computer model in sagittal plane was designed to simulate different levels of AM- and PL bundle tears. Results showed that the degree of anterior instability was related to the amount of partial ACL disruption and remnants may add to postoperative mechanical stability of the injured knee.

The importance of the ACL remnants, with conservative treatment, was also shown by Bak et al. [22]. They evaluated the natural history of partial ACL tears 5 years after the initial injury. Of 34 knees, 73% had a negative Lachman test and 27% a +1 or +2 positive Lachman test. Instrumental laxity testing in 24 knees showed 2 mm or less difference in laxity, compared with the uninjured knee. The largest side-to-side difference was 4.5 mm. However, only 62% had a good excellent knee function, and a significant decline in activity was seen. They concluded that ACL remnant may have an important role in the immediate rehabilitation period by providing additional mechanical strength while the graft is in the healing process.

A second important advantage of saving fibers may be that the residual portion of the ACL may maintain its blood supply, providing a support for the healing process in the graft. In an animal study by Bray et al. [23], standardized partial injuries were surgically induced to the anterior cruciate ligament in rabbits and 4 months after the injury, the ACL was dissected and compared to a control group. The results showed direct injury induced significant increase in blood flow and vascular volume.

The vascularization of the human native ACL was investigated by Dodds and Arnoczky [24]. They described a vascularized synovial envelope around the intact ACL and periligamentous vessels penetrating the ligament transversely and anastomosing with a longitudinal network of endoligamentous vessels. Spared parts of the native ACL tissue may enhance the vascularization of the ACL augmentation. The authors also stated that the extremities of ACL have a greater vascular density and the proximal part has greater vascularity compared to the distal part.

The time interval for maturity and remodeling, following arthroscopically assisted ACL reconstruction, was described by Falconiero et al. [25]. Superficial and deep biopsy specimens at different intervals from 3—120 months after ACL reconstruction were examined under light microscopy in 48 patients. The authors concluded that revascularization and ligamentization occur over a 12-month period following autogenous ACL reconstruction, with peak maturity evident after 1 year. By the 12-month period, the graft maturity resembles that of a normal ACL. Additionally, two of the four parameters observed, vascularity and fiber pattern, show statistically significant evidence that maturity may occur at an earlier time ranging from 6 to 12 months.

Saving ACL fibers may also maintain some proprioceptive innervation of the ACL. The joint position sense may be increased which may allow a faster and safer return to sports.

Schultz et al. described mechanoreceptors that resemble Golgi tendon organs beneath the synovial membrane of the ACL [26]. They published the first detailed description of mechanoreceptors in human ACL and suggested that they may have proprioceptive function. Schutte et al. reported that human ACL is extensively innervated and that neural elements comprise approximately about 1% of the area of the ligament [27]. Proprioception of the knee has been measured in various ways, such as the joint position sense test by Co et al. [28] and Corrigan et al. [29] threshold to detection of passive motion by Barrack et al. [30], and latency of reflex hamstring contraction by Beard et al. [31]. It has been reported that in an ACL-deficient knee, proprioceptive function is less than that found in a normal knee.

An important study was performed by Adachi et al. [32]. They showed that the proprioceptive function of the ACL is correlated to the number of mechanoreceptors in the ACL. The authors measured the correlation between the number of mechanoreceptors and the accuracy of joint position sense in 29 knees. Interestingly, they also found mechanoreceptors in patients having a long interval between the ACL injury and the surgery and concluded that surgeons should...
consider preserving ACL remnants during ACL reconstruction. These findings were reconfirmed by Georgoulis et al. [33]. They investigated the presence of neural mechanoreceptors in the remnants of the ruptured ACL as a possible source of reinnervation of the ACL autologous graft. The remainder of the torn ACL was selected for histological investigation from 17 patients during ACL reconstruction 3 months to 3.5 years after injury. They noted free neural ends in all patients. In patients with an ACL remnant adapted to the PCL, mechanoreceptors exist even 3 years after injury. The authors also stated that if the theory accepts that restoration of proprioception is the result of reinnervation of the ACL, leaving the ACL remnants as a source, may be a potential benefit to the patient.

Ochi et al. explained the restoration of knee function not only in terms of the reconstruction of the ACL as a mechanical restraint, but also as a result of a sensory reinnervation of the reconstructed ACL [11]. They found somatosensory evoked potentials in about 50% of the investigated ACL remnants as confirmation that the original sensory neurons are preserved to some extent in the ACL remnants. The occurrence of this in patients means that the ACL remnant may be an important source of neuralization for the graft. The authors also stated that if the theory accepts that restoration of proprioception is the result of reinnervation of the ACL, leaving the ACL remnants as a source, may be a potential benefit to the patient.

Several years ago, the clinical benefit of ACL augmentation was recognized and described by Adachi et al. [19]. They compared 40 patients in which they performed a selective reconstruction of the AM or PL bundles to a group of patients with complete ACL reconstruction. The ACL augmentation group showed significantly better anteroposterior stability and terminal stiffness than the ACL reconstruction group. The side-to-side difference of anterior displacement, as measured by the KT-2000 arthrometer, was significantly improved to an average of 0.7 mm in the augmentation group compared to 1.8 mm in the reconstruction group. The final inaccuracy of joint position sense of the augmentation group was 0.7°, while that of the reconstruction group was 1.7°, which showed a significant difference.

The authors concluded that ACL augmentation, which can preserve ACL remnants with mechanoreceptors, is superior to ACL reconstruction from the viewpoint of position sense and joint stability. Siebold and Fu [35] published preliminary results using autologous doubled or tripled Semitendinosus tendon and femoral extra cortical Endobutton® fixation, showed good clinical results for AM and PL bundle augmentation at an average of 1 year postoperatively. The objective and subjective IKDC, Cincinnati Knee Score, and the KT-1000 increased significantly from preoperatively to follow-up in all patients. The non-surgical treatment is the first option to discuss, especially in low demanding patient. A specific rehabilitation program is necessary, and the physician has to follow and check the patient until the return to full sport activities. In case of instability feeling or unsatisfactory subjective results, the surgical option will be proposed. However two studies [13,22] have shown possible evolution to a complete tear or poor clinical result.

**Operative treatment**

The first step consists in meticulous knee laxity assessment under anesthesia, the pivot shift test sensibility is largely improved under anesthesia [36]. This test is the main global test to assess the functional status of residual ACL fibers [2,36]. The surgical treatment has some common points with classic ACL reconstruction in terms of graft choice, rehabilitation program and time to return to sport activities. The differences are in arthroscopic knee analysis, notch cleaning, tunnels positioning, drill guide used and graft size.

The patient is placed in supine position, and a leg holder can be used [35]. The lower limb must be free to allow a full flexion angle and free limb motion to evaluate the tension and the quality of remaining ACL fibers [4]. The arthroscopic procedure is started with two portals. Antero-lateral arthroscopic portal is done close to the patellar tendon and an antero-medial instrumental portal 15 mm medial to the patellar tendon. Some authors propose to do a third low antero-medial portal to access the PL bundle reconstruction [35]. After a brief fat pad debridement, a global knee evaluation is performed to check the cartilage and the meniscus status. Then an ACL remnant analysis is performed. First of all, the visual aspect is studied to confirm that femoral and femoral remaining fibers attachments are located inside the anatomic ACL footprints. Then mechanical fibers properties are tested in Cabot’s position to tend the fibers and a probe is used to test their resistance (Fig. 6). The final diagnosis of a partial tear is done by the arthroscopic visual and probing step, matched with the clinical exam under anesthesia and the laxity analysis [13].

The AM bundle is isometric so probing is done between 60° and 90° flexion in neutral rotation through the antero-lateral portal. In some cases, it is difficult to make a difference between a PCL healing and a true intact AM bundle [13]. The probing has to be done after a mild debridement using a non-motorized instrument. It is important to look for the ruptured bundle to remove it; the knee is placed close to the extension to have a very good view on the anterior part of the tibia. This part of ACL sometimes looks like a clapper placed under the inter meniscus ligament and could provide a "Cyclops’s syndrome" [37].

The PL bundle has some specific features. The insertion is low on the lateral condyle and the direct observation through the anterolateral portal is incomplete. The best option is to switch the scope to the anteromedial portal, in this way the surgeon has a direct view of the insertion [35]. Then the knee has to be moved in flexion and in extension to give some tension in this bundle. The best leg position to explore it is in flexion close to 80° and combined to a varus with an external rotation of the hip (Cabot’s position) [4].

Two other points are analyzed. The quality of the blood supply of each bundle is noted, this might help in determining the future environment of the future graft [32,33]. The Notch width is measured to adapt the graft size according to the size of remnant in order to avoid notch impingement especially with the roof, leading to a deficit of extension [4].
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Graft selection
It can be a systematic use of one graft according to the surgeon’s experience; it can be a selective indication depending of the type of sport activities [38]. Most of authors report the use of hamstring tendons [38–40]. The graft consists in the semi-tendinosus doubled or tripled with a preserved tibial insertion or a combination of a Gracilis and Semi-tendinosus in a free quadruple graft [4,19,20,37,41–43]. The graft selection has to deal with difficulty to pass the graft in the joint and maybe explains why a bone block procedure is not chosen. The space left in the notch by the intact bundle makes 7 to 8 mm graft to be the ideal size [4,41,44].

Technical features and specificities for partial reconstruction

AM bundle reconstruction. Arthroscopic procedure starts with the AM bundle debridement carefully done to avoid any damage of PL bundle. Siebold and Fu [35] recommend to set the tibial drill guide to 60° and the tunnel will start 1.5 cm medial to the anterior tibial tuberosity. A K-wire is positioned 4 to 5 mm lateral to the medial tibial spine and 4 to 5 mm posterior to the anterior rim of the ACL stump. The anterior landmark is the anterior part of the ACL to prevent any impingement with intercondylar notch. An extension position of the knee can be done once the K-wire is in the joint to test the absence of impingement. The AM femoral insertion is located using the remnant fibers or using the clock position, 11 o’clock position for a right knee and 1 o’clock for a left knee. Then a guide wire is positioned in the center of the femoral insertion, the knee is flexed to a maximum flexion close to 140°. The femoral AM tunnel is drilled through the low antero-medial portal with a headed reamer. The drill can be inserted in a cannula to avoid PL fibers damage. The use of a re-entry guide outside-in is another option [43], the guide is positioned in an over-the-top position with an offset of 5 to 7 mm, always using the clock position, and then the tunnel is drilled from outside-in and prevents any damage of the internal structure. When drilling, the final arrival in the joint has to be done hand-made or with low speed to prevent any lesion of the bundle remnant, especially in the tibial side (Fig. 6).

PL bundle reconstruction. The position of the tibial tunnel is more medial and starts 3.5 cm medial to the tibial tuberosity. The intra-articular position is located in the posterior part of the tibial ACL insertion 5 mm medial to the lateral eminentia intercondylaris. The femoral side is then marked, using the anatomical landmark, which is the most reliable. The clock positioned is not the best option because of a really large variability in its insertion. Some authors [37]

Figure 6  Remnants tested with a probe to assess the correct quality of residual fibers.

Figure 7  Reconstruction of AM bundle: a) residual PL bundle in anatomic situation with both tunnels tibial and femoral, prepared for the AM reconstruction. A suture is passed from the tibia to the femur to tract the graft. b) The graft in place in anatomic AM situation.
still use it and positions it at the 9 o’clock position for the right knee or 3 o’clock for the left knee. Siebold and Fu [35] proposed to set up the position an average of 5 mm posterior to the shallow articular cartilage of the lateral femoral condyle.

The drilling is done from the anteromedial portal but it can be difficult, especially in a small knee. An accessory medial portal can be used just above the medial meniscus anterior horn. The medial condyle can be damaged and a headed reamer is necessary. An outside-in guide technique can be used to be sure to prevent any damage of the AM bundle.

**Graft fixation.** This depends on the technique, for the inside out technique authors [19,35,45] use mostly an Endobutton® system for the femoral side and an absorbable screw in the tibial side, and for the outside in technique an absorbable screw is used in both tunnels [43]. The fixation is done after a preconditioning and cycling method. For the PL bundle the angle of flexion is 0 to 10° and for the AM the angle of fixation is more variable. Some authors [35] fix it in 50 to 60° degrees of flexion, others fix it around 20° flexion. An original technique is described by Buda et al. [41] The graft is passed through the femoral tunnel, fixed with a staple in an over-the-top position and driven back through the same tunnel and sutured to its own origin. Once the graft is fixed, the full range of motion is tested and also the absence of any impingement between the intercondylar roof, PCL and lateral edge of the lateral condyle to prevent any complication like Cyclops’s syndrome, lack of motion or pain.

**Clinical outcome**

Mott [42] was the first to propose an ACL augmentation surgery in acute ACL tear using the semi-tendinosus. He points out the fact that it gives back a perfect ligament strength compared to normal ACL. Adachi et al. [19] and Ochi et al. published the first results of an ‘‘augmentation’’ procedure compared to a classic ACL reconstruction. They have shown better result in term of residual laxity with KT 2000 in the ‘‘augmentation’’ group. Then other series were published in 2006 by Ochi et al. [20]. They reconstructed 13 AM bundle and 4 PL bundle using the semi tendinosus. The conclusion insisted on the favorable influence of vascularity and reinnervation of the graft. In 2009, Ochi et al. [45] published a new series of 45 patients with a minimum of two years follow-up. The residual laxity measurement showed a really good correction of the anterior tibial translation on the KT 2000 with only 0.5 mm side-to-side difference. A perfect healing of the graft in post op MRI was demonstrated, and he showed that the joint position sense was improving post operatively. Those results corroborated the study [46] done in 2002 about the correlation between the number of mechanoreceptors in ACL remnants and the joint position sense.

Buda et al. [41] performed a prospective analysis of the results of augmentation surgery in 47 patients. The clinical results were good or excellent in 95.7% of cases. He showed also a good correlation with the clinical result and the graft integration and graft signal on the MRI examination.

Sonnery-Cottet et al. [43] reported 36 patients with AM bundle reconstruction using the semi-tendinosus with a very good correction of the laxity 0.8 mm side to side difference, but he had two arthrolysis for a Cyclops’s syndrome at 4 and 13 months post operatively, and insisted on the fact that the graft shouldn’t be over size in this partial reconstruction, he recommended a 7 to 8 mm diameter like Buda.

In summary, there are few publications comparing classical ACL reconstruction and ACL augmentation procedures, and no comparative studies between reconstructions leaving ineffective remnant and efficient remnant. Such a study will be helpful to assess the effect of the good environment on the graft healing or the mechanical effect of an ‘‘intact’’ bundle.

**Indications and incidence of different factors**

ACL augmentation in partial tear could be supported by several factors. First of all clinical factors: substantial number of partial tears progress to complete tears with an increased laxity and a higher rate of meniscal and cartilage injuries [3,15,47–49]. Some authors [13,38] reported that the delay between injury and surgery is significantly higher in complete tear than partial tear. Local factors: ACL remnant provides blood supply and innervation, constituting a good environment for the graft increasing the chance of graft healing [32,33,46,50]. The type of sport, the sport level and the patient expectations have also to be considered. Kocher et al. [51] identified other factors such as tears involving more than 50% of the ligament, tears of the posterolateral bundle, a grade B (glide) pivot shift, a hard stop Lachman test and a skeletal age of more than 14-years-old. The risk of degenerative joint disease after partial ACL tear is not clearly identified, however Kannus and Jarvinen [52] in a non-operative treated patients study reported 15% of degenerative lesions eight years after a partial ACL tear, without any instability.

**Conclusion**

Partial ACL tears are more often suspected; their frequency is ranged from 10 to 27% of isolated ACL tears. Definition needs to be clear and consensual; confusion exists between partial rupture and healing. Continuous remnant ACL fibers bridging the femur and tibia, from native femoral ACL footprint to native tibial ACL footprint could be a good definition. Diagnostic must be evocated on clinical and imaging arguments accumulation but it is only resulting from arthroscopic examination. The main issue is to assess the mechanical properties of these fibers. Palpation with a probe is the best option; the knee has to be placed in Cabot’s position to tighten residual ACL fibers. The final treatment decision must be taken after this thorough arthroscopic testing. As it is high technical demanding, remnant ACL can be preserved only if they have good mechanical quality. It can get a great benefit for saving these fibers to protect the graft and to carry out vessel during healing process. The presence of mechanoreceptors in the residual ACL fibers is also a real advantage during the rehab protocol and to return to complete sport level. An appropriated selection of portal is needed and a medial accessory portal can be used. The size...
of the notch can be an issue so the graft size needs to be matched to empty space. The pivot shift test under anesthesia is one of the most important factors, a hard stop Lachman test, MRI finding, level and type of sport, arthroscopic aspect of remnant and its mechanical properties, allow the surgeon to make a decision between non operative treatment, ACL augmentation and standard ACL reconstruction.

Conflict of interest statement
None.

References

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