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Does a lateral plasty control coupled translation during antero-posterior stress in single-bundle ACL reconstruction? An in vivo study

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Abstract The objective of this study was to quantify, in vivo, the reduction of knee laxity obtained by an extra-articular procedure, added to hamstring single-bundle (SB) anterior cruciate ligament (ACL) reconstruction in controlling coupled tibial translation during the Lachman and drawer tests. Twenty-eight patients were evaluated with a computer-assisted kinematic evaluation protocol; patients with associated ligament tears or meniscal damages were not included in the study. All patients underwent an hamstring ACL with an additional extra-articular procedure. During the intervention, tibia was tracked during the Lachman and drawer tests with ACL-deficient knee, after SB fixation and after extra-articular plasty fixation, performed with the remnant part of the hamstring tendons, from end of lateral condyle to Gerdy's tubercle. Statistical analysis was performed to see whether there was a difference in knee laxity after the tests in the three steps. At 30°, the SB graft reduces AP translation of about 5 mm ($P < 0.05$) while the extra-articular procedure controls lateral tibial compartment, reducing translation by 1.6 mm ($P < 0.05$). At 90° the SB graft reduces AP translation more in the lateral compartment ($P < 0.05$), while the extra-articular procedure contributes in controlling tibial translation reducing laxity by 1 mm ($P < 0.05$) in both compartments. Result shows that, in vivo, the addition of an extra-articular procedure to single-bundle ACL reconstruction may be effective in controlling coupled tibial translation during the Lachman test and reduces AP laxity at 90° of flexion.

Keywords ACL · Single bundle · Lateral plasty · Laxity · Computer-assisted evaluation

Introduction

Reconstructive procedures for the anterior cruciate ligament (ACL) have become a common surgery in a large number of patients with reported clinical successes ranging from 70 to 95% [1, 2, 7, 12]. Lie et al. [20] related this phenomenon to the persistence of a residual secondary rotational laxity, which is not detectable with standard clinical tests. This residual rotational laxity could potentially lead to degenerative joint disease [15, 16, 35].

Several reconstructive procedures in the 1980s and early 1990s were proposed, combining intra- and extra-articular procedures with the rationale of improving the control of rotatory instabilities of the knee, but at that time the effect of an additional extra-articular plasty was difficult to be analyzed, in vivo, separately from the ACL graft. Recently, Zantop [41] has underlined that antero-lateral rotational instabilities could increase tibial translation on ACL-deficient knees; therefore, the lateral plasty could be a valid solution in these combined and often underestimated lesions.

Clinical studies have shown contradictory results. Roth et al. [36], Strum et al. [38] and O'Brien et al. [32] have found no beneficial effects regarding stability in adding an extra-articular plasty to an intra-articular ACL reconstruction. Jensen et al. [13] affirmed that the extra-articular plasty had no control on knee laxity but reduces the

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sensation of “giving way”. On the other hand, Noyes and Barber [30] and Lerat et al. [18] have found significant difference in knee stability when an extra-articular procedure was associated with ACL reconstruction.

Also in in vitro studies, there was no general consensus about the effect of the additional extra-articular procedure to knee laxity. These studies were in agreement only in indicating that there was a load sharing between the intra- and extra-articular portions and, in particular, that the load on the ACL graft diminished with knee extension. Anyway, the effect of this load sharing remained matter of debate. Engebretsen et al. [6] and Carson et al. [3] indicated that the extra-articular procedure prevents anterior subluxation of tibial plateau, protecting overloading on the ACL graft. Draganich et al. [5] have suggested that the extra-articular procedure combined to intra-articular reconstruction may over-constraint the internal tibial rotation and that did not control antero-posterior tibial translation. Lobenhoffer et al. [21] demonstrated that lateral tenodesis provides only a small strain-relieving effect. O’Brien et al. [32] indicated that there was no clinical difference between these two techniques, but patients with extra-articular procedure had more lateral pain.

Recently, Ferretti et al. [29] have shown, in vivo, that a single-bundle (SB) graft with added extra-articular tenodesis controls primary internal rotation better than double-bundle graft. Also clinical follow-up studies at 5 years [23] have shown that the combined intra- and extra-articular procedure has excellent results, comparable or even superior to patellar tendon and four-strand hamstring techniques [40].

Our hypothesis is that the additional extra-articular procedure, added to SB hamstring over the top ACL reconstruction, can control coupled tibial translation under the stress test. The objective of our study was to quantify, in vivo, the reduction of knee laxity obtained by the extra-articular procedure, added to the single-bundle ACL reconstruction, evaluating coupled tibial translation during the Lachman and drawer tests.

Materials and methods

Patient selection

From May to September 2006, 28 consecutive patients underwent arthroscopic ACL reconstruction with a kinematic, computer-assisted protocol at our institution; 21 were men and 7 women, the average age was 30 years (range 18–58), and the average time injury to surgery was 10 months (range 3–48). All subjects included in the study had preoperative C or D IKDC score. Patients with previous ligament reconstruction on the operated knee, concomitant meniscal injury or associated ligament injuries to the collaterals and capsule and severe chondral defect, pointed out by the MRI, were not included in the study.

All patients, included in the study, underwent an arthroscopic single-bundle ACL reconstruction performed with doubled gracilis and semitendinosus tendon graft with an additional extra-articular procedure [23] (Fig. 1). All ACL lesions were arthroscopically confirmed. The study design was approved by the Institutional Review Board of the Institute, and all patients provided their informed consent.

Intra-operative protocol

The patients were evaluated intra-operatively with a computer-assisted kinematic evaluation protocol that has shown highly repeatability and reliability [27, 39]. Hereafter, the main steps of the computer-assisted procedure are summarized: after performing graft harvesting and tibial tunnel drilling, reference frame was fixed on tibia and femur with a 3-mm bicortical Schanz screw, reference point on both bones were acquired with a navigated pointer to define local coordinate system on both bones. After bone registration, the operating surgeon performed standard clinical tests at maximum force to evaluate the antero-posterior (AP) joint laxities at 30° and 90° of flexion in the ACL-deficient knee; during the tests all six degrees of freedom of the joint were recorded by the computer for kinematic analysis [26, 27].

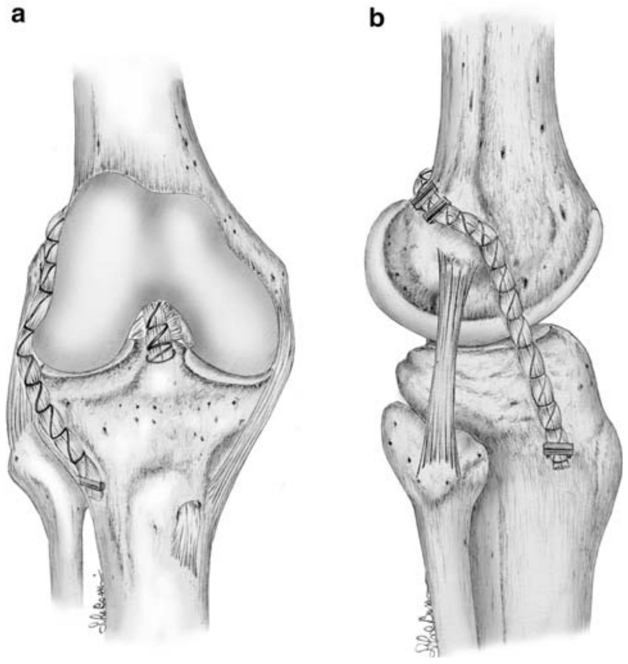

Fig. 1 Frontal (**a**) and sagittal (**b**) view of the ACL reconstructive technique

The SB graft was inserted into tibial tunnel, fixed with two staples on the femur in the over the top position. In this position, the femoral graft is near the insertion of antero-medial bundle of native ACL insertion [33] and the graft is able to mimic its function. After graft fixation, laxity tests were repeated.

After this step, the additional extra-articular (EA) procedure was executed passing the remaining part of the graft under the fascia lata to reach Gerdy's tubercle which was fixed with another staple. Laxity tests were repeated again.

Surgeries were performed by two surgeons. To reduce the bias of the study, the same surgeon performed all the tests on all patients. The average intra-tester standard deviation (SD) for manual tests computed with computer-assisted procedure is 0.8 mm for AP. The surgeon was able to check the degree of knee flexion with the navigation system during the tests but was blinded to the results of laxity tests.

Laxity under the AP stress test was defined as the tibial displacement (mm) on its transverse plane. The displacement was measured in three different points: on midpoint of tibial plateaus (Fig. 2, point C), which is the measure of tibial displacement under standard clinical tests, and medial (Fig. 2, point M) and lateral (Fig. 2, point L) plateaus. The displacement on these two points was utilized to evaluate coupled tibial translation during the Lachman and drawer tests.

Statistical analysis

To quantify the effect of the SB graft and the EA procedure, we compared the knee laxity of ACL-deficient knee with laxity obtained after SB (Δ_SB) fixation and EA (Δ_SB + EA) fixation, respectively. This approach was chosen to normalize data on patients' preoperative laxity, and therefore reduce inter-patient variability.

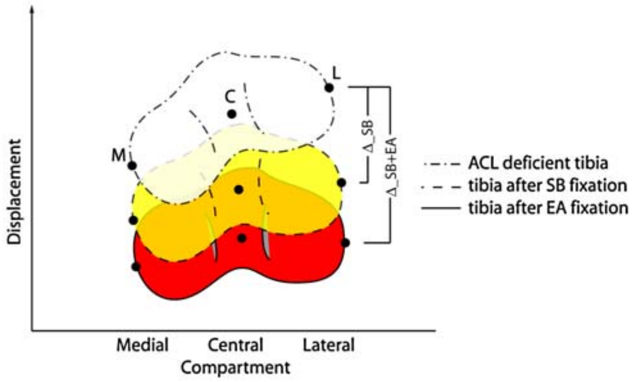

Fig. 2 Tibia displacement during AP test. *M* Antero-posterior displacement on medial plateaus, *C* antero-posterior displacement on tibial center, *L* antero-posterior displacement on lateral plateaus; *Δ_SB* difference between ACL-deficient knee and knee after single-bundle graft fixation; *SB + EA* difference between ACL-deficient knee and knee after extra-articular procedure on medial compartment

Since the data obtained were normally distributed (Shapiro–Wilk, $P < 0.16$) and test were repeated on the same subjects, paired sample Student's *t* test was utilized.

The statistical analysis was performed with Analyse-it 1.73 Software (Analyse-it Software Ltd., Leeds, UK). Sample power analysis [11, 17] on the basis of the hypothesis of finding at least 1 mm or 1° of difference in postoperative results with the repeatability of the stress tests, defined in previous studies [25], indicates that the study was powered at 0.9 with at least 28 patients. The level of significance was set at $P = 0.05$.

Results

For ACL-deficient knees, the average AP translation measured at the center of tibia was 13.3 ± 3.3 mm at 30° and 10.3 ± 1.6 mm at 90°, in the medial plateaus was 12.2 ± 2.3 mm at 30° and 7.7 ± 4.6 mm at 90°, and in the lateral plateaus was 14.3 ± 3.1 mm at 30° and 12.9 ± 3.5 mm at 90°.

At 30° of flexion SB graft reduced tibial displacement at tibial center by 4.8 ± 1.6 mm ($P < 0.01$) and additional EA procedure increases this reduction by 0.9 ± 1.1 mm at 30° ($P = 0.055$). Laxity on medial plateaus was not reduced using the EA procedure ($P = 0.741$), while on the lateral plateaus, the reduction was 1.6 ± 1.5 mm ($P = 0.015$; Fig. 3).

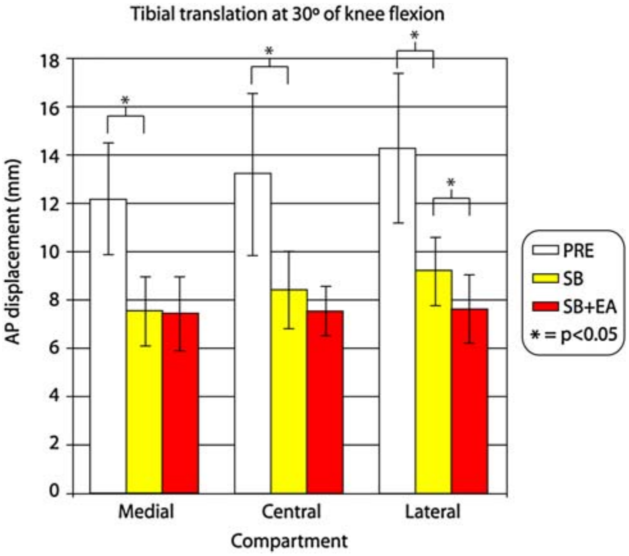

Fig. 3 Tibial translation at 30° of flexion during the Lachman test, measured in three different compartment *PRE* ACL-deficient knee, *SB* knee after single-bundle fixation, *SB + EA* knee with single-bundle and extra-articular tenodesis

At 90° of flexion SB graft reduced tibial displacement at tibial center by 3.2 ± 1.1 mm ($P < 0.01$) and additional EA procedure increases this reduction by 1.0 ± 0.8 mm ($P = 0.024$). Laxity on medial plateaus was reduced by SB graft of 1.8 ± 1.5 mm ($P = 0.038$), while on the lateral plateaus, the reduction was 4.5 ± 1.3 mm ($P > 0.001$). The SB graft reduced AP laxity by 2.77 mm, more in the lateral compartment than in the medial one ($P > 0.001$). The additional extra-articular procedure causes a further significant reduction of knee laxity of about 1 mm ($P > 0.05$) in both compartments (Fig. 4).

Discussion

Our hypothesis is that the additional extra-articular procedure, added to SB hamstring over the top ACL reconstruction, can control coupled tibial translation under stress test, so we evaluated the role of the extra-articular procedure, added to the graft, in controlling combined tibial translation during the Lachman and drawer tests.

The evaluation was performed with the help of an intra-operative navigation system, focused on kinematic evaluation of the knee. This methodology has the advantage of collecting the data in vivo from the same knee under different experimental conditions (ACL-deficient knee, SB reconstruction, SB plus EA procedure), thus reducing the effect of inter-subject variation and significantly increasing the statistical power of the data.

We have found that, despite the SB hamstring graft has a primary role in reducing statistically the knee laxity, an extra-articular procedure, added to the graft, is effective in further controlling the laxity: near extension, the SB graft reduces AP translation while the extra-articular procedure controls internal rotation, reducing by 1.6 mm the translation of lateral tibial compartment. This result shows that the coupled tibial translation, which is not controlled by SB graft, is reduced by the EA procedure. In contrast, in flexion, the SB graft reduces coupled AP translation in both compartments, while the extra-articular procedure contributes in controlling tibial translation reducing laxity by 1 mm in both compartments.

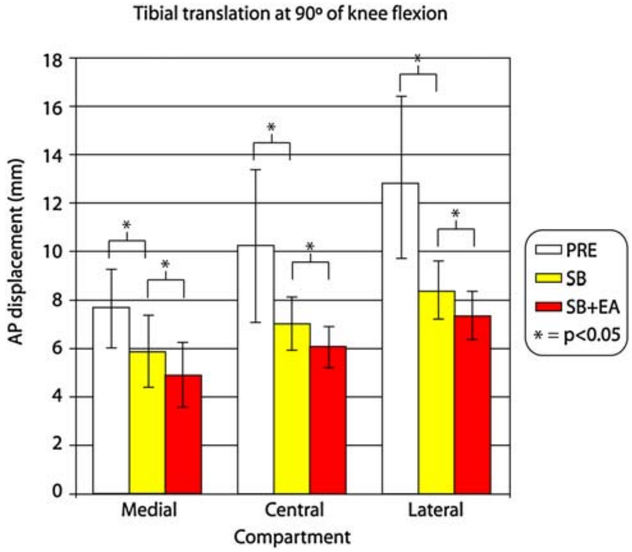

Fig. 4 Tibial translation at 90° of flexion during the drawer test, measured in three different compartments. *PRE* ACL-deficient knee, *SB* knee after single-bundle fixation, *SB + EA* knee with single-bundle and extra-articular tenodesis

Our results confirm the in vitro studies of Engebresten et al. [6] about subluxation of lateral plateaus prevention performed by the EA procedure. Moreover, the control of the lateral compartment at 30° may explain the reduction of "giving away" sensation reported by Jensen et al. [13] and the good clinical outcome, observed in clinical studies, using this combined procedure [24].

These results are in agreement with previous biomechanical studies [28, 30, 34]. Woo et al. [8, 10, 37], on in vitro studies, have clearly demonstrated that there is an uneven distribution of forces between the antero-medial, which is replaced by the SB graft, and postero-lateral bundles of the intact ACL thought the range of motion of the knee. In extension, the antero-medial bundle is not able to control internal tibial rotation and the PL bundles have higher in situ forces than the antero-medial bundle, playing an important role in controlling internal rotation, while the antero-medial bundle has much higher loads than the postero-lateral at 90° of flexion [8].

Logan in 2004 [22], in an in vivo weight-bearing MRI study of the ACL-deficient knee, suggested that laxity is antero-lateral with internal tibial rotation during knee flexion. This antero-lateral laxity was detected also by Colombet et al. [4] and Lie et al. [19] which found, in vitro, that a SB reconstruction is not able to control tibial rotation leaving a residual pivot shift phenomenon. Similarly, Georgoulis et al. [9] showed that the tibia was abnormally internally rotated throughout the gait cycle in ACL-deficient knees and this was only partially corrected by SB reconstruction.

Our study had some limitations; we performed the measurements during surgery with an inflated tourniquet, which might have increased muscle tension. Moreover, our tests were manually performed by the same surgeon. These two factors are the most critical point of the study, and might have biased our findings, anyway, were consistent with in vitro studies found in the literature. In addition, the navigated procedure in previous articles was found to have high intra-surgeon repeatability in an in vivo setup [25, 27]. Another limitation is that we did not perform the pivot shift test, which has been found to be an important test for combined rotatory loads and also correlated with the clinical outcome [14, 19, 31]. Pivot shift was not performed because we did not want to put excessive stress on the reconstructed ACL immediately after surgery. Anyway, the evaluation of AP displacement on medial and lateral compartment at 30 and 90° of flexion could describe the pivot shift effect, which is defined as the forward subluxation of the lateral tibial plateau on the femoral condyle in extension and spontaneous reduction in flexion. Another limitation is the lack of a healthy control group. This was be hard to achieve since this would mean that the contralateral knee would have been to be analyzed using the same protocol, i.e. Steinmann pins in the healthy contralateral knee. The purpose of this article, however, was to analyze the effect of the lateral plasty in controlling knee laxity at time zero. These results will be utilized during follow-up to correlate joint laxity with clinical outcome.

In conclusion, our study demonstrated that in vivo the addition of an extra-articular procedure to single-bundle ACL reconstruction may be effective in controlling coupled tibial translation during the Lachman test and reduces AP laxity at 90° of flexion.

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