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ORIGINAL ARTICLE

Morphometric analysis and functional correlation of tibial and femoral footprints in anatomical and single bundle reconstructions of the anterior cruciate ligament of the knee

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KEYWORDS
Double bundle anterior cruciate ligament;
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Summary
Introduction: The anterior cruciate ligament (ACL) is composed of an infinite number of fibers whose individual anatomical and biomechanical features have been well defined. Although numerous biomechanical studies have shown that reconstruction that is as anatomical as possible results in better control of rotational laxity, very few studies have investigated the surface area of tibial and femoral insertion sites in these reconstructions. The aim of this study was to compare the surface areas of tibial and femoral insertion sites in single and double bundle reconstructions and correlate these findings with the isometry profile obtained. Our hypothesis was that double bundle (DB) reconstruction results in better filling of the native ACL footprint thus increasing the biomechanical value of available graft tissue.
Patients and methods: Forty-six patients underwent computer navigated ACL using hamstring tendons: 23 underwent single bundle (SB) and 23 DB reconstruction. The Praxim navigation station equipped with ACL logics software made it possible to digitize insertion site footprints, register perioperative data for graft position as well as anteroposterior and rotational laxities and pivot shift.
Results: There was a statistically significant difference between the two groups for tibial and femoral insertion site surface areas: 71 $mm^2 \pm 17$ (SB) versus 99.9 $mm^2 \pm 30$ (DB) for the tibia, 67 ± 11 mm^2 (SB) versus 96.9 $mm^2 \pm 28$ (DB) for the femur. Isometry profiles showed that anisometry was favorable in all cases: 2.5 mm ± 2 for SB; 2.9 mm ± 2 for the anteromedial bundle (AMB) with DB and 9.6 mm ± 3.7 for the posterolateral bundle. When both groups were combined, there was a statistically significant correlation between the size of tibial insertion surface area and anteroposterior and rotational laxity.

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Discussion. — This study confirms that better filling of native ACL footprint surface areas results in better control of anteroposterior laxity.
Level of evidence. — Level IV.

Introduction

For many years reconstruction of the anterior cruciate ligament (ACL) was limited to one bundle, either the patellar or the pes anserine tendon with clinical results that were satisfactory but whose failures were usually attributed to poor graft position [1—3]. However, it must be remembered that the ACL is not a simple cylinder. Numerous anatomical, biomechanical and histological studies have clearly shown that this ligament is the sum of an infinite number of fibers each with its own separate tibial and femoral insertion and specific mechanical behavioral features that define an envelope of anterior and rotational laxity. It is generally agreed that the ACL can be described as two bundles: the anteromedial and posterolateral bundles [4—10]. The biomechanical role of the posterolateral bundle (PLB) has been clearly shown to participate in controlling rotational laxity [11—17]. To improve the clinical results of single bundle (SB) ligament reconstruction (failure rates between 10 and 20% [3]), numerous authors have proposed double bundle (DB) reconstruction techniques [18—20]. Nevertheless, very few clinical studies have shown that anatomic ACL reconstruction improves control of anteroposterior laxity or rotational laxity [19—24]. One of the hypotheses supporting anatomic reconstruction could be histological: couldn't the significant increase in tissue coverage alone be the parameter explaining these improved results? Each of the fibers of the two bundles is organized in relation to its anatomical insertion site to respond to two-dimensional mechanical stresses.

The aim of this study was to compare the surface areas of tibial and femoral attachments after SB and DB reconstructions and correlate these results to the biomechanical profile by calculating anisometry and perioperative laxity.

We hypothesized that DB reconstruction would provide better filling of the surface area of native ACL footprints and increase the biomechanical value of available graft tissue.

Patients and methods

Forty-six patients underwent computer navigated ACL reconstruction: 23 underwent SB (reconstruction with pes aserine tendons) and 23 anatomic DB reconstruction. Knees with peripheral and/or meniscal ligament injuries were excluded. The time between injury and surgery was a mean 67 days (10—207). Both cohorts of patients were comparable and there was no statistically significant difference in sex, age, side, delay to surgery or laxity between the groups. This was a continuous prospective non-randomized study with random allocation.

Computer navigated surgery

We used the Praxim navigation station (Praxim La Tronche, France) equipped with ACL logics software, an application that uses the so-called bone morphing technology [25]. The tibial and femoral footprints of both bundles were digitized with an optical navigation system, the implantation surface areas were calculated and isometry profiles were determined [26]. ACL logics software makes it possible to identify anteroposterior (AP) and rotational laxity as well as to perform a perioperative pivot shift test (Colombet index) before and after reconstruction.

Surgical technique

Single bundle reconstruction

The tibial tunnel was placed in the most anteromedial part of the native anatomic ACL insertion site while avoiding notch impingement. The position of the femoral tunnel was as isometric as possible in the fibers of the anteromedial bundle (AMB) of the native ACL.

Double bundle reconstruction

The tibial tunnel of the AMB was positioned forward and inside, near the medial tibial spine while avoiding notch impingement. In the femur, the center of the AMB bundle was positioned in the fibers of the AMB of the native ACL in an isometric position. The tibial tunnel for the PLB was located inside the triangle which was limited: laterally by the posterior horn of the lateral meniscus, behind by the anterior margin of the posterior cruciate footprint, in front and inside by the posterolateral margin of the anteromedial tunnel while preserving at least 2 mm of distance between the two. These two tunnels diverged. The femoral tunnel for the AMB was placed, starting from the ''over-the-top'' position at 11 o'clock for the right knee and 1 o'clock for the left knee with between 5 and 7 mm of offset depending on the diameter of the AMB while leaving at least 1 mm of distance from the posterior femoral cortex. The femoral tunnel of the PLB was positioned in the anatomical footprint of the ACL below and in front (arthroscopic view) of the AMB tunnel, while preserving a bony bridge of 2 mm between the two tunnels. The center of the PLB made it possible to obtain a favorable anisometry curve in all cases (tense during extension, relaxed during flexion).

Statistical analysis

Quantitative data were reported as means, standard deviations, minimum and maximum values. The Student *t* test for paired series was used to compare pre- and postoperative

Table 1 Laxity, isometry, and areas according to the type of reconstruction.

	Single bundle	Double bundle	
Lachman (mm)			
Before reconstruction	11.7 ± 2.3	10.8 ± 2.6	n.s
After reconstruction	4.5 ± 2.6	3.4 ± 3.7	$P < 0.01$
Internal rotation (degree)			
Before reconstruction	21.4 ± 5.2	20.4 ± 4.4	n.s
After reconstruction	17.5 ± 4	13.2 ± 4.9	$P < 0.01$
Pivot shift (index)	0.17 ± 0.06	0.21 ± 0.16	n.s
Isometry (mm)	2.5 ± 2	AMB: 2.9 ± 2PLB: 9 ± 3.7	–
Areas (mm^2)			
Tibia	71 ± 17	99.9 ± 30	$P < 0.01$
Femur	67 ± 11	96.9 ± 28	$P < 0.01$

PLB: posterolateral bundle; AMB: anteromedial bundle.

scores and the Chi^2 test was used for comparisons of groups. A 5% risk of a Type I error was considered acceptable to determine the significance of comparative tests. Statistical tests were performed with Stat View 4.5 software.

Results

The results are given in Table 1.

Insertion sites

Single bundle reconstruction

The surface area of the graft was 71 mm^2 ± 17 (55–85) for the tibia and 67 mm^2 ± 11 (52–79) for the femur. The isometry profile was always favorable with a mean anisometry of 2.5 mm ± 2 (0–4).

Double bundle reconstruction

The surface area of DB (anteromedial [AM] and posterolateral [PL]) grafts was 99.9 mm^2 ± 30 (73,23–148,50) for the tibia and 96.94 mm^2 ± 28 (66.73–141.15) for the femur. The isometry profiles showed that the AMB fibers were nearly isometric (0–115°), a mean 2.91 mm ± 2 (1–6). The anisometry profile of the PLB was favorable in all cases, a mean 9.6 mm ± 3.7 (6–13).

Surface areas of tibial and femoral insertion sites were statistically different between the two groups ($P < 0.01$).

Laxity

After reconstruction there was a significant difference between the two groups for AP laxity (mm): 4.5 ± 2.6 (SB) and 3.4 ± 3.7 (DB) ($P < 0.01$) and internal rotational laxity: 17.5° ± 5.2 (SB) et 13.2° ± 4.9 (DB) ($P < 0.01$) (Table 1). No statistically significant difference was found for the pivot shift test between the two groups (Colombet's index): 0.17 ± 0.06 (SB) and 0.21 ± 0.016 (DB).

There was a statistically significant correlation between the surface area of the tibial insertion site and AP laxity and internal rotation laxity, all groups combined, while there was no significant correlation between the pivot shift index and femoral or tibial insertion site surface areas.

Discussion

The aim of this study was to compare the surface areas of tibial and femoral insertion sites following SB and DB ACL reconstructions and to correlate results with the laxity. A statistically significant difference was found in support of increased filling of native ACL footprints with DB reconstructions. We also observed an improvement in correction of AP and internal rotational laxity with DB reconstruction, which was significantly correlated to increasing the filling of ACL insertion sites. Ishibashi et al. [21] evaluated the role of the AMB and the PLB in the control of laxity in 32 cases of DB ligament reconstruction with the computer aided navigation system Orthopilot. They found that the PLB played an important role in controlling laxity when the knee was near extension while the role of the AMB was continuous throughout knee flexion. On the other hand, the two bundles did not play a role in internal rotation. Steckel et al. [12] showed that AP laxity after DB reconstruction or SB reconstruction with the AMB alone was comparable to that in an intact knee. Correction of internal and external rotational laxity as well as Lachman test results were better with DB reconstruction. In these studies, tunnels for SB reconstruction were placed in the same position as that for the AMB in DB reconstructions. Kanaya et al. [27] placed SB reconstruction grafts nearer to the PLB resulting in control of AP and rotational laxity that was similar to that in DB reconstructions. Feretti et al. [28,29] did not find any significant difference for AP and rotational laxity in an in vivo study comparing the two techniques (SB versus DB).

While it has not been confirmed that placing the PLB in the native ACL PLB footprint results in better control of rotational laxity because of its inclined position, adding another bundle that is tense when the knee is near extension plays a role in controlling the anterior compartment [30]. We found that PLB and AMB isometry were identical when the knee was near extension. Thus, adding the PLB to the AMB should logically result in a significant increase in the amount of graft tissue available to correct the anterior compartment. This is supported by our results showing a significant relationship between graft insertion site surface area and correction of AP laxity. Graft inclination seems fundamental for the correction of AP laxity and rotational laxity, emphasizing the importance of graft position both in single and DB grafts [31—37].

We did not find any difference in pivot shift results: the results of the literature on this subject are controversial. [19,38,39]. The parameters for data acquisition with navigation systems are either planar or biplanar making it possible to define three dimensional coordinates linking two points in space: either the ends of a fiber (to calculate isometry); or the linear displacement of two points (to calculate laxity). These calculations are determined with the knee in a particular position and do not take into account the dimension of time. Thus, the mathematical translation of pivot shift is not realistic with existing tools. An envelope of passive range of motion has been described for DB reconstruction with, for certain authors, better control of pivot shift. [14,40]. Our study does not confirm these results and shows that the test is not reproducible and that the proposed index probably does not reflect the dynamic three-dimensional reality of the pivot shift. Musahl et al. [41] performed an in vitro study using a robot to study continuous knee flexion and its bidimensional AP and rotational components. Hoshino et al. [42] evaluated pivot shift with an electromagnetic system that measured acceleration.

The following are the limits to our study: the relatively few number of subjects. Also, in vivo studies using navigation systems can only be perioperative and do not reflect normal clinical conditions: in the future non-invasive tools should make it possible to measure the parameters of laxity over time.

Conclusion

So-called anatomical or DB ACL reconstruction makes it possible to fill more of the native ACL surface area as well as to increase the biomechanical value of the graft tissue and obtain better control of anteroposterior and rotational laxity of the knee. The navigation tool provides validation of the favorable anisometric profile of both bundles in the anatomic ACL footprint so that results are near the isometric envelope.

Disclosure of interest

The authors declare that they have no conflicts of interest concerning this article.

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