Analysis of anatomic positioning in computer-assisted and conventional anterior cruciate ligament reconstruction

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Introduction
Anterior cruciate ligament (ACL) reconstruction should be anatomic while achieving favorable anisometric behavior to avoid impingement with the femoral notch. Computerization enables these biomechanical conditions to be optimally fulfilled; but what of anatomic positioning? The present study compared the positioning of tibial and femoral tunnels, drilled using either a conventional ACL guide or a navigation system, using the anatomic foot-print areas of the native ACL.

Material and methods: This cadaver study used computerized recording to compare tibial and femoral ACL attachment areas to the positioning of tunnels created either conventionally or under computer-guided navigation.

Results: Computer guidance enabled the tibial and femoral tunnels to be systematically positioned within the anatomic area and, as regards the tibial area, within the anterior third near to the medial tibial spine, without femoral notch impingement. Anisometry was in all cases favorable, at a mean 3.3 ± 0.7 mm; using a conventional guide, anisometry was favorable in only 50% of cases, at a mean 5.4 ± 1.2 mm.

Conclusion: Computer-guided navigation ensured implant positioning within the so-called anatomometric area of the native ACL attachment, avoiding impingement with the femoral notch.

Level of evidence: Level 2.

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Introduction
Whatever the technique of anterior cruciate ligament (ACL) reconstruction, tibial and femoral tunnel positioning is a
key point to success. Positioning should be anatomic, within the native ACL area, with minimal anisometry and free of femoral notch impingement. The main factor of failure is defective graft positioning [1]. According to Gillquist [2], the difficulty in positioning the tunnels lies in the great intersubject variations in anatomy. According to Jagodzinsky et al. [3], proper tibial tunnel positioning free of femoral notch impingement varies from 36 to 62% of the anteroposterior width of the tibial insertion area. There is thus no predefined position that will guarantee ideal positioning in any knee for the surgeon using a standard guide. Quality of positioning, however, largely underlies the variation from 75 to 90% good objective clinical results found in the literature [4,5].

To improve the quality of results, it thus seemed necessary to increase the accuracy of tunnel positioning, and computer-assisted surgical navigation has made this feasible [6—11]. Since 1993, numerous studies conducted in computer-assisted surgical navigation has made this necessary to increase the accuracy of tunnel positioning, and objective clinical results found in the literature [4,5]. However, largely underlies the variation from 75 to 90% good objective clinical results found in the literature [4,5].

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Materiel and methods

A cadaver study was performed following our center’s protocols and guidelines. Ten fresh non-pathologic human knee specimens with intact ACL and free of history of surgery underwent ACL reconstruction on a single procedure carried out by a single experienced operator: single-bundle ACL reconstruction with hamstrings graft (semitendinosus + gracilis). Preliminary arthroscopy confirmed ACL integrity. The navigation system was set up, and the tibial and femoral native ACL insertions were recorded by the software. The ACL was then sectioned. The tibial and femoral native ACL insertions were recorded by the software. The ACL was then sectioned. The tibial and femoral native ACL insertions were recorded by the software. The ACL was then sectioned. The tibial and femoral native ACL insertions were recorded by the software. The ACL was then sectioned.

Navigation system

The navigation system was the Surgetics Station® (Praxim Medivision, La Tronche, France), with dedicated ACL reconstruction software. The software records the spatial positions of the transplant, calculates its biomechanical behavior and visualizes the potential risk of notch impingement. There are four stages of acquisition: calibration, setting up and recording rigid-body reference frames, digitized acquisition of reference points for assessing knee laxity, and performance of Bone-Morphing® sequences; these have been previously described [11—13]. Complementary dedicated software was created for the study, to record native ACL contours on both the tibial and femoral sides. Nine points trace the contour of the anatomic ACL insertion.

Figure 1 Distribution of ACL tibial insertion in six regions.

A 3D representation of each knee was available on-screen for the operator to navigate transplant positioning.

Conventional guide

For the tibia, the PCL Related® tibial guide was used, and for the femur the in/out femoral guide (Smith & Nephew Inc., Andover, ME). The operator positioned the center of the tibial tunnel as anatomically as possible. The femoral guide was introduced via the anteromedial portal, with the knee in 120°, at 10.30 position for right knees and 1.30 for left. Femoral guide offset was determined according to transplant diameter, to provide a maximum 1.5 mm margin between tunnel circumference and posterior femoral cortex (on average, transplant radius plus 1 mm). Each selected tibial or femoral tunnel center was recorded by the navigation software, which then mapped femoral isometry on-screen, so that the operator could choose a femoral point within the envelope of favorable isometry. For this, an isometry curve was also visible on-screen, to visualize graft behavior over a range of knee positions from complete extension (extension 0) to 110° flexion.

Computerized guidance system

A protocol employing the ACL Logics system was used [14]. When the instruments had been calibrated and the rigid-body reference frames set up, the ACL insertions were recorded with a minimum 6—9 points on the tibial and femoral surfaces, using a digital pointer introduced via a third arthroscopy portal. An adaptation of the Bone-Morphing® program recorded a graphic digital native ACL map at the tibial and femoral bone surface. The ACL was then resected. The operator navigated tibial tunnel positioning as anteriorly as possible, avoiding notch impingement (with the map continuously on-screen), and then femoral tunnel positioning within a minimal anisometry area, respecting the curve of “favorable” anisometry. After automatic recording, the various positions were correlated to the native ACL anatomic insertion areas. All the data were saved to a CD-ROM. To allow systematic analysis, insertion areas were divided into six regions (Fig. 1) [15] for the tibia and four for the femur: A, B (proximal region, anterior and posterior), and D, C (distal region, anterior and...
posterior) (Fig. 2). If the tunnel center lay outside of the native anatomic region, the point was noted as ′: e.g., B′ lay outside of region B.

Results

Location of tibial tunnel center (Table 1).

The above parameters were recorded for each knee:

- the conventional guide enabled positioning in the most posterior part of the native ACL insertion area in 50% of cases (regions 1, 2, 3, 4). Positioning was anatomic in nine cases, sometimes slightly lateraled, but in two cases was medial and in one case non-anatomic, just behind the insertion;
- with computer-assisted guidance, there was never notch impingement with the most anterior part of the tibial tunnel. The tunnel center was systematically forward of the line between the tibial spines, in the anterior third (five out of 10 cases) or at the junction between the anterior and central thirds (five out of 10 cases). The tunnel center was always medialized, and anatomically positioned (Fig. 3).

Location of femoral tunnel center (Table 1, Fig. 4):

- the conventional femoral guide (without computer-assisted navigation) provided a mean anisometry of 5.4 ± 1.2 mm, a favorable anisometry curve in 50% (Table 2) of cases and anatomic positioning in all cases;
- with computer-assisted navigation, the femoral tunnel center was anatomically positioned and in the anterior and proximal part behind the native ACL insertion. It was very often very close to the transition line (separating the favorable and unfavorable anisometry regions), and forward of it in only one case; in nine cases out of 10, it was within the favorable area. The mean anisometry of the central fiber was 3.3 ± 0.7 mm (range, 2–4 mm).

Discussion

Computer-assisted navigation was validated in ACL reconstruction with respect both to isometry and clinical results [7,14,16]. However, there were no studies comparing positioning of the isometric ACL envelope and its computerized anatomic representation. On the femoral side, we deter-

mined a transition line (Fig. 5): in all cases, this crossed the anatomic area of the ACL, dividing the insertion into two semicircles of unequal size. The smaller, anterior semicircle, forward of the line, is the unfavorable anisometry area and the posterior semicircle behind the line the favorable anisometry area. ACL isometry progressively increases proximally to distally on this femoral map, which enables an “ideal” area Z to be determined for perfect transplant isometry corresponding to a part of the neoligament: this is situated on the lateral part of the femoral notch, behind the transition line (favorable anisometry curve) in the proximal and most isometric area (anisometry less than 3 mm) (Fig. 4). Thus, positioning the implant on the lateral side of the notch, behind the transition line, in the ideal area, guarantees implantation in an anatomic position with a theoretic central fiber providing optimal isometry. According to Friederich [17,18], a transition line separates fibers stretched in flexion and those stretched in extension, with the isometric area lying along the line; the area forward of it corresponds to positive anisometry, with fibers stretched in flexion, and the posterior area to negative anisometry, with fibers relaxed in flexion.

Functional anatomy

Interpretation of isometry curves. The isometry curves of the points along the line of transition are distinct: always horizontal in the case of proximal points, with slope increasing distally, corresponding to increasing anisometry of the transplant, which remains, however, stretched in extension and relaxed in maximum flexion. This has practical consequences for the choice of femoral tunnel:
Table 1  Position of tibial and femoral tunnels centers.

<table>
<thead>
<tr>
<th>No. of knee</th>
<th>Tibia (areas)</th>
<th>Femur (areas)</th>
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<tr>
<td></td>
<td>Conventional</td>
<td>Navigation</td>
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<td>1</td>
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<td>1L</td>
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<td>5L</td>
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☀: favorable region; ☐: unfavorable region.

- the position may be proximal, on the transition line, and can be considered isometrically optimal; but is it anatomic? We showed how a conventional in/out femoral guide positioned at 1.30 in a left knee or 10.30 in a right knee ensured an anatomic position, but with a risk of drilling the tunnel too far forwards, into unfavorable anisometric area;
- on the other hand, the position may be more distal, behind the transition line: in that case, it is in an anatomic area, with greater but still favorable anisometry; this is known

Figure 4  Femoral tunnel: a: in black: outline of the femoral ACL insertion projected onto the isometry map on the medial side of the lateral condyle; b: conventional guide (in blue): slightly forward of the transition line, within anatomic area B. Unfavorable isometry curve with anisometry of 4 mm; c: computer-assisted guide (in black): directly on the transition line, within anatomic area A (anterior proximal). Horizontal isometry curve with anisometry of 2 mm.
as lateralized positioning. The position is unproblematic for reconstruction, but may induce residual sagittal laxity: the more distal the position, the greater the anteroposterior laxity; however, it may also have the advantage of better controlling rotational laxity, as it is nearer to the posterolateral bundle.

In fact, the ACL needs to be seen as an infinity of fibers in continuity, each with its own anisometry. As it happens, there are no ideal "isometric" fibers, the nearest thing being the most anterior of them [15,17–19]. Incorrect tunnel positioning results in most cases from conventional guides being poorly adapted to the extreme intersubject variations in femoral notch anatomy. Yet correct tunnel positioning is absolutely essential, both anatomically [12], especially to avoid any notch impingement [20,21], and for the isometric envelope [22].

Navigation tools distinguish the mechanical behavior of each ACL bundle. The operator can choose the implant position, for reconstruction close either to the anteromedial bundle in the anatomic area with minimal anisometry, or to the posterolateral bundle, still in an anatomic area but with greater anisometry [23,24]. The operator can thus choose the bundle best adapted to the particular laxity of the knee. Mathematical models correlating anisometry and laxity remain to be defined.

The present study demonstrated the possibility of achieving isometric behavior in the central fiber in an anatomic position on the femoral side; but is such a position compatible with avoidance of notch impingement? One way of avoiding impingement would be to position the graft more vertically; but this would have the drawback of poorer control of anterior laxity and internal rotation [24]. With conventional guides, it is not possible to be sure of finding a tibial point compatible with the requirements of minimal anisometry and non-impingement in an anatomic area. Computer-assisted navigation achieves these objectives.

**Conclusion**

The ACL Logics navigation system enabled us to be sure of positioning the graft in the anatomic area of the native ACL, with optimal anisometric behavior in the theoretic central fiber. Such anatomometric positioning is individual. It should, however, not be forgotten that any navigation system depends on the operator’s choice of criteria defining the system. It is also entirely up to the operator to position the tunnel centers, independently of the navigation system. It is also mandatory to have sufficient experience in ligament surgery and in surgical navigation if incoherence is to be avoided — although it remains possible to cross over from the navigation protocol to a conventional one.

**Disclosure of interest**

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

**References**

Computer-assisted anatomy of the anterior cruciate ligament


