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The slope of anterior cruciate ligament bundles for accurate transtibial anatomic reconstruction: a cadaveric study

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Objectives

Several studies have shown that femoral tunnel placement during double bundle anterior cruciate ligament reconstruction through the anteromedial (AM) portal is more accurate compared with the transtibial technique. Our hypothesis is that, for proper transtibial placement of the femoral tunnels, not only the anatomical sites of the tibial tunnels are important but also the slope of the tibial tunnels should match the native slope of the corresponding bundle. The anatomic insertions of the anterior cruciate ligament bundles in the femur and the tibia are well reported in the literature, but to our knowledge no study has reported the degrees of slope of the bundles.

Materials and methods

We examined eight cadaveric knees of middle-aged adults. The angle between each bundle and the tibial plateau was measured in both planes. The sagittal plane was measured between the bundle and the posterior tibial plateau with the knee flexed at 90°. The coronal plane was measured between the bundle and the lateral tibial plateau with the knee flexed at 90°.

Results

In the sagittal plane, the mean slope angle was 55.5° for the AM bundles and 90.6° for the posterolateral (PL) bundles. In the coronal plane, the mean slope angle was 80.6° for the AM and 81.3° for the PL bundles.

Conclusion

Focusing on the slope angles of the PL bundle in the sagittal plane (90.6°), we found that this bundle is oriented almost perpendicular to the tibial plateau. This means that for proper transtibial drilling the starting point should be from the posteromedial surface of the tibia behind the medial collateral ligament.

Clinical relevance

We confirm that transtibial drilling of the PL bundle is not applicable with the classic starting points on the AM surface of the tibia, and thus transportal techniques are better.

Keywords:
anatomic, anterior cruciate ligament, double bundle, tibial slope

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Introduction

Double bundle (DB) anterior cruciate ligament reconstruction (ACLR) has become increasingly popular during the last few years [1].

Muneta *et al*. [2] suggested that the DB ACLR procedure could enhance healing at the bone tendon junction by increasing the contact area and thus the stability of the knee joint could be better controlled. They reported that the two femoral tunnels were created at the 10:30 and 11:30 (or 12:30 and 1:30) positions, respectively. However, anatomic reconstruction is achieved when the two grafts are attached to the center of the anatomical attachment of the anteromedial (AM) and posterolateral (PL) bundles in the femur as well as the tibia [3,4].

Gougoulias *et al*. [5] in a radiographic study of single bundle ACLR concluded that, by using anatomical landmarks and increased tibial tunnel obliquity, optimal femoral tunnel positioning could be achieved using the transtibial technique.

With the new concept of femoral tunnels below the residents ridge [6–8] the angle of drilling has become more horizontal, and it is impossible to obtain the proper angle transtibially.

Several studies have shown that femoral tunnel placement during double bundle ACLR through the AM portal is more accurate compared with the transtibial technique [9–11].

Our hypothesis is that for proper transtibial placement of the femoral tunnels not only the anatomical sites of the tibial tunnels are important but also the slope of the tibial tunnels (which correspond to the angle of the tibial aiming device) should match the native slope of the corresponding bundle as well (Fig. 1).

The anatomic insertions of the anterior cruciate ligament (ACL) bundles in the femur and the tibia are well reported in the literature [12,13], but to our knowledge this is the first report on the degree of slope of the two bundles of the ACL in relation to the tibial surface.

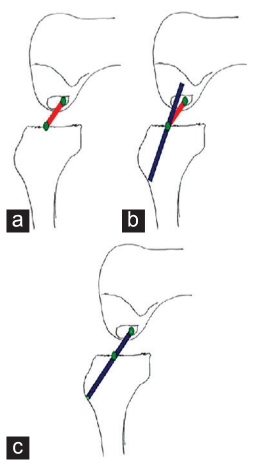
Materials and methods

We examined 10 formalin-preserved cadaveric knees of middle-aged adults (six men and four women). The age of the cadavers ranged between 30 and 55 years. Two knees were excluded because of advanced arthritic changes.

The lower limb was resected 20 cm proximal to the distal femoral line and 20 cm distal to the proximal tibia including the knee joint and all surrounding soft tissues. The skin and subcutaneous tissues were removed circumferentially. The extensor mechanism was reflected downward and kept attached to the tibial tuberosity.

Using an electric saw, the medial femoral condyle and the posterior cruciate ligament (PCL) were removed. This resection started from the middle of the roof of the intercondylar notch in between the ACL and the PCL and was extended upward 7 cm and then completed by a horizontal cut. All lateral and posterior structures were left intact so as to keep the normal relation between the tibia and the lateral femoral condyle.

Figure 1



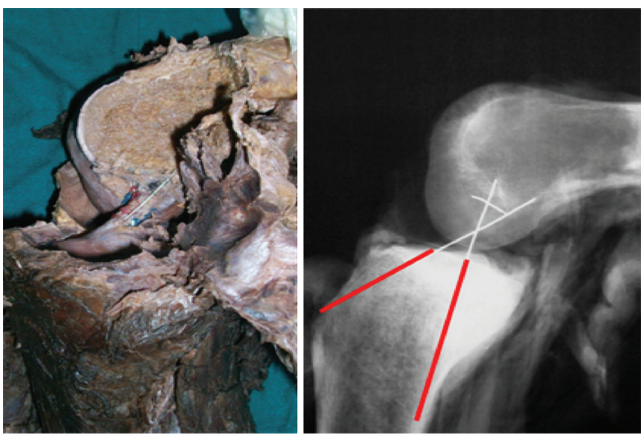
Explanation of the hypothesis of the study. (a) The normal inclination of the anterior cruciate ligament anteromedial bundle (AM) (red line), with the normal tibial and femoral attachment points (green circles). (b) Tibial tunnel (blue) with incorrectly chosen tibial inclination angle despite correct choice of the tibial entry point leads to incorrectly positioned femoral tunnel. (c) A correctly chosen tibial entry point and inclination angle leading to a correctly positioned femoral entry point for the AM bundle.

The bundles of the ACL were identified on the basis of the tensioning pattern and the orientation of their fibers throughout passive extension and flexion of the knee. The fibers that were tense at full extension and relaxed at flexion were considered the PL bundle. These fibers were confirmed to be the PL bundle by its attachment to the PL half of the ACL tibial attachment and to the anterior half of the femoral ACL attachment with the knee flexed to 90°. The bundles were sutured with different colored sutures (red for the AM bundle and blue for the PL bundle). During the dissection we preserved as much as possible from soft tissue around the knee to keep the normal relation between the tibia and femur, but resection of the PCL was not avoidable for accurate identification of ACL bundles and accurate placement of the needles. Taking this into consideration we applied anterior drawer force on the tibial fixation device while performing the following steps.

The knee was positioned in 90° flexion (the standard position used during ACL reconstruction in our institute). The middle of the medial and anterior border of the tibial attachment of each bundle was identified using a roller placed on the side and in front of each bundle, respectively. The same was done for the superior and anterior borders of the femoral attachment of each bundle. Two needles were inserted on the side of each bundle (starting from the identified middle of the medial border of the tibial attachment of each bundle to the identified middle of the superior border of the femoral attachment of the same bundle). A digital photograph and a lateral radiograph were taken (Fig. 2).

These needles were then removed. Two more needles were inserted in front of each ACL bundle (starting from the identified middle of the anterior border of the

Figure 2



Digital photograph and radiograph showing the bundle slope in the sagittal plane.

tibial attachment of the bundle to the identified middle of the anterior border of the femoral attachment of the same bundle).

The medial femoral condyle was replaced and fixed with two transfixing pins to restore the normal coronal alignment of the lateral femoral condyle in relation to the tibial surface. A digital photograph and an anteroposterior radiograph were taken (Fig. 3).

Measurements

Using electronic goniometer software (MB Ruler), the angles between each bundle and the tibial plateau were measured from the radiograph in each view. In the sagittal plane, the inclination angles were measured between each bundle and the posterior tibial plateau. In the coronal plane, the slope angles were measured between the bundle and the lateral tibial plateau.

To improve the validity and reliability the dissection of all cadavers, all measures were taken by a single ACL expert surgeon.

Statistical analysis

Using the one sample *t*-test the mean value of the angles obtained for the AM bundle in the sagittal view was compared with the mentioned angle (45°) for tibial tunnel drilling for the same bundle in the study by Zantop *et al.* [4].

Using the same test the mean value of the angles obtained for the PL bundle in the sagittal view was compared with the maximum and minimum mentioned angles (40 and 80°) for tibial tunnel drilling for the same bundle in the study by Zantop *et al.* [4].

Figure 3

Digital photograph and radiograph showing the bundle slope in the coronal plane.

Because of the limited available samples and the religious and cultural background in our locality, we applied the post-hoc power analysis test using computer software (G*Power 3.1.3) taking into consideration the effect size (d = 0.5) and α value of 0.05.

Results

It was found that the inclination angle in the lateral view ranged between 51 and 60° for the AM bundle, with a mean of 55.5 ± 1°.

For the PL bundles, the same angle ranged between 87 and 93°, with a mean of 90.6 ± 1.2° (Table 1).

In the anteroposterior view, the inclination angle ranged between 76 and 86° for the AM bundle, with a mean of 80.6 ± 1.9°.

For the PL bundles, the same angle ranged between 78 and 86°, with a mean of 81.3 ± 1.9° (Table 2).

Table 1 The slope angles of the anteromedial and posterolateral bundles in the sagittal plane

Specimens	Sagittal slope angle of the AM	Sagittal slope angle of the PL
Knee 1	54	93
Knee 2	51	93
Knee 3	57	89
Knee 4	54	90
Knee 5	60	87
Knee 6	59	91
Knee 7	53	90
Knee 8	56	92
Mean	55.5	90.6
Mode	54.0	93.0
Median	55.0	90.5
SD	1.0	1.2

AM, anteromedial; PL, posterolateral.

Table 2 The slope angles of the anteromedial and posterolateral bundles in the coronal plane

Specimens	Coronal slope angle of the AM	Coronal slope angle of the PL
Knee 1	82	82
Knee 2	76	78
Knee 3	79	79
Knee 4	80	80
Knee 5	80	81
Knee 6	85	85
Knee 7	86	87
Knee 8	77	78
Mean	80.6	81.3
Mode	80.0	78.0
Median	80.0	80.5
SD	1.9	1.9

AM, anteromedial; PL, posterolateral.

Using the one sample *t*-test we found a statistically significant difference between the mean angle for the AM bundle in our study and the used angle for drilling tunnels for the same bundle (45°) in the study by Zantop *et al.* [4].

Using the one sample *t*-test we found a statistically significant difference between the mean angles for PL bundle in our study and the used angles for drilling the tunnels for the same bundle (40–80°) in the study by Zantop *et al.* [4]. The resulting power of the study using the post-hoc power test was $P = 0.43$.

Discussion

Previous single bundle reconstruction techniques were mainly designed to control anterior tibial loading, but were shown to be insufficient to control a combined rotatory load [11].

Yasuda *et al.* [12] and Cha *et al.* [13] emphasized the importance of reconstruction of the native ACL footprint by the anatomical placement of the tunnels of each bundle, as well as drilling two separate femoral and tibial tunnels.

Although the transtibial femoral tunnel drilling is very familiar to many surgeons, it was found to be less accurate, especially for the PL bundle [14].

Even minimal displacements on the femoral attachment is particularly significant [15,16], which is why the AM portal drilling of the femoral tunnel is becoming more popular [17].

The problem of the transtibial technique is that the tibial tunnel limits the direction of the drill bit to allow proper positioning of the femoral entry point. This means that the angle of drilling the tibial tunnel should match the native slope angle of ACL bundles to aim for the correct femoral entry point. Combining this with the correct anatomic insertion sites, it should facilitate one-shot drilling of the femoral tunnels and pulling of the grafts and avoid angulation of the grafts at the edge of the tunnels.

Aglietti *et al.* [18] and Muneta *et al.* [19] described the transtibial technique and recommended the coronal angle for the tibial tunnel drilling to be 65° for the AM bundle and 45° for the PL bundle. Tjoumakaris *et al.* [20] described the AM portal technique adjusting the aiming device to 45° for the AM bundle and to 55° for the PL bundle. These authors did not explain the reason why they adjusted the aiming device to these angles, and they did not describe the angle in both the sagittal and coronal planes, which is needed for the three-dimensional position of the tibial tunnel.

In the radiograph we found angulation in the intraosseous part of the inserted needles. This was because we first placed the needle inside the tibial tunnel in the identified middle point (regardless of the bundle inclination) and then we moved the needle to touch the middle of the femoral attachment. We consider that this angulation has negligible effect on the accuracy of the measurements because the measurements were considered on the intra-articular part of the needle and not on the intraosseous part.

In our study the slope of the AM bundle in the sagittal plane was 55.5° and that in the coronal plane was 80°. These angles can be achieved by drilling the tibial tunnel guide in a manner similar to that used for the single bundle reconstruction. Thus, for the AM bundle, the transtibial method can reach a well-positioned anatomic femoral tunnel.

In the PL bundle we made two observations. The first is that the mean slope angle of the PL bundle in the sagittal plane was 90.6°. This means that it is almost perpendicular to the tibial plateau. Therefore, for proper transtibial drilling of the femoral tunnel for the PL bundle, the proper starting point should be from the posteromedial surface of the tibia behind the medial collateral ligament (MCL) in the sagittal plane. Aglietti *et al.* [18] described the starting point of the PL bundle to be just in front of the MCL. Zelle *et al.* [21] recommended placing the starting point of the PL tunnel posterior to that of the AM tunnel and just anterior to the MCL; however, on the basis of the results of this study the accurate starting point would be behind the MCL.

The second observation is that the mean slope angle of the PL bundle in the coronal plane was 80°, which means that the PL bundle passes almost tangential to the lateral wall of the notch (Fig. 2).

This means that the tibial tunnel should be drilled near the center of the posterior surface of the upper tibia in the coronal plane. This explains why the currently used transtibial techniques are inaccurate to reach the anatomic femoral attachment site of the PL bundle.

These two observations question the possibility of drilling the femoral tunnel for the PL bundle transtibially.

The limitation of this study, besides the limited number of samples, is that we did not try to measure the same angles in different degrees of knee flexion, which might have changed the inclination of the PL bundle, thus allowing accurate transtibial drilling.

The knees used were from both sexes, but their number does not allow undertaking statistical analyses of intersex differences. This is a further limitation of the study, as there are anatomical peculiarities of women's knees, including a relatively narrower notch, that may exert a definite influence on the direction of the ACL.

Conclusion

This is the first study to investigate the slope angles for ACL bundles and it confirms that transtibial drilling of the PL bundle is not applicable with the classic starting points on the AM surface of the tibia, and thus the transportal techniques are better.

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Conflicts of interest

There are no conflicts of interest.

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