Pattern of Angular Change of the Anterior Cruciate Ligament Across the Range of Knee Flexion and the Related Anatomical Dimensions

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Improper femoral and/or tibial tunnel placements are major causes of failure in anterior cruciate ligament (ACL) reconstruction. The 52 embalmed cadaveric knees were measured the dimensions of the surgical related structures using vernier caliper and goniometer. The intercondylar notch width was 17.4 ± 2.3 mm and slope of the roof was 31.3 ± 3.4 degrees. The average length of ACL was 21.6 ± 2.5 mm. The relation of tibial attachment was 47.98 % of the width of the lateral tibial plateau and 49.8 % anteriorly, when it was measured through ACL attachment. Angle of ACL in sagittal plane was decreased during knee flexion. On the contrary, angle of ACL in coronal plane was increased during knee flexion. According to this study, The expected femoral tunnel at 10.00 am to 10.30 am could be performed by arthroscopic transtibial technique using the 48% of tibial width anteriorly for intraartricular tibial-tunnel drill-guide placement and aiming for sagittal and coronal plane of 52.0 ± 4.6 / 20.9 ± 3.9 , 46.2 ± 5.1 / 26.8 ± 4.6 degrees, and 41.6 ± 5.1 / 32.0 ± 4.3 degrees while knee flexion degree were as 60, 90, and 120 degrees , respectively.

Keywords: *Anterior cruciate ligament, Tibial tunnel, Femoral tunnel, Transtibial technique*

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The anterior cruciate ligament (ACL) injury occurs during high impact or sporting activities. A disability outcome of ACL injuries is severe knee instability, which can lead to osteoarthritis[1]. The primary reason for reconstructing a ruptured ACL is to cure symptomatic knee instability. The ACL can be anatomically divided into two bundle: the anteromedial and the posterolateral bundles, named for the orientation of their tibial insertion[2]. Conventional ACL reconstruction procedures have grafted only the anteromedial bundle. This ligament can maintain knee integrity and limit of anterior tibial translation[3]. However, under more complex rotatory motions, such as internal tibial rotation and valgus rotation, these reconstruction procedures are less successful[4]. To improve the results of ACL reconstruction procedures, double-bundle and two-bundle reconstruction procedures have been developed [5-7]. These procedures were included the other separated location of the femoral tunnel for the posterolateral bundle. A solid bony bridge separates the two femoral tunnels. Like the position of the anteromedial bundle, the method to identify the location of the femoral attachment of the posterolateral bundle in the arthroscopic visual field is based on the position related to the clock face or other unclear landmarks[6,7]. Therefore, there is a high possibility that their tunnel position for both anteromedial and posterolateral bundles are not located on the anatomical attachment. The correct angles of the two bundles in both coronal and sagittal planes may not be the same as natural intact ACL. Some patients may continue to suffer pain and instability[8,9]. We study the natural ACL and others related anatomical dimensions to provide more information for the arthroscopic ACL reconstruction procedure.

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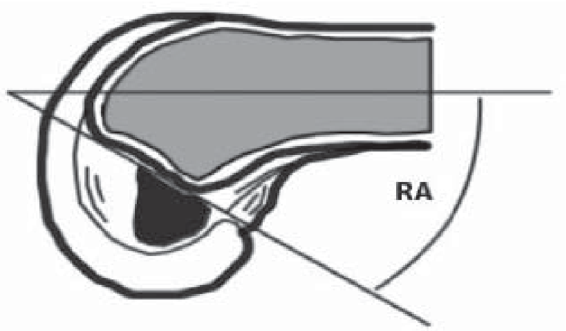
Material and Method

Fifty-two embalmed cadaveric knees that had intact articular surface and ACL were selected for this study. The cadavers were recorded ages, sexes, sides and measured relative lengths of the tibia from the upper border of the tibial tuberosity to the lowest point of the medial malleolus by a measuring tape.

Muscles and soft tissues around the knee joint were removed by dissection. Medial condyle of femur was cut by a hand-saw to expose the ACL. The guide wire were inserted into intercondylar notch close to its roof, and then angle of intercondylar roof was measured between the guide wire and supracondylar ridge of femoral shaft [Fig. 1 (a)]. The length of intercondylar notch was measured from the entrance to the exit point of the guide wire. In the middle of the length of intercondylar notch, the height of intercondylar notch was measured perpendicularly to the lowest point of lateral femoral condyle [Fig. 1 (b)]. And then anterior and posterior widths of intercondylar notch were measured from the center of height of intercondylar notch. Tibial attachment of ACL was observed. The center of posterior half of the tibial attachment in antero-posterior direction were marked and measured to the anterior edge of the tibial plateau (AB) [Fig. 2]. From medial border to lateral border and anterior border to posterior border of the tibial attachment were measured [Fig. 3 (a)]. Distance from the most anterior rim to the posterior border of the tibial plateau was measured (AC), and then compared with the former parameter to calculate the relative length of ACL tibial attachment on the tibial plateau in percent (AB/ACx100). The femoral attachment of ACL was observed and measured from the upper border to the lower border and from the anterior border to the posterior border of femoral-attachment area [Fig. 3 (b)]. The length of ACL was measured from the center of the tibial attachment to the center of the femoral attachment. The diameter of ACL was measured at the middle one third of ACL length from side to side, and from anterior to posterior directions. The direction of ACL fiber from the tibial to the femoral attachment in sagittal and coronal plane were measured when the knee were positioned at 60, 90, 120 and 135 degrees of knee flexion respectively. All the distances were measured by vernier caliper and the angular data were measured by goniometer. The measurements were recorded three times and the average values were calculated. Descriptive statistics and data analysis was done using SPSS for windows.

Results

The 52 embalmed cadaveric knees were included in this study. The average age was 67.30 ± 17.09 years. There were 36 males and 16 females. Right knees



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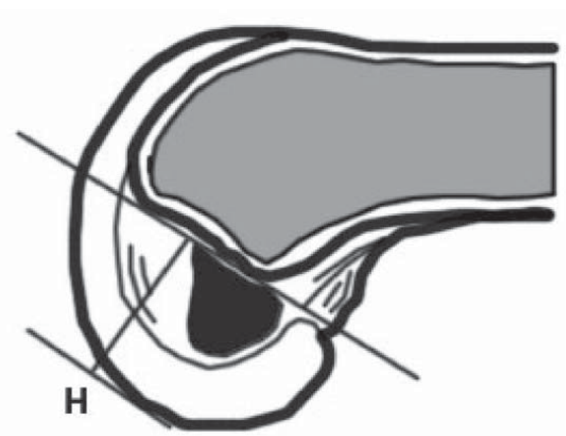


[b]

Fig. 1 Measurements and data of the intercondylar notch
(a) Angle of intercondylar roof (RA) is 31.31 ± 3.40 degrees (Mean ± SD)
(b) Height (H) and length of intercondylar notch are 24.68 ± 2.16 mm and 25.91 ± 2.04 mm

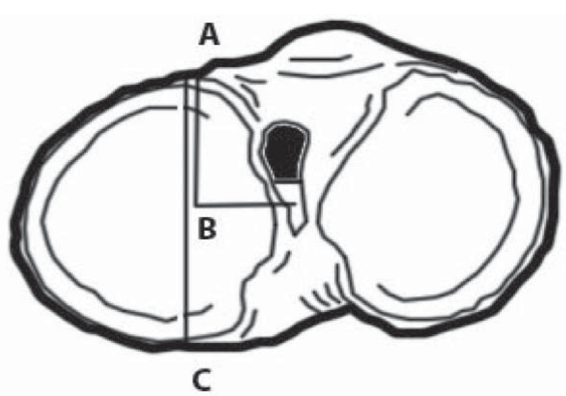
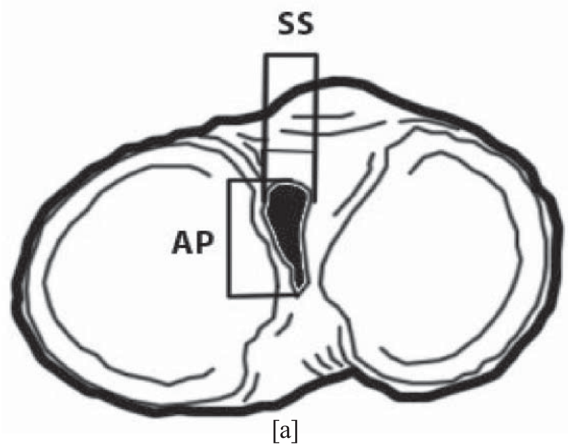


Fig. 2 The position of ACL tibial attachment comparing with the distance of tibial width (AB/ACx100) is 47.98% anteriorly



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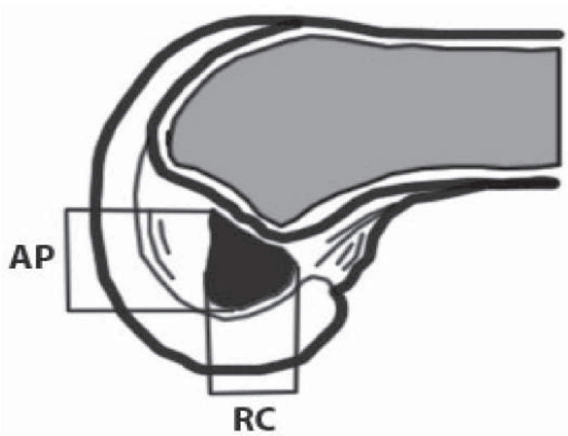

[b]

Fig. 3 The attachment of ACL
(a) Tibial attachment of ACL (side-to-side dimension (SS) is12.65 ± 3.60 mm and anterior-to-posterior dimension (AP) is 23.03 ± 4.30 mm)
(b) Femoral attachment of ACL (rostral-to-caudal dimension (RC) is 18.21 ± 2.73 mm. and anterior-to-posterior dimension (AP) is13.41 ± 3.71 mm)

and left knees were 27 and 25 in number, respectively. The average length of the tibia was 33.33 ± 2.23 cm. The mean height of the body was 158.6 cm. The correlation between the body height and the tibial length is; body height = 3.17 (tibial length) + 53.07 cm.

The average angle of the intercondylar roof was 31.31 ± 3.4 degrees. The mean of the length of the intercondylar notch was 25.90 ± 2.04 mm. The average height of the intercondylar notch was 24.68 ± 2.16 mm. The average anterior and posterior width of the intercondylar notch were 17.41 ± 2.25 and 17.30 ± 2.62 mm, respectively.

The average distance of ACL tibial attachment from side to side was 12.65 ± 3.6 mm (range 4.3-19 mm) and from anterior border to posterior border was 23.03 ± 4.3 mm (range 13.7-35 mm). The position of ACL tibial attachment was 47.98 % anteriorly compared with the distance from anterior border to posterior border of tibial plateau.

Different from the tibial attachment, the study demonstrated that there were no obvious landmarks on the posterior aspect of the notch at the junction of the intercondylar roof and the medial wall of the lateral femoral condyle. The ACL was sharply resected with a knife, leaving 1 mm long ligament tissue at the femoral attachments. On the medial surface of the laterial femoral condyles, a foot print of the ACL attachment was in the form of an egg, occupied posterior half of the medial surface of the lateral condyle with its long axis inclined toward the posterior direction by 30 degree to the long axis to the femur. This femoral attachment divided into upper and lower parts, begin at 8 or 9 o'clock position to 11 o'clock position. The upper half was attached by the anteromedial bundle, and the lower half was the posterolateral bundle. These two bundles were closed together as single bundle at the 10 o'clock position. The average distance of ACL femoral attachment from the upper border to the lower border of the attachment site was 18.21 ± 2.73 mm (range 13.3-25.4 mm) and in anterior to posterior was 13.41 ± 3.72 mm (range 6.4-23.5 mm). The average length of ACL was 21.63 ± 2.46 mm (range 18.2-28.5 mm).

Tibial attachment is more obvious at the footprint of the ACL insertion. The posterolateral bundle attachment on the tibia was located at the most posterior aspect of the area between the tibial eminences. The anteromedial bundle is anterior to the posterolateral bundle in line with the posterior portion of the anterior horn of the lateral meniscus. The average dimension from the medial border to the lateral border was 5.80 ± 1.38 mm (range 3.5-8.5 mm) and from the anterior border to the posterior border was 8.99 ± 1.38 mm (range 6.5-12.5 mm).

The angle of ACL when knee position in full extension was 62.47 ± 5.46 / 12.08 ± 4.56 degrees (sagittal plane / coronal plane), 60 degrees of knee flexion was 52.02 ± 4.59 / 20.86 ± 3.88 degrees (sagittal plane / coronal plane), 90 degrees of knee flexion was 46.22 ± 5.07 / 26.75 ± 4.57 degrees (sagittal plane / coronal plane), 120 degrees of knee flexion was 41.68 ± 5.09 / 31.94 ± 4.29 degrees (sagittal plane / coronal plane),and 135 degrees of knee flexion was 36.61 ± 6.72 / 35.44 ± 5.07 degrees (sagittal plane / coronal plane) [Fig. 4].

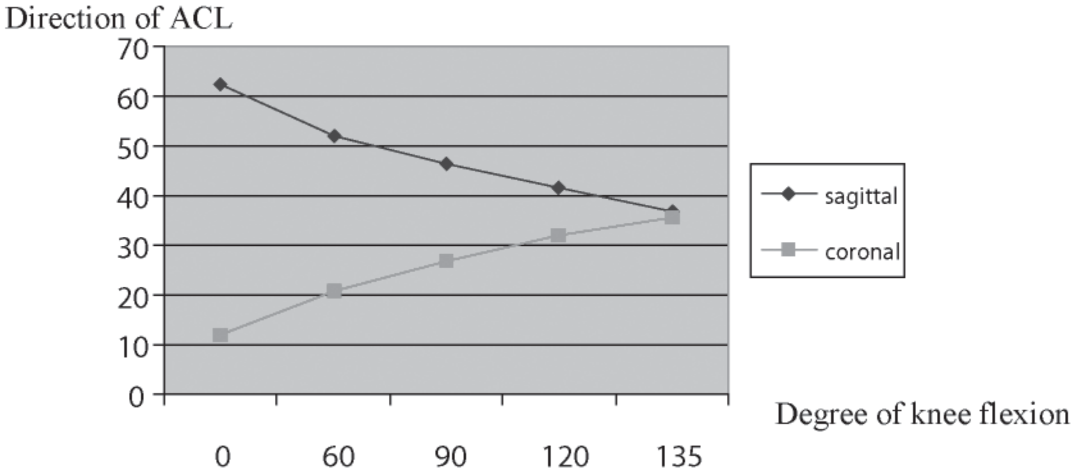

Fig. 4 The directions of ACL in sagittal plane and coronal plane when knee position was between 0 and 135 degree flexion

Discussion

It was generally agree that technical error is the cause of failure for the large majority of primary ACL reconstruction, representing about 70% of the cases. Restoring antero-posterior stability and a full range of motion in the ACL deficient knee through ACL reconstruction is technically challenging with the outcome dependent on many variables[8]. Placement of the femoral tunnel is a critical step and can have a significant effect on outcome[10]. Consequently, current methods of determining the position of the tunnel need to be scrutinized. Recent experiments have shown that small changes in the position of the femoral attachment of ACL grafts had a large effect on both the AP laxity pattern of the knee and the graft tension pattern as the knee flexed[11]. The femoral graft attachments that allowed the least deviation from normal AP laxity were placed isometrically and anatomically, duplicating the anteriomedial fibre bundle of the ACL[12]. Biomechanical studies revealed that the posterolateral bundle can not be overlooked. Only the anteromedial bundle has high in situ force at larger flexion angles of the knee; but the posterolateral bundle has a little bit higher in situ force near extension, than the anteromedial bundle, responding to anterior tibial load. Under combined rotatory load, the trends of load sharing between the antromedial and the posterolateral bundles were consistent as the amount of internal tibial torque varied, with the anteromedial bundle always having a higher in situ force than the posterolateral bundle[13]. The 10 o' clock position for posterolateral bundle more effectively resists rotatory loads when compared with the 11 o' clock position for the anteromedial bundle as evidenced by smaller anterior tibial translation and higher in situ force in the graft[14]. Except for some condition, the posterolateral bundle is important in load sharing with the antromedial bundle. For this reason, many surgeons prefer to reconstruct both the anteromedial and the posterolateral bundles.

An individual error that an experienced surgeon could be expected to make during the ACL reconstructive procedure is the error of the femoral tunnel placement. This issue may be explained by the more difficult orientation of the femoral insertions[10]. The anatomical geometry of bony condylar epiphysis, as a biological structure, is round and curved features. The roof of the intercondylar notch is an arch-liked structure that has no square angles or flat surfaces, but the curved surfaces continue from the medial wall along the roof to the lateral wall of the intercondylar notch. Narrow and wide intercondylar notches have different shapes. Narrow notches tend to be more A-shaped or wave-shaped while wider notches tend to be more round or shaped like an inverted U[15-17]. The posterior edge of the intercondylar roof is also a round geometry that varies in shape across individuals. Another factor influences the shape of the intercondylar notch is degenerative change. Osteoarthritis can has effects on the shape of the intercondylar notch due to bony spurs or growth. The guide system provides placement of Kirshner wire by referencing the over-the-top position. Each guide is used in the standard manner and a Kirshner wire is inserted through the guide. The area of the intercondylar roof represents area that varies from 11-to-1 o'clock position to 9-to-3 o'clock position on the clock faces, depending on the individual shape of the intercondylar notch. From this point of view, 9:30 o'clock position of a surgeon may be exactly the same position as 10 or 10:30 o'clock position of another surgeon, and 10:30 o'clock position of the femoral tunnel in a patient placed by a surgeon may not be exactly the same position, probably a little bit lower or higher, in another patient of different intercondylar notch shape. The femoral offset guide used for tunnel placement can reach over-the-top position differently on the varied-radius round surface of the posterior edge of the intercodylar notch, especially when the guide is aimed from different angle produced by the different tibial tunnel or the different ports. This controversy should not be the point, but the correctly placed tunnel position should depend on the final results; the correct natural angles of the intact ACL ligament on both the coronal and the sagittal planes.

The average surface dimension of the fan-shaped ACL tibial attachment, so called "footprint", was 12.7 ± 3.6 mm width and 23.0 ± 4.3 mm on anterior-posterior aspect. The tibial-tunnel placement site was at the center of the posterior half of the ligamentous insertion area. This study revealed that the tibial tunnel was 47.98% anteriorly of antero-posterior dimension of tibial plateau. The radiological study of Lintner[18] also demonstrated that the insertion of ACL on tibia was 40% of anterior or 60% of posterior tibial plateau[18]. This position could be utilized to determine the exiting point of tibial tunnel during operation.

Natural intact ACL do not have a gap between the two bundles, through the biomechanics of the anteromedial and the posterolateral bundles are different[13]. In this study, the angles of the ACL were measured across the range of the knee motion as a single ligament. The angles of the ACL on the coronal plane change with knee flexion in an opposite direction compared to the angular changes on the sagittal planes. These angular parameters are used as the initial guidance for tunnel aiming. Using a standard, single-incision endoscopic ACL reconstruction technique, with the knee positioned in 90 degree of flexion, the ACL tibial guide is set at an appropriate 45 degree angle in the sagittal plane for the tibial tunnel placement. At this angle, the guide wire can be drilled through the tibia and continuing to the femoral attachment, at correct natural ACL angle. For two bundle ACL reconstruction, this aiming angle represents the bony bridge between the anteromedial tunnel above and the posterolateral tunnel below. If the guide wire misses the right femoral tunnel position, for adjustment without reinsertion of the guide wire, increasing knee flexion can lower the femoral attachment down or decreasing knee flexion can lift the femoral attachment up. For patellar tendon graft, more than 50 degree for the longer tibial tunnel is required. Then 60 degree of the knee flexion can accomplish creation an alignment between the tibial and the femoral tunnels. But in less knee flexion, transtibial technique will result in a longer femoral tunnel, and the guide wire exit point is higher above the femoral condyle.

Dimensions of the intercondylar notch are importance for arthroscopic ACL reconstructive procedures. This study revealed that the intercondylar roof forms an angle of 31 degree with the longitudinal axis of the femur. The femoral attachment at the posterior arch can be inspected and drilled clearly in the position at 60 degree of knee flexion. The anterior arch of the intercondylar roof does not cover the posterior arch, starting from at this angle. At higher degree of knee flexion, the posterior arch and the entire intercondylar roof come into the arthroscopic view.

Notch width documented in this study was 17.4 mm. Odensten and Gillquist[19] reported a notch width of 21 mm and Koukoubis et al[20] reported it as 19.2 mm. Herzog et al[21] found that the notch width in the direct cadaveric measurements was 20.3 mm. Murshed et al[22] recorded the notch with of 20.2 mm. Anderson et al[23] observed the notch width of 23.7 mm in male and 20.5 mm in female basketball players. This smaller notch width may be explained by small body size of the Asian people and the osteoporotic change in geriatrics. Notchplasty should be considered during the ACL reconstruction procedure in patients having notch width less than 17 mm.

Because the femoral attachment is approximately on the middle one-third of the posterior half of the lateral wall of the intercondylar notch, the more intercondylar notch highten, the more vertical in both sagittal and coronal planes of the anterior cruciate ligament lies. Contrarily, longer the intercondylar notch is, lesser the angle of the anterior cruciate ligament will be.

Data from this study showed that both the area dimensions of the femoral and the tibial attachment of the ACL were more than twice of the cross-sectional dimension of the ACL. Avulsion of the ACL from its attachments is rarely occurred. Concerning this anatomical features, rigid fixation of the tendon graft at the surface bony level of the tunnels are also recommended to imitate the natural design. The ACL is approximately 20 mm long in this study, this parameter limits the intraarticular length of the tendon graft to be subtracted from the total length of the ligament prepared in advance. The result is the lengths to be divided between intraosseous parts of the tendon graft in the femoral and the tibial tunnel.

The average length of ACL in this cadaveric study and in our clinical study was quite similar. This study showed that the average length was 21.6 ± 2.5 mm and the length of intraarticular semitendinosus graft was 17.3-22.6 mm measured during ACL reconstruction. According to the result of Fineberg[24], the average length of ACL was 34.0-38.0 mm, which was close to the result from the 3D model created from MRI section of Boisgard[25]. In the study of Boisgard, the average length of ACL was 34 mm when the knee was in 0-70 degrees of flexion. However, variations in length may depend on the body size different in nationality. In this study tibial length is 33.33 ± 2.23 cm (the average body height is 158.6 cm).

Conclusion

The natural angle between the anterior cruciate ligament and the tibial plateau depends on the relative position of the tibial and the femoral attachment. This angle can be reproducible using transtibial single-incision technique. The radiographs of the knee, both lateral view and anterior-posterior view, should be obtained postoperatively to verify the accuracy of the tibial and the femoral tunnel placements.

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รูปแบบการเปลี่ยนแปลงของมุมระหว่าง เอ็นไข้วหน้าของข้อเข่ากับผิวข้อที่เกิดจากการเปลี่ยนมุมงอเข่าและขนาดของโครงสร้างที่เกี่ยวข้อง

ธันวา ตันสถิตย์, สุริยพงษ์ เสาวพฤทธ์, วิชาญ กาญจนถวัลย์, ฐานิสรา โฉมเกิด

การเจาะอุโมงค์เพื่อร้อยเอ็นใหม่ในกระดูกหน้าแข้งและกระดูกต้นขาผิดตำแหน่งเป็นความผิดพลาดที่ทำให้การรักษาล้มเหลวในการผ่าตัดสร้างเอ็นไขว้หน้า (ACL) ในข้อเข่า ผู้วิจัยจึงได้ศึกษาสัดส่วนของโครงสร้างภายในข้อเข่าในศพอาจารย์ใหญ่จำนวน 52 เข่าโดยวัดระยะทางด้วย Vernier caliper และใช้ Goniometer วัดมุม ผลการวิจัยพบว่าลักษณะของ intercondylar notch มีความกว้างด้านหน้าเฉลี่ย 17.4 $\pm$ 2.3 มิลลิเมตร และมีมุมเฉลี่ยระหว่าง roof ของ notch กับแกนของ femur 31.3 $\pm$ 3.4 องศา ACL มีความยาวเฉลี่ย 21.6 $\pm$ 2.5 มิลลิเมตร ระยะทางจากศูนย์กลางจุดเกาะไปยังขอบด้านหน้าของ tibia คิดเป็นร้อยละ 47.98 ของระยะห่างที่สุดจากขอบหน้าถึงขอบหลังของกระดูก tibia และมีทิศทางของ ACL ทำมุมกับ anterior tibial shaft มากขึ้น ในขณะที่ทำมุมกับแนวผิวข้อแคบลงเมื่อข้อเข่างอมากขึ้น จากผลการวิจัยสามารถนำไปใช้ในการผ่าตัดสร้าง เอ็นไขว้หน้าในข้อเข่าโดยเฉพาะในขั้นตอนกำหนดตำแหน่งและทิศทางในการเจาะ tibial tunnel และ femoral tunnel โดยวิธีการเจาะและกรอผ่านกระดูก tibia กล่าวคือ ตำแหน่งของ tibial tunnel ควรอยู่ทางด้านหน้า เป็นสัดส่วน 48 เปอร์เซ็นต์ของความกว้างของกระดูก tibia ในแนวหน้า-หลัง และทิศทางของ tibial tunnel ขึ้นอยู่กับการงอข้อเข่า ถ้าจัดมุมข้อเข่างอ 60 องศา ทิศทางของ tibial tunnel ในแนว sagittal ทำมุมกับแนวผิวข้อ 52.0 $\pm$ 4.6 องศาในแนว coronal และทำมุมกับแนวสันกระดูก tibia 20.9 $\pm$ 3.9 องศา หรือตำแหน่งในการเจาะ femoral tunnel 10.30 นาฬิกา ถ้าจัดมุมข้อเข่างอ 90 องศา ทิศทางของ tibial tunnel ในแนว sagittal ทำมุมกับแนวผิวข้อ 46.2 $\pm$ 5.1 องศาในแนว coronal และทำมุมกับแนวสันกระดูก tibia 26.8 $\pm$ 4.6 องศา หรือตำแหน่งในการเจาะ femoral tunnel 10.15 นาฬิกา ถ้าจัดมุมข้อเข่างอ 120 องศา ทิศทางของ tibial tunnel ในแนว sagittal ทำมุมกับแนวผิวข้อ 41.6 $\pm$ 5.1 องศาในแนว coronal และทำมุมกับแนวสันกระดูก tibia 31.9 $\pm$ 4.3 องศา หรือตำแหน่งในการเจาะ temoral tunnel 10.00 นาฬิกา