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# THE TIBIAL APERTURE SURFACE ANALYSIS IN ANTERIOR CRUCIATE LIGAMENT RECONSTRUCTION PROCESS

*ANALIZA POVRŠINE OTVORA TUNELA NA GOLENJAČI PRILIKOM REKONSTRUKCIJE PREDNJEG UKRŠTENOG LIGAMENTA*

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**Summary**

**Introduction.** The tibial tunnel aperture in the anterior cruciate ligament reconstruction is usually analyzed as an ellipse, generated as an intersection between a tibial plateau and a tibial bone tunnel. The aim of this study is to show that the tibial tunnel aperture, which utilizes 3D tibial surface bone model, differs significantly from common computations which present the tibial tunnel anterior cruciate ligament aperture surface as an ellipse. **Material and Methods.** An interactive program system was developed for the tibial tunnel aperture analysis which included the real tibia 3D surface bone model generated from a series of computed tomography images of ten male patients, their mean age being 25 years. In aperture calculation, the transverse drill angle of 10º was used, whereas sagittal drill angles of 40º, 50º and 60º were used with the drill-bit diameter set to 10 mm. The real 3D and 2D tibial tunnel aperture surface projection was calculated and compared with an ellipse. **Results.** According to the calculations, generated 3D aperture surfaces were different for every patient even though the same drill parameters were used. For the sagittal drill angles of 40º, 50º and 60º, the mean difference between the projected 3D and 2D area on the tibial plateau was 19.6 ± 5.4%, 21.1 ± 8.0% and 21.3 ± 9.6%, respectively. The difference between the projected 3D area on the tibial plateau and ellipse surface was 54.8 ± 16.3%, 39.6 ± 10.4% and 25.0 ± 8.0% for sagittal drill angles of 40º, 50º and 60º, respectively. **Conclusion.** The tibial tunnel aperture surface area differs significantly from the ellipse surface area, which is commonly used in the anterior cruciate ligament reconstruction analysis. Inclusion of the 3D shape of the tibial attachment site in the preoperative anterior cruciate ligament reconstruction planning process can lead to a more precise individual anatomic anterior cruciate ligament reconstruction on the tibial bone. Both tibial aperture area generated in 3D and its projection on a tibial plateau are larger than the ellipse surface; therefore, individual characteristics of each patient have to be taken into consideration.

**Key words:** Anterior Cruciate Ligament; Anterior Cruciate Ligament Reconstruction; Arthroscopy; Tibia; Imaging, Three-Dimensional; Tomography, X-Ray Computed; Knee Joint

**Sažetak**

**Uvod.** Kod rekonstrukcije prednjeg ukrštenog ligamenta kolena otvor tunela na golenjači prikazuje se i analizira kao elipsa koja nastaje u preseku zglobne površine golenjače i tunela u golenjači. Cilj ovog rada je da površinu otvora na golenjači prikazanu u prostoru (3D) uporedimo sa uobičajenim načinom prikazivanja otvora tunela kao elipse. **Materijal i metode.** Razvijen je interaktivni kompjuterski program za analizu površine otvora tunela na osnovu realne prostorne 3D površine dobijene iz serije snimaka kompjuterzovane tomografije kod deset muškaraca prosečne starosti 25 godina. U izračunavanju je korišćen transferzalni ugao bušenja od 10 stepeni, burgija prečnika 10 milimetara, dok su sagitalni uglovi bili 40, 50 i 60 stepeni. Realne 3D i 2D projekcije površina otvora tunela na golenjači su izračunate i upoređene sa površinama elipsa. **Rezultati.** Izvršena izračunavanja pokazala su da su 3D površine otvora tunela na golenjači različite za svakog pacijenta, sa istim parametrima bušenja. Za sagitalni ugao bušenja 40, 50 i 60 stepeni, prosečne razlike između 3D i 2D površine bile su 19,6 ± 5,4%, 21,1 ± 8% i 21,3 ± 9,6%. Prosečne razlike za iste uglove između 3D projekcije i površine elipse bile su 54,8 ± 16,3%, 39,6 ± 10,4% i 25 ± 8%. **Zaključak.** Površine otvora tunela na golenjači značajno se razlikuju od površine elipse koja se uobičajeno koristi u analizi rekonstrukcije prednjeg ukrštenog ligamenta kolena. Uvođenje prostornog 3D oblika pripoja prednjeg ukrštenog ligamenta kolena u preoperatrivno planiranje dovodi do preciznije i individulano anatomske rekonstrukcije na golenjači. Prostorna 3D površina otvora tunela na golenjači i njegova 2D projekcija na zglobnoj površini golenjače veći su nego površina elipse, te se moraju uzeti u obzir individualne karakteristike svakog pacijenta.

**Ključne reči:** Prednji ukršteni ligament; Rekonstrukcija prednjeg ukrštenog ligamenta; Artroskopija; Golenjača; 3D Imidžing; CT; Zglob kolena

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***Abbreviations***

CT – computed tomography
ACL – anterior cruciate ligament
PCL – posterior cruciate ligament
SB – single bundle
DB – double bundle
ACL-R – anterior cruciate ligament reconstruction
BTB-SB – bone to bone single bundle

## Introduction

One of the most common surgical interventions on a knee is anterior cruciate ligament (ACL) reconstruction [1]. An optimal anatomical replacement of ACL is essential to achieve the knee stability [2]. The ultimate goal of anatomic reconstruction surgery is to restore the native anatomy, i.e. to create femoral and tibial tunnel apertures that are similar in size and orientation to the native anterior cruciate ligament insertion [3]. Graft failure, such as a graft impingement and graft stretching, may be caused by malpositioned or nonanatomic tunnel placement resulting in the failed restoration of knee kinematics and persistent instability [4].

A great interest in the tibial insertion morphology of the ACL is shown in two critical reviews [5, 6] which have tried to draw a large number of conclusions in order to enable improvements in surgical procedures. It seems that standard tunnels actually reproduce only a fraction of the native ACL. Tibial tunnel aperture varies with the tunnel diameter and angle [7, 8]. The shape, size and position of the intraarticular aperture of the drilled tibial tunnel affects the drill-bit diameter, and sagittal (angle at which the tunnel intersects the tibial plateau) and transverse angle (tibial drill-guide adjustment by rotating the guide around the tibial shaft) [8, 9]. In recent studies, tibial aperture was analyzed as an ellipse, which is generated as an intersection between a tibial plateau and a tibial bone tunnel [7, 10–12]. Since human anatomy has a complex 3D structure with considerable individual differences, additional anatomic research using 3D imaging analysis and its clinical application are necessary in order to improve the ACL reconstruction [13–15].

Since ACL is attached to the bone three-dimensionally, the aim of this study is to show that tibial tunnel aperture area surface calculated by means of the 3D bone surface model differs from common computations which present tibial tunnel aperture area as an ellipse.

## Material and Methods

The procedure of the study was approved by the Local Human Research Ethical Committee. The study sample included 10 male patients, their mean age being 24.9 ± 6.2 years, who agreed to participate in the research and had computed tomography (CT) knee scans done.

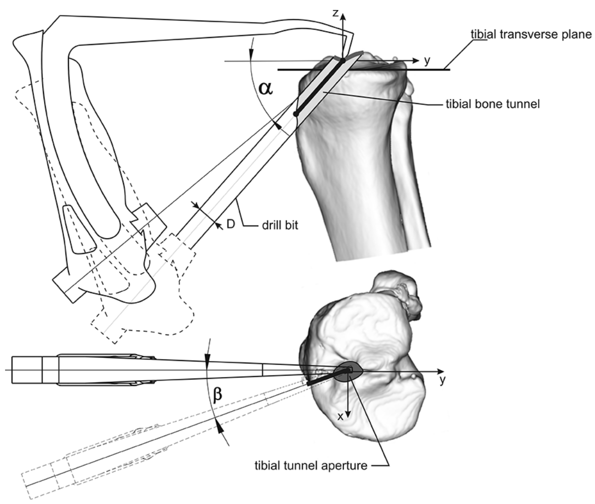


**Figure 1.** Parameters in the ACL reconstruction process. Transverse drill angle (b), sagittal drill angle (a), drill-bit diameter (D)
***Slika 1.*** *Parametri u procesu rekonstrukcije prednjeg ukrštenog ligamenta. Transferzalni ugao bušenja (*b*), sagitalni ugao bušenja (*a*), prečnik burgije (D)*

The parameters of the ACL reconstruction process are presented in **Figure 1.** All 10 patients had 3D aperture surface and 3D aperture surface projected on tibial plateau calculated for a drill-bit diameter (D) of 10 mm, transverse drill angle (β) of 10° and drill-guide angles (α) of 40°, 50° and 60°.

The centre of the tibial ACL footprint was consistently located at 44% along the length of the tibial plateau, measured from the anterior edge of the tibia [16] in reference to the Amis-Jakob line [17]. Anatomic centre of the ACL tibial footprint is two-fifths of the medial-lateral width of the interspinous distance [18].

A system based on the open-source library Visualization ToolKit (VTK) [19] is developed for tibial 3D surface model generation, resulting in a tibial 3D surface model in STL (STereoLithography) file format (as a collection of many triangle surfaces). The orientation of the generated model depends on the patient's position during a CT scan. For correct analysis results, the bone model is orientated to the appropriate position, which is done interactively using the developed program system. A generated tibial bone of one patient is shown in **Figure 2** (left), produced on the MakerBot Replicator 2X printer. **Figure 2** (right) shows an enlarged complex 3D shape of ACL tibial attachment site.

The main purpose of the developed program system is to calculate the aperture surface on the tibial bone. If the program system creates the aperture surface as a hole in the bone, the geometry information of 3D surface is lost. Because of that, the drill-bit is defined as a cylindrical shape within the developed system and is approximated with vectors **(Figure 3)**. The tibial guide position as well as

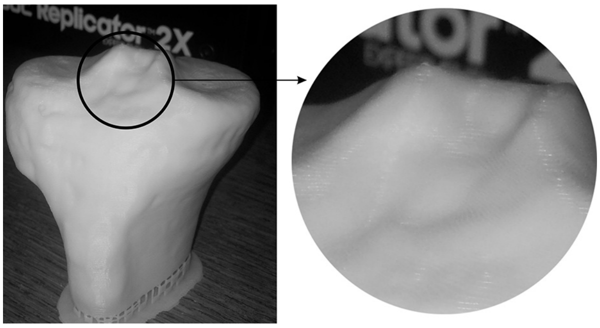

**Figure 2.** Generated tibial bone model of one patient produced on the MakerBot Replicator 2X printer (left), and enlarged complex 3D shape of the ACL tibial attachment site (right)
***Slika 2.*** *Generisani model golenjače izrađen na MakerBot Replicator 2X štampaču (levo) i uveličani prikaz kompeksnog 3D pripoja prednjeg ukrštenog ligamenta na golenjači (desno)*

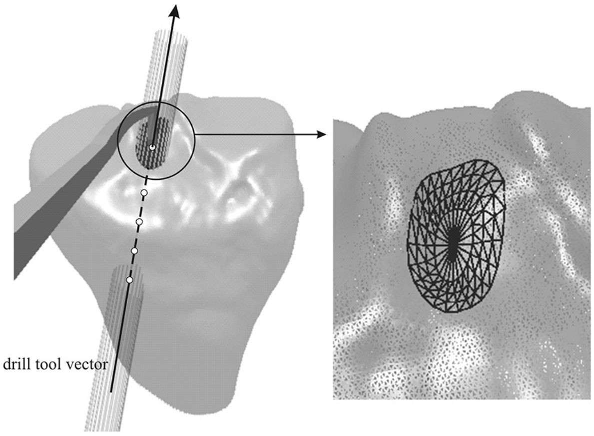


**Figure 3.** Drill-bit approximated with vectors (left), and generated triangulated 3D aperture surface on the tibial bone (right)
***Slika 3.*** *Burgija aproksimirana vektorima (levo) i generisana 3D površina otvora na golenjači (desno)*

transverse (β) and sagittal drill angles (α) are set in the program system too. To calculate the aperture surface, intersections of all drill tool vectors in a bone model should be determined. As shown in **Figure 3** (left), a drill tool vector can intersect the bone model at many points. For aperture surface generation, only the points that intersect the tibial plateau surface are important. After the intersection points with the tibial plateau are determined, a triangulated aperture surface can be generated by connecting adjacent points (**Figure 3**, right). Subsequently, 3D surface area can be calculated as a sum of these triangle areas. For fast intersection calculation, AABB (Axis-Aligned Bounding Box) algorithm from CGAL (Computational Geometry Algorithms Library) is used [20].

## Results

The calculated tibial tunnel aperture surfaces for all 10 patients are presented in **Figure 4**. Apertures generated on the left and right knees are shown in numbers 1–5 and numbers 6–10, respectively. The ellipse surfaces are the same for all patients, as already presented in **Figure 4** (left). However, it can be seen that aperture surfaces differ for every patient, the drill parameters being the same, because the tibial attachment site surface is different for every patient and is 3-dimensional.

**Table 1** gives the calculated values for 3D tibial aperture area (3D), aperture area projected on tibial plateau (2D), ellipse area (EA), difference between 3D aperture area and 3D aperture area projected on tibial plateau (3D-2D), and difference between 3D aperture area projected on tibial plateau and ellipse surface (2D-EA). The ellipse surface area depends only on a drill-bit diameter and sagittal-drill angle, and is 122.2 $mm^2$, 102.5 $mm^2$ and 90.7 $mm^2$ for sagittal-drill angles of $40^0$, $50^o$ and $60^0$, respectively.

The mean 3D aperture surface areas for $40^0$, $50^o$ and $60^0$ sagittal drill angles are 225.6 ± 19.6 $mm^2$, 173.2 ± 16.0 $mm^2$ and 137.7 ± 15.5 $mm^2$, respectively. 3D aperture surfaces projected on tibial plateau (2D) areas for $40^0$, $50^o$ and $60^0$ sagittal drill angles are 189.2 ± 19.9 $mm^2$, 143.1 ± 10.7 $mm^2$ and 113.3 ± 7.8 $mm^2$. For sagittal drill angle of $40^o$, the mean difference between the 3D surface and the projected 3D surface on tibial plateau are 19.6 ± 5.4%, whilst the difference between the projected 3D surface on tibial plateau and ellipse are 54.8 ± 16.3%. For sagittal drill angle of $50^o$, the mean difference between the 3D surface and the projected 3D surface is 21.1 ± 8.0%, and the difference between the projected 3D surface and ellipse is 39.6 ± 10.4%. The calculated results for sagittal drill angle of $60^o$ show that the mean difference between the 3D surface and the projected 3D surface on tibial plateau is 21.3 ± 9.6% and the difference between the projected 3D surface and ellipse is 25.0 ± 8.0%.

## Discussion

The most important finding of this study is that the generated tibial tunnel aperture surface is different for every patient in the ACL reconstruction process and it differs significantly from the ellipse (by which aperture surface is mostly presented) for the same drill parameters. When the sagittal drill angle increases, the difference between the projected 3D aperture surface on tibial plateau and the ellipse surface decreases. But even for the sagittal drill angle of $60^o$, this difference is 25.0 ± 8.0. **Figure 5** shows the tibial bone profile analysis for the patient No. 4, for the used sagittal-drill angle of $50^o$ and transverse angle of $10^o$. The generated tibial bone profile line on 3D tibial bone is shown in **Figure 5** (left). A drill bit intersection with the real bone profile is presented in **Figure 5** (middle). It may be seen that the attachment profile line is not flat, as it is assumed if

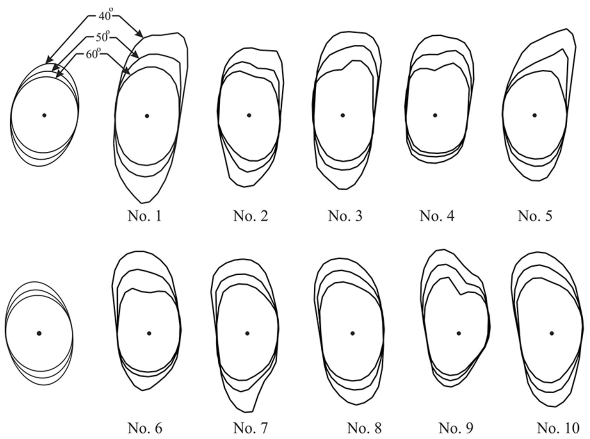


**Figure 4.** Generated aperture surfaces for sagittal drill angles of 40°, 50° and 60°, transverse angle of 10° and drill-bit diameter of 10 mm for all ten patients are presented. Numbers 1-5 present apertures generated on the left knees and numbers 6-10 present apertures generated on the right knees. Respective ellipse surfaces are shown on the left

***Slika 4.*** *Generisane površine otvora za sagitalne uglove bušenja od 40°, 50° i 60°, transferzalni ugao bušenja od 10° i prečnik burgije od 10 mm za deset pacijenata. Brojevi 1−5 predstavljaju površine otvora generisane na levim kolenima, dok brojevi 6−10 predstavljaju površine otvora generisane na desnim kolenima. Odgovarajuće površine oblika elipse prikazane su sa leve strane.*

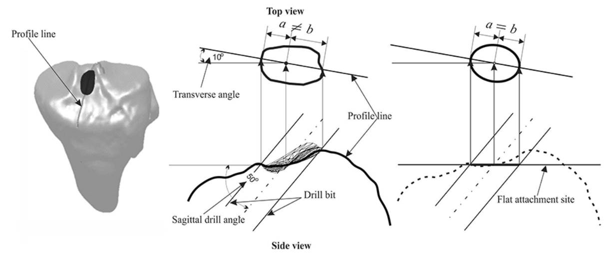


**Figure 5.** Tibial bone profile line for transverse angle of 10° (left), side and top views of generated real aperture surface (middle) and side and top views of generated ellipse aperture surface if it is assumed that tibial ACL attachment site is flat (right)

***Slika 5.*** *Profilna linija golenjače za transferzalni ugao bušenja od 10° (levo), pogledi sa strane i odozgo na generisanu stvarnu površinu otvora (u sredni) i pogledi sa strane i odozgo na generisanu površinu otvora oblika elipse pod pretpostavkom da je površina pripoja prednjeg ukrštenog ligamenta ravna (desno)*

the aperture surface is considered to be an ellipse, as in **Figure 5** (right). The length of the generated aperture surface and its centre are another two important parameters of generated tibial tunnel aperture surface that should be taken into consideration and they are given in **Figure 5.** For the ellipse aperture surface, the larger axis length is symmetrical relevant to the centre of tibial insertion (a=b in **Figure 5,** right), but when the real aperture surface is analyzed, it can be seen that the larger axis length is not symmetrical relevant to the centre of tibial insertion and it depends on the ACL insertion site area shape (a≠b in **Figure 5**, middle). This means that the centre of the tibial insertion is not the centre of the generated aperture surface on the tibial bone. It depends on the individual patient's ACL attachment site surface shape.

The "classical" single-bundle (SB) procedure is performed by drilling bone tunnels according to the graft diameter, without considering the relationship between the size of the natural insertion site area and the reconstructed area. This results in a randomized reconstruction of the original ACL tibial footprint [8]. Kopf [7] showed that only 57% of the native tibial insertion was reproduced with standard drilling. Nonanatomic SB techniques were largely successful at a short-term follow-up, but do not completely restore knee kinematics and can lead to long-term degenerative changes [21]. The advantages of anatomic reconstruction in restoring joint kinematics were described by Bedi et al. [22] in biomechanical cadaveric study, showing that different ACL fibers added to different knee functions, and when a constant central femoral tunnel position was used, tibial tunnel position of a SB ACL graft had a critical effect on the knee stability and impingement. Positioning the tibial tunnel in the anterior aspect of the footprint position ("a horizontal graft") controls the Lachman and pivot-shift maneuver better than the posterior tibial footprint positioning. The authors' opinion is that the tibial tunnel position in the center of the native ACL footprint may offer the best compromise of favorable knee kinematics with an acceptably low risk of graft impingement after ACL reconstruction. Consequently, by placing the bone tunnels in a defined position, the surgeon defines the biomechanical footprint of the ACL-reconstruction (ACL-R).

The ACL-R has recently focused on moving tunnels from the conventional, nonanatomic position to the native insertion of the ACL to restore the normal knee kinematics and improve the patient's recovery. Anatomic ACL-R is the functional restoration of the ACL to its native dimensions depending on the patient's individual anatomy [23]. Sadoghi et al. [24] compared the anatomic and nonanatomic SB and DB (double-bundle) ACL reconstructions and established that the results in the knee kinematics were not significantly different from the uninjured knee kinematics in anatomic reconstructions.

During the ACL-R, the drill-bit diameter, and sagittal and transverse drill angles affect the size and orientation of the tibial tunnel aperture, and influence the restoration of the native anatomy of the tibial insertion [7, 8]. A great variation of the shape and size of ACL insertion sites is important to consider before the tunnels are drilled. In the 2D projection, the tibial ACL insertion site can vary in shape and size, although 77.8% of specimens had elliptical and 22.2% of them had triangular shaped tibial insertions [25]. The tibial graft position in both SB and DB ACL reconstruction usually shows as a circle or an ellipse that do not give an accurate representation of the position of graft sites on their insertion. In real situations, they appear as irregular surfaces that are considered as an ellipse in order to simplify calculations [26]. The area of the 2D tibial insertion (projected on the tibial plateau) ranged from 114 $mm^2$ to 229 $mm^2$ [18, 27, 28] and in some studies [13, 29] it was concluded that there were critical bony and soft tissue landmarks of the tibial insertion site. The importance of native insertion sites in achieving anatomic ACL reconstruction has motivated several morphometric studies on insertion sites of the ACL [16, 30–32]. These insertion sites, although 3-dimensional, are often reported in 2-dimensions using the system for the tibia by Amis and Jakob [17].

For the anatomical coverage of the original ACL insertion, Rabuck et al. [23] recommended pre-operative measurement of the sagittal magnetic resonance imaging, the patellar tendon, the ACL insertion site and ACL length. Sielbold [8] developed the concept of "insertion site table" based on the idea of a "complete footprint restoration" which makes it necessary to first measure the length of the tibial ACL insertion site with a ruler from anterior to posterior.

Depending on the drill-bit diameter and the angle of drilling, the surface of the ellipse is changed for the anatomical coverage of the original ACL insertion. If the sagittal angle of the drilled tibial tunnel is smaller, the surface of the tibial insertion is larger and closer to its anatomic shape; also, if transverse angle is smaller, the anatomical coverage of the original ACL insertion is larger [7]. An optimal combination of these parameters should be selected during the anatomic reconstruction of the ACL because the decrease of the angle of penetration results in shorter tibial tunnel and a disproportion between the graft length and tunnel length, particularly in bone to bone single bundle techniques. In another cadaveric study, Piasecki et al. [33] found that the use of the more proximal tibial tunnel starting position (smaller sagittal drill angle) allowed more anatomic overlap with the native ACL footprints.

The ACL footprint was usually evaluated with a two-dimensional technique. In recent studies, tibial aperture is analyzed as an ellipse, generated as intersection between a tibial plateau and a tibial bone tunnel [7, 12]. Because of that, real bone geometry is not taken into calculations. Two publications reported measured 3D areas [13, 18]. Understandably, the area

**Table 1.** Calculated aperture surface areas for ten patients
***Tabela 1.*** *Proračunate površine otvora na golenjači za deset pacijenata*

| | Sagittal drill angle | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 40° | | | | 50° | | | | 60° | | | |
| | 3D ($mm^2$) | 2D ($mm^2$) | 3D-2D ($mm^2$) (%) | 2D-EA ($mm^2$) (%) | 3D ($mm^2$) | 2D ($mm^2$) | 3D-2D ($mm^2$) (%) | 2D-EA ($mm^2$) (%) | 3D ($mm^2$) | 2D ($mm^2$) | 3D-2D ($mm^2$) (%) | 2D-EA ($mm^2$) (%) |
| Patient No. | | | | | | | | | | | | |
| Ellipse area (EA) | | 122.2 | | | | 102.5 | | | | 90.7 | | |
| 1 | 261.3 | 230.6 | 30.7 (13.3) | 108.4 (88.7) | 177.9 | 158.3 | 19.6 (12.4) | 55.8 (54.4) | 136.2 | 121.3 | 14.9 (12.3) | 30.6 (33.7) |
| 2 | 223.2 | 182.0 | 41.2 (22.6) | 59.8 (48.9) | 154.7 | 130.2 | 24.5 (18.8) | 27.7 (27.0) | 123.3 | 104.2 | 19.1 (18.3) | 13.5 (14.9) |
| 3 | 253.3 | 206.5 | 46.8 (22.7) | 84.3 (69.0) | 199.7 | 155.2 | 44.5 (28.7) | 52.7 (51.4) | 153.7 | 119.3 | 34.4 (28.8) | 28.6 (31.5) |
| 4 | 211.3 | 167.7 | 43.6 (26.0) | 45.5 (37.2) | 175.8 | 138.1 | 37.7 (27.3) | 35.6 (34.7) | 144.3 | 112.9 | 31.4 (27.8) | 22.2 (24.5) |
| 5 | 220.4 | 191.9 | 28.5 (14.9) | 69.7 (57.0) | 151.8 | 136.1 | 15.7 (11.5) | 33.6 (32.8) | 113.1 | 105.1 | 8 (7.6) | 14.4 (15.9) |
| 6 | 200.8 | 172.9 | 27.9 (16.1) | 50.7 (41.5) | 156.2 | 132.9 | 23.3 (17.5) | 30.4 (29.7) | 117.8 | 102.9 | 14.9 (14.5) | 12.2 (13.5) |
| 7 | 221.6 | 185.0 | 36.6 (19.8) | 62.8 (51.4) | 166.8 | 139.3 | 27.5 (19.7) | 36.8 (35.9) | 135.2 | 112.6 | 22.6 (20.1) | 21.9 (24.1) |
| 8 | 218.1 | 191.8 | 26.3 (13.7) | 69.6 (57.0) | 173.4 | 149.2 | 24.2 (16.2) | 46.7 (45.6) | 142.2 | 120.6 | 21.6 (17.9) | 29.9 (33.0) |
| 9 | 211.7 | 163.9 | 47.8 (29.2) | 41.7 (34.1) | 185.5 | 134.9 | 50.6 (37.5) | 32.4 (31.6) | 154.7 | 109.8 | 44.9 (40.9) | 19.1 (21.1) |
| 10 | 234.5 | 199.7 | 34.8 (17.4) | 77.5 (63.4) | 190.5 | 156.9 | 33.6 (21.4) | 54.4 (53.1) | 156.1 | 124.7 | 31.4 (25.2) | 34.0 (37.5) |
| mean±SD | 225.6±19.0 | 189.2±19.9 | 36.4±8.1 (19.6±5.4) | 67.0±19.9 (54.8±16.3) | 173.2±16.0 | 143.1±10.7 | 30.1±11.2 (21.1±8.0) | 40.6±10.7 (39.6±10.4) | 137.7±15.5 | 113.3±7.8 | 24.3±11.1 (21.3±9.6) | 22.6±7.8 (25.0±8.7) |

3D tibial aperture area (3D), aperture area projected on tibial plateau (2D), ellipse area (EA), difference between 3D aperture area and 3D aperture area projected on tibial plateau (3D-2D) and difference between 3D aperture area projected on tibial plateau and ellipse surface (2D-EA). Drill-bit diameter is set to 10 mm, transverse drill angle of 10°, and sagittal drill angles of 40°, 50° and 60°

data measuring the plane surface of the ACL femoral origin and tibial insertion are smaller than the data resulting from the entire 3D surface. In our analysis, the difference between 3D aperture surface and its projection on the plane surface is 19.6 ± 5.4%, 21.1 ± 8.0% and 21.3 ± 9.6% for the used sagittal-drill angles of $40^0$, $50^o$ and $60^0$, respectively. However, there are significant individual differences in aperture surfaces among all the patients, which confirm that during the ACL reconstruction, individual characteristics of every patient should be taken into consideration. Anatomic ACL reconstruction is the restoration of the native ACL insertion site with essential respect to individual patient's characteristics. If ACL restoration and bone tunnel are more anatomically placed, the knee stability and kinematics are better. With respect to the rear entry guide, it is a device that is useful for assisting the surgeon to place the ACL in an anatomic position, but this device is not a perfect one. The patient's anatomy and the inherent variations have to be fully understood to be able to consistently place the ACL in an anatomic position.

Although the importance of anatomic ACL reconstruction is being increasingly appreciated, surgeons can still find it difficult to reliably identify the ACL insertions using arthroscopic techniques alone. Previous studies have shown that computer-aided surgical navigation is effective in tunnel positioning guiding, but performance studies of a fluoroscopic overlay system, as an alternative to improve tunnel positioning, are lacking [16, 34]. Since ACL is attached to the bone three-dimensionally, the improvement of the ACL footprint can be obtained by further anatomic research using 3D camera or computer graphics [13, 15].

Limitation of the study is in a relatively small number of research subjects. In addition, a center of tibial attachment for all patients is selected according to the literature data [16, 18]. It is also necessary to further investigate detailed measuring of the ACL insertion site on cadavers, which is expected to give the real position of the ACL tibial insertion site in space.

## Conclusion

Results presented in this study show that there is an individual difference between real 3D aperture surface projected on tibial plateau and ellipse surface which is commonly used in the anterior cruciate ligament reconstruction analysis. This difference is 54.8 ± 16.3%, 39.6 ± 10.4% and 25.0 ± 8.7%, for sagittal drill angles of $40^o$, $50^o$ and $60^o$, respectively. The centre of the generated aperture surface can also differ from the centre of the tibial anterior cruciate ligament attachment site. A complex tibial bone anterior cruciate ligament insertion site geometry is different for every patient, so it is required that in the anterior cruciate ligament reconstruction analysis 3D tibial bone geometry is taken into consideration. This can lead to the more precise native anterior cruciate ligament reconstruction on tibial bone.

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