General Hospital Subotica, Department of Orthopedics and Traumatology, Subotica[1]
General Hospital Bijeljina, Bijeljina, Bosnia and Herzegovina[2]
Clinical Centre of Vojvodina, Novi Sad
Clinic of Orthopedic Surgery and Traumatology[3]
University of Novi Sad, Faculty of Medicine Novi Sad[4]

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RADIOGRAPHIC ANALYSIS OF THE TIBIAL TUNNEL POSITION AFTER ANTERIOR CRUCIATE LIGAMENT RECONSTRUCTION

RADIOGRAFSKA ANALIZA POLOŽAJA TUNELA NA GOLENJAČI POSLE REKONSTRUKCIJE PREDNJEG UKRŠTENOG LIGAMENTA

Vladimir RISTIĆ[1], Nenad RISTIĆ[2], Vladimir HARHAJI[3,4], Mile BJELOBRK[3] and Vukadin MILANKOV[3,4]

Summary

Introduction. The aim of the study was to analyze the tibial tunnel position after anterior cruciate ligament reconstruction. **Material and Methods.** The study included 830 patients who underwent this operative procedure. There were four times more male than female patients. The tibial tunnel placement was analyzed on frontal and lateral radiograph images of the knee joint. **Results**. The average frontal tibial index was 55% (35 – 68%), the average frontal tibial angle was 75 degrees (58 – 90), the sagittal tibial index was 30% (15 – 52%) and the sagittal tibial angle was 68 degrees (50 – 89). **Conclusion**. A significant deviation from these values may potentially lead to failure of the anterior cruciate ligament reconstruction.

Key words: Anterior Cruciate Ligament Reconstruction; Knee Joint; Tibia; Radiography; Graft Survival; Bone-Patellar Tendon-Bone Grafts; Reconstructive Surgical Procedures; Tendons; Bone Screws

Sažetak

Uvod. Studija ima za cilj da analizira položaj tunela na golenjači nakon rekonstrukcije prednjeg ukrštenog ligamenta. **Materijal i metode.** Istraživanje je obuhvatilo 830 pacijenata kojima je izvršena rekonstrukcija ligamenta. U uzorku smo više od četiri puta imali zastupljene muškarce. Položaj tunela na golenjači analiziran je frontalnim i bočnim radiografskim snimcima kolena. **Rezultati.** Prosečna vrednost frontalnog tibijalnog indeksa iznosi 55% (35–68%), frontalnog tibijalnog ugla 75 stepeni (58–90), sagitalnog tibijalnog indeksa 30% (15–52%) i sagitalnog tibijalnog ugla 68 stepeni (50–89). **Zaključak.** Značajnija odstupanja od navedenih vrednosti potencijalno mogu dovesti do neuspeha rekonstrukcija prednjeg ukrštenog ligamenta.

Ključne reči: rekonstrukcija prednjeg ukrštenog ligamenta; zglob kolena; tibija; radiografija; preživljavanje kalema; kost-ligament čašice-kost kalemi; rekonstruktivne hirurške procedure; tetive; koštani zavrtnji

Introduction

Anterior cruciate ligament (ACL) reconstructions are successful in providing excellent results in about 80 – 90% of all performed operations [1–5]. However, the reconstructions sometimes fail, in regard to stability and symptoms that significantly reduce the patient's quality of life [1–6]. Incorrect tibial and femoral tunnel placement has been recognized as a common technical error leading to failure [1–3]. During the last decades, knowledge about normal ACL anatomy has been in focus, especially its attachements (footprints) [1, 2, 7, 8]. The aim of reconstructive surgery is to achieve proper anatomical graft tunnel placement.

A tibial tunnel placed too far anteriorly may result in pain secondary to roof impingement in extension and flexion contracture [1, 2, 7]. A tibial tunnel placed too far posteriorly will result in a vertically placed ACL graft that may lack rotational stability [2, 8].

The aim of this study is to analyze the tibial tunnel placement after ACL reconstructions. These results and comparison with the results of other studies should lead to the improvement of these surgical techniques.

Material and Methods

The Ethics Committee of the Clinical Center of Vojvodina has approved this retrospective study conducted at the Clinic of Orthopedic Surgery and Traumatology. It included 830 patients with complete ACL rupture operated in the period from January 01, 2013 to December 31, 2015. There were 677 males (81.6%) and 153 females (18.4%).

All of the ACL reconstructions were performed using a bone-patellar tendon-bone autograft. Anteroposterior and lateral radiograph images of the knee joint were made postoperatively. Anterioisterior images were made in full extension and profile images in passive extension of the knee joint. The X-ray machine was 100 cm away from the X-ray cassette, and X-rays were directed under 90 degrees above. The tibial tunnel position was determined according to X-ray images.

Corresponding Author: Dr Vladimir Ristić, Opšta bolnica Subotica, 24000 Subotica, Izvorska 3, E-mail: ristic@tippnet.rs

Abbreviations

ACL – Anterior cruciate ligament
MRI – Magnetic Resonance Imaging
BPTB – bone-patellar tendon-bone
PCL – posterior cruciate ligament
MARS – Multicenter ACL Revision Study
CL – central lateral wall
ML – medial lateral wall
AC – anterior edge of the tibial plateau
AB – depth of the tibial plateau

Measurements of the depth of the tibial plateau (AP) images were as follows **(Figure 1)**: M1: frontal tibial index (FTI) CL/ML x 100 (%) and M2: frontal tibial angle (FTA) (degrees). Profile images were used in measurements of **(Figure 2)**: M3: sagittal tibial index (STI) AC/AB x 100 (%) and M4: sagittal tibial angle (STA) (degrees).

Measurements were performed on radiographic images, using high-precision calibration. The angle measurement accuracy was 0.5 degrees, and linear measurement accuracy was 0.5 mm. The minimum, mean, maximum values and standard deviation were calculated for each monitored parameter **(Table 1)**.

The patients whose X-rays were of inadequate quality were excluded from the study, because precise measurements could not be made.

The collected data were entered into a special database created in Microsoft Excel program, and the statistical analysis was performed using the IBM SPSS software (version 23). The statistical significance level was $p < 0.05$.

Results

The analyzed radiographic images showed the following results:

M1: Frontal tibial index CL/ML x 100 (%)

The frontal tibial index ranged from 34.71 to 67.52% with an average of 54.60% (SD 3.5814). Only one patient had a ML diameter between 30 – 40%, 67 patients had 40 – 50%, 702 between 50 – 60%, and 60 of them between 60 – 70%.

M2: Frontal tibial angle

The frontal tibial angle ranged from 57.87 to 89.57 degrees, 74.90 degrees on average (SD 5.4007). The distribution of frontal tibial angle was the following: 6 images from 55 to 60 degrees, 25 from 60 to 65, 121 from 65 to 70, 130 from 80 to 85, and 19 from 85 to 90 degrees. The most frequent interval was between 75 and 80 degrees (277 images), and afterwards between 70 and 75 degrees in 252 images.

M3: Sagittal tibial index AC/AP x 100 (%)

The sagittal tibial index ranged between 15.17 and 52.44% with an average of 29.70% (SD 5.6290). The tibial tunnel was most frequently localized between 20 and 30% of AB diameter (412 patients), followed by 30 – 40% (358 patients), then 40 – 50% (32 patients), 15–20% (26) and only two patients had an AB diameter between 50 and 55%.

M4: Sagittal tibial angle

The sagittal tibial angle ranged from 50.46 to 89.10 degrees with an average of 68.03 degrees (SD 6.2026). The distribution intervals of this angle were as follows: 8 patients had 50 – 55 degrees, 71 between 55 and 60, 193 60 – 65, 249 65 – 70, 189 70 – 75, 93 75 – 80, 25 80 – 85 and only two patients had 85 – 90 degrees in the sagittal plane.

Discussion

The incidence of ACL injury has been increasing, and the most frequently injured are young, physically active persons [3–5, 9–13]. Surgical reconstruction is the method of choice in the treatment of these injuries in recreational and professional athletes who have high levels of physical activity. The primary goal of the surgery is the re-establishment of stability, allowing nor-

Table 1. Radiographic measurement analysis
Tabela 1. *Vrednosti merenja dobijene radiografskom analizom snimaka*

	N *Broj*	Minimum *Minimum*	Maximum *Maksimum*	Average *Srednja vrednost*	Standard deviation *Standardna devijacija*
CL diameter/*Izmeren CL dijametar (mm)*	830	28.1081	63.5135	48.4636	4.7042
ML diameter/*Izmeren ML dijametar (mm)*	830	50.0000	110.8333	88.8399	7.4333
Frontal tibial index CL/MLx100 (%) *Frontalni tibijalni indeks CL/MLx100 (%)*	830	34.7133	67.5276	54.5810	3.6451
AC diameter/*Izmeren AC dijametar (mm)*	830	8.5399	32.5140	17.8147	3.5956
AP diameter/*Izmeren AP dijametar (mm)*	830	34.0476	73.8888	60.0559	5.2031
Sagittal tibial index AC/APx100 (%) *Sagitalni tibijalni indeks AC/APx100 (%)*	830	15.1786	52.4419	29.7005	5.6290
Frontal tibial angle (degrees) *Frontalni tibijalni ugao (u stepenima)*	830	57.87	89.57	74.90	5.4007
Sagittal tibial angle (degrees) *Sagitalni tibijalni ugao (u stepenima)*	830	50.46	89.10	68.03	6.2026

CL – centralni lateralni zid, ML – medijalni lateralni zid, AC – prednja ivica tibijalnog platoa, AB – dubina tibijalnog platoa

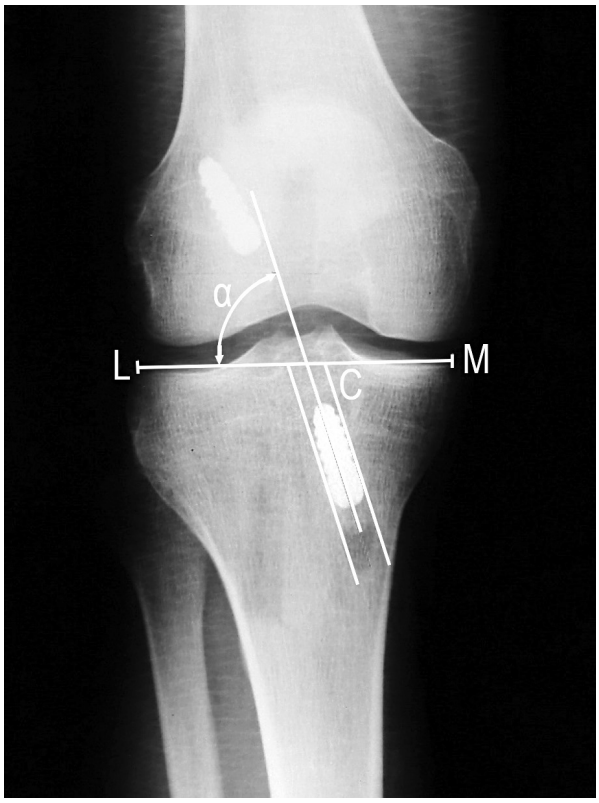

Figure 1. Anteroposterior X-ray measurements
Slika 1. *Merenja na anteroposteriornom rendgenskom snimku*

Figure 2. Lateral X-ray measurements
Slika 2. *Merenja na profilnom rendgenskom snimku*

mal knee function. All patients included in this study had arthroscopically-assisted ligament reconstruction with a modified Clancy technique [14]. Patellar tendon was used as bone-tendon-bone graft. This retrospective study included 830 patients, and there were four times more male than female patients (82%:18%). In most studies that analyzed ACL reconstructions, males were 2 – 5 times more prevalent [3–6, 9, 10], although it is known that the risk of ACL rupture is 2 – 8 times higher in females, depending on the type of sport [11–13].

The native ACL attaches in anatomical areas in front of and between the intercondylar tibial eminence to the semicircular area of the posteromedial part of the lateral femoral condyle. Its length ranges from 31 to 38 mm, and its diameter ranges from 7 to 12 mm [15]. The cross-sectional area changes in relation to the height of the section. The surface on the proximal attachment (34 mm^2, 35 mm^2) is in the middle section, while in the distal attachment it is 42 mm^2 on average [16]. Some ACL fibers on distal insertion are connected to the lateral meniscus [16].

The anterior horn of lateral meniscus and the posterior cruciate ligament (PCL) happen to be the most often used intra-articular landmarks for positioning the guiding needle in the tibia during ACL reconstruction [17–19]. Jackson and Gasser recommended using an imaginary line extended medially from the posterior border of the anterior horn of the lateral meniscus [17] and Ziegleretal et al. [18] and Morgan et al. [19] recommended using a location seven millimeters anterior to the anterior margin of the PCL with the knee flexed to 90° as an ideal place for distal attachment. Intraoperatively, we also placed a guiding wire 7 mm in front of the PCL and medially from the edge of the anterior horn of the lateral meniscus, which is consistent with most authors [20–22]. However, Heming et al., and Edwards et al. [23, 24], considered that the center of the attachment (tibial footprint) is up to 15 mm in front of the PCL fibers. Werner et al. [25] also did not agree that these landmarks were ideal, because they did not provide consistently good results.

One of the main factors which affect the final outcome of treatment and re-establishment of the passive stability of the joint is a correctly performed surgical technique. Most of the errors related to the surgical technique include generally inadequate, non-anatomical position of the graft [3, 20, 21, 26]. Its position is determined by the position of the femoral and tibial tunnels. The tibial graft position is not as important as the femoral [3, 27, 28], except in case of transtibial arthroscopically assisted reconstruction, when the tibial tunnel automatically determines the position of the femoral tunnel. Femoral tunneling by anteromedial portal has eventually overcome the transtibial technique, because the anatomical position of the graft cannot be achieved using the transtibial technique which may result in instability [3, 26–28].

The place of tibial insertion is much more accessible, manageable, and easier to determine by the surgeon. However, positioning the tibial tunnel too

far forward results in "roof impingement" or inappropriate contact of the graft with the roof of the intercondylar notch, in extended knee. This can lead to over-tightening and rupture of the graft during knee flexion [20, 21]. If the graft is placed medially to the anterior tibial eminence, there is an improper contact with PCL, which results in the impossibility of knee flexion [22]. If the graft is placed laterally to the external tibial eminence, there is a contact with the medial side of the lateral femoral condyle. Consequently, there is an anterior instability of the knee joint [29]. However, in the study of Sommer et al. [30] tibial insertion had no significant effects on the postoperative instability of the knee.

Knowledge about the anatomy of a normal ACL is a key factor to the success of reconstructive surgery. In order to determine the physiological position of the tibial attachment of ACL, Parkinson et al. [31] analyzed 76 magnetic resonance imaging (MRI) images and 26 3D computed tomography (CT) images of uninjured knees. Insertion of the ACL in the frontal plane was located at 48% ± 2% from the medial edge of the tibial plateau. In 83 subjects, Inderhaug et al. [1] found the value of the frontal tibial index of 40% (36 – 45%). Arcuri et al. [32], as we did, followed the radiographic determination of the tibial tunnel position and found that the average position of the tunnel in the frontal plane was 27.8% of the lateral edge of the tibial plateau. According to a Multicenter ACL Revision Study (MARS) conducted at 52 centers by 82 surgeons, who analyzed knee radiographs after revision ACL reconstructions [33], the distance of tibial tunnel of the medial edge of the plateau was on average 45.4% ± 3.8% of ML in diameter. In our research, the frontal tibial index (CL/ML x 100%) value was on average the same as in an non-injured knee and did not deviate from the values obtained in other studies (54.5% of the lateral, or 45.5% of the medial edge of the tibial plateau).

Frank et al. [2] used MRI images of 100 subjects and came to a conclusion that the tibial ACL insertion in the sagittal plane was on average 36 ± 6%, from 28% to 63% of the distance from the front edge of the tibial plateau of the total AP diameter of the plateau. Most authors also recommended that the tibial tunnel should be localized at 44–46% of the AP diameter [1, 32, 34]. When the position of tibial tunnel in the sagittal plane was determined relative to the anterior horn of the lateral meniscus, the average value of the sagittal tibial index was 37% ± 5.2% [25]. The majority of tunnels (66% of all) were located from 30.0–39.9% of the AP diameter; 18% of tunnels were between 40% and 44.9%; 10% over 45.0%, and 6% in the range of 25.0 - 29.9% [25]. The average values of the tibial ACL insertion in sagittal plane were 38–39% of the AP diameter [31, 33], and more than 70% of the values were in the range from 30 and 50%. The sagittal tibial index values in our study differed from the above mentioned studies, because the tibial insertion of graft in our study was set more anteriorly (29.7% of the AB diameter). Also, compared to radiographic measurements in the study conducted by Ninković et al. [5] which included 39 patients, our results were not significantly different.

Beside the localization of the tibial entry point, the tibial graft angles in the frontal and sagittal planes are also important factors. Too vertical positioning of the graft in the plane of the joint leads to its excessive tension, reduced flexion, increased anterior tibial translation, degeneration and graft rupture [20, 21]. The ideal angle is considered to be less than 75 degrees (30 to 71 degrees) [1, 20–22, 33]. When the frontal tibial angle is less than 75 degrees, it does not affect the appearance of the above-mentioned postoperative complications. Also, it is necessary to avoid a too steep angle; it is recommended to drill the tunnel at an angle of about 65 degrees, although it varies from 59 to 75 degrees [20–22]. The average value of frontal tibial angle in this study was 74.80 degrees, which is in accordance with the above recommendations.

These landmarks on the tibial tunnel were used in a cadaveric study [19] and the resulting sagittal angle was found to be 68% (64–72%). Another study on cadavers [22] found that most of the fibers were isometric in the sagittal view if the angle was 60 degrees, and tunnel centered at 46% (42–50%) from the anterior joint line. In MARS study [33] the average value of the sagittal angle of the tibial tunnel was 83.3 degrees. Arcuri et al. [32] achieved the angle of 73.48 degrees. In a similar study on MRI images [35] the average angle was 54.5 (51–58.5) degrees, while the angle of the tunnel in the frontal plane was 72.38 degrees (69–76). In our study, the sagittal tibial angle was 68.03 degrees on average, which is in accordance with the recommendations [19–22] and does not differ significantly from the values obtained in these studies.

The main limitation of this study is that it is basically a radiographic research. With this imaging technique or inadequacy of the X-rays, it is not always possible to perform precise measurements. These difficulties can be overcome by using CT or MRI, but their price and exposure to doses of radiation restricts their use, especially in a large number of subjects. This study opens up the possibility of subsequent comparisons of clinical and radiographic results, based on which more accurate correlations and guidelines will be obtained for further researches.

Conclusion

Tibial tunnel in the frontal plane is located at the lateral edge of the tibial plateau, at 54.58% of the total plateau diameter. The average angle of the tunnel in the frontal plane is 74.80 degrees. Tibial tunnel in the sagittal plane is distant from the anterior edge of tibial plateau by 29.69% of the total anteroposterior plateau diameter. On average, the angle of the tibial tunnel in the sagittal plane is 68.03 degrees. Deviations from these values may potentially lead to the failure of anterior cruciate ligament reconstruction.

The results are in line with the results of most other studies.

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