

Research Article / Araştırma Makalesi

Variances of the intraarticular landmarks for anterior cruciate ligament tibial footprint: Tibial eminencies have less variability than lateral meniscus on sagittal magnetic resonance scans

Ön çapraz bağ tibial ayak izi için eklem içi kılavuzlar: Sagittal manyetik rezonans taramalarında, tibial eminensiyalar lateral menisküsten daha az varyansa sahiptir

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ABSTRACT

Objective: The purpose of this study was to analyze the sagittal plane variations of intraarticular landmarks for single bundle anterior cruciate ligament (ACL) reconstruction including lateral meniscus, medial and lateral tibial eminencies.

Methods: T2 weighted sagittal magnetic resonance (MR) scans of 80 skeletally mature patients aged between 18 to 60 years and without any sign of ligament and meniscal injuries were viewed. Midpoint of ACL, most posterior aspect of anterior horn of lateral meniscus (LMAH), tip of medial eminence (ME) and lateral eminence (LE) were identified on widest antero-posterior (A-P) distance of tibial plateau according to of Staubli-Rausching method and variances were compared.

Results: Mean location of center of tibial footprint of ACL at sagittal plane was found as $38.0 \pm 4.2\%$ (range, 29-51%) on A-P distance of tibial plateau. Location of posterior border of LMAH, ME and LE were $38.0 \pm 12.4\%$ (range, 21-62%), $52.3 \pm 4.2\%$ (range, 41- 60%) and $59.5 \pm 4.4\%$ (range, 51-69%), respectively. Difference between the variances of ACL midpoint and LMAH was large enough to be statistically significant ($p < .001$) with a large effect size ($f=0.59$), however differences between the variances of ACL midpoint and bony landmarks were not significant (ME, $p=.65$; LE, $p=.33$). Intra and interobserver agreement for measurement of all parameters were detected as moderate to good.

Conclusion: There was no constant relationship between ACL midpoint and posterior border of LMAH on sagittal plane MR images. Difference of variances between ACL midpoint and ME and LE were significantly lower than of variances of LMAH.

Keywords: Anterior cruciate ligament, lateral meniscus, tibial eminence, anatomic variations

ÖZ

Amaç: Bu çalışmanın amacı, tek demet ön çapraz bağ (ÖÇB) rekonstrüksiyonu için kullanılan lateral menisküs, medial ve tibial eminensiya eklem içi kılavuzlarının sagittal düzlem varyasyonlarını analiz etmektir.

Gereçler ve Yöntemler: Yaşları 18 ile 60 arasında değişen ve herhangi bir bağ ve menisküs yaralanması belirtisi olmayan 80 erişkin hastanın T2 ağırlıklı sagittal manyetik rezonans (MR) taramaları incelendi. ÖÇB orta noktası, lateral menisküs ön boynuzunun (LMAH) en arka yüzü, medial (ME) ve lateral eminensin (LE) yerleşimleri, tibial platonun en geniş antero-posterior mesafesinde (A-P) Staubli ve Rausching yöntemine göre tanımlandı ve varyanslar karşılaştırıldı.

Bulgular: Sagittal planda ÖÇB'nin tibial ayak izi merkezinin ortalama konumu, tibial plato A-P mesafesinde $38,0 \pm 4,2$ (aralık, %29-51) olarak bulundu. LMAH'nin arka sınırının, ME ve LE'nin yerleşimi sırasıyla $38,0 \pm 12,4$ (%21-62), $52,3 \pm 4,2$ (%41- %60) ve $59,5 \pm 4,4$ (%51-69) idi. ÖÇB orta noktası ve LMAH'nin varyansları arasındaki fark, istatistiksel olarak anlamlı olacak kadar büyüktü ($p < .001$, etki boyutu büyük, $f=0.59$), ancak ÖÇB orta noktası ve tibial eminesiyaların varyansları arasındaki fark anlamlı değildi (ME, $p=.65$; LE, $p=.33$). Tüm parametrelerin ölçümü için gözlemciler içi ve gözlemciler arası uyum orta ile iyi düzeydeydi.

Sonuç: Sagittal plan MR görüntülerinde ÖÇB orta noktası ile LMAH arka sınırı arasında sabit bir ilişki yoktu. ACL orta noktası ile ME ve LE arasındaki varyans farkı, LMAH'nin varyanslarından anlamlı olarak daha düşüktü.

Anahtar Sözcükler: Ön çapraz bağ, lateral menisküs, tibial eminensiya, anatomik varyasyon

INTRODUCTION

Anterior cruciate ligament (ACL) ruptures are one of the most common injuries among athletes and incidence of this disabling injuries is steadily increasing (1). Anatomical reconstruction has become the main stream treatment moda-

lity of this injuries as it provided superior clinical outcomes compared to non-anatomic reconstructions (2-4). Identifying the center of ligament insertion on both tibia and fe-

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mur is of utmost importance during single bundle anatomic reconstructions (5, 6).

Femoral insertion of ACL attachment was extensively investigated in the past decades, however tibial insertion of the ACL has not attracted the same attention. Several landmarks have been proposed for correct tibial tunnel placement, including posterior cruciate ligament (PCL) (5), back ridge of the knee (7) and medial tibial eminence (8). Posterior border of the anterior horn of lateral meniscus (LMAH) is the most commonly used anatomic landmark for placing the tibial tunnel and assumed to be naturel landmark for the center of tibial footprint for single bundle anatomic reconstruction (2). However, recent anatomic and radiological studies have challenged this assumption and reported inconsistent relationship between center of tibial footprint and LMAH due to variable anatomy of lateral meniscus (9).

Sagittal location of ideal tibial tunnel has been described based on limited sample size cadaveric studies with different measurement methods (10, 11). However, in current attempts for individualized ACL reconstruction, number of studies regarding relationship between relevant landmarks and center of ACL tibial insertion are quite limited. Furthermore, anatomic variances of local anatomy have not been studied extensively. The aim of this study was to report relationship between anterior-posterior location of ACL tibial insertion and to investigate bony and soft tissue landmarks including, LMAH, medial and lateral eminences.

MATERIALS AND METHODS

This study was approved by Koc University Faculty of Medicine ethics committee with an IRB number of 2020.213.IRB-1.063 and waived to obtain informed consent.

Patients

Institutional MRI data repository was retrospectively viewed to enroll 40 MR image of adult male knees. Age and body mass index matched cohort of 40 MR image of adult female knees were additionally enrolled. Inclusion criteria were skeletally mature patients aged between 18 to 60 years and without any sign of ACL, PCL, collateral ligament and meniscal injuries. Patients with significant osteoarthritis, history of an ACL or meniscal surgery were excluded. All MR imaging were performed with a 1.5 Tesla GE MR in a standard position with a leg positioner to avoid any rotation of the extremity. Consensus readings of one researcher and one radiologist were used to confirm eligibility of knee MR scans.

Technique

T2 weighted sagittal scans were analyzed by an independent researcher on GE Healthcare PACS viewer with an accuracy of 0.1 mm. The most anterior and the most posterior aspect of the tibial plateau was marked on separate scans according to the method of Staubli and Rausching (10). Then these scans were superimposed to capture the widest portion of tibial plateau perpendicular to mechanical axis of tibia. Next, perpendicular lines were dropped from the most anterior part and the most posterior part of ACL tibial footprint and then ACL midpoint was identified. The distance of ACL midpoint in relation to the measured distance of the tibial plateau in an anterior-posterior direction was measured as a percentage, so no magnitude correction was needed. (Figure 1) On separate scans, posterior border of the anterior horn of the lateral meniscus (LMAH), tip of medial (ME) and lateral eminences (LE) were identified and same measurement method was repeated for each parameter. (Figure 2)

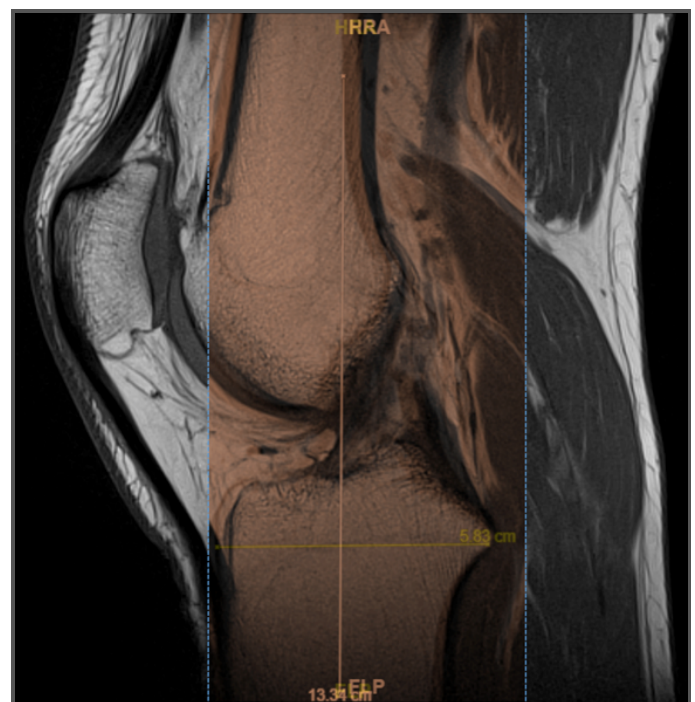


Figure 1. A digital line was drawn on the widest part of the tibial plateau; perpendicular to the tibial mechanical axis (black white background), and then a second scan showing ACL midpoint (red background) was superimposed digitally. The distance of the ACL midpoint in relation to the measured distance of the tibial plateau in an anterior-posterior direction was measured as a percentage as shown.

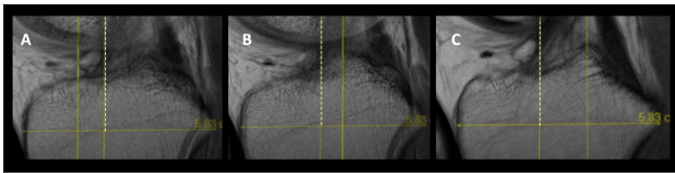


Figure 2. Dotted white line represents the ACL midpoint. Measurements of A) posterior border of the lateral meniscus anterior horn, B) lateral eminence and C) medial eminence. Please note that lateral eminence is relatively small and more round compared to medial eminence.

To determine intra-observer agreement, randomly chosen 40 MR images were reviewed 3 weeks later by the same observer. Another independent researcher analyzed the same 40 scans with the same protocol to calculate intra-observer agreement.

Statistical Analysis

A priori power analysis revealed that, at least 44 patients were needed to test the hypothesis with an effect size of 0.5 and type I error of 5% that meets the power requirement of 0.90. Sample size rounded up to 80 to further power the results and decrease type II error rate. Statistical analyses were performed using SPSS software version 21.0.0 (IBM Corp, Armonk, New York).

Descriptive statistics were used to express the location of ACL midpoint and other relevant landmarks on sagittal plane. Normality of the data was verified with Shapiro-Wilkins test. Two sample t-test with pooled variances were used to average percentages of study parameters. Levene’s test with F distribution was used to compare the variances of ACL midpoint with LMAH, ME and LE. Partial eta-squared values (η^2) were obtained to calculate effect size (f) with the following formula $f^2 = \eta^2 / (1 - \eta^2)$. Effect sizes were interpreted as $f = 0.1$ is a small effect, $f = 0.25$ is a medium and $f = 0.4$ is large effect according to Cohen *et al.* (12) Intraclass correlation coefficients (ICC) were calculated using two-way random model with 95% confidence intervals (CI) to determine intraobserver and interobserver agreement of measurements. Level of significance was set .05 and all values were two-tailed if otherwise indicated.

RESULTS

The study cohort included 36 right and 44 left MR images of 40 male and 40 female patients with a mean age of 45.3 ± 14.7 years (range, 18-60). The mean location of ACL midpoint at sagittal plane was found on $38.0 \pm 4.2\%$ (range, 29-51%) on A-P distance of tibial plateau. Location of posterior border of LMAH, ME and LE were $38.0 \pm 12.4\%$ (range, 21-62%), $52.3 \pm 4.2\%$ (range, 41-60%) and $59.5 \pm 4.4\%$ (range, 51-69%), respectively. The difference between ACL midpoint and ME and LE was significant ($p < .001$), however there were no significant differences between the averages of ACL midpoint and LMAH ($p = .97$).

The difference between the variances of ACL, LMAH, LE and ME was significant ($p < .001$) with a large effect size ($f = 0.64$) (Figure 3). In subgroup analyses, difference between the variances of ACL midpoint and ME was not significant ($p = .65$) with an observed small effect size ($f = 0.035$). Similarly, the difference between the variances of ACL midpoint and LE was not significant ($p = .33$) with an observed small effect size ($f = 0.077$). On the other hand, difference between the variances of ACL midpoint and LMAH was large enough to be statistically significant ($p < .001$) with an effect size of 0.59, that indicates that the magnitude of the difference between the averages were large.

Intra and interobserver agreement for measurement of ACL-midpoint, LMAH, ME and LE showed moderate to good agreement with ICC values presented in Table 1.

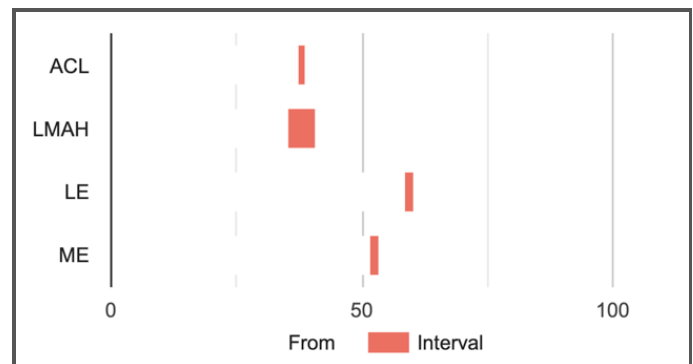


Figure 3. Confidence intervals for the average of deviations

Table 1. Intra-observer and inter-observer agreements for measurements

	Intra-observer		Inter-observer	
	ICC	95% CI	ICC	95% CI
ACL-midpoint	0.813	0.776 - 0.814	0.786	0.732-0.798
LMAH	0.756	0.712- 0.803	0.656	0.603-0.711
ME	0.711	0.665-0.751	0.694	0.632-0.734
LE	0.734	0.701-0.767	0.685	0.648-0.719

ICC, intraclass correlation co-efficient; CI, confidence interval; ACL, anterior cruciate ligament; LMAH, anterior horn of lateral meniscus; ME, medial eminence; LE, lateral eminence

DISCUSSION

The most important finding of this study was, despite a close proximity between ACL midpoint and posterior border of LMAH, there was no constant relationship between two anatomic structures on MR images. The difference of variances between ACL midpoint and LMAH was significantly larger than of variances of ME and LE.

A lot of effort has been spent for years to identify the footprint centers to perform anatomic ACL reconstructions. On sagittal plane, placement of tibial tunnel more anteriorly on tibia may cause notch impingement of the graft whereas placing posteriorly may cause posterior cruciate ligament impingement (13). Using the posterior border of LMAH as a tibial tunnel landmark was defined by Jackson and Gessler and later corroborated to be a useful intraarticular landmark for determining the midpoint of ACL tibial footprint (3, 5, 14). In a cryosectional and magnetic resonance arthrography study, Staubli and Rauschnig reported that ACL midpoint was located at 44% of the total midsagittal diameter from the anterior margin of the tibia (10). Several cadaveric, radiographic and three-dimensional computed tomography studies have evaluated this measurement and reported that the center of ACL tibial footprint was located at average A-P distance of 38.5 % to 40.7 %, with outliers (2, 15-17). A systematic review of studies that investigated Staubli and Rauschnig method showed that the weighted mean of the tibial footprint center in the A-P distance was 42% and 5th and 95th percentiles were 39% and 46%, respectively (18). In our study, ACL midpoint was found to be located at $38.0 \pm 4.2\%$ (range, 29-51%) similar to the previous reports. However, LMAH was found to be between 21% to 62% of the A-P distance of the tibial plateau, and difference of variances between ACL midpoint and LMAH was large enough to be statistically significant ($p < .001$, $f = 0.59$). Substantial anatomic variations of the both lateral meniscus and ACL tibial attachment may explain this mismatch (8, 19, 20). Furthermore, a former partial meniscectomy of the anterior horn of the meniscus may change anatomy and make it a less reliable landmark (8). Therefore, reproducible methods are required to determine the anatomic sagittal location of the ACL tibial tunnel.

Edwards et al. (7) first described the lateral face of ME as a reliable landmark for anatomic ACL reconstruction, but only as a medial-lateral parameter. Authors suggested that due to proximity of these two anatomic structures, the distances between the ME and the centers of the ACL attachments did not vary significantly, despite the range of overall knee sizes. In a cadaveric study by Ferretti et al. (8) it has been reported that the medial tibial eminence demon-

strated less variability and had a constant relationship with the center of the ACL when compared with the lateral meniscus. However, this study was performed on eight cadaveric knees and the accuracy of their findings were limited. To the best of our knowledge, current study is the first to analyze variations of LMAH and tibial eminences in relation to ACL tibial center on MR images. Both medial and lateral eminences showed relatively small variances compared to variances of LMAH. Findings of this study validate the recommendations of Ferretti et al. (8) in a larger sample size.

We recommend to reevaluate the LMAH as an intraarticular reference point for anatomic ACL reconstruction. A more predictable tunnel position may be determined with the use of bony landmarks when footprint is not clearly visible during arthroscopic surgery. Although this study does not specifically investigate the outcomes of tunnel positioning according to aforementioned landmarks, previous reports suggested improved outcomes with rather anatomic ACL reconstructions (21). Currently, navigation assisted surgeries are gaining attention in every field of medical practice and treatments are tend to be tailored according to patients. Our findings may be helpful to develop software algorithms that set correlation between the tibial eminences and the ACL midpoint. Nonetheless, we agree with previous reports suggesting that ACL tunnel placement should be individualized as ACL tibial insertion is variable between patients (7-9, 20, 22).

This study has some limitations worth to mention. First, this study is based on MR images and further validation is needed with large sampled cadaveric studies. Secondly, all reference points were marked on different scans and our measurement technique may prone to errors. However, ICC values showed moderate to good agreement in repeated measurements. Thirdly, we did not analyze the sagittal-oblique scans of ACL, which would be very helpful to detect ligament injuries. But our series included knees without ligament injuries and we thought that results obtained from standard knee images might be more generalizable compared to oblique images. Finally, coronal plane analyzes of landmarks have not performed in this study, but further research is needed to determine the impact of variances of eminences on medial-lateral positing of tibial tunnels.

CONCLUSION

There was no constant relationship between ACL midpoint and posterior border of LMAH on sagittal plane MR images. The difference of variances between ACL midpoint and ME and LE were significantly lower than variances of LMAH.

Ethics Committee Approval / Etik Komite Onayı

The approval for this study was obtained from Institutional Ethics Committee of Koç University, İstanbul, Turkey (Decision no: 2020.213.IRB1.063 Date: 13.05.2020).

Conflict of Interest / Çıkar Çatışması

The authors declared no conflicts of interest with respect to authorship and/or publication of the article.

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Author Contributions / Yazar Katkıları

Concept All authors; Design All authors; Supervision KA; Materials KA; Data Collection and/or Processing LA; Analysis and Interpretation KA; Literature Review KA; Writing Manuscript KA; Critical Reviews KA, LA.

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