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Research Article

The Measurement of the Distance between the Anterior Cruciate Ligament and the Anterior Root of the Medial Meniscus and its Clinical Implications

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Introduction

The anterior cruciate ligament (ACL) is a critical structure within the knee joint, primarily responsible for maintaining anteroposterior stability and controlling rotational forces during movement. Anatomically, the ACL comprises two functional bundles—anteromedial and posterolateral—that are tensioned during different phases of knee flexion and extension, providing dynamic stability to the knee joint [1]. Injury to the ACL, particularly tears, can result in significant knee instability, often necessitating surgical intervention for active individuals [2].

The medial meniscus, a fibrocartilaginous structure located between the femoral condyle and tibial plateau, serves as a load distributor, shock absorber, and stabiliser within the knee joint [3]. The anterior root of the medial meniscus is crucial for maintaining the proper biomechanics of the meniscus. Damage to the anterior root has been shown to mimic total meniscectomy, leading to increased tibiofemoral contact pressures and accelerating degenerative changes within the joint [4].

The importance of ACL reconstruction lies in its ability to prevent recurrent knee instability, which can lead to meniscal tears, cartilage damage, and early osteoarthritis if left untreated [5]. The procedure is highly prevalent, with an estimated 100,000 to 200,000 ACL reconstructions performed annually in the United States alone [6]. Despite the success of ACL reconstruction, one of the leading causes of revision surgery is tunnel malposition [7]. Improper tunnel placement alters the biomechanics of the reconstructed ligament, resulting in graft failure, continued instability, or loss of range of motion. Accurate tunnel placement is therefore critical to the long-term success of ACL reconstruction and the prevention of revision surgeries [8].

Current anatomical landmarks, such as the anterior horn of the lateral meniscus and the tibial spine, are commonly used for tibial tunnel placement; however, they are associated with variability in positioning, leading to potential misplacement of the tunnel [9]. This measurement will not only aid in ACL surgery and postoperative assessment; it will also give an insight regarding the risk of iatrogenic anterior root injury during intramedullary nailing of the tibia as the drilling of the entry point might risk injuring the root [10]. The hypothesis of this study is that measuring the distance between the anterior border of the ACL and the posterior border of the anterior root of the medial meniscus on sagittal MRI will provide a consistent anatomical landmark. If this measurement is reliable, it could help surgeons achieve more accurate tibial tunnel placement during ACL reconstruction and help in the postoperative assessment of the tibial tunnel position.

Methodology

1. Patient Demographics and Study Details

A total of 151 knees from 151 patients aged between 17 and 77 were included in the study at Jordanian University Hospital. The MRI images were examined after obtaining consent from the ethics committee. The study focused on patients who underwent knee MRI scans from January 2017 to the end of 2022, utilising the Philips Ingenia 1.5 T MRI system with Omega HP gradient system.

2. Measurement Method and Parameters

Two physicians (one radiologist and one orthopaedic surgeon who had been trained in using the radiology software) performed measurements on the MRI images to prevent bias. The measurements were performed by drawing a horizontal line between the posterior edge of the anterior horn of the medial meniscus and the anterior edge of the ACL on a T2W sagittal spare image of the middle cut of the ACL.

3. Imaging Techniques

All measurements were performed on the sagittal plane with multi-slice, turbo-spin- echo, T1-weighted images with the following parameters: 540/8/1.5 (TR/TE/NEX); slice thickness 3.5 mm, inter-slice gap 0.5 mm, matrix 340×320. At the same time, T2-weighted images had the following parameters: 2500/80/1, matrix 375×320, slice thickness 3.5 mm, and inter-slice gap 0.5 mm for coronal and sagittal images.

4. Inclusion and Exclusion Criteria

Examined MRI knee scans were for patients between 17 and 70 years of age, with scans performed between January 2017 and the end of 2022 and reported by the radiologist as "normal". Scans with any reported pathological findings, previous surgeries, or deformities were not even considered.

5. Statistical Analysis

In this study, descriptive statistics were used to analyze the measured distances between the ACL and the medial meniscus anterior root. The mean provided a central value, while the standard deviation measured variability. A 95% confidence interval was calculated to estimate the range within which the true population mean likely falls, offering a measure of precision. This interval was derived using the standard error of the

mean, assuming a normal distribution, to help make reliable inferences about the population based on the sample.

Results

The study included 151 patients, 87 males (54.7%) and 72 females (45.3%). The average distance between the anterior border of the ACL and the posterior border of the anterior root of the medial meniscus is 6.72 mm with a standard deviation of 1.80 mm. The 95% confidence interval for the mean is (6.43 mm, 7.01 mm), indicating that the true mean distance lies within this range with 95% confidence.

Discussion

The statistical analysis of the measured distances between the anterior border of the ACL and the posterior border of the anterior root of the medial meniscus on sagittal MRI yielded a mean distance of 6.72 mm, with a standard deviation of 1.80 mm. To assess the precision of this estimate, a 95% confidence interval was calculated, ranging from 6.43 mm to 7.01 mm. This interval suggests that the true mean distance is likely to fall within this range, providing a reliable reference for surgical planning, particularly for tibial tunnel placement in ACL reconstruction. The relatively narrow confidence interval reflects the consistency of the measurements across the sample population.

The findings of this study reveal two critical clinical implications, particularly in knee surgeries. First, the measured distance between the ACL and the anterior root of the medial meniscus highlights their close anatomical proximity. This relationship is especially important in procedures like intramedullary nail insertion for tibial fractures, where entry through the anterior proximal tibia risks damaging the medial meniscus root [17 18]. Improper insertion or drilling can lead to root injury, resulting in biomechanical dysfunction similar to a meniscectomy with increased tibiofemoral contact pressure and accelerated cartilage degeneration [19 20 21 22]. These results emphasise the need to carefully consider the meniscal root during intramedullary tibial nail insertion to prevent long-term joint damage, with the possibility of moving the entry point laterally to avoid medial meniscus root injury.

Secondly, the consistency of this measurement has significant implications for improving tibial tunnel placement during ACL reconstruction surgery; it provides a reliable anatomical landmark that surgeons can

reference when positioning the tibial jig through the medial portal. Current techniques for tibial tunnel placement, which often rely on landmarks such as the anterior horn of the lateral meniscus or the tibial spine, have shown variability and can lead to tunnel misplacement—a leading cause of ACL reconstruction failure and revision surgeries [23 24] . The distance measured in this study, approximately 6.72 mm on sagittal MRI, serves as a critical point for guiding jig placement. However, because the arthroscopic placement of the tibial jig is oblique to the axis of the measured distance, the effective distance on the jig is likely closer to 7 mm, providing an adjusted reference during surgery. If combined with the currently used references, the anterior horn of the lateral meniscus and the tibial eminance, this measurement ensures that the tibial tunnel is positioned in a way that closely mirrors the native anatomy of the ACL insertion, potentially reducing complications such as graft impingement or altered biomechanics [25 26 27].

Limitations:

One limitation of this study is the reliance on MRI for measurement, which, while accurate, can vary depending on imaging quality, patient positioning, and slice orientation. This variability may introduce slight inconsistencies in the measured distance between the ACL and the anterior root of the medial meniscus across different institutions or imaging modalities. Additionally, this study only evaluated the anatomical relationship in a single plane (sagittal), which may not fully capture the three-dimensional complexity of knee joint anatomy during surgery. Another limitation is that the study did not directly correlate the measurements with clinical outcomes from ACL reconstruction surgeries, leaving a gap in understanding how well these measurements translate into improved surgical success. Moreover, this study involved a limited population, which may not represent the full variability of anatomical differences in diverse patient groups, such as those with preexisting joint abnormalities or varying levels of joint degeneration.

Future Directions:

Future research should aim to validate these findings in a larger and more diverse cohort to ensure that the measurements apply broadly across different patient populations. Studies could also explore the three-dimensional anatomical relationship between the ACL and the medial meniscus root to provide a more comprehensive guide for tibial tunnel placement. Additionally, correlating these measurements with postoperative outcomes, such as graft stability, knee function, and long-term success rates, would provide clinical evidence of the benefit of using these anatomical landmarks for tibial tunnel placement. Another area for further exploration could be the development of intraoperative imaging techniques or navigation systems

that utilise this measurement to guide surgeons in real-time, enhancing precision in ACL reconstruction surgeries. Finally, future studies could investigate how these measurements interact with other anatomical variables, such as meniscal slope or ACL inclination, to refine surgical techniques further and reduce tunnel misplacement.

Conclusion

In conclusion, this study highlights the consistent anatomical relationship between the ACL and the anterior root of the medial meniscus, offering a valuable reference for intramedullary tibia nail postoperative knee pain complications and improving tibial tunnel placement during ACL reconstruction. The measured distance provides a reliable intraoperative guide that can reduce the risk of tunnel misplacement, potentially enhancing surgical outcomes and reducing revision rates. Further research is needed to validate these findings in diverse populations and assess their direct impact on postoperative success. These insights could contribute to more precise, anatomically informed ACL reconstruction techniques.

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