

TIBIAL ACL FOOTPRINT: CORRELATION BETWEEN PREOPERATIVE MRI AND INTRAOPERATIVE ARTHROSCOPIC MEASUREMENTS—A PROSPECTIVE COMPARATIVE STUDY

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ABSTRACT

Background: Accurate identification of the native anterior cruciate ligament (ACL) tibial footprint is essential for anatomic ACL reconstruction. Magnetic resonance imaging (MRI) is routinely used for preoperative assessment; however, visualization of the complete tibial insertion may be limited by imaging resolution, soft-tissue overlap, and partial-volume effects. Direct arthroscopic visualization permits identification of the bony margins of the native footprint and may therefore provide a more accurate measurement. **Aim:** To study the tibial ACL insertion-site length in patients undergoing primary ACL reconstruction and compare preoperative MRI measurements with intraoperative measurements obtained using an arthroscopic ruler. **Materials and Methods:** This prospective comparative observational study was conducted over 18 months in the Department of Orthopaedics, Adichunchanagiri Institute of Medical Sciences, B.G. Nagara. Fifty patients aged >18 years with clinically and MRI-confirmed ACL insufficiency, with or without associated meniscal or collateral ligament injuries, were included. The tibial ACL footprint length was measured preoperatively on MRI and subsequently measured intraoperatively using an arthroscopic ruler after adequate visualization of the tibial insertion. Demographic and clinical variables, including age, sex, side involved, weight and associated injuries, were recorded. Statistical analysis was performed using SPSS, with $p < 0.05$ considered statistically significant. **Results :** The mean preoperative tibial footprint length was 13.00 ± 2.36 mm, whereas the mean intraoperative measurement was 14.36 ± 2.41 mm. The intraoperative measurement was significantly greater than the MRI measurement ($p < 0.001$). The difference remained significant in patients aged <30 years (12.41 ± 2.10 mm vs 12.69 ± 1.53 mm; $p = 0.047$) and >30 years (12.75 ± 2.36 mm vs 12.98 ± 1.68 mm; $p = 0.036$). Similar significant differences were observed on both right and left sides. Associated injuries did not substantially alter the underlying footprint dimensions, although intraoperative measurements were consistently higher. **Conclusion:** Preoperative MRI provides a useful estimate of the ACL tibial footprint but consistently underestimates its length compared with direct intraoperative assessment. Arthroscopic visualization and measurement may therefore improve identification of the native tibial footprint and assist in accurate tunnel placement during anatomic ACL reconstruction.

Keywords: anterior cruciate ligament, tibial footprint, magnetic resonance imaging, arthroscopy, ACL reconstruction, arthroscopic ruler

INTRODUCTION

The anterior cruciate ligament is a fundamental stabilizer of the knee, providing resistance to anterior tibial translation and contributing substantially to rotational stability. It consists principally of anteromedial and posterolateral functional bundles, which demonstrate different patterns of tension throughout the range of knee motion. Loss of ACL integrity can result in recurrent instability, secondary meniscal injury, cartilage damage and, ultimately, degenerative osteoarthritis.

Anatomic ACL reconstruction aims to reproduce the native insertion sites of the ligament as closely as possible. The tibial ACL footprint is located anterolaterally on the tibial plateau, medial to the anterior horn of the lateral meniscus and anterolateral to the tibial spine. Its dimensions and orientation demonstrate individual variability and are important determinants of graft positioning and tunnel placement.

The evolution from traditional single-bundle reconstruction toward anatomic and double-bundle techniques has increased the importance of accurate identification of the native ACL footprint. Appropriate knowledge of the tibial footprint helps the surgeon determine tunnel position and size and may reduce the risk of non-anatomic graft placement.

MRI is the principal preoperative imaging modality for ACL injury. It provides information regarding ligament integrity, associated meniscal and chondral lesions and the anatomy of the ACL insertion. However, MRI-based assessment of the tibial footprint may be affected by the oblique orientation of the ACL, the difficulty in defining the exact anterior and posterior margins and soft-tissue overlap. Previous investigations have consequently reported variable agreement between MRI-derived and direct anatomical measurements.

Schwartzberg et al. specifically evaluated the relationship between MRI and arthroscopic measurements of the ACL tibial insertion and demonstrated the potential usefulness of MRI for preoperative prediction. However, the ability of MRI to reproduce the actual intraoperative dimensions remains clinically relevant, particularly when planning anatomic reconstruction.

Direct arthroscopic assessment allows removal of residual ACL tissue and synovium and permits identification of the peripheral bony margins by probing. The present study was therefore undertaken to compare preoperative MRI-derived tibial ACL footprint measurements with direct intraoperative measurements obtained using an arthroscopic ruler.

Aim

To study tibial insertion-site length in patients undergoing primary ACL reconstruction and compare preoperative MRI measurements with intraoperative measurements using an arthroscopic ruler.

Objectives

- To measure the preoperative tibial ACL insertion-site length and compare it with the intraoperative measurement.
- To assess the relationship between tibial footprint measurements and demographic and clinical parameters including age, side of involvement and associated injuries.

MATERIALS AND METHODS

Study Design and Setting

A prospective comparative observational study was conducted over a period of 18 months in the Department of Orthopaedics, Adichunchanagiri Hospital and Research Centre, B.G. Nagara, Mandya District, Karnataka. The dissertation's methodology section describes the study design as descriptive/cross-sectional, while the abstract describes it as prospective comparative; the present manuscript emphasizes the paired preoperative–intraoperative comparison.

Study Population

Patients presenting with ACL-deficient knees and planned for primary ACL reconstruction were considered for inclusion.

A total of 50 patients were included in the final study. The study population consisted of adults of either sex with clinically and MRI-confirmed ACL insufficiency, with or without associated meniscal or collateral ligament injuries.

Inclusion Criteria

- Age >18 years.
- Patients of either sex.
- ACL insufficiency confirmed by clinical examination and MRI.
- ACL insufficiency with or without associated meniscal or collateral ligament injury.

Exclusion Criteria

Patients were excluded if they were:

- Younger than 18 years.
- Medically unfit for surgery because of significant comorbidities.
- Patients with associated intra-articular fractures or established knee arthritis.
- Patients in whom the interval between MRI and arthroscopic reconstruction exceeded three months.
- Patients with contraindications to MRI, including pacemakers or incompatible implants.

Data Collection

After institutional ethics committee approval and written informed consent, eligible patients underwent detailed history taking and clinical examination. Radiological evaluation included plain radiographs and MRI of the knee. ACL insufficiency was confirmed clinically and radiologically.

The demographic parameters recorded included age, sex, weight and side of involvement. Associated injuries, particularly meniscal and ligamentous injuries, were also documented.

MRI Assessment

Preoperative MRI was used to identify and measure the tibial ACL footprint. High-resolution MRI assessment was performed with the knee in full extension. The coronal plane was used for identification of the tibial footprint and surrounding landmarks, while sagittal imaging was used to confirm the measurement. Only fibers inserting directly onto the tibia were considered part of the footprint.

The tibial footprint length was measured along its anteroposterior dimension. Figure 22 of the dissertation demonstrates a representative MRI measurement of 13.0 mm following three-dimensional sequencing.

Intraoperative Assessment

During arthroscopic ACL reconstruction, the tibial footprint was directly visualized through standard arthroscopic portals. Residual ACL fibers and overlying soft tissue were trimmed sufficiently to expose the complete tibial footprint. The peripheral margins were identified and measured using an arthroscopic ruler.

The length was measured along the anteroposterior axis, while the width was measured along the mediolateral axis.

The dissertation's representative case demonstrated identical nominal measurements of 13.0 mm on MRI and with the arthroscopic ruler in one patient, illustrating the measurement technique.

Statistical Analysis

Quantitative variables were expressed as mean and standard deviation, while qualitative variables were expressed as frequencies and percentages. Comparative and association analyses were performed using appropriate statistical tests, including Student's t-test, chi-square test and Fisher's exact test. Statistical analysis was performed using SPSS software, with $p < 0.05$ considered statistically significant.

RESULTS

Study Population

Fifty patients with ACL insufficiency were included. The majority belonged to the young and middle-aged adult groups, particularly the 21–30-year and 31–40-year age groups. There was a clear male predominance. Right- and left-sided knee involvement was approximately equally distributed.

Among patients with associated injuries, medial meniscal injuries were the most frequently reported, followed by combined posterior cruciate ligament and medial collateral ligament injuries, while lateral meniscal injuries were less frequent.

Comparison of Preoperative and Intraoperative Tibial Footprint Measurements

The principal finding of the study was that intraoperative measurement consistently demonstrated a larger tibial ACL footprint than preoperative MRI assessment.

Measurement	Mean SD (mm)	p-value
Pre-operative	13.00 ± 2.36	
Intra-operative	14.36 ± 2.41	< 0.001*

The Mean difference was therefore approximately 1.36 mm, with intraoperative measurement demonstrating a significantly greater footprint length than MRI measurement.

Correlation with Age

Patients younger than 30 years had a mean preoperative footprint of 12.41 ± 2.10 mm compared with an intraoperative measurement of 12.69 ± 1.53 mm ($p = 0.047$).

Among patients older than 30 years, the corresponding measurements were 12.75 ± 2.36 mm and 12.98 ± 1.68 mm, respectively ($p = 0.036$).

Age Group (years)	Mean (Pre-op)	Mean (Intra-op)	SD (Pre-op)	SD (Intra-op)	p-value
< 30 years	12.41	12.69	2.10	1.53	0.047
>30 years	12.75	12.98	2.36	1.68	0.036

Thus, intraoperative measurements were significantly higher in both age groups, indicating that the discrepancy between MRI and direct measurement was not substantially influenced by age.

Correlation with Side of Involvement

For right-sided ACL injuries, the mean preoperative measurement was 12.54 ± 2.39 mm compared with 12.82 ± 1.63 mm intraoperatively ($p=0.042$).

For left-sided injuries, the corresponding values were 12.72 ± 1.52 mm and 12.83 ± 1.50 mm ($p=0.036$).

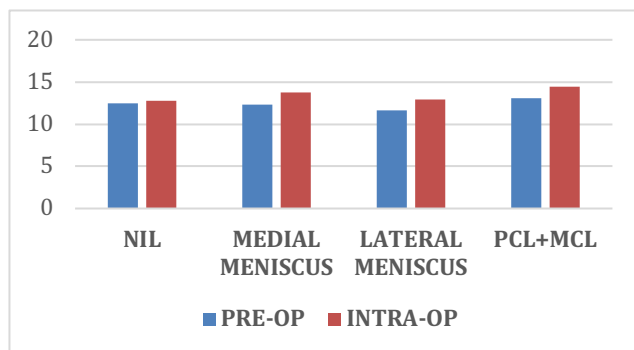
The increase in intraoperative measurements was therefore present on both sides, without evidence of a clinically meaningful laterality-related difference.

Age Group (years)	Mean (Pre-op)	Mean (Intra-op)	SD (Pre-op)	SD (Intra-op)	p-value
< 30 years	12.41	12.69	2.10	1.53	0.047
>30 years	12.75	12.98	2.36	1.68	0.036

Associated Injuries

Among patients without associated injuries, the mean footprint increased from 12.50 ± 2.12 mm on MRI to 12.80 ± 1.60 mm intraoperatively ($p=0.034$).

In patients with medial meniscal injuries, measurements increased from 12.30 ± 2.12 mm to 13.75 ± 2.01 mm ($p=0.048$). Patients with lateral meniscal injuries demonstrated an increase from 11.65



± 1.95 mm to 12.90 ± 1.88 mm ($p=0.041$), while patients with combined PCL and MCL injuries demonstrated an increase from 13.10 ± 2.40 mm to 14.45 ± 2.30 mm ($p=0.039$).

Overall, associated meniscal or ligamentous injuries did not appear to substantially alter the underlying tibial footprint morphology. The consistent increase in intraoperative measurements across these subgroups suggests that the principal difference was related to the method of assessment rather than the associated injury itself.

DISCUSSION

The present study demonstrates that direct intraoperative measurement of the ACL tibial footprint provides a significantly larger measurement than preoperative MRI. The mean footprint increased from 13.00 ± 2.36 mm on MRI to 14.36 ± 2.41 mm during arthroscopic assessment, with a highly significant difference ($p<0.001$).

The ACL tibial footprint is anatomically important because tunnel placement within the native insertion site is a fundamental component of anatomic ACL reconstruction. The tibial insertion is relatively large and is situated medial to the anterior horn of the lateral meniscus and anterolateral to the tibial spine.

MRI remains indispensable for preoperative planning because it permits evaluation of ACL integrity and associated intra-articular pathology. However, footprint measurement on MRI is technically challenging. The ACL has an oblique orientation, and the exact anterior and posterior limits of the tibial insertion may be difficult to define. Soft-tissue structures and partial-volume effects can further obscure the true margins.

The findings of the present study are particularly relevant when planning anatomic or double-bundle ACL reconstruction. Accurate knowledge of the native tibial footprint helps determine whether the available footprint can accommodate the intended tunnel configuration and assists in avoiding tunnel malposition or convergence.

The study by Schwartzberg et al. examined the correlation between MRI and arthroscopic tibial insertion-site length and is particularly relevant to the present investigation. Their work, involving 52 patients and two independent MRI raters, demonstrated the potential of MRI to estimate the tibial insertion site but also highlighted methodological challenges in translating imaging measurements to the intraoperative setting.

The greater intraoperative measurements observed in the present study may be explained by direct visualization of the footprint after removal of residual synovial tissue and ACL remnants. Arthroscopic probing also permits identification of the true peripheral bony margins. In contrast, MRI measurements are dependent on the ability to recognize these margins from imaging slices.

The consistency of the findings across age groups is notable. Both patients younger than 30 years and those older than 30 years demonstrated statistically significant increases in intraoperative measurements. This suggests that age did not materially modify the discrepancy between MRI and arthroscopic measurements.

Similarly, both right- and left-sided knees demonstrated significantly greater intraoperative measurements. This supports the observation that the ACL tibial footprint does not demonstrate a clinically meaningful laterality-related difference in this cohort.

The presence of associated injuries also did not appear to substantially influence the underlying footprint anatomy. Although each subgroup demonstrated statistically significant increases in intraoperative measurements, the direction of change was consistent. The findings therefore support the interpretation that the discrepancy primarily reflects the measurement technique rather than alterations in footprint morphology caused by associated meniscal or ligamentous injuries.

From a surgical perspective, these findings emphasize that MRI should be considered a preoperative guide rather than an absolute representation of the intraoperative footprint. Direct arthroscopic assessment remains important before finalizing tibial tunnel placement. The dissertation's measurement technique specifically emphasizes identification of the outer edge of the footprint and measurement along the anteroposterior and mediolateral axes.

Clinical Implications

The findings have several implications for ACL reconstruction:

- Preoperative MRI is valuable for planning but may underestimate tibial footprint length.
- Direct arthroscopic visualization should be used to confirm the native tibial insertion.

- Tunnel placement should be based on recognized anatomic landmarks rather than MRI measurements alone.
- Individualized assessment may be particularly important when considering double-bundle or footprint-preserving reconstruction.
- Accurate footprint identification may improve the reproducibility of anatomic ACL reconstruction.

LIMITATIONS

The study was conducted at a single institution with a relatively small sample size of 50 patients. The study population consisted of patients undergoing ACL reconstruction and therefore may not represent the entire population. In addition, the study primarily evaluated footprint length rather than providing a comprehensive three-dimensional characterization of footprint area and morphology.

The dissertation also proposed assessment using two preoperative raters, but the reported results primarily present the overall preoperative measurement rather than detailed inter-rater reliability statistics. Therefore, future studies with larger multicentric cohorts, standardized MRI protocols and formal interobserver and intraobserver reliability analyses would strengthen the evidence.

CONCLUSION

This study demonstrates that intraoperative arthroscopic assessment provides a more accurate representation of the ACL tibial footprint than preoperative MRI measurement. The mean intraoperative tibial footprint was significantly greater than the corresponding MRI measurement, indicating that MRI consistently underestimated the footprint length in this cohort.

The discrepancy between MRI and intraoperative measurements was observed consistently across different age groups and both sides of knee involvement. Associated meniscal and ligamentous injuries did not substantially modify the underlying footprint dimensions. These findings suggest that the difference is primarily attributable to the method of assessment rather than clinically meaningful anatomical variation.

Therefore, although preoperative MRI remains an important tool for surgical planning, meticulous intraoperative identification, visualization and measurement of the tibial ACL footprint should be considered an important component of anatomic ACL reconstruction. Direct arthroscopic assessment may facilitate more accurate tunnel placement and better reproduction of native ACL anatomy.

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