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Original Research Article

Preoperative prediction of length of the femoral tunnel in single bundle anterior cruciate ligament reconstruction in knee MRI

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ABSTRACT

Background: This study aims to find the correlation between the length of the femoral tunnel and morphological parameters of the knee in the magnetic resonance imaging (MRI) before anatomical single-bundle anterior cruciate ligament (ACL) reconstruction and if these variables can be used for preoperative prediction.
Methods: A prospective study of 30 patients undergoing ACL reconstruction by the same surgeon. Anthropometric measurements (weight, height, BMI) and knee morphological parameters were assessed using MRI. These included anteroposterior (AP) knee length, trans-epicondylar length, axial notch area, notch outlet length, posterior condyle length, notch width index (NWI), Blumensaat's line length, and lateral wall of the notch dimensions. Intraoperative femoral tunnel length was measured and correlated with these parameters.
Results: A strong positive correlation was found between patient height and femoral tunnel length ($r=0.797$, $p<0.001$). Significant positive correlations were also observed between femoral tunnel length and both AP length of the knee ($r=0.355$, $p=0.04$) and trans-epicondylar length ($r=0.377$, $p=0.040$). Interestingly, a moderate negative correlation was found between BMI and femoral tunnel length ($r=-0.425$, $p=0.019$).
Conclusions: Patient height, AP knee length and trans-epicondylar length could be helpful predictors of femoral tunnel length in preoperative planning for in single-bundle ACL reconstruction.

Keywords: Anterior cruciate ligament reconstruction, Femoral tunnel length, Anthropometry, Knee morphology, MRI, Preoperative planning, Single-bundle technique

INTRODUCTION

Anterior cruciate ligament (ACL) reconstruction is a fundamental treatment to restore knee stability and function after an ACL tear. The occurrence of ACL injuries in developing countries has been consistently rising due to the surging popularity of sports and physical activities.[1,2] The effectiveness of ACL restoration depends significantly on the accurate positioning and sufficient length of the femoral tunnel. Achieving the ideal length of the femoral tunnel remains challenging due to inadequate tunnel length and incorrect placement of the tunnel sleeve in ACL replacement. Inadequate tunnel length can lead to several complications, such as weakened attachment and reduced graft integration with the body, which can eventually affect the patient's outcomes during the rehabilitation phase.[3] Recent research has emphasized the importance of patient-specific anatomical features in determining the outcomes of surgical procedures. Individual differences in the anatomy of the knee and body proportions can significantly affect the optimal parameters for creating a tunnel in the femur.[4] Anthropometric measurements, which include height, weight, Body mass index (BMI), and limb length, provide vital information on body proportions and may be related to knee joint dimensions. The structure of the knee, including factors like the size of the femoral condyles, the width of the intercondylar notch, and the characteristics of the tibial plateau, is crucial in determining the space available and the best position for the femoral tunnel.[5] MRI provides exceptional soft tissue and bone imaging, allowing for precise evaluation of knee morphology and accurate measurement of critical anatomical landmarks. MRI helps in the preoperative planning process, where surgeons can predict the difficulty of inadequate tunnel length. This study intends to significantly optimise ACL reconstruction techniques by clarifying the intricate connection between patient-specific anatomical parameters and the femoral tunnel length.

The discoveries could potentially facilitate and enhance the durability of grafts, improve their biological integration, and finally result in improved functional outcomes and patient contentment. Our study aims to enhance our knowledge of ACL restoration and contribute to the continuous improvement of this essential orthopaedic treatment. This can be done only by utilising sophisticated imaging techniques and investigating the complex connections between patient anatomy and surgical factors. This research can affect the immediate surgical results and long-term knee health, functional rehabilitation, and overall quality of life for patients after ACL reconstruction.

METHODS

Study design

It is a prospective interventional study.

Study duration

The study was conducted over a period from July 2022 to April 2024.

Study population and source of data

Patients presenting to the Department of Orthopaedics, JSS Hospital, JSS Academy of Higher Education and Research, Mysore.

Sample size

The study included a total of 30 patients, comprising 28 males and 2 females. Clinical trial registration number and the date of registration. Registration number: JSS/MC/PG/IEC-141/2022-23.

Inclusion criteria

The study included patients undergoing single-bundle ACL reconstruction by knee arthroscopy. Individuals from all age groups were eligible for inclusion.

Exclusion criteria

A history of previous knee surgery for ligamentous injury was excluded.

After approval by the institutional ethics committee. The patient's height, weight, BMI, and intra-operative femoral tunnel length were measured by a single assessor. Pre-operative MRI, using the sagittal and axial sections, The following measurements were calculated using RadiAnt DICOM software (Figures 1 and 2): the anteroposterior (AP) length of the knee (mm), the length of Blumensaat's line (mm), the height of the lateral wall of the intercondylar notch (mm), the trans-epicondylar length (TEL) (mm), the length of the notch outlet (mm), the length of the lateral posterior condyle (mm), the area of the lateral wall of the intercondylar notch (mm²), and the notch width index (NWI). The axial notch area was assessed using axial MRI views. Pre-operatively, using the slice of the MRI image that could evaluate the longest length between the medial and lateral epicondyles of the femur, the trans-epicondylar length (TEL), the length of the notch outlet, and the lengths of the medial and lateral posterior condyles were measured. Notch width index (NWI) was calculated as the length of the notch outlet/the length of the medial and lateral posterior condyle×100. The axial notch area was evaluated using the same slice. The notch was outlined, and the posterior border of the notch was defined as the line between the inner medial and lateral femoral condyles, characterised by a sudden change in slope. The area of the lateral wall was measured using the semicircle formula and the lateral wall of the femoral condyle. MRI slices were used to measure the notch area.

The measurements were calculated using these formulas.[7-10]

$$\text{Body Mass Index} = \frac{\text{Weight (kg)}}{\text{Height(m)}^2}$$

Measurement of Notch area in Axial view

$$\text{Area}= \frac{22/7 \text{ x (notch outlet length/2) 2}}{2}$$

Measurement of Notch Width Index

$$\text{NWI}= \frac{\text{Notch outlet length}}{\text{Posterior Condyle Length}} X100$$

Measurement of the area of the lateral wall of the notch.

$$\text{Area}= \frac{22 \times (\text{height of the lateral wall of notch})^2}{7 \times 2} \quad 11$$

The notch was outlined, and the posterior border of the notch was determined as the line between the inside medial and lateral femoral condyles with a sudden slope change.

Surgical procedure

ACL reconstruction was performed on all patients by the same surgeon. A standard arthroscopic anterolateral portal and a far medial portal were used. The position of the far medial portal from where visualisation of the ACL footprint was optimal. Delineation of the anatomic landmarks of the lateral condylar ridge and bifurcate ridge was facilitated by electrothermal ablation.

The femoral point of entry was marked with a bone awl at the ACL footprint under arthroscopic guidance. With the knee in maximal hyperflexion, a guide pin was introduced into the femur, and a 4.5 mm cannulated drill bit was used to create the femoral tunnel.

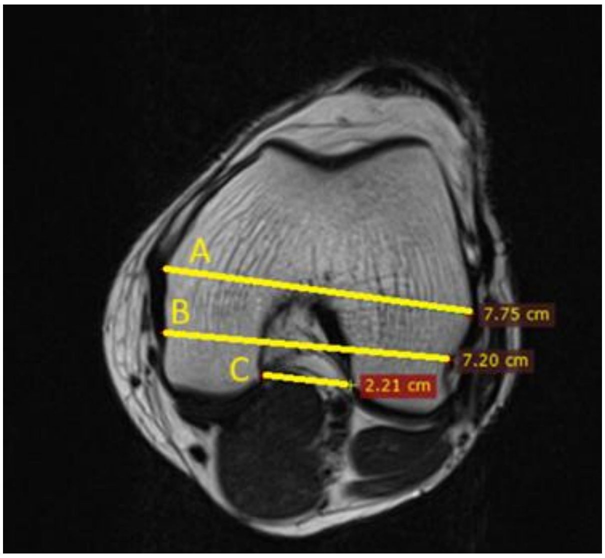

Figure 1: MRI knee T2 weighted axial slice: (A) measurement of trans-epicondylar length, (B) posterior condyle length and (C) notch outlet length.

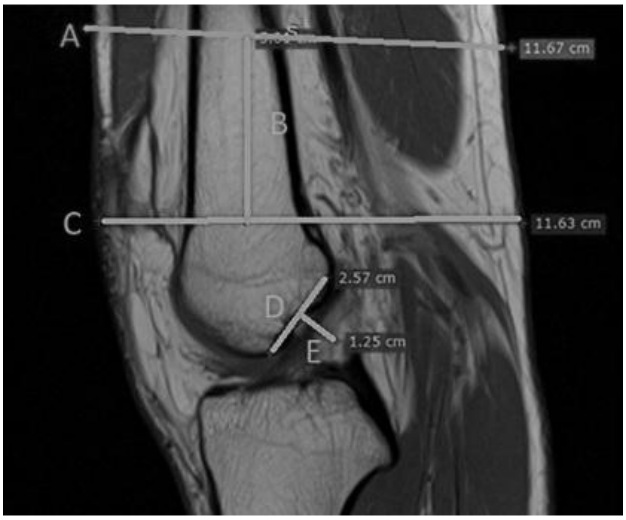

Figure 2: MRI knee T2 weighted axial slice: measurement of AP length of the knee, length of Blumensaat's line, the height of the medial wall of the lateral condyle: Line (A) AP diameter of the knee for the study line, (B) 5 cm from line A line, (C) AP diameter of the knee at the level of the superior border of the patellaline, (D) Blumensaat's lineline and (E) length of the medial surface of the lateral condyle.

The femoral tunnel length was measured with a depth gauge (Figure 3). Correlations of femoral tunnel length with anthropometry and MRI parameters were determined. P value<0.05 will be considered statistically significant.[12] The coronal and sagittal obliquity angles used by the surgeon significantly influence the femoral tunnel length (Table 1).

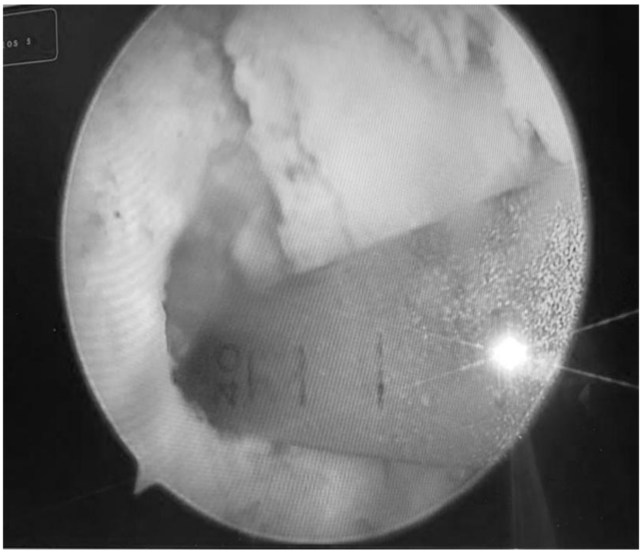

Figure 3: Intraoperative measurement of femoral tunnel length.

Table 1: Demography of the patients.

Sex of the patient	Males	Females
Total 30	28	02

Statistical analysis

The data was entered into Excel 2019 and analysed using SPSS version 26. Pearson correlation analysis assessed the relationships between intraoperative femoral tunnel length and the anthropometric and knee morphology measures. The statistical significance of the correlations was assessed using a p value threshold of 0.05.

RESULTS

All 30 patients underwent a preoperative anthropometric assessment after a knee MRI. 28 were male and 2 were female (Table 2). Participants' weight ranged from 54 kg to 94 kg, with a mean of 76.1 kg and a standard deviation of 10.6 kg. Heights varied between 1.49 m and 1.80 m, with a mean of 1.7 m and a standard deviation of 0.1 m. BMI values spanned from 18.8 kg/m² to 39.1 kg/m², with an average BMI of 26.8 kg/m² and a standard deviation of 4.4 kg/m². The mean intraoperative femoral tunnel length was 40.03±4.6 mm (range: 30-50 mm).

The correlation analysis between intraoperative femoral tunnel length and anthropometric measures reveals that the Pearson correlation coefficient is 0.797 (p value<0.001), suggesting a strong positive correlation between patient height and femoral tunnel length (Figure 4). This indicates that tall patients are associated with a longer femoral tunnel. The Pearson correlation coefficient is -0.425 (p value=0.019), showing a moderate negative correlation between BMI and femoral tunnel length (Figure 5). This suggests that higher BMI is associated with shorter femoral tunnel length.

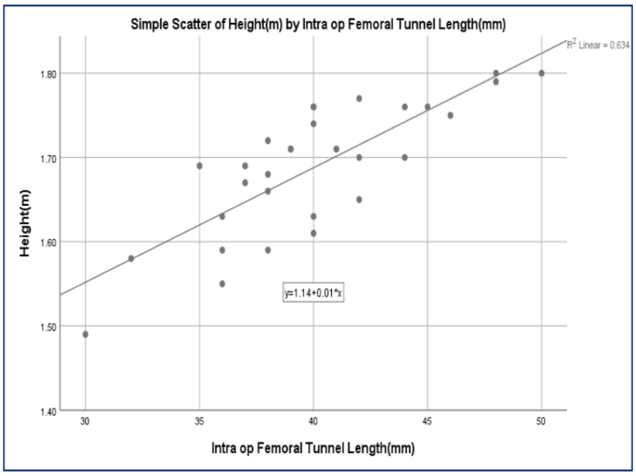

Figure 4: Scatter plot showing the correlation between height and femoral tunnel length.

The AP length of the knee (mm) shows a positive correlation with femoral tunnel length, with a correlation coefficient of 0.355 (p value=0.040). This suggests that a greater AP length of the knee is associated with a longer femoral tunnel length.

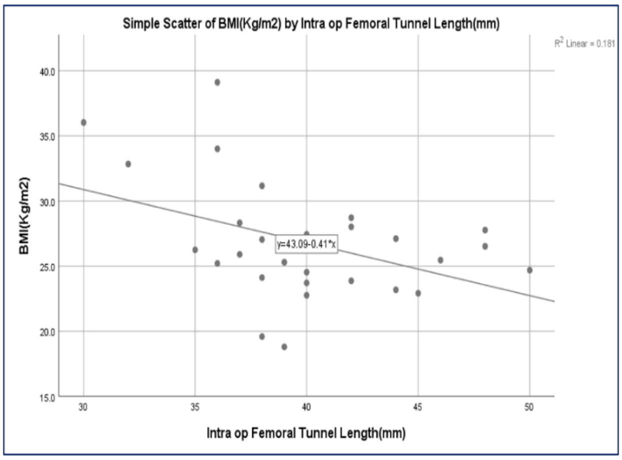

Figure 5: Scatter plot showing the correlation between BMI and femoral tunnel length.

Similarly, Trans-Epicondylar Length (mm) also demonstrates a positive correlation with femoral tunnel length, with a coefficient of 0.377 (p value=0.040) (Table 3). A larger trans-epicondylar length is associated with a longer femoral tunnel. Weight (Kg), Notch area (axial) (mm²), Notch outlet length (mm), Length of posterior condyle (mm), Notch width index (NWI) (%), Length of Blumensaat's line (mm), height of the lateral wall of the notch (mm), and area of the lateral wall of the notch (mm²) did not show significant correlations with femoral tunnel length, as their p values indicate a lack of statistical significance. These results highlight significant positive correlations with AP length and trans-epicondylar length, while other factors do not show significant associations with femoral tunnel length (Table 4).

Table 2: Shows the coronal and sagittal obliquity angles used by the surgeon.

Coronal angle	Sagittal angle	Tunnel length impact	Clinical notes
30°	45°		Safe for most anatomies
45°	45°	Comparable to TT technique	Balanced obliquity and length
60°	45°	Longer tunnel	Enhances graft fixation
60°	60°	Longest tunnel	Ideal for maximizing graft contact
30°	60°	Variable	May risk posterior cortex injury

Addressing the potential confounding among parameters. Body Height vs. AP knee length is taller individuals tend to have longer AP knee dimensions, which may influence the tunnel trajectory and graft length.

Table 3: Demography of patients.

Total patients	Males	Females
30	28	2

Table 4: Correlation of intraoperative femoral tunnel length with anthropometric measures.

Variables		Intra op femoral tunnel length (mm)
Weight (kg)	Pearson correlation	0.092
	P value	0.630
	N	30
Height (m)	Pearson correlation	0.797**
	P value	<0.001
	N	30
BMI (kg/m²)	Pearson correlation	-0.425*
	P value	0.019
	N	30

P value is determined by Pearson correlation analysis, and a p value less than 0.05 is statistically significant; a negative correlation is indicated by -, and a positive correlation is by +.

Height, weight, and knee morphology is femoral tunnel length has been shown to correlate with height, weight, and bony morphology of the knee, including the Blumensaat's line and intercondylar notch area.

Table 3: Correlation of intraoperative femoral tunnel length with knee morphology measures.

MRI Morphometric Parameters		Intra op femoral tunnel length (mm)
AP length of the knee (mm)	Pearson correlation	0.355*
	Sig. (2-tailed)	0.04
	N	30
Trans-epicondylar length (mm)	Pearson correlation	0.377*
	Sig. (2-tailed)	0.040
	N	30
Notch area (axial) mm^2	Pearson correlation	0.079
	Sig. (2-tailed)	0.680
	N	30
Notch outlet length (mm)	Pearson correlation	0.088
	Sig. (2-tailed)	0.643
	N	30
Length of posterior condyle (mm)	Pearson correlation	0.192
	Sig. (2-tailed)	0.308
	N	30
Notch width index (NWI)%	Pearson correlation	0.023
	Sig. (2-tailed)	0.902
	N	30
Length of Blumensaat's line (mm)	Pearson correlation	0.313
	Sig. (2-tailed)	0.093
	N	30
The height of the lateral wall of the notch (mm)	Pearson correlation	0.274
	Sig. (2-tailed)	0.143
	N	30
The area of the lateral wall of notch (mm^2)	Pearson correlation	0.262
	Sig. (2-tailed)	0.162
	N	30

P value is determined by Pearson correlation analysis, and a p value less than 0.05 is statistically significant; a negative correlation is indicated by -, and a positive correlation is by +.

Sex and BMI

These factors may indirectly affect graft diameter and tunnel length due to differences in soft tissue and bone structure.

DISCUSSION

The most important finding of this study was that the height, trans-epicondylar length and AP length of the knee showed a significant positive correlation with femoral tunnel length. BMI showed a negative correlation with femoral tunnel length. However, the axial parameters (NWI, notch outlet length, weight, posterior condyle length, length of Blumensaat's line and the axial notch area) and femoral tunnel placement showed no significant correlation with the length of the femoral tunnel. This suggests that the inadequacy of tunnel length can be predicted before surgery to avoid complications. Preoperative assessment of anatomical and demographic parameters such as body height, AP knee length, and femoral condyle morphology can be used to predict femoral tunnel length. This enables surgeons to anticipate and mitigate the risk of inadequate tunnel length, which may compromise graft fixation and healing. Based on current literature, a minimum femoral tunnel length of 35 mm is generally considered adequate for cortical suspensory fixation techniques, while lengths below 25 mm are associated with increased risk of posterior cortex blowout and insufficient graft incorporation.

The femoral tunnel, in particular, plays a crucial role in graft stability and overall knee function after reconstruction. Our study aimed to investigate the correlation between femoral tunnel length in anatomical single-bundle ACL reconstruction and various anthropometric and knee morphology parameters assessed through preoperative MRI. The anthropometric data in our study, with a mean weight of 76.1 kg, a mean height of 1.7 m, and a mean BMI of 26.8 kg/m², is crucial for understanding and analysing our findings. Some distinctions become evident after comparing these findings to the study conducted by Iriuchishima et al.[11] The study presents an extensive collection of knee morphology measurements, encompassing AP length, trans-epicondylar length, notch size, and several other parameters. These measurements are essential for comprehending the anatomical variances that could impact the outcomes of ACL restoration.

The positive correlation between height and femoral tunnel length aligns with findings from prior research observed in a study done by Yahagi Y et al.[13] Another study by Gupta et al, observed similar results in their Indian cohort.[14] Likewise, Iriuchishima et al, discovered a correlation in their Japanese patients. The uniformity observed among different populations enhances the argument for using the patient's height as a prognosticator of femoral tunnel length in preoperative preparation. The same study also discusses the correlation of tunnel length with a CT scan of the knee, which is not necessary for the treatment because of the financial burden for the patient.[15] We studied the correlation using preoperative MRI for the morphological parameters. In our study, the discovery of a significant inverse relationship between BMI and femoral tunnel length is an original addition to the existing body of knowledge. Prior research has not thoroughly investigated this association, which could have significant ramifications for ACL restoration in individuals with elevated BMI. A negative association means that as BMI increases, femoral tunnel length tends to decrease. This could reflect anatomical variation in patients with higher BMI, specifically, a tendency for wider pelvic or femoral structures with altered geometry affecting drilling angles. A shorter lateral condyle or thinner cortex in individuals with greater adipose tissue distribution. In surgical terms, excess soft tissue in higher-BMI patients may obscure landmarks or alter drill orientation, causing inadvertent shortening of the femoral tunnel.

It is worth noting that our study did not find any significant link between the length of the femoral tunnel and the dimensions of the notch (such as area, outlet length, and breadth index). This differs from prior research by Iriuchishima et al, which indicated the significance of notch morphology in the likelihood of ACL damage and reconstruction planning.[15] Our research indicates that although the size of the notch is significant for the overall anatomy of the ACL, it may not be a reliable indicator of the length of the femoral tunnel in particular. In our study, there is a lack of a substantial link between the length of Blumensaat's line and femoral tunnel length. This is particularly intriguing, given that this line is commonly utilised as a benchmark in ACL reconstruction. Iriuchishima et al, discovered a substantial positive correlation in their study. Our study offers insights into the connections among anthropometric measurements, knee shape, and femoral tunnel length in anatomical single-bundle ACL restoration. The link with height and the noteworthy connections with AP knee length and trans-epicondylar length provide potential prognostic indicators for preoperative strategising. Nevertheless, the absence of association with several knee morphological parameters contradicts certain prior discoveries, emphasising the necessity for additional research in this field. These findings add to the increasing knowledge base of enhancing ACL restoration techniques and results. While the study provides valuable insights into the influence of coronal and sagittal obliquity angles on femoral tunnel length in ACL reconstruction, several methodological limitations compromise the generalizability and interpretive power of its findings:

Limited sample size and demographics

The cohort (n=30) is small and predominantly male, restricting applicability across broader populations, especially given known anatomical and biomechanical differences between sexes.

Lack of MRI reliability data

The absence of intra- and inter-observer reliability statistics for MRI measurements raises concerns about reproducibility. Without these metrics, the precision and consistency of the angle and tunnel length assessments remain uncertain.

Unaddressed confounding variables

Factors such as limb alignment, graft type, surgical technique (transportal vs. outside-in), and tunnel orientation in 3D space could significantly influence outcomes and deserve further discussion.

Insufficient comparison with existing literature

The manuscript would benefit from deeper engagement with previous studies on femoral tunnel length modulation, including biomechanical implications and clinical outcomes, to better contextualize its contributions.

Limitations

The study's sample size is relatively small. This limited sample size may restrict the generalizability of the results. The majority of male participants (93.3%) restricts the generalizability of our findings to female patients. Due to its limited scope to a single institution, this study may not comprehensively represent the varied patient groups encountered in different geographical regions or healthcare settings.

CONCLUSION

There is a positive correlation between patient Height, AP length of a knee and trans-epicondylar length with femoral tunnel length. The height of the individual plays a significant role as a guide tool in the pre-operative assessment of femoral tunnel length. These metrics can potentially be valuable predictors for determining the inadequate femoral tunnel length compilation during preoperative planning for ACL reconstruction.

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Conflict of interest: None declared
Ethical approval: The study was approved by the Institutional Ethics Committee (JSS/MC/PG/IEC-141/2022-23)

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