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Research Article

Accuracy of positioning of tibial tunnel in Anterior Cruciate Ligament reconstruction using multiple intra-operative landmarks

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ABSTRACT

Background: Anterior cruciate ligament reconstruction (ACLR) aims to restore knee stability and function by accurately positioning the tibial tunnel. Previous studies have indicated variability in tibial tunnel placement, often based on data from Western populations. This study aims to evaluate the accuracy of post-operative radiographs in replicating intraoperative tibial tunnel positions based on anatomical landmarks specific to the Indian population.
Methods: This prospective observational cross-sectional study was conducted over 18 months, involving 74 patients (18-40 years old) undergoing single-bundle anatomical ACLR. The surgeries were performed by six experienced surgeons at RG Kar Medical College, Kolkata. Post-operative anteroposterior (AP) and lateral (Lat) radiographs were used to assess the coronal and sagittal positions and angles of the tibial tunnels. The positions were calculated as percentages from specific anatomical landmarks, with coronal and sagittal tunnel angles measured accordingly.
Results: The study analyzed mean values and statistical tests for tunnel positions and angles. Significant differences were observed among different anatomical landmarks. The ACL footprint and the posterior border of the anterior horn of the lateral meniscus (PBoAHoLM) were the most accurate for coronal plane tunnel positioning ($Z = 7.98$). For sagittal alignment, PBoAHoLM was the most reliable ($Z = 7.24$). The study highlighted that native footprints and specific landmarks effectively replicated tibial tunnel angles in both planes.
Conclusion: Tibial tunnel position was most accurately reproduced when surgeons used both Footprint of ACL & Posterior border of ARLM as landmarks. As a single landmark, the surgeons operating with the footprint of ACL produced the most accurate Tibial Tunnel. Shaving off the remnant footprint of ACL is not necessary to create the ideal tibial tunnel position.

Keywords: *ACL reconstruction, tibial tunnel, anatomical landmarks, radiographic assessment, knee stability, Orthopedic surgery, Indian population, intraoperative guide.*

INTRODUCTION

Current trends in Anterior cruciate ligament reconstructions (ACLRs) aim at anatomical reconstruction of the Ligament with restoration of physical & biomechanical properties. In this context, ACLRs have a low but non-negligible failure rate. The failure rate following ACLR, despite improvements, varies from 3% to 11%(1). Graft placement and tibial/femoral tunnel location largely determines the outcome of anterior cruciate ligament (ACL) reconstruction surgery(2,3). Postoperative plain radiographs offer a dependable and accurate method for evaluating the precise positioning of the graft(4,5) An audit study found that 65% of cases had femoral tunnels and 59% had tibial tunnels placed inappropriately on sagittal plane radiographic views(6). The study examined the radiographic positions of the tibial and femoral tunnels in a cohort of patients who underwent arthroscopic anatomic ACLR using anatomical landmarks(7) . Improper positioning of the bone tunnels, not in accordance with the anatomy, is a frequent cause that can result in the unsuccessful integration of the ACL graft(8). Improper positioning of the tunnels can cause abnormal tension in the graft, leading to either knee stiffness or recurring instability(9). All of these complications can be avoided by accurately assessing the placement of the guide wire during surgery using various techniques, including the use of tibial guides, fluoroscopy, and computer-assisted surgery(10,11). Precisely locating the tunnels is a formidable undertaking. This not only reduces the stretching of the graft but also prevents the risk of the graft tearing again by avoiding interference with the notch and enhancing rotational stability(12).

The definition of the optimal tunnel position has experienced significant alterations over time. The transportal technique for ACL reconstruction is based on the concept of anatomical ACL reconstruction, in contrast to the earlier transtibial technique. This idea prioritizes the replication of the original ACL's normal anatomical structure. This can be achieved by placing the ACL graft at the midpoint between the original insertion sites of the ligament(13) . To implement this principle, it is necessary to refer to different anatomical landmarks. It has been discovered that these landmarks are not uniform and may be lacking in certain individuals. Preserving the soft tissue of the torn ACL near its attachment site appears to be beneficial for maintaining post-reconstruction proprioception(14). Therefore, removing the remaining tissue to accurately identify the footprints of the original ACL is not a favorable choice(15) . However, it is difficult to determine the exact centre of the footprint within the remaining preserved remnants. Prior reports indicated substantial divergence in tunnel placement. An effective method to reduce subjectivity in guidewire placement is to utilize intraoperative fluoroscopy to verify the position of the guidewire(10,16,17). The typical radiographic positioning of the tibial tunnel, as described in the literature, primarily relies on data from the western population(3,9,15,18). There is a lack of information in the literature to adapt this concept specifically for the Indian population(3). The objective of our study was to investigate this issue and determine the intra-operative positions of osseous & soft tissue landmarks that would aid surgeons to drill their tibial tunnels with accuracy. There is uncertainty regarding the location of the tunnel exit, specifically over the tibial plateau. Several landmarks are considered to be the standard ones, such as 7.5mm Posterior & Slight Medial to The Posterior Border of Anterior Horn of lateral meniscus (PBoAHoLM) or, 7 mm anterior to the Posterior Cruciate Ligament (PCL). as well as the measurement of 2/5th of the Medio-Lateral (ML) width of the Interspinous Distance. The study is thus being performed to determine, how accurately post-operative radiograph can capture the reproducibility of marked Tibial position with reference to per-operative landmarks. Which would allow us to establish a more advanced intraoperative reference guide in order to attain more favorable clinical outcomes following ACLR.

METHODOLOGY

Study Design: Prospective Observational descriptive cross-sectional study.

Period Of Study: 18 months

Study Population: Patients who had ACL reconstruction attending Outpatient/Inpatient department of Orthopaedics, RG Kar, Kolkata

Sample Size: Sample size of 74 was included for this study.

Inclusion Criteria:

1. Patients between 18 - 40 years of age of either sex.
2. Unilateral, Isolated ACL injury.

Exclusion Criteria

1. Open injury around knee
2. Associated life threatening/ polytrauma patients
3. Associated ipsilateral lower limb fracture(s).
4. Any pre-existing knee pathology or previous knee surgery
5. Multi-ligament injuries
6. Patients undergoing double-bundle ACLR

Data Collection

All 74 cases operated by 6 experienced Surgeons of our institution, underwent Single Bundle Anatomical ACLR in Supine knee flexed, foot hanging posture using Hamstring Isograft. Intra-operative tibial elbow zig placement was documented and reference(s) used was recorded.

Figure 1: Arthroscopic View of Acufex© Tibial Drill Guide Placement

Post-Operatively Antero-posterior (AP) & Lateral(Lat) Skiagrams of operated knee was obtained. The Coronal Tunnel Position & Angle are hereafter determined using AP, while the Sagittal Tunnel Position & Angle are determined using Lat radiographs respectively.

For Tunnel Positions we did the AP assesment as per the method described by *Pietrini et al*, while the Lat assesment was done using *Amis and Jakob's* technique

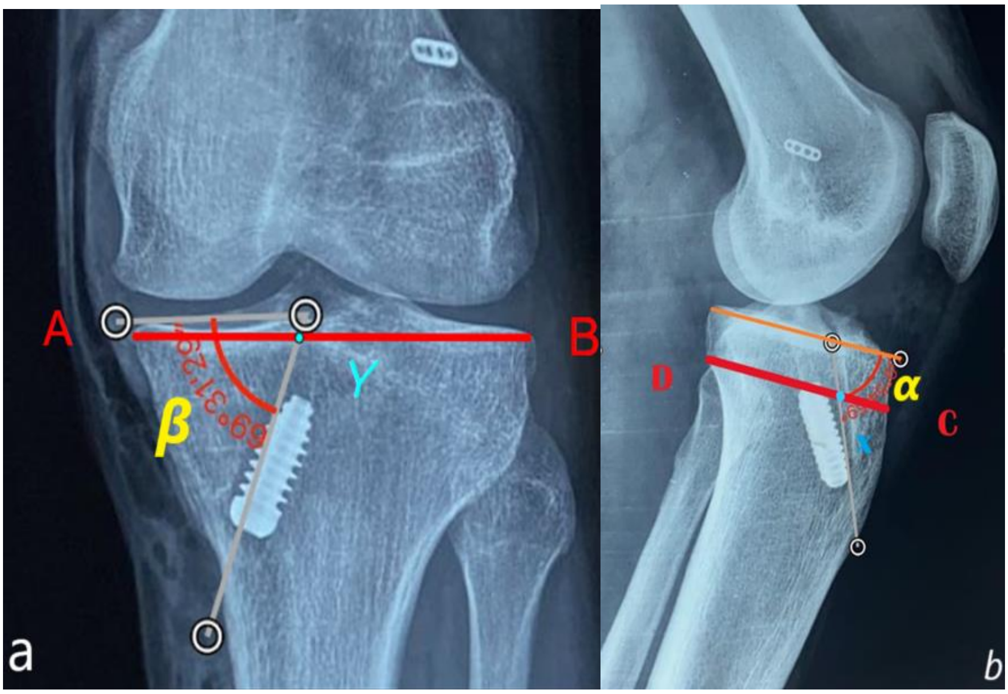

*Figure 2 (a): Showing Antero-Posterior X-Ray of knee with widest portion of Tibial Plateau (AB) and point of intersection of mid point of tunnel width in AP view with AB (X). Coronal position of Tunnel = AY/AB *100 . β representing tibial tunnel angle in coronal plane.*

*Figire 2 (b): Showing Later X-Ray of knee with widest portion of Tibial Plateau (CD) and point of intersection of mid point of tunnel width in AP view with CD (Y). Sagittal position of Tunnel = CX/CD*100 . **α** representing tibial tunnel angle in sagittal plane.*

The Tunnel Positions were calculated as percentage from anterior most & medial most points on AP & Lat Radiographs respectively, posterior most & lateral most points being 100%. The coronal tunnel angle being the angle subtended at the point of intersection of midpoint of the tunnel width on AP view with line joining the medial most point at the tibial plateau.

The sagittal tunnel angle being the angle subtended at the point of intersection of midpoint of the tunnel width on Lat view with the line joining the anterior most point over the tibial plateau

RESULTS

Values are charted onto a Microsoft-Excel spreadsheet analysed using descriptive statistics and making comparisons among various groups. Categorical data were summarized as proportions and percentages (%) and quantitative (Discrete) data were summarized as mean ± **SD.**

The following statistics were calculated in the present analysis

The Arithmetic Mean:

The most widely used measure of Central tendency is arithmetic mean, usually referred to simply as the mean, calculated as

$$\overline{x} = \frac{\sum x}{n}$$

So arithmetic mean is the sum of all the numbers in the series divided by the count of all numbers in the series

The Standard deviation (σ): It is calculated by using the formula

$$\sigma = \sqrt{\frac{\sum x^2}{n} - \left(\frac{\sum x}{n}\right)^2}$$

So the standard deviation (SD) is a measure that is used to quantify the amount of variation or dispersion of a set of data values.

Z-score : Is a statistical measure that describes how many standard deviations a specific data point is from the mean of a data set. It is used to standardize scores on the same scale, allowing comparison between different data sets.

Formula:

$$Z = \frac{(X - \mu)}{\sigma}$$

where:

- X is the value being measured,
- μ is the mean of the data set,
- σ is the standard deviation of the data set.

RESULTS

The study included 74 subjects, comprising 42 subjects in the range of 18-25 years, majority ~86% males, 39 cases (53%) had left knee injury; The frequency distribution of the references used was analyzed.

Table 1: Showing landmarks used while placing tibial zig

A	Center of ACL Footprint
B	Posterior Border of Anterior Horn of Lateral Meniscus
C	Anterior Intermeniscal Ligament
D	PCL
E	Interspinous Ridge

Reference AB was the most frequently used, with 21 subjects (28.38%), followed by DE with 23 subjects (31.08%). Reference A was used for 13 subjects (17.57%), while references AC, B, C, and D were less commonly used, each accounting for 1 to 4 subjects. Reference AE was the least utilized, with only 1 subject (1.35%).

With this as references used the overall measurement of tibial tunnel was found to be:

Table 2: Showing Mean ± SD of Tunnel position & angle in Coronal & Sagittal planes.

Statistics	Position of the tibial tunnel on coronal radiograph (%)	Angle of the tibial tunnel on coronal radiograph (°)	Position of the tibial tunnel on sagittal radiograph from anterior edge of tibia (%)	Angle of the tibial tunnel on sagittal radiograph (°)
Mean	48.3027	64.145	44.24392	65.50703
SD	6.860827	6.825087	10.57852	7.45167

The 6 surgeons operated using the following 8 combinations of landmark during tunnel placement. Their respective measurements and statistical significance is being shown in Table 2.

Table 3: 8 subgroups based on landmark(s) used by the operating surgeons and their individual Mean ± SD values for tunnel position and angle in Coronal and Sagittal views.

Mean	**Statistics**			
Reference(s) used	Position of the tibial tunnel on coronal radiograph (%)	Angle of the tibial tunnel on coronal radiograph (°)	Position of the tibial tunnel on sagittal radiograph from anterior edge of tibia(%)	Angle of the tibial tunnel on sagittal radiograph (°)
A	48.29±6.86	64.07±6.82	44.40±10.58	65.46±7.45
AB	48.22±7.54	64.27±7.50	44.21±11.26	65.61±8.13
AC	47.13±6.61	63.92±6.58	43.21±10.33	66.16±7.21
AE	46.18±5.67	62.97±5.64	42.27± 9.40	65.22±6.27
B	47.86±7.35	64.65±7.32	43.95±11.07	66.90±7.94
C	48.08±7.40	64.12±7.36	44.07±11.11	65.46±7.99
D	44.33±3.82	61.12±3.79	40.41±7.54	63.37±4.41
DE	47.31±5.88	63.09±5.84	43.42±9.60	64.48±6.47

Next Z-values of these 8 subgroups were derived

Table 4: Z-values of the tunnel positions & angles in sagittal & coronal axes according to reference(s) used (n=74)

	Coronal position of tunnel %	Sagittal position of tunnel %	Sagittal tibial angle°	Coronal angle of tunnel °
Reference(s) used	Z Value	Z Value	Z Value	Z Value
A	7.97	7.04	6.49	6.47
AB	7.98	7.03	7.12	6.45
AC	7.03	7.04	7.07	5.91
AE	7.00	6.51	6.74	5.34
B	6.53	7.24	6.49	6.18
C	6.19	6.35	6.31	6.34
D	6.84	5.71	6.74	6.27
DE	7.08	3.67	4.93	6.37

The analysis of mean values and associated statistical tests for coronal position of tunnel (%) and coronal angle of tunnel (°) revealed significant variations among the groups examined. Group AB exhibited the highest mean coronal position of tunnel at 7.98% (Z = 7.98, P < 0.001), followed closely by group A at 7.97% (Z = 7.97, P < 0.001), indicating statistically significant differences compared to other groups. Conversely, group C displayed the lowest mean coronal position at 6.19% (Z = 6.19, P < 0.001). Regarding coronal angle of tunnel (°), group A also demonstrated the highest mean at 6.47° (Z = 6.47, P < 0.001), while group AE had the lowest at 5.34° (Z = 5.34, P < 0.001).

Based on the analysis of mean values and corresponding statistical tests for sagittal position of tunnel (%) and sagittal angle of tunnel (°), significant differences were observed across the groups. The results showed that group B exhibited the highest mean sagittal position of tunnel at 7.24% (Z = 7.24, P < 0.001), followed closely by groups A (7.04%, Z = 7.04, P < 0.001), AB (7.03%, Z = 7.03, P < 0.001), and AC (7.04%, Z = 7.04, P < 0.001). In contrast, group C displayed the lowest mean sagittal position at 6.35% (Z = 6.35, P < 0.001), indicating a statistically significant variation across the groups. Similarly, for sagittal angle of tunnel (°), group AB showed the highest mean at 7.12° (Z = 7.12, P < 0.001), while group DE had the lowest at 3.67° (Z = 3.67, P < 0.001).

Table 7 shows, that the ACL footprint and the Posterior Border of Anterior Horn of Lateral Meniscus (PBoAHoLM) are the most accurate landmarks for establishing the tibial tunnel location in coronal plane (Z-score: 7.98). The footprint of ACL alone delivers approximately identical accuracy (Z-score: 7.97) to the former when situating the tunnel in coronal plane. PCL and Interspinous Ridge both locate coronal tunnels accurately (Z-score: 7.08).

The Posterior Border of Anterior Horn of Lateral Meniscus (PBoAHoLM) (Z-score: 7.24) is the best marker for sagittal tibial tunnel alignment. When utilized alone (Z-score: 7.04), with the PBoAHoLM (Z-score: 7.03), or with the Anterior Intermeniscal Ligament (AIL), the footprint of ACL yields equivalent accuracy. Interestingly, posterior landmarks like PCL and Interspinous Ridge (Z-score: 3.67) create tunnel angles inaccurately.

The native footprint and PBoAHoLM (Z-score:7.12) landmarks best mimic the tibial tunnel angle in sagittal plane. It seems to be replicated with most other landmarks. The tunnel angle may be regulated by the tibial elbow zig. Finally, the footprint of ACL (Z-score: 6.47) and the footprint of ACL and PBoAHoLM (Z-score: 6.45), most precisely recreated the coronal plane tibial tunnel angle.

The statistical assessment is summarised in [Table 5];

Table 5: Table showing accuracy of different landmarks, in single or in combination, which has/have achieved the best results with respect to the given parameters.

Parameters	Landmark(s)
Coronal positioning of tunnel	AB
Coronal tibial angle	A
Sagittal positioning of tunnel	B
Sagittal tibial angle	AB
Overall	AB>A

On comparison of different landmark(s), the combination of footprint of ACL (A) with Posterior Border of Anterior Horn of Lateral Meniscus (B) is the best landmark for tibial tunnel placement for ACL reconstruction. It is followed by the footprint of ACL (A) alone, which is also a very accurate landmark

DISCUSSION

While the surgical approach for creating an appropriate tibial tunnel has received less attention compared to the femoral side, however, subsequent investigations have highlighted the significance of the tibial tunnel location and shown its impact on the outcomes of anatomical ACL restoration(19).

Inaccuracies in the positioning of the tibial tunnel can give rise to various complications and result in negative kinematic consequences [Table 6]. Therefore, positioning the tibial tunnel accurately is essential.

Table 6: Table showing how Malpositioning of tibial tunnel can lead to various kinematic adversities

Tibial tunnel position		**Kinematic consequences**
Anterior		Tight in flexion(12,19,20) Notch-impingement during extension(12,20)
Posterior		Tight in extension(21,22) PCL impingement(23,24)
Medial		Impairs knee flexion(20,21)
Lateral		Medial condyle side-wall impingement(25–27)
Coronal	More (>75 °)	Reduced flexion, increased laxity, compress PCL(28–30)

Currently, there is a lack of standardized arthroscopic guidance for Tibial Zig Placement as it is evident in this extensive literary search [Table 7].

Table 7: Table showing results of analysis of tibial tunnel position and angle from previous studies and their corresponding years

Authors	Year	Coronal tunnel position (%), from medial	Coronal tibial angle	Sagittal tunnel position (%), from anterior	Sagittal tibial angle
Sharma et al(29)	2021	45.48± 2.55	69.46± 7.57	41.35± 7.3	
Ristić et al(31)	2018	54.58±3.64	74.90±5.40	29.7±5.62	68.03±6.20
Nema sk et al(3)	2017	44.16± 3.98	67.56± 8.9	35.17± 7.41	
Padua R et al(32)	2016		29.7±11.6	44±6	
De Melo Silva et al(33)	2015		64.81		
Avadhani et al(19)	2010			35-46	
Pinczewski et al.(21)	2008	46 ± 3		<50	
Khalfayan et al(34)	1996	43 (range 35 to 50)		26 (range 13 to 39)	
Jackson et al(22)	1994			37-47	

.

Therefore, we propose that our method of employing soft tissue and/or bony features as a reference may provide a widely accepted standard for the precise placing of tibial tunnels.

Our Study confirmed findings of Shimodaira et al, that the footprint of ACL, if preserved, serves as a reliable guide for zig placement(35). For preserving post-reconstruction proprioception, it appears to be advantageous to preserve the soft tissue of the ruptured ACL near its attachment site. Consequently, it is not recommended to remove the residual tissue to determine the surrounding bony landmarks. However, the precise location of the footprint's centre among the intact ACL stump remains difficult to ascertain. The accuracy further improves with using multiple bony & soft tissue landmarks than simply relying on any one landmark for tunnel placement.

The Posterior Border of Anterior Horn of Lateral Meniscus or the ARLM is also a reliable landmark. But only when used in conjunction with the footprint of ACL as guide. Our study agrees with the finding of Dimitriou et al **(36)** that the ARLM is a reliable intra-operative landmark. But certain safety precautions to be definitely followed while using it as a landmark. The study showed how Tunnel drilling, if done more than 2.6mm away from ARLM medial margin yields excellent outcome.

The Anterior Intermeniscal Ligament (AIL) as described by Dr. Robert LaPrade **(37)** is a variable anatomical landmark with multiple anatomical variations. Hence it is not a reliable landmark to refer to. This is also the case in our study as tunnels made with AIL as landmark were not accurate.

There has been a lot of controversies surrounding whether or not the Posterior Cruciate Ligament of the knee is a reliable landmark for Tibial Tunnel Placement. Some has referred to the Anterior Border of Footprint of PCL**(38)**, while some have referred to the Retro Eminence Ridge (RER)**(39)** found directly ahead of the former. In our opinion, the posterior portion of Tibial Plateau has a more constant surface anatomy as compared to the Anterior part, so these can be a valid reference point as far as positioning the Tibial Zig is concerned. However, there are certain pitfalls also like the broad nature of PCL attachment, abundance of soft tissues in the inter-cruciate zone hindering accurate landmark estimation, more so for the RER. Shaving off is always an option but it also has the added risk of injuring the PCL. Hence in our opinion, PCL is to be reserved as a landmark in cases it is properly visualised or non-visualisation of the more Anterior Landmarks and only for the AP placement of the zig while the ML estimation in these cases can be done using the Interspinous ridge**.**

CONCLUSION

Tibial tunnel position was most accurately reproduced when surgeons used both Footprint of ACL & Posterior border of ARLM as landmarks. As a single landmark, the surgeons operating with the footprint of ACL produced the most accurate Tibial Tunnel. Shaving off the remnant footprint of ACL is not necessary to create the ideal tibial tunnel position.

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