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3D CT evaluation of femoral and tibial tunnels in anatomic double bundle anterior cruciate ligament reconstruction

Shekhar Tank [a], Saurabh Dutt [b,*], Rakesh Sehrawat [b], Vinod Kumar [b], Dhananjaya Sabat [b]

[a] *SGT Medical College and Research Institute, Gurgaon, Haryana, India*
[b] *Maulana Azad Medical College and Lok Nayak Hospital, New Delhi, India*

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A B S T R A C T

Background: An anatomical double bundle ACL reconstruction replicates the anatomy of native ACL as the tunnels are made to simulate the anatomy of ACL with AM and PL bundle foot prints. The goal of anatomic ACL reconstruction is to tailor the procedure to each patient's anatomic, biomechanical and functional demands to provide the best possible outcome. The shift from single bundle to double bundle technique and also from transtibial to transportal method has been to provide near anatomic tunnel positions.
Purpose: To determine the position of femoral and tibial tunnels prepared by double bundle ACL reconstruction using three dimensional Computed tomography.
Study design: A prospective case series involving forty patients with ACL tear who underwent transportal double bundle ACL reconstruction.
Method: Computed tomography scans were performed on forty knees that had undergone double bundle anterior cruciate ligament reconstruction. Three-dimensional computed tomography reconstruction models of the knee joint were prepared and aligned into an anatomical coordinate axis system for femur and tibia respectively. Tibial tunnel centres were measured in the anterior-to-posterior and medial-to-lateral directions on the top view of tibial plateau and femoral tunnel centres were measured in posterior to anterior and proximal-to-distal directions with anatomic coordinate axis method. These measurements were compared with published reference data.
Results: Analysing the Femoral tunnel, the mean posterior-to-anterior distances for anteromedial and posterolateral tunnel centre position were 46.8% ± 7.4% and 34.5% ± 5.0% of the posterior-to-anterior height of the medial wall and the mean proximal-to-distal distances for the anteromedial and posterolateral tunnel centre position were 24.1% ± 7.1% and 61.6% ± 4.8%. On the tibial side, the mean anterior-to-posterior distances for the anteromedial and posterolateral tunnel centre position were 28.8% ± 4.3% and 46.2% ± 3.6% of the anterior-to posterior depth of the tibia measured from the anterior border and the mean medial-to-lateral distances for the anteromedial and posterolateral tunnel centre position were 46.5% ± 2.9% and 50.6% ± 2.8% of the medial-to-lateral width of the tibia measured from the medial border. There is high Inter-observer and Intra-observer reliability (Intra-class correlation coefficient).
Discussion and conclusion: Femoral AM tunnel was positioned significantly anterior and nearly proximal whereas the femoral PL tunnel was positioned significantly anterior and nearly distal with respect to the anatomic site. Location of tibial AM tunnel was nearly posterior and nearly medial whereas the location of tibial PL tunnel was very similar to the anatomic site Evaluation of location of tunnels through the anatomic co-ordinate axes method on 3D CT models is a reliable and reproducible method. This method would help the surgeons to aim for anatomic placement of the tunnels. It also shows that there is scope for improvement of femoral tunnel in double bundle ACL reconstruction through transportal technique.

1. Introduction

The anatomic insertion of the anteromedial and posterolateral bundles of ACL is now well-defined. The philosophy of ACL

* Corresponding author.
E-mail addresses: saurabhdutt22@yahoo.com (S. Tank), Shekhartank83@gmail.com (S. Dutt), drrsehrawat@gmail.com (R. Sehrawat), drkumarvinod@rediffmail.com (V. Kumar), drdsabat@rediffmail.com (D. Sabat).

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reconstruction has been reformulated to emphasize the requirement to reproduce as much of the anatomic native insertion as possible, thereby restoring anatomy.[1–3] Biomechanical analysis of anatomic ACL reconstruction suggested that an anatomical ACL reconstruction may produce a better biomechanical outcome, especially during rotatory loads.[4] In the field of ACL reconstruction, any double bundle reconstruction is not anatomical, an anatomical reconstruction replicates the anatomy of native ACL as the tunnels are made exactly at the AM and PL bundle foot prints, it is a technically demanding procedure which requires expertise as well as experience.[1] Tunnel position influences knee stability and post-operative clinical outcomes. Tunnel malpositioning is a common cause of recurrent instability after ACL reconstruction.[3] 3D CT scan have been used to evaluate the tunnels location after ACL reconstruction, as they can provide excellent perspective of the tunnel aperture, good visualization of bony structure and shape of the intercondylar notch, that preclude the use of a conventional 2-dimensional CT scan for measurement of the ACL tunnels location.

The purpose of our study was to evaluate the location of femoral and tibial tunnels in anatomic double bundle ACL reconstruction by 3-Dimensional computed tomography models using co-ordinate axis method as described in literature[5] This method describes the tunnel position relative to entire medial wall of the lateral femoral condyle, including areas both within and outside the anatomic ACL insertion area.[5,6,14] These tunnel positions were then compared with reference data of established anatomic double-bundle (anteromedial and posterolateral) tunnel positions and previous similar studies.[5,7–9] Since we used aimer devices for creation of the tunnel, our study also determines how useful are such devices for creation of anatomic tunnels.

2. Materials and methods

Computed tomography scans were performed on forty knees in forty patients (all male), with a mean age [and standard deviation] of 26.40 ± 8.54 years; range, 21–42 years) who underwent an arthroscopic transportal double-bundle anterior cruciate ligament reconstruction using ipsilateral Semitendinosis and gracilis autograft with time interval being 6 months from the date of surgery. Exclusion criteria included multi ligamentous injuries and previous knee surgeries. Female patients operated for ACL reconstruction during the tenure of study were excluded from the study as their femoral footprint and condylar area was found to be smaller in order to accommodate two tunnels for double bundle reconstruction. The surgical procedures were performed by two surgeons between 2013 and 2017. Senior surgeon had experience of more than 15 years in knee arthroscopy and had done more than 50 double bundle ACL reconstruction prior to this study. Position for AM and PL tunnel was determined intra operatively using anatomical references of Resident's ridge and bifurcate ridge. The femoral tunnels were drilled with the help of aimer (Smith & Nephew offset Endofemoral Aimer & Guide) while keeping the knee in 120° of flexion with AM tunnel drilled first followed by PL tunnel. On the tibial side, PL tunnel was drilled first followed by the AM tunnel with the knee in 90° of flexion. Computed tomography scans (without intravenous contrast) of the operated knee were performed six months after the surgery. CT Scan were done using Standard algorithm and protocol. All the patients wore lead shields during the CT scan to minimise the radiation exposure. Institutional review board approved the research work.

Tunnel measurements with use of three-dimensional computed tomography were performed as already described and established.[5,14–16] Femoral measurements were made in posterior to anterior and proximal to distal direction. Tibial measurements were made in medial to lateral and anterior to posterior direction. All measurements were expressed in the percentage of the maximum dimension. Position of the tunnel was determined with mean and the standard deviation. The data obtained was compared with the available literature that involved measurements through coordinate axes method as shown in Figs. 1 and 2.

Clinical evaluation included Lysholm score, IKDC score and KT-1000 arthrometer.

Tunnel position was determined using independent *t*-test with significance level set at $p < 0.05$ to facilitate the tunnels comparison.

Two observers were utilized to assess Inter-observer and intra-observer reliability. The observers included a radiologist who had extensive experience in musculoskeletal imaging and 3D CT analysis and an orthopaedic surgeon who was not part of the operating team.

Intra class correlation coefficient was determined to determine inter observer and intra observer reliability of the co-ordinate axes method.

3. Results

3.1. Femoral tunnel positions

The mean posterior-to-anterior distances for anteromedial (AM) and posterolateral (PL) tunnel centre position were 36.8% ± 7.4% (B/C) and 30.5% ± 5.0% (A/C), respectively, of the posterior-to-anterior height of the medial wall of the lateral femoral condyle measured from the posterior border (From F1 to F2 in Fig. 1). The mean proximal-to-distal distances for the anteromedial and posterolateral tunnel centre position were 24.1% ± 7.1% (a/c) and 61.6% ± 4.8% (b/c), respectively, of the proximal-to-distal depth of the medial wall of the lateral condyle measured from the proximal border (From F3 to F4 in Fig. 1).

3.2. Tibial tunnel positions

The mean anterior-to-posterior distances for the anteromedial and posterolateral tunnel centre position were 28.8% ± 4.3% (A/C) and 46.2% ± 3.6% (B/C), respectively, of the anterior-to posterior depth of the tibia measured from the anterior border (From T1 to T2 in Fig. 2). The mean medial-to-lateral distances for the anteromedial

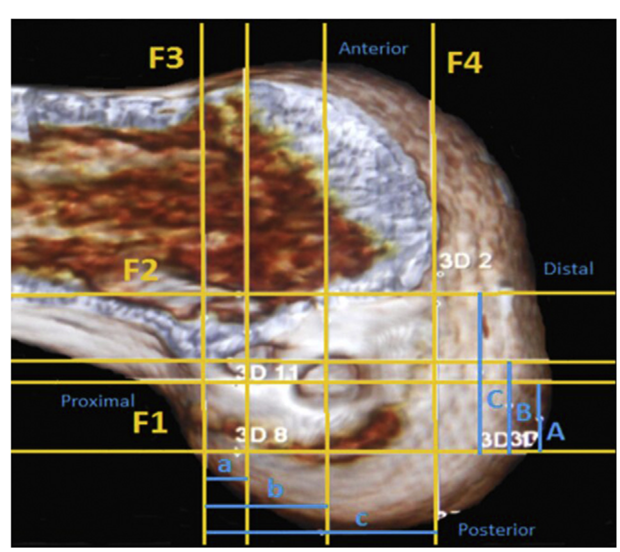

Fig. 1. Direct view of medial wall of lateral femoral condyle revealing anteromedial and posteromedial tunnels. Lines F1-4 as described in the text.

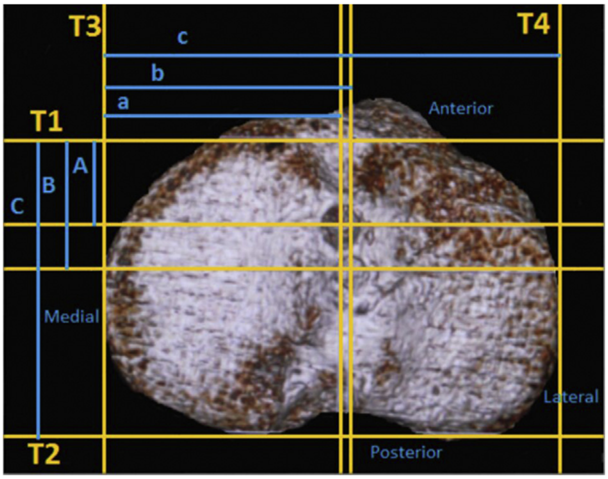

Fig. 2. Top axial view of proximal tibia revealing anteromedial and posterolateral view. Lines L1-4 as described in text.

and posterolateral tunnel centre position were 46.5% ± 2.9% (a/c) and 50.6% ± 2.8% (b/c), respectively, of the medial-to-lateral width of the tibia measured from the medial border (From T3 to T4 in Fig. 2).

Tunnel positions as determined by the co-ordinate axes method is summarized in Table 1 and 2.

Reliability estimates for the co-ordinate axes method are presented in table no.3 (see Table 3).

Excellent Inter-observer and Intra-observer reliability (Intraclass correlation coefficient range from 0.844 to 0.995) was observed for determining the location of the tunnels (Table 3).

3.3. Clinical results

The clinical results are as shown in Table 4. The post operative Lysholm score was 93.9 ± 3.95 points and it differed significantly from the pre operative score of 60.4 ± 3.73 (p value < 0.001). The lachmann test was negative in 37 out of 40 operated patients with 3 patients showing grade 1 positive status in the post operative follow up. Pivot shift test was positive in 36 patients and 4 patients had positive pivot shift in the follow up. KT-1000 examination (at 25° flexion and 30 lb) showed that the mean side-to-side difference in anterior knee laxity was 1.3 mm. The side-to-side difference was less than 3 mm in 37 (92.5%) patients. It was 3–5 mm of difference in 3 (7.5%) patients. The IKDC score improved significantly in the post operative follow up when compared to pre operative score (p value < 0.001). No patient had postoperative infection or re rupture in the follow up. Final post operative evaluation was done 1 year after the ACL reconstruction.

4. Discussion

Recent ACL reconstruction techniques attempt to replicate the anatomy of the native ACL, so the importance of anatomic double bundle reconstruction is stressed.[1,5,9,10] There is emphasis on anatomic ACL reconstruction that mimics the natural two bundle anatomy of the ACL. Double bundle reconstruction has shown improved rotational stability and improved anterior laxity.[12] This is shown to led to better kinematics of the knee.[13] Knowledge of the ACL attachment areas and their positions relative to reproducible landmarks is a prerequisite for accurate tunnel placement.[10,11] This study was undertaken to evaluate the femoral tunnel position in anatomic double bundle reconstruction.

Tunnel location has traditionally been determined from plain radiographs, which provide a two-dimensional projection of the three-dimensional bone geometry. Accurate measurements from two dimensional radiograph are dependent on alignment of the bone with the imaging plane, which may be difficult to achieve reliably and can introduce errors in estimated tunnels position. Furthermore, potentially important osseous landmarks, such as the lateral intercondylar ridge or bifurcate ridge, are not visible on conventional radiograph.[8] CT scan provides good visualization of shape of the intercondylar notch, bony structure and osseous landmark and provide direct graft or native ACL observation without artefacts. 3D reconstruction allows accurate tunnel visualization, quantification of distances and diameters.[11,15]

This study shows that even with the anteromedial portal technique, the femoral tunnel can be erroneously made more anteriorly than the anatomical footprint. The femoral tunnels in our study were significantly anterior when compared to reference data from the cadaveric study on double bundle ACL reconstruction.[5] AM tunnel was drilled first using the offset aimer device to have a distance of 2–3 mm from the posterior wall. PL tunnel was drilled after the AM tunnel and was not independent of it. This is in contrast to the previous work by Basdekis et al. where similar aimer devices were used for tunnel creation and anatomical positions were obtained.[11] This discrepancy can be due to the difference in method of tunnel position determination as they determined the tunnel location using 'Footprint angle' method and we used the co ordinate axes method. This adds to the strength of our study and challenges the notion that using aimer devices always lead to anatomical tunnel position. The constraint in using anteromedial portal for tunnel preparation could also lead to this anterior placement of femoral tunnel. An accessory anteromedial portal might lead to a more anatomical tunnel preparation.[4] Free hand drilling of the tunnel without using the aimer device can result in tunnel being more anatomically placed.[15]

Comparing the tibial tunnels, position of tibial AM and PL tunnel were similar to the reference data without significant difference.

Lee YS et al. had also conducted a similar study and used anatomic co-ordinate method to evaluate the femoral and tibial tunnel location.[8] On comparison, findings of this study were very similar to our study. In posterior to anterior direction, position of femoral AM and PL tunnel were significantly anterior to reference data but comparatively posterior to our study (insignificant). In proximal to distal direction position of femoral AM and PL tunnels were similar to our study. Tibial AM and PL tunnels location were similar without significant difference to our study and reference data from the cadaveric work by Forsythe et al.[5] This validates our method of tunnel position evaluation.

Table 1
Measurement of Femoral tunnels with co ordinate axes method and comparison with previous studies.

Mean ± S.D. (Range)	A/C	B/C	a/c	b/c
Our Study	30.5 ± 5.0% (p < 0.05)	36.8 ± 7.4% (p < 0.05)	24.1 ± 7.1%	61.6 ± 4.8%
Forsythe B et al.[5] (Reference)	15.3 ± 4.8%	23.1 ± 6.1%	28.2 ± 5.4%	58.1 ± 7.1%
Lee YS et al.[8]	27.1% (15–33) (p < 0.001)	28.5% (17–36) (p < 0.001)	26.6% (19–35)	62.9% (47–73)

All values are expressed in percentages of the corresponding maximum dimension in the particular direction.

Table 2
Measurement of tibial tunnels with co ordinate axes method and comparison with previous studies.

Mean ± S.D. (Range)	A/C	B/C	a/c	b/c
Our study	28.8 ± 4.3%	46.2 ± 3.6%	46.5 ± 2.9%	50.6 ± 2.8%
Forsyth B et al.[5] (Reference)	25.0 ± 2.8%	46.4 ± 3.7%	50.5 ± 4.2%	52.4 ± 2.5%
Lee YS et al.[8]	25.7% (21–28)	44.7% (39–53)	50.4% (45–54)	51.4% (45–54)

All values are expressed in percentages of the corresponding maximum dimension in the particular direction.

Table 3
Inter-observer and intra-observer reliability for anatomic Co-Ordinate axis method.

INTRACLASS CORRELATION COEFFICIENT					
INTRAOBSERVER FEMUR	A/C	0.960	INTEROBSERVER FEMUR	A/C	0.966
	B/C	0.917		B/C	0.917
	a/c	0.969		a/c	0.961
	b/c	0.844		b/c	0.861
INTRAOBSERVER TIBIA	A/C	0.982	INTEROBSERVER TIBIA	A/C	0.983
	B/C	0.994		B/C	0.983
	a/c	0.992		a/c	0.989
	b/c	0.995		b/c	0.984

Table 4
Clinical results.

	PRE SURGERY	AT FINAL FOLLOW UP	P VALUE
LYSHOLM SCORE (95% Confidence Interval Value)	60.4 ± 3.73 (53.1, 67.7)	93.9 ± 3.95 (86.2, 101.6)	<0.001
LACHMANN TEST (n = 40)	40	37	<0.001
NEGATIVE		3	
POSITIVE			
PIVOT SHIFT TEST (n = 40)	40	37	<0.001
NEGATIVE		3	
POSITIVE			
IKDC SCORE (95% Confidence Interval Value)	43.64 ± 2.67 (38.4, 48.9)	93.93 ± 2.78 (88.5, 99.4)	<0.001
SIDE TO SIDE DIFFERENCE WITH KT-1000 ARTHROMETER (95% Confidence Interval Value)	3.7 ± 1.5 (0.7, 6.6)	1.3 ± 0.8 (−0.27, 2.9)	<0.001

Data are given as means ± standard deviations.
IKDC - International Knee Documentation Committee.

CT and 3D reconstruction with subtraction imaging provides an unparalleled radiological view similar to the one achieved arthroscopically. The anatomic landmarks used for CT evaluation can be observed during arthroscopic evaluation of the knee and guide the surgeon in creating near anatomical tunnel position. Landmarks like blumensaat's line give only one dimensional picture of the three dimensional tunnel thus making it difficult to determine the exact tunnel location using them as reference. Computed tomography with 3D reconstruction determines three dimensional aspect of the tunnel and hence is a reliable and reproducible tool to determine tunnel positions post operatively.

4.1. Limitations

There are certain limitations of this study. First limitation of this study was that the CT scans of the knee were not performed in the immediate post operative period but after an interval of 6 months. During this time, the tunnel could have widened and the aperture could have migrated from the original position.

Second limitation was the less number of patients enrolled in the study. Another limitation of our study is that all the patients were male. Female patients had smaller condylar area rendering them unsuitable for double bundle ACL reconstruction. Finally, the absence of the control group is a limitation. A comparison with double bundle ACL reconstruction using another graft or different technique of drilling the tunnels would increase the power of this study.

5. Conclusion

In our study we found that tunnels through AM portal were significantly anterior to the anatomical footprint than expected. Even with AM portal and aimer devices, there are chances of non-anatomical placement of tunnels, more so of PL tunnels, so there is need to further evolve the techniques of footprint visualization and tunnel placement. Free hand drilling can be opted for instead of regular aiming devices to create the tunnel. The radiological evaluation done on CT-Scan with 3D reconstruction images, using co-ordinate axis method for tunnels position is a reliable and effective method and could be used for future reference.

Ethical approval

All procedures performed in studies involving human participants were in accordance with the ethical standards of the institution and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards.

6. Informed consent

Informed consent was obtained from all individual participants included in the study.

CRediT authorship contribution statement

Saurabh Dutt: Writing - original draft, preparation, Visuali. **Shekhar Tank:** Data curation, Project administration. **Rakesh Sehrawat:** Formal analysis. **Vinod Kumar:** Conceptualization, Methodology, Investigation. **Dhananjaya Sabat:** Writing - review & editing.

Declaration of competing interest

All the authors declare that they have no conflict of interest.

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