Journal of Clinical Orthopaedics and Trauma 10 (2019) 586–592

Contents lists available at ScienceDirect

Journal of Clinical Orthopaedics and Trauma

journal homepage: www.elsevier.com/locate/jcot

Radiological evaluation of tunnel position in single bundle anterior cruciate ligament reconstruction in the Indian population and their clinical correlation

Anindya Debnath [a, *, 1], Rajeev Raman [a], Paras Kumar Banka [a], Sanjay Kumar [a], Hirak Debnath [b]

[a] Department of Orthopaedics, Medical College and Hospitals, Kolkata, West Bengal, India
[b] Agartala Govt. Medical College, Agartala, Tripura, India

ARTICLE INFO

Article history:
Received 28 May 2018
Received in revised form
28 September 2018
Accepted 11 October 2018
Available online 12 October 2018

Keywords:
ACL reconstruction
Radiological assessment
Tunnel position
Clinical outcome
Single bundle

ABSTRACT

Background: Proper positioning of osseous tunnels during single bundle arthroscopic ACL reconstruction, which gives reproducibly good clinical outcome, is a matter of concern. Little evidence is there correlating tunnel position in arthroscopic ACL reconstruction with their clinical outcome in Indian population. Our aim in this study was to examine if the radiological tunnel-positions were significantly associated to the clinical outcomes.

Methods: ACL reconstruction was performed in 147 young patients with an isolated ACL tear. They were followed up prospectively for the next two years. Clinical assessment of each patient was done using the International Knee Documentation Committee (IKDC) evaluation form before surgery and at two years later the surgery. At the same time, the radiological assessment was done on standard digital radiographs.

Results: Considering the anterior and posterior-most points on the Blumensaat's line as 0% and 100% respectively the average position of the femoral tunnel was at 84.8%. Similarly, the tibial tunnel was at 46.8% along the tibial plateau. On the coronal plane the average position of the tibial tunnel was at 45.6% point along the tibial plateau (measured from the medial-most point towards laterally). The mean position of the femoral tunnel in the coronal plane was at 43.2% along the broadest part of the distal femur (measured from the lateral extent). The average inclination angle of the graft measured 19.6° (along the coronal plane).

Conclusion: Ideal clinical outcome was significantly associated with the placement of the femoral tunnel along the sagittal plane. Placement of the femoral tunnel should not be beyond the 85% mark along the Blumensaat's line from the anterior-most point. No correlation was established between clinical results and any of the remaining radiological parameters described above.

1. Introduction

In order to achieve a successful anterior cruciate ligament (ACL) reconstruction, optimum placement of the graft is crucial.[1–3] Non-anatomical placement of the bone tunnels is a very common cause that can lead to the failure of the ACL graft.[4] Malpositioning of the tunnels can give rise to abnormal tension in the graft, and thereby either stiffness of the knee, or recurrent instability.[5–7] These are all preventable by correctly judging guide wire placement intra-operatively by several techniques such as the use of femoral guides, fluoroscopy, and computer-assisted surgery.[8–10]

Accurate placement of the tunnels is a challenging task. This not only minimizes the graft stretching but also averts the risk of re-rupture by avoiding notch impingement and improves rotational control.[2,11]

The definition of the ideal tunnel position has observed major changes from time to time. In contrast to the earlier transtibial technique of ACL reconstruction, the newer transportal technique has its foundation in the concept of anatomical ACL reconstruction.

* Corresponding author.
E-mail address: adn.ortho@gmail.com (A. Debnath).
[1] Permanent Address: Netaji Road (Thana Road), Dharmanagar, Tripura, India. PIN: 799250.

https://doi.org/10.1016/j.jcot.2018.10.003
0976-5662/

This novel concept emphasizes on reproducing the normal anatomy of the original ACL. This is achieved by placing the ACL graft at the center of the insertion sites of the original ligament.[4] In order to implement this principle one has to take reference of various anatomical landmarks. It has been found that these landmarks are not consistent and may be absent in some individuals.[12,13] Retaining the soft tissue of the torn ACL near its attachment site apparently helps to maintain post-reconstruction proprioception; hence clearing the remnants to accurately identify the footprints of the original ACL is not a favorable option.[14] On the contrary, locating the center of the footprint within those preserved remnants becomes a challenging task. Earlier reports showed significant variation in tunnel positioning.[15] One way of making guidewire placement less subjective is by using intraoperative fluoroscopy to cross-check the guidewire's position.[16,17] The standard radiographic position of tunnels described in the literature is mostly based on western population.[2,6,11,18,19] To customize this concept to the Indian population there is insufficient information available in the literature.[20]

The purpose of our study was to address this problem and find out what radiological positions of osseous tunnels are consistent with the optimum clinical outcome. Probably, this would also enable us to set a superior intraoperative reference guide to achieve more favorable clinical results after arthroscopic ACL reconstruction.

2. Material and methods

2.1. Study design and ethical clearance

It was an institution based prospective study. Ethical approval was granted by the Institutional Ethics Committee.

2.2. Selection of study population

This study was conducted on adult patients who underwent arthroscopic anterior cruciate ligament reconstruction between August 2013 and September 2015 at Medical College and Hospital, Kolkata. The criteria followed, have been mentioned below.

Inclusion criteria:

a. Patients aged between 18 and 40 years.
b. Clinically and radiologically diagnosed with isolated anterior cruciate ligament injury.
c. Affirms history of instability of knee.

Exclusion criteria:

a. Patients whose age fell out of this range.
b. Patients with generalized ligament laxity.
c. Associated meniscal injury or, osteochondral defects.
d. Patients with history of previous meniscal surgery.
e. Multidirectional instability
f. Patients undergoing revision ACL reconstruction.
g. Patients not willing to participate.

A written and informed consent was must for participation in the study. A total of 173 randomly selected patients fulfilled above criteria and were taken into the study. All of them were evaluated both clinically and radiologically. By the end of two years 19 patients were lost to follow up and consequently excluded from the study. Seven patients with inadequate quality radiographs denied to repeat radiological examination. They were also excluded from the study. Remaining 147 patients represent the final study population. There were 91 male (62%) and 56 (38%) female patients. The average age of the patients was 26.4 year (range: 18–36 year, SD 4.4).

2.3. Surgical procedure

All these patients underwent arthroscopic anatomical single-bundle anterior cruciate ligament reconstruction using four-strand hamstring tendon autografts at the aforementioned institute. Grafts were fixed rigidly with interference screws (PROFILE™ Interference Titanium Screw of DePuy Mitek, Inc., Raynham, USA) at both femoral and tibial attachment sites.

2.4. Post-operative rehabilitation program

Postoperatively, long knee extension brace was applied in 5° of knee flexion before shifting the patient out of the operation theater. Isometric muscle strengthening exercises were started as soon as the patient was out of the anesthetic effect. From next day onward weight-bearing was allowed as tolerated with crutches. Active range of motion exercises was started with a gradual increase in the range to achieve the target of 0°-90° flexion by 4 weeks and full pre-operative range by the 6 weeks. Brace was discontinued after 4 weeks. Jogging along a straight line, swimming was started at 3 months. Squatting and competitive sports were delayed till 6 months.

2.5. Radiological assessment

Standing anteroposterior (AP), posteroanterior (PA) in 30° flexion, lateral radiographs of the knee were obtained before the operation and at two years after the surgery. Radiographs of poor exposure or incorrect positioning were rejected and proper images were retaken in such circumstances. All images were collected in DICOM format and linear and angular measurements were done using SE Media Viewer Software (AGFA, version 4.0.0.0). The position of the tunnels was assessed in the DICOM images as per the technique laid by Princzewski et al.[11] In this study this was independently done by an orthopedic resident (Author- HD). The technique is described below.

2.5.1. Posterior femoral tunnel

Lateral view radiograph was used for measuring this parameter. The most anterior point on the Blumensaat's line was arbitrarily taken as 0%. Similarly, the posterior-most point as considered as 100%. The midpoint of the femoral tunnel was located and the position was measured in terms of percentage in the above mentioned scale Fig. 1.

2.5.2. Anterior tibial tunnel

Measurements were done on lateral view radiographs. Along the tibial plateau, the anterior and posterior ends were arbitrarily taken as 0% and 100% respectively. The midpoint of the tibial tunnel was measured along that line in percentage Fig. 1.

2.5.3. Medial tibial tunnel

Anteroposterior radiographs are used for this measurement. The location of the tibial tunnel was marked in the coronal plane along the tibial plateau and measured as percentage from the medial end Fig. 2.

2.5.4. Lateral femoral tunnel

Anteroposterior radiographs were found suitable for the assessment of this parameter. In this, the position of the femoral tunnel was marked in the coronal plane. Distance from lateral femoral condyle was measured in percentage along the widest imaginary line on the distal femur Fig. 2.

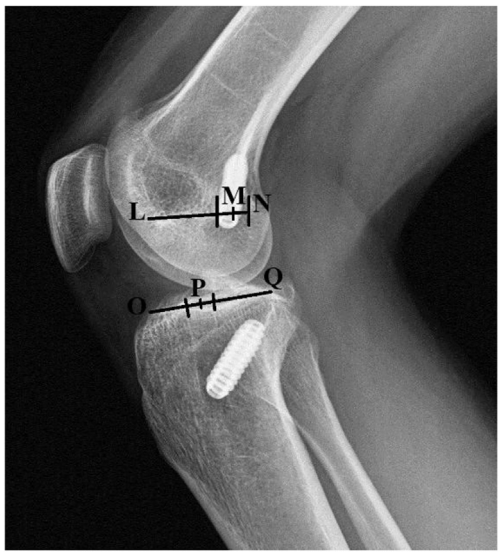

Fig. 1. Posterior Femoral Tunnel (PFT) and Anterior Tibial Tunnel (ATT) both are measured in the lateral view radiograph. PFT (in %) = (LM/LN) × 100, ATT (in %) = (OP/OQ) × 100.

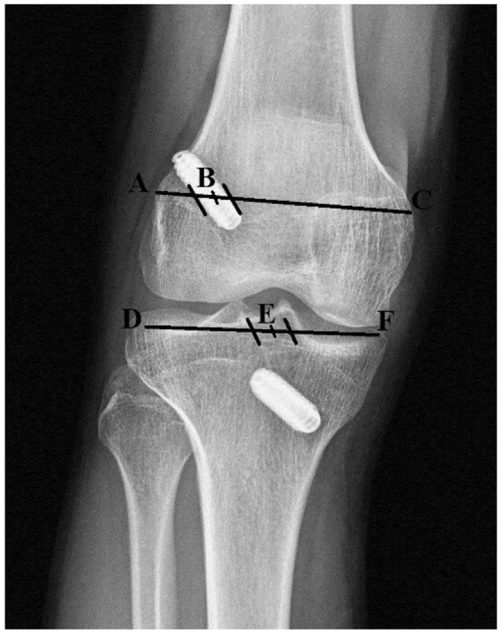

Fig. 2. Medial Tibial Tunnel (MTT) and Lateral Femoral Tunnel (LFT) both are measured in the anteroposterior radiograph. MTT (in %) = (EF/DF) × 100, LFT (in %) = (AB/AC) × 100.

2.5.5. Graft inclination

This was measured in PA radiograph taken in 30° flexion of the knee joint. Medial walls of the tibial and femoral tunnels were joined and the angle formed by this line with the perpendicular drawn on the tibial plateau was measured. This was taken as the angle. Fig. 3.

2.6. Clinical assessment

There were minimum two clinical assessments for each patient, using the International Knee Documentation Committee (IKDC) evaluation form. First assessment was done before the surgery, and the other assessment two years after the surgery. "Ideal outcome" was defined as fulfilling the following four criteria:

a. Subjective knee function: Normal (or almost normal);
b. Range of movement: IKDC Grade A (which means < 3° loss of extension and <5° loss of flexion);
c. Laxity: IKDC Grade A (referring to grade 0 pivot and laxity < 3 mm)
d. Radiology: No radiological evidence suggesting degenerative changes.

Those individuals failing to achieve so were labeled as having "not-ideal outcome".[11]

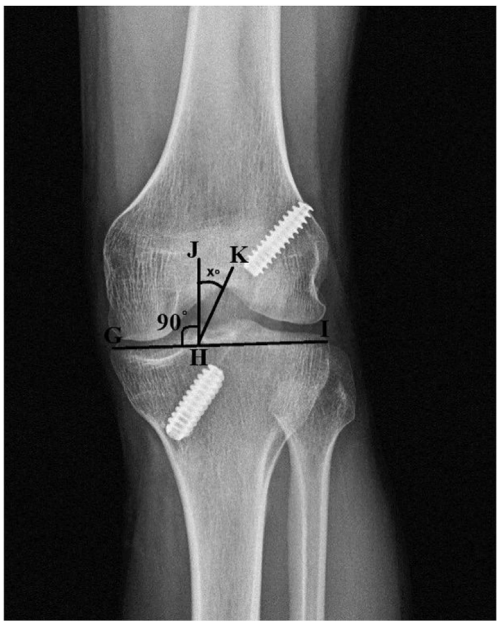

Fig. 3. Graft inclination angle is measured on the posteroanterior view taken at 30° flexion. Here, GI represents the tibial plateau. HK joins the medial walls of tibial and femoral tunnels. JH is the line perpendicular to GI. The angle JHK is the graft inclination angle.

2.7. Analysis

Various radiological parameters of osseous tunnel position in both the groups were analyzed by applying the Mann Whitney *U* test. A p-value <0.05 was considered to be statistically significant.

3. Results

3.1. Posterior femoral tunnel

The midpoint of the femoral tunnel was located at a mean of 84.8% [standard deviation (SD) 2.9] posteriorly along Blumensaat's line. The distribution of the individual values is depicted in the scatter diagram below Fig. 4.

3.2. Anterior tibial tunnel

Position of the tibial tunnel was measured at a mean of 46.8% (SD 1.9) with their distribution as shown below Fig. 5.

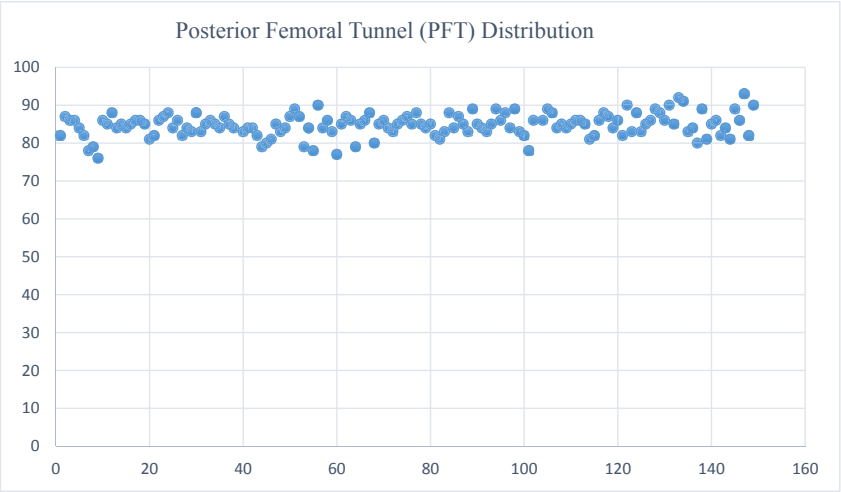

Fig. 4. Posterior femoral Tunnel(PFT) distribution.

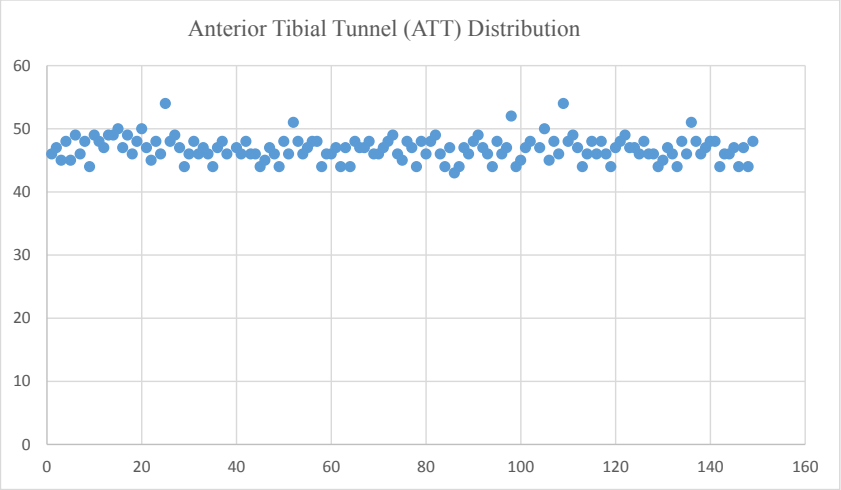

Fig. 5. Anterior tibial Tunnel(ATT) distribution.

3.3. Medial tibial tunnel

On anteroposterior films the midpoint of the tibial tunnel was at a mean of 45.6% (SD 1.9) lateral from the medial end of the plateau. Individual measurements were as below Fig. 6.

3.4. Lateral femoral tunnel

The femoral tunnel was positioned at a mean of 43.2% (SD 1.8) medial from the lateral femoral condyle. The distribution has been shown below Fig. 7.

3.5. Graft inclination

The average graft inclination angle was 19.6° (SD 2.0) as measured with reference from an imaginary vertical line drawn in the coronal plane. The distribution is shown in the chart below Fig. 8.

3.6. Clinical results

At the follow up of two years, among the 147 individuals, 129 had “ideal outcome” and the remaining 18 had “not-ideal outcome”. Among them 7 had chronic pain, 13 had laxity, 2 patients came back with a tear of reconstructed ACL, 6 had a restriction of movements Fig. 9.

The patients with chronic pain were dealt with oral analgesics and a course of physiotherapy. Restriction of squatting, sitting crossed-legged, climbing stairs and competitive sports were advised to them. Except for the 2 patients having a complete tear of the reconstructed ACL, others patients presenting with laxity were managed conservatively by physiotherapy (muscle strengthening exercises, proprioceptive training) and temporary supportive braces. Two patients who came with torn ACL were advised revision surgery. One among them refused to undergo further surgical intervention; the other was later operated and did well with revision ACL reconstruction. Among the 6 patients with stiffness, all were initially subjected to conservative management with physiotherapy. Four among them improved well, remaining 2 were subjected to manipulation under anesthesia but ultimately required arthroscopic arthrolysis for adequate release of intra-articular adhesions Table 1.

It has been found that among various radiological tunnel position parameters, position in the femur in the sagittal plane has a

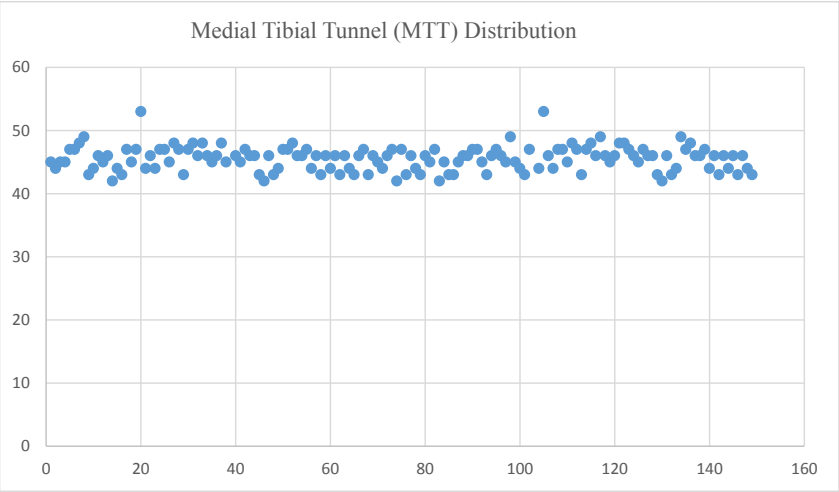

Fig. 6. Medial tibial Tunnel(MTT) distribution.

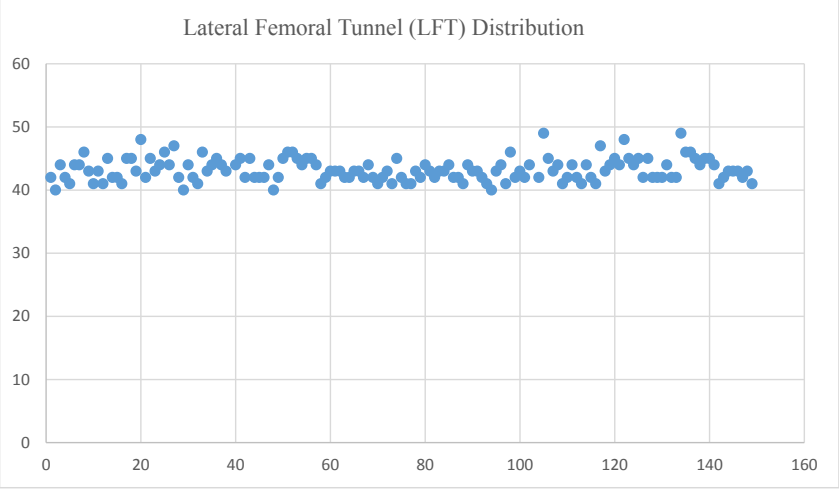

Fig. 7. Lateral femoral Tunnel(LFT) distribution.

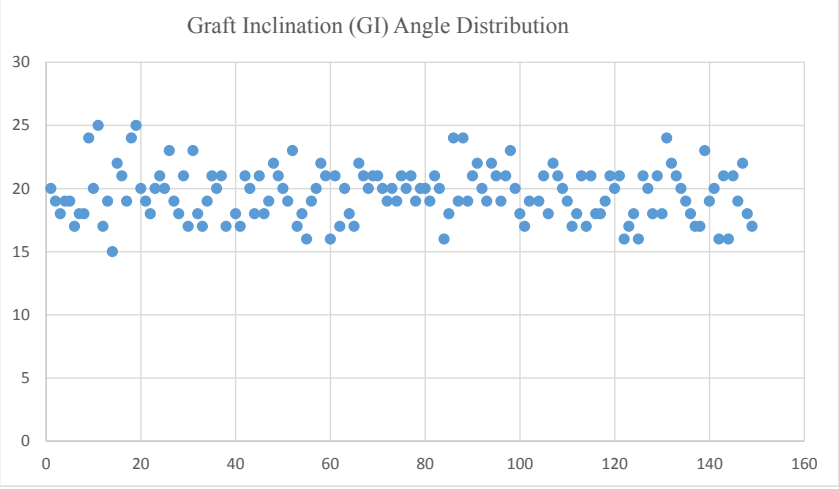

Fig. 8. Graft inclination (GI) angle distribution.

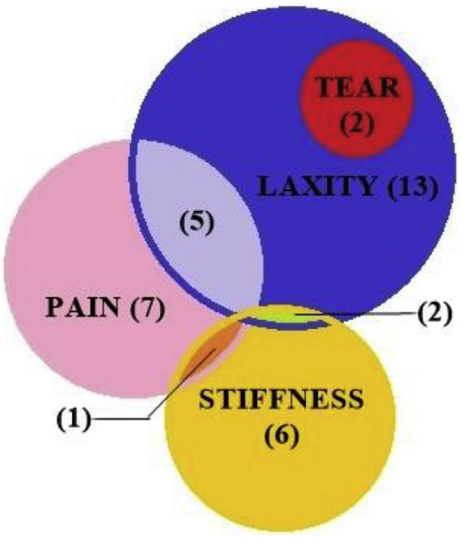

Fig. 9. Clinical Results in not-ideal outcome group.

significant association with the clinical outcome. In the ideal clinical result group, the femoral tunnel was 84.6% (mean value) posteriorly placed along the Blumensaat's line. The same in the non-ideal outcome group was at 86.3% posteriorly placed (mean value). This difference was statistically significant (Mann-Whitney *U* test, $p = 0.007$). The association between clinical outcome and the other parameters are not significant statistically.

3.7. *Relationship between tunnel placement and different non-ideal clinical results*

Patients presenting with chronic pain, laxity, and stiffness during the two years follow up were analyzed. Various tunnel position parameters in these patients were taken into consideration and any statistically significant relationship between each of these parameters and any of these conditions was sought. The relationship between tunnel parameters and the outcome of tear of reconstructed ACL could not be tested due to the very small sample size ($n = 2$). Mann Whitney *U* test was applied in each of them. P-value <0.05 was taken to be significant. No statistically significant relationship was established between any of the tunnel position parameters and any of the outcome types mentioned Table 2.

4. Discussion

The position of the tunnels is a matter of concern in arthroscopic ACL reconstruction. The consensus is now towards anatomical reconstruction by transportal technique. Incorrect positioning of tunnels has been reported in various proportions. While it was in as high as 50% of cases in earlier studies[21,22]; a recent study documented less incidence (23%).[23] Erroneous placement of either tibial or femoral tunnel or both together have been associated with various poor outcomes.[2,21] Among these, the erroneous position of the femoral tunnel is the most commonly reported cause of failure.[4]

In our study, we attempted to assess average tunnel positions and to see if any statistically significant relationship is there between tunnel position parameters and the outcome. Observed overall average positions were PFT: 84.8%, ATT 46.8%, MTT 45.6% and LFT 43.2%. Graft inclination angle was 19.6°. This is similar to an earlier study by Pinczewski et al.[11] (PFT: 86%, ATT 48%, MTT 47%, LFT 43% and graft inclination angle 19°).

Studies have shown that excessive anterior placement of the femoral tunnel can have various adverse outcomes. The tension in such graft can be high enough to restrict the movement. The consequence may either be elongation or, the ultimate failure of the graft.[21,24] A too posterior position of femoral tunnel can cause impingement and loss of movement or rupture.[21,24]

Tibial tunnel placed >50% posteriorly along the tibial plateau can result in loss of flexion and a significant increase in the rupture rate as compared to the <50% group.[11] Anterior placement of the tibial tunnel can cause roof impingement in extension.[25] Medial placement of tibial tunnel causes PCL impingement.[25] A medially placed femoral tunnel can cause PCL impingement of the ACL graft.[5] Vertically placed grafts are less stable rotationally. This was more frequently encountered in the transtibial drilling of the femoral tunnel than the transportal technique.[26,27]

Our study showed a statistically significant association between femoral tunnel position in the sagittal plane and the clinical outcome; whereas it failed to demonstrate the same between other position parameters and such outcome. We could conclude that to optimize clinical result femoral tunnels should be placed at around 85% posteriorly along the Blumensaat's line as more posteriorly placed tunnels led to an unfavorable outcome and this association was statistically significant. The rupture rate was relatively low ($n = 2$) in our study as compared to other studies. Few of the reasons could be the higher commitment towards anatomical graft placement at our center and a well-planned and coordinated, yet flexible rehabilitation program offered to the patients before allowing them to return to competitive sports.

Table 2
p values obtained by applying Mann Whitney *U* test (<0.05 was taken as significant).

Clinical outcome	PFT	ATT	MTT	LFT	GI
Pain	0.144	0.395	0.171	0.116	0.184
Laxity	0.131	0.276	0.095	0.093	0.055
Stiffness	0.059	0.430	0.749	0.369	0.562

Table 1
Comparison between 2 groups of patients (Ideal outcome* vs non-ideal outcome† patient groups).

Parameter	Mean value in Ideal Outcome cases	Mean value in Non-ideal Outcome cases	Mann Whitney *U* test (p value‡)
PFT	84.6	86.3	**0.008**
ATT	46.8	47.2	0.542
MTT	45.5	46.3	0.285
LFT	43.1	44.2	0.129
GI Angle	19.5	20.6	0.093

*Defined as having normal or nearly normal subjective knee function; grade A IKDC range of movement i.e., <3° loss of extension and <5° loss of flexion; grade A IKDC laxity assessment i.e., grade 0 pivot and <3 mm laxity clinically and no evidence of radiological degenerative changes.
†All other cases that didn't fit in the above definition.
‡Significant if < 0.05.

There are a few shortcomings of our study. We have a follow up of 2 years, while some of the important adverse outcomes (e.g. early onset of osteoarthritis) cannot be monitored in such a short span. Here we presented the data obtained from one single center catering service to a less diversified ethnic population. A multicentric study with a longer follow up would be more adequate.

5. Conclusion

This study found that “ideal clinical outcome” was significantly associated with the placement of the femoral tunnel along the sagittal plane. The femoral tunnel should not be placed beyond the 85% mark along the Blumensaat's line from the anterior-most point. The position of the femoral tunnel in the coronal plane showed no statistically significant relationship with the clinical outcome. Same was true between the tibial tunnel position in either of the coronal and the sagittal planes and the clinical results.

Conflicts of interest

Nil.

Financial disclosure

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

References

1. Chhabra A, Diduch DR, Blessey PB, Miller MD. Recreating an acceptable angle of the tibial tunnel in the coronal plane in anterior cruciate ligament reconstruction using external landmarks 1. *Arthrosc J Arthrosc Relat Surg*. 2004;20(3):328–330.
2. Khalfayan EE, Sharkey PF, Alexander AH, Bruckner JD, Bynum EB. The relationship between tunnel placement and clinical results after anterior cruciate ligament reconstruction. *Am J Sports Med*. 1996;24(3):335–341.
3. Amendola A, Menon M, Clatworthy M, Fowler PJ. The effect of fixation technique on graft position in anterior cruciate ligament reconstruction. *Iowa Orthop J*. 2003;23:29.
4. Trojani C, Sbihi A, Djian P, et al. Causes for failure of ACL reconstruction and influence of meniscectomies after revision. *Knee Surg Sports Traumatol Arthrosc*. 2011;19(2):196–201.
5. Simmons R, Howell SM, Hull ML. Effect of the angle of the femoral and tibial tunnels in the coronal plane and incremental excision of the posterior cruciate ligament on tension of an anterior cruciate ligament graft: an in vitro study. *JBJS*. 2003;85(6):1018–1029.
6. Howell SM, Gittins ME, Gottlieb JE, Traina SM, Zoellner TM. The relationship between the angle of the tibial tunnel in the coronal plane and loss of flexion and anterior laxity after anterior cruciate ligament reconstruction. *Am J Sports Med*. 2001;29(5):567–574.
7. Fujimoto E, Sumen Y, Deie M, Yasumoto M, Kobayashi K, Ochi M. Anterior cruciate ligament graft impingement against the posterior cruciate ligament: diagnosis using MRI plus three-dimensional reconstruction software. *Magn Reson Imaging*. 2004;22(8):1125–1129.
8. Kawakami Y, Hiranaka T, Matsumoto T, et al. The accuracy of bone tunnel position using fluoroscopic-based navigation system in anterior cruciate ligament reconstruction. *Knee Surg Sports Traumatol Arthrosc*. 2012;20(8):1503–1510.
9. Musahl V, Burkart A, Debski RE, Van Scyoc A, Fu FH, Woo SLY. Accuracy of anterior cruciate ligament tunnel placement with an active robotic system: a cadaveric study. *Arthrosc J Arthrosc Relat Surg*. 2002;18(9):968–973.
10. Meuffels DE, Reijman M, Verhaar JAN. Computer-assisted surgery is not more accurate or precise than conventional arthroscopic ACL reconstruction: a prospective randomized clinical trial. *JBJS*. 2012;94(17):1538–1545.
11. Pinczewski LA, Salmon LJ, Jackson WFM, von Bormann RBP, Haslam PG, Tashiro S. Radiological landmarks for placement of the tunnels in single-bundle reconstruction of the anterior cruciate ligament. *J Bone Joint Surg Br*. 2008;90(2):172–179.
12. Kopf S, Pombo MW, Szczodry M, Irrgang JJ, Fu FH. Size variability of the human anterior cruciate ligament insertion sites. *Am J Sports Med*. 2011;39(1):108–113.
13. Zauleck MK, Gabriel S, Fischmeister MF, Hirtler L. Origin of the anterior cruciate ligament and the surrounding osseous landmarks of the femur. *Clin Anat*. 2014;27(7):1103–1110.
14. Lee B-I, Kwon S-W, Kim J-B, Choi H-S, Min K-D. Comparison of clinical results according to amount of preserved remnant in arthroscopic anterior cruciate ligament reconstruction using quadrupled hamstring graft. *Arthrosc J Arthrosc Relat Surg*. 2008;24(5):560–568.
15. Topliss C, Webb J. An audit of tunnel position in anterior cruciate ligament reconstruction. *Knee*. 2001;8(1):59–63.
16. Hughes AW, Dwyer AJ, Govindaswamy R, Lankester B. The use of intraoperative fluoroscopy for tibial tunnel placement in anterior cruciate ligament reconstruction. *Bone Joint Res*. 2012;1(10):234–237.
17. Bernard M, Hertel P, Hornung H, Cierpinski TH. Femoral insertion of the ACL. Radiographic quadrant method. *Am J Knee Surg*. 1997;10(1):14–21.
18. Bedi A, Maak T, Musahl V, et al. Effect of tibial tunnel position on stability of the knee after anterior cruciate ligament reconstruction: is the tibial tunnel position most important? *Am J Sports Med*. 2011;39(2):366–373.
19. Sadoghi P, Kröpfl A, Jansson V, Müller PE, Pietschmann MF, Fischmeister MF. Impact of tibial and femoral tunnel position on clinical results after anterior cruciate ligament reconstruction. *Arthrosc J Arthrosc Relat Surg*. 2011;27(3):355–364.
20. Nema SK, Balaji G, Akkilagunta S, Menon J, Poduval M, Patro D. Radiologic assessment of femoral and tibial tunnel placement based on anatomic landmarks in arthroscopic single bundle anterior cruciate ligament reconstruction. *Indian J Orthop*. 2017;51(3):286.
21. Sommer C, Friederich NF, Müller W. Improperly placed anterior cruciate ligament grafts: correlation between radiological parameters and clinical results. *Knee Surg Sports Traumatol Arthrosc*. 2000;8(4):207–213.
22. Behrend H, Stutz G, Kessler MA, Rukavina A, Giesinger K, Kuster MS. Tunnel placement in anterior cruciate ligament (ACL) reconstruction: quality control in a teaching hospital. Knee Surgery. *Sport Traumatol Arthrosc*. 2006;14(11):1159–1165.
23. Reynaud O, Batailler C, Lording T, Lustig S, Servien E, Neyret P. Three dimensionalCT analysis of femoral tunnel position after ACL reconstruction. A prospective study of one hundred and thirty five cases. *Int Orthop*. 2017;41(11):2313–2319.
24. Harner CD, Irrgang JJ, Paul J, Dearwater S, Fu FH. Loss of motion after anterior cruciate ligament reconstruction. *Am J Sports Med*. 1992;20(5):499–506.
25. Howell SM, Hull ML. Checkpoints for judging tunnel and anterior cruciate ligament graft placement. *J Knee Surg*. 2009;22(2):161.
26. Strauss EJ, Barker JU, McGill K, Cole BJ, Bach Jr BR, Verma NN. Can anatomic femoral tunnel placement be achieved using a transtibial technique for hamstring anterior cruciate ligament reconstruction? *Am J Sports Med*. 2011;39(6):1263–1269.
27. Dargel J, Schmidt-Wiethoff R, Fischer S, Mader K, Koebke J, Schneider T. Femoral bone tunnel placement using the transtibial tunnel or the anteromedial portal in ACL reconstruction: a radiographic evaluation. *Knee Surg Sports Traumatol Arthrosc*. 2009;17(3):220–227.