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ORIGINAL ARTICLE

Evaluating Angles of Tunnel Projection in Post Reconstruction of Anterior Cruciate Ligament Injury: A Radiological and International Knee Documentation Committee Score Correlation Study

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Abstract

Background/Aim: The tunnel placement angles accuracy in reconstruction of anterior cruciate ligament (ACL) injury with single bundle graft was critical for reviving function and knee stability. Radiological X-rays could provide reliable metric to predict ACL success. The aim of this research was to review the connection among tunnel of tibiofemoral inclination angles, measured through radiological (X-ray) imaging and functional result as appraised by the International Knee Documentation Committee (IKDC) score.

Methods: A retrospective study was conducted on patients with reconstruction of ACL injury with single bundle graft. Radiographic images were used to measure the femorotibial tunnel inclination angles post-surgery. IKDC scores were collected to assess knee function and patient outcomes. Statistical analysis was done to evaluate the correlation between tunnel projection angles and IKDC scores.

Results: The study included 60 number of patients. The average IKDC score was 73.3 %, with 17 samples having an IKDC score > 75 % and 43 samples having an IKDC score < 75 %. Statistical analysis showed that the Bernard-Hertel percentage was significantly related to the IKDC score ($p = 0.05$). Patients with tunnel angles within the optimal range demonstrated higher IKDC scores, indicating better knee function and stability.

Conclusion: Accurate femorotibial tunnel placement in ACL reconstruction, as assessed through radiological imaging, is associated with improved functional outcomes. This study highlights the importance of precise surgical technique in optimising patient recovery and knee function post-ACL reconstruction.

Key words: Anterior cruciate ligament reconstruction; Arthroscopy; Knee Injuries; Radiography; Healthcare.

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Introduction

Injury of anterior cruciate ligament (ACL) is amongst the most commonly reported injury of the knee ligament requiring reconstructive surgery, particularly prevalent among athletes.[1] Approximately over 200,000 ACL injuries happened annually in the United States, with half necessi-

tating surgery. However, only Norway, Denmark and Sweden have national internet-based registries accurately recording ACL reconstruction surgeries. Data from these registries show ACL injury rates of 38 per 100,000 in Denmark, 34 per 100,000 in Norway and 32 per 100,000 in Sweden. In Indonesia, knee injuries are the second most prevalent after back pain, with an ACL injury rate of 9 % among 48 per 1,000 patients.[2] As a result, these cases have created a significant economic burden. It is estimated to cost the US a total of USD 291 million per year, averaging USD 11,431 per procedure.[3, 4]

ACL reconstruction (ACLR) has become a standard symptomatic treatment over the past two decades, with advancements in techniques and rehabilitation improving outcomes. An accurate tibiofemoral tunnel projection is crucial for satisfactory result, with post-operative X-rays providing reliable validation of graft placement. However, failures still occur in 0.7 % to 10 % of cases.[5] People often cite improper tunnel placement as a cause of failure, with anterior tibial tunnel projection leading to impingement of the graft impingement. Technical errors were the most causative failure, accounting for 22 % to 79 % of cases.[6]

Post-operative analysis of femorotibial tunnel placement is beneficial for predicting surgical success and planning revisions. Radiographic analysis helps surgeons' critique and improve surgical techniques.[7] Post-operative X-rays can identify risk factors for graft failure and other poor outcomes, including improper tunnel placement and excessive valgus or varus alignment.[5] Although MRI and CT scans are used for evaluation, X-rays are preferred due to lower radiation exposure and cost.[8]

With increasing ACL revision cases and a lack of studies on post-operative femorotibial tunnel placement, this research aims to provide valuable insights into tunnel placement to minimise graft failure and enhance surgical success and patient satisfaction in patients after ACL reconstruction.

Methods

Study design and sample collection

This research was observational analytic study. It compared radiological parameters and International Knee Documentation Committee (IKDC) scores of patients who underwent ACLR between 2021 and 2023 at Dr Soetomo General Hospital, Surabaya, Indonesia. Criteria of inclusion for this study were: (1) patients with medical records at Dr Soetomo General Hospital, Surabaya, Indonesia; (2) patients aged 17 and above; and (3) patients diagnosed with ACL injury who have undergone surgery. Exclusion criteria for this study were (1) patients unwilling to have their medical records used as primary data; (2) Patients who have not only ACL reconstruction or re-rupture ACL; (3) Patients with more than one ligament injuries in their knee; (4) Patients without complete medical records or X-ray results.

X-ray measurements

Femoral tunnel inclination angle: measure the angle that is made from a straight line that drawn across the centre of the femur diaphysis and another line that drawn across the midportion of the femur tunnel (Figure 1A).[9]

Benhard Hertel percentage: measures the insertion area percentage considering the Blumensaat line. It involves measuring the distance from the posterior cortex to the centre of the femur tunnel and the trans-osseous distance from the femoral intercondylar to the femoral endo-button or projection line (Figure 1B).[9]

Tibial tunnel inclination angle: measured by a line that passes through the internal tibial plateau from the anteroposterior and another one from the line drawn across the centre of the tibial tunnel that intercepts it (Figure 2A).[9]

Amis – Jakob percentage: the assessment is conducted by measuring the width of spine of the tibia and the distance from the medial border of spine of the tibia to the midportion of the tibial tunnel and the results are presented as a percentage (Figure 2B).[9]

IKDC subjective score: the questionnaire consists of 18 points that measure symptoms, sports activities and daily function, with a maximum score of 100 %. Higher scores indicate no sports limitations, absence of symptoms and improved functional capacity.[10]

Statistical analysis

All data were matched against inclusion and exclusion criteria. Eligible data were used as the total sample. Data were descriptively processed and statistically analysed using SPSS 25. The Shapiro-Wilk test was first conducted; when the data

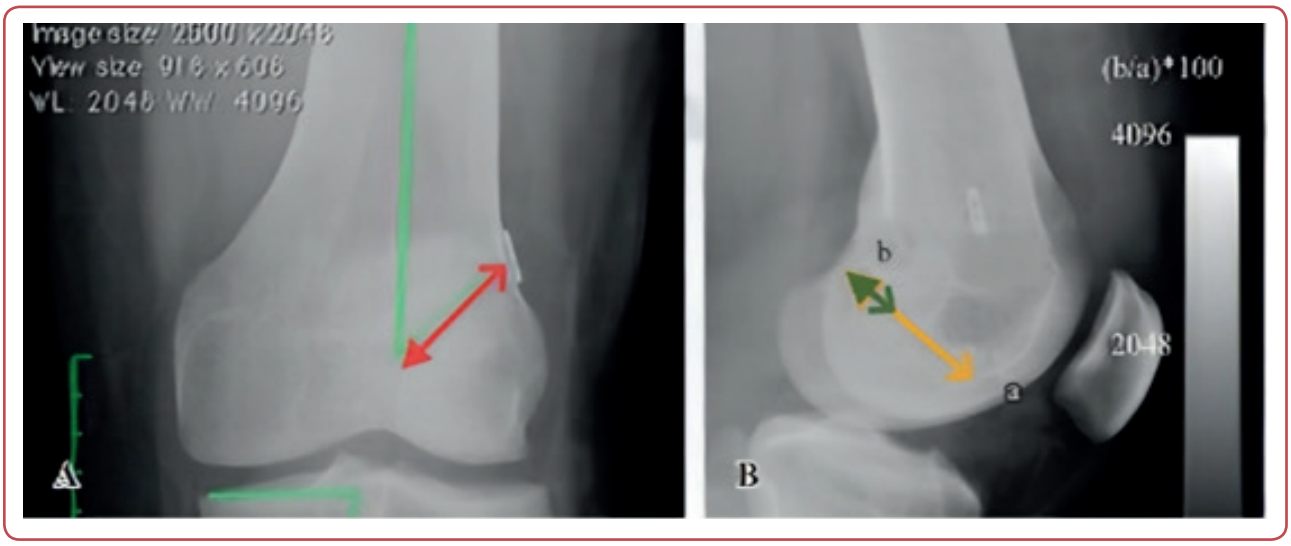

Figure 1: A. Femoral tunnel inclination angle, B. Benhard Hertel percentage[9]

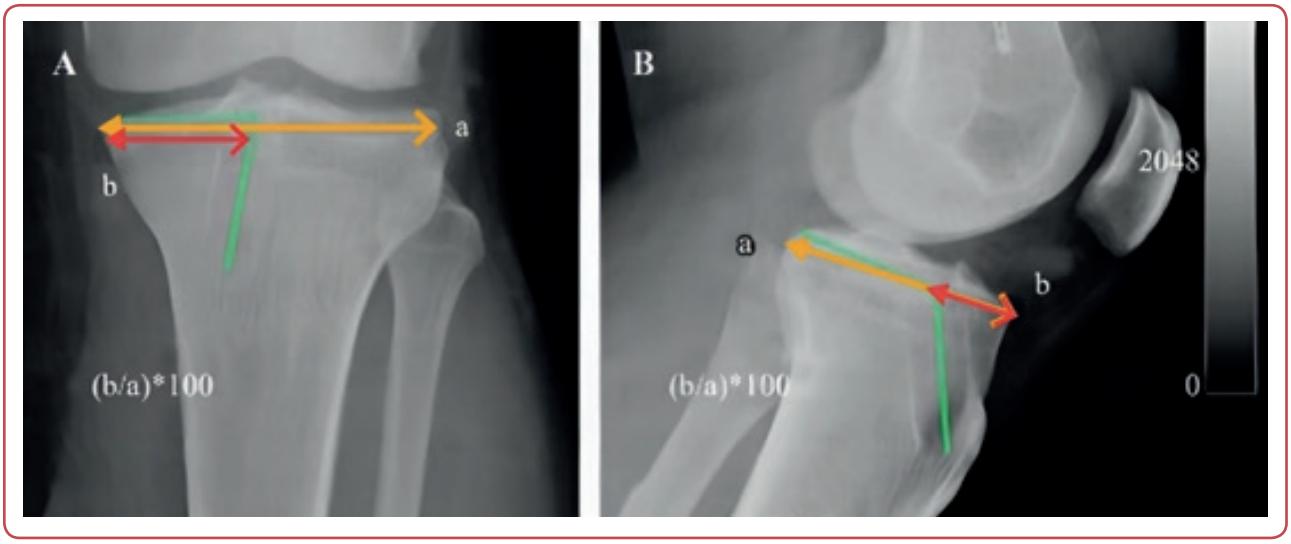

Figure 2: A. Tibial tunnel inclination angle, B. Amis – Jakob percentage[9]

were normal ($p > 0.05$), correlation was tested using the independent T-Test. When the data were not normal ($p < 0.05$), the Mann-Whitney test was used.

Results

In this study, a total of sixty patients who underwent reconstruction of ACL using hamstring graft and single bundle technique between 2021 and 2023 were included. Among these patients, 75 % (n = 48) were male with an average age of 26.3 years (ranging from 17 to 43 years). According to IKDC scores, the average score for all samples was 75.6 %, with 17 samples scoring > 75 (considered good) and 43 scoring < 75 % (considered fair).

The independent T-tests revealed that Tibia Inclination Angle and Amis-Jakob line percentage did not significantly correlate with IKDC scores ($p = 0.803$ and $p = 0.205$, respectively). And for the variables with non-normal distribution, their values were compared to ordinal IKDC scores (grouped into good and fair IKDC outcomes). The Mann Whitney test showed that Femur Inclination Angle did not significantly correlate with IKDC groups ($p = 0.66$), while the Bernard-Hertel grid percentage showed a significant association ($p = 0.05$). This indicates that the Bernard-Hertel grid percentage is related to whether IKDC scores were good or fair (Table 1).

Table 1: Average evaluation results for each variable[1, 11]

No	Variable	Mean ± SD	Median	Min	Max	Reference	p-value
1	Femur inclination angle	42.10 ± 9.77	33^0	29^0	42^0	$17\text{-}39^0$	0.660*
2	Bernard – Hertel percentage	35.30 ± 10.10 %	33.5 %	20.0 %	68 %	24-27 %	0.050*
3	Tibia inclination angle	61.20 ± 7.45	62.5^0	52^0	74^0	$65\text{-}70^0$	0.803^
4	Amis – Jakob percentage	36.90 ± 5.80 %	36.0 %	24.0 %	50 %	27-60 %	0.205^
5	IKDC	75.60 ± 12.16 %	77.0 %	27.6 %	100 %	> 75 %	0.660*

*IKDC: International Knee Documentation Committee score; *Mann-Whitney test; ^Independent-T test;*

Table 2: Number of samples with variable values within normal limits and grouped based on good or bad International Knee Documentation Committee (IKDC) score[1, 11]

No	Variable	Mean ± SD	Median	Q1	Q3	Range	Based on standard score
			IKDC < 75 (n = 43)				
1	Femur inclination angle	42.80 ± 10.22	42.05^0	36.1^0	47.35^0	$28.3\text{-}75.8^0$	32 % (8/25)
2	Bernard – Hertel percentage	32.30 ± 10.10 %	28 %	25.0 %	41 %	20-51 %	58.3 % (7/12)
3	Tibia inclination angle	61.50 ± 8.62	61.9^0	54.15^0	66.25^0	$45.7\text{-}80.4^0$	40 % (4/10)
4	Amis – Jakob percentage	38.20 ± 6.21 %	37.5 %	34.3 %	42 %	27-50 %	27.6 % (16/58)
			IKDC > 75 (n = 17)				
1	Femur inclination angle	41.70 ± 9.65	40.05^0	34.85^0	46.3^0	$28.3\text{-}74.6^0$	68 % (17/25)
2	Bernard – Hertel percentage	36.80 ± 9.85 %	35 %	30 %	42 %	24-68 %	41.67 % (5/12)
3	Tibia inclination angle	61.0 ± 6.9	60.8^0	54.15^0	64.1^0	$50.6\text{-}77.3^0$	60 % (6/10)
4	Amis – Jakob percentage	36.20 ± 5.54 %	35.5 %	32 %	40.8 %	24-47 %	72.40 % (42/58)

Comparisons of the four variables between good (IKDC > 75) and fair (IKDC < 75) IKDC scores are detailed in Table 2. Femur inclination angle distributions for good and fair IKDC scores were similar, ranging between 34-48 degrees. Similar distributions were observed for Bernard-Hertel grid percentages, ranging between 28-42 %. Tibia inclination angles showed a wider range for fair IKDC scores, overlapping with favourable IKDC outcomes. Amis-Jakob line percentages indicated a lower spread for IKDC > 75, suggesting a correlation between lower AJ percentages and good IKDC outcomes.

Discussions

Evidence suggests that anatomical strategies better mimic natural knee kinematics than isometric techniques, supporting the shift from isometric to anatomical ACLR in recent decades. Researchers have identified improper tunnel placement in femur as a common cause of graft failure.[11, 12] Previous studies by Abebe et al and Byrne et al underscore the importance of anatomical tunnel placement of the femur in ACLR to restore natural knee kinematics and reduce post traumatic osteoarthritis (PTOA), ACLR failure and cartilage and meniscal injuries.[13, 14] Research by Geng et al suggests that deeper and lower femoral tunnels result in a more oblique graft orientation, enhancing both anteroposterior and rotational stability.[15]

Post-ACLR outcomes are influenced by length of the graft within the tunnel, femur graft bending angle and inclination angle.[16] The femoral inclination angle influence graft pressure within the tunnel of femur, potentially causing tunnel widened or failure of the graft with an acute angle of the grafts. While the preservation of the native ACL inclination during ACLR remains debatable regarding achieving functional clinical outcomes, higher graft inclination angles have been associated with graft laxity.[17, 18] Snoj et al reported that femoral tunnel inclination significantly influences inclination of the ACL graft in the same plane, with a positive correlation amid coronal and sagittal graft inclination. Their study recommends adjusting femoral tunnel inclination, independent drilling techniques to achieve a better outcome in restoring natural ACL inclination. However, they

did not find a direct impact of femoral tunnel inclination on clinical outcomes or degenerative changes.[18]

Presented study found a quadratic curve for femoral tunnel inclination angle, indicating a parabolic relationship peaking at 40 degrees. Most samples exhibited femoral tunnel inclination angles in the 30–50-degree range, with good IKDC scores (≥ 75) more frequently found within this range, though not statistically significant (p = 0.606). This range is higher than previously considered normal (17-39 degrees), suggesting that slightly higher femoral inclination angles may yield better functional outcomes.[1, 19]

According to Bernard et al, correct placement approximately 24.8 % posterior and 28.5 % proximal to the Blumensaat's line ensures that the graft can mimic the natural biomechanics of the ACL.[20] Presented study's findings a significant relationship between Bernard-Hertel percentage and IKDC scores add crucial evidence to the importance of precise tunnel placement. An almost linear correlation emphasizes that higher Bernard-Hertel percentages correlate with better functional outcomes, reflected in higher IKDC scores (p = 0.050). Overall, this evidence shows that placing the femoral tunnel in a way that takes into account anatomy not only improves mechanical stability but also leads to better functional recovery, as shown by the IKDC score. These findings are clinically significant for surgeons planning and performing ACLR, highlighting the critical role of precise tunnel placement for long-term success and patient satisfaction.

Tibia and femoral tunnel placements affect PCL and roof impingement, with undesired clinical consequences such as loss of motion and instability. Cuomo et al demonstrated that the Howell 65° guide, positioning of the tibia tunnel in extension to avoid roof impingement, warrant a placement of the graft as anatomical as possible on the tibial side and could be expected to yield good outcomes.[21] Presented study on tibia inclination angle similarly found that most data fell within the 50–70-degree range, with good IKDC values observed between 60-100, though not significantly (p = 0.803). This angle range aligns with previous normal ranges (65-70 degrees), indicating that tibial tunnel placement within this range may offer optimal functional outcomes.

To achieve precise placement at the tibial site and avoid graft-roof contact in extension position, an anteroposterior assessment of ACL insertion in the mid-sagittal/lateral plane of the knee extension is necessary. Studies on graft placement and knee anatomy conclude that insertion at the tibial should be precisely posterior to avoid impingement of the graft toward the femur. There's consensus on typical graft tension patterns during knee flexion, where graft tension should approximate full knee extension.[1, 19] The Amis and Jakob line, crossing along the widest posterior angle of the medial tibial plateau, parallel to the medial joint line, serves as a reference ranging from 27 % to 60 %.[22]

This study found significant results for the Amis-Jakob line percentage, peaking at 30 %, with most data distributed within the 30-40 % range. A clear declining trend in the quadratic curve suggests that higher Amis-Jakob percentages may lead to lower IKDC scores, though not statistically significant (p = 0.205). This indicates that excessively high Amis-Jakob line percentages in tunnel placement may result in suboptimal functional outcomes.

Phiamthipmanas et al reported a threshold for Patient Acceptable Symptom State (PASS) was of 75.9 for patients post-ACLR, with sensitivity 0.83 and specificity 0.96, respectively, depending on patient health, sociodemographic characteristics, expectations and injury severity.[23] Studies on knee cartilage recovery mention Minimum Clinically Important Difference (MCID) variations post-surgery. Liu et al found an IKDC MCID of 9.9 post-allograft meniscus transplantation.[24] Ogura et al reported an osteochondral allograft surgery MCID of 9.8, consistent with this study's average IKDC score of 75.7 % ± 12.16 %, with 28.3 % achieving good results.[25]

Conclusion

In summary, an IKDC score of 75 % serves as a benchmark for assessing good knee condition post-ACLR. Several parameters contribute to achieving this benchmark: Bernard-Hertel percentage above 30 %, femoral inclination angle in the range of 25-55^0, tibial inclination angle in the range of 55-65^0 and Amis-Jakob line percentage in the range of 25-35 %. Although only the Bernard-Hertel percentage showed statistically significant results, all values fall within established ranges from prior research.

Ethics

Ethical Clearance was granted by the Dr Soetomo General Academic Hospital, clearance No 0927/KEPK/II/2024, dated 27 February 2024. Written consent has been obtained from all study subjects prior to their participation.

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None.

Conflicts of interest

The authors declare that there is no conflict of interest.

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Data access

The data that support the findings of this study are available from the corresponding author upon reasonable individual request.

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