# Femoral tunnel reaming method in anterior cruciate ligament reconstruction cannot be determined from plain radiographs alone

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**Background:** The precise location of tunnel placement significantly influences the outcome of anterior cruciate ligament (ACL) reconstruction, and an accurate understanding of tunnel placement remains paramount during postoperative assessment. Despite this, surgeons commonly estimate tunnel position and the method used to ream the tunnel based on plain radiographs alone. This study aims to determine the accuracy and reliability with which orthopaedic surgeons and musculoskeletal specialists can identify femoral tunnel (FT) reaming technique using standard postoperative radiographs alone, and to evaluate whether perceived tunnel malposition influences assumptions about reaming method.

**Methods:** This cross-sectional diagnostic study reviews postoperative radiographs from 40 ACL reconstructions (ACLRs) performed by the senior author. Twenty transtibially-reamed knees were matched with 20 anteromedially-reamed knees according to age, gender and body mass index (BMI). Surgical technique was identical for both groups, with the exception of FT reaming method, and postoperative radiographs were routinely obtained two weeks after surgery. Fifteen blinded orthopaedic or musculoskeletal trained reviewers evaluated radiographs for tunnel position and assumed reaming method. A kappa analysis was used to determine agreement among reviewers and assumed reaming method error rates were assessed parametrically.

**Results:** Reaming method was chosen correctly 64% of the time. However, the overall kappa value was low at 0.26. Transtibial error rate correlated with negative judgements of FT placement with a Pearson correlation coefficient of 0.648 (P=0.01).

**Conclusions:** These results suggest that the reaming method cannot be reliably determined using standard postoperative radiographs, and that evaluators who judge the tunnel placement to be poor may be biased toward assuming the tunnel was reamed transtibially. Surgeons should be careful not to associate failed ACLR with particular reaming methods without additional data.

**Keywords:** Sports medicine; radiograph; anterior cruciate ligament reconstruction (ACLR); tunnel position

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## Introduction

Anterior cruciate ligament (ACL) reconstruction is a relatively common operation in the USA, and the incidence has been steadily rising (1,2). Recent data estimate that 100,000 to 150,000 ACL reconstructions (ACLRs) are performed in the USA each year, with a lifetime cost of $38,121 per case (1-3). Although surgical management of ACL tears is considered the gold standard, ACLRs are still prone to failure (3-5). Surprisingly, this failure rate has not improved significantly over the past 30 years despite numerous developments in graft selection, tunnel drilling techniques, surgical approaches, and single-bundle versus double-bundle reconstruction (4-7).

While the causes of ACLR failure are multifactorial, the most common technical error is non-anatomic femoral and tibial tunnel placement (8-10). Small changes in tunnel placement have been shown to significantly affect knee kinematics following ACLR (11). In recent years, the transtibial (TT) method of reaming the femoral tunnel (FT) has become less commonly utilized (12). In contrast, the anteromedial (AM) reaming approach has risen in popularity, as it allows for more accurate and anatomic FT placement that better approximates the native ACL footprint (13,14). Similarly, the outside-in technique provides an alternative method for independent FT drilling with comparable anatomic accuracy. While biomechanical, anatomical, and cadaver studies have demonstrated potentially improved tunnel position when reaming anteromedially, comparisons of clinical outcomes between the two methods have been mixed (8,14-28).

As tunnel placement exerts a critical influence on the outcome of ACLR, the ability to assess tunnel position remains paramount, not only in the postoperative evaluation of an ACLR, but also for preoperative planning in the case of revision ACLR surgery (29). Traditionally, assessing tunnel position has been accomplished with the use of plain radiographs; however, this method has yielded inconsistent results due to variability in radiographic positioning, difficulty in accurately visualizing the femoral and tibial tunnel apertures, and limited ability to assess three-dimensional (3D) orientation (29-32). Even with direct arthroscopic visualization and computed tomography (CT), tunnel placement remains difficult to evaluate, and significant variability amongst surgeons' opinions in evaluation of the same knee (33). Despite the challenges of tunnel assessment, it is not uncommon for surgeons to judge tunnel position and its associated methods of reaming after only a cursory review of plain radiographs.

This study's primary aim was to evaluate how accurately the method of FT reaming can be determined by review of postoperative X-rays alone, without the use of templates, measuring guides, or advanced imaging. Additionally, a secondary objective was to assess the propensity to associate a particular reaming method if the overall FT placement was considered poor by the evaluator. We hypothesized that evaluators would not be able to reliably determine the method of FT reaming based on plan radiographs alone. Furthermore, when the placement of the FT is judged to be poor by an evaluator, we hypothesized that there would be a tendency to also assume the tunnel was reamed transtibially. We present this article in accordance with the STARD reporting checklist (available at https://aoj.amegroups.com/article/view/10.21037/aoj-25-41/rc).

### Highlight box

**Key findings**

- Surgeons and musculoskeletal specialists demonstrated only modest accuracy when attempting to identify femoral tunnel (FT) reaming technique using standard postoperative radiographs alone.
- Agreement among reviewers was low, indicating substantial variability and limited reliability in visual assessment.
- A bias was observed in which poorly positioned tunnels were more frequently attributed to transtibial reaming.

**What's known and what's new?**

- It is well recognized that FT position is critical to anterior cruciate ligament reconstruction success and that imaging is routinely used to evaluate tunnel placement.
- This study uniquely shows that, without formal measurement tools or advanced imaging, clinicians cannot consistently determine drilling technique from routine radiographs and are subject to cognitive bias in interpretation.

**What's the implication, and what should be changed now?**

- Postoperative radiographs alone should not be used to draw conclusions about surgical technique or to assign blame in cases of graft failure.
- Greater emphasis should be placed on objective assessment tools, standardized measurement methods, or advanced imaging before attributing outcomes to specific reaming approaches.
- Awareness of interpretive bias may improve clinical decision-making and revision surgery planning.

## Methods

This study was conducted in accordance with the Declaration of Helsinki and its subsequent amendments. The University of Kentucky Medical Center's Institutional

 

Review Board approved this retrospective diagnostic study (No. 13-0381-P1H) and informed consent was provided for the patients or legal guardians. We reviewed the operative reports of primary ACLRs from the senior author during the years 2012–2014. No cases that met inclusion criteria for this study were excluded from consideration. Patients undergoing revision ACLR, history of osteotomy or open reduction internal fixation around the knee, or patients with poor quality radiographs were excluded from this study. In total, 119 cases were reamed TT and 101 cases were reamed through the AM portal, independent of the tibial tunnel. Twenty cases of TT reaming were chosen at random using a random number generator and then matched with 20 cases of AM reaming according to age (within ±2–5 years), body mass index (BMI) (within ±3 kg/m$^2$), and gender. Three groups of evaluators at our University Hospital were used in this study: (I) attending orthopaedic surgeons with fellowship training in sports medicine or fellowship trained musculoskeletal radiologists; (II) current sports medicine fellows who had completed five years of orthopaedic surgery residency; and (III) fifth year orthopaedic surgery residents in an Accreditation Council for Graduate Medical Education (ACGME)-accredited USA orthopaedic surgery program who had completed at least 6-months of sports medicine training. Each reviewer was provided with the same 20 TT-reamed and 20 AM-reamed radiographs.

### *Operative technique and postoperative radiographs*

The operative technique was performed similarly for both subsets of patients, except for the FT reaming method. Two standard arthroscopy portals were used for both techniques. No intraoperative imaging was used. Bone-patellar tendon-bone autografts were used in all cases, and fixation was obtained with interference screws in the femoral and tibial tunnels (femoral screw inserted retrograde from inside-out at the tunnel aperture; tibial screw inserted antegrade from outside-in along the tunnel trajectory), as screw position influences postoperative radiographic appearance.

In all cases, the senior author attempted to place the FT as close as possible to the native anatomic ACL footprint, regardless of the drilling technique. Both the TT and the AM techniques were used during the study period. Technique selection reflected surgeon preference and patient-specific factors such as tunnel trajectory, notch width, and anatomic considerations. Although the AM technique has become increasingly preferred due to evidence supporting more anatomic tunnel placement with independent reaming, both methods are still viable. The tibial tunnel was reamed using an intra-articular guide placed at the isometric point of the native tibial ACL insertion. For the TT method, the FT was reamed through the tibial tunnel, and for the AM method, the FT was reamed through the standard AM portal. All radiographs were obtained at the first postoperative visit, approximately 2 weeks after surgery. These included an anteroposterior (AP) projection, a notch view (45 degrees of flexion measured with a goniometer) and a lateral projection. Lateral radiographs were assessed for rotational adequacy based on femoral condylar overlap, and only images demonstrating ≤6 mm of posterior femoral condyle offset were considered acceptable for FT evaluation, consistent with prior radiographic validation studies. All radiographs were performed with the same technique and the same equipment, by staff with equivalent training.

### *Data collection and surveys*

A spreadsheet was constructed for each patient using Microsoft Excel (Microsoft, Redmond, WA). Spreadsheets for each patient were then compiled into a workbook that contained all 40 patients. The radiographic images for each patient were obtained from the hospital's digital picture archiving and communication system (PACS) using default contrast and brightness settings, and embedded uniformly into the spreadsheet (*Figure 1*). Once embedded in the spreadsheet, image settings could not be changed. Evaluators were instructed not to make additional markings or measurements on the images. No patient identifying information was included in the spreadsheets, and no information regarding reaming method or surgical technique was present. Patients with extensive trauma or multi-ligament injuries were not included in the radiograph selection process. The same 40 radiographs were provided to all reviewers, and reviewers were not informed of how many cases of each reaming method were included in the study. Questions regarding the respondent's opinion about tunnel placement and reaming method were posed for each case based on the AP, notch, and lateral views of the knee. The spreadsheet workbooks were emailed to the respondents, and each respondent was allowed to finish the questionnaire at their own convenience. There was no time limit. Macro functions recorded each of the evaluators' responses in a master spreadsheet. Evaluators were given a maximum of 3 separate reminders and one in-person reminder to participate. Evaluators who failed to respond


**Figure 1** AP and lateral radiographs demonstrating tunnel position. Postoperative radiographs demonstrate ACLR tunnels reamed with the accessory medial (A,B) and TT (C,D) techniques. Reaming method could not be reliably determined from plain radiographs. Femoral tunnel is located using the white arrow (D). ACLR, anterior cruciate ligament reconstruction; AP, anteroposterior; TT, transtibial.

after these reminders were excluded from the study, and complete case analysis was used to address missing data.

### *Statistical analysis*

The Statistical Package for the Social Sciences (SPSS) for Mac (version 22.0; SPSS, Chicago, IL) was used for statistical analysis. A kappa analysis was used to test the agreement among reviewers for their assessment of which reaming method was used. We summarized errors and correct responses and then examined parametric relationships between the data. The TT error rate was defined as the probability of erroneously assessing a drilling type as TT, rather than AM. The AM error rate was defined as the probability of erroneously assessing a drilling type as AM. Using a paired sample $t$-test, we examined the hypothesis that participants tended to erroneously evaluate TT radiographs more often than AM radiographs. Using Pearson correlation, we assessed the relationship between the TT error rate and negative judgments about the FT placement. Significance was determined as $P<0.05$.

## Results

A total of 40 patients were included, including 18 females (45%) and 22 males (55%), with a mean age of 24 years (range 12–47 years). Mean BMI was 25.9 kg/m$^2$ [standard deviation (SD) =5.83]. No significant differences in gender,

 

**Table 1** Overall patient demographics

| Characteristic | Value (n=40) |
|---|---|
| Age, years | 24 [12–47] |
| Gender | |
| Female | 18 [45] |
| Male | 22 [55] |
| BMI, kg/m$^2$ | 25.9±5.83 |

Data are presented as mean [range], or n [%], or mean ± SD. BMI, body mass index; SD, standard deviation.

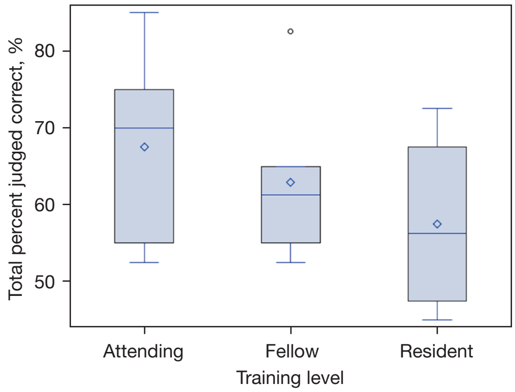


**Figure 2** Proportion of accurate assessments of femoral tunnel drilling technique across training levels. This figure displays how frequently reviewers at different stages of training correctly identified the femoral tunnel reaming method. Although individuals with more advanced training showed slightly higher accuracy, these differences did not reach statistical significance.

age, or BMI existed between the TT and AM groups (*Table 1*).

Fifteen reviewers participated in this study. Four of these were attending physicians (three sports medicine fellowship-trained orthopaedic surgeons and one fellowship-trained musculoskeletal radiologist), six were orthopaedic surgery sports medicine fellows, and five were senior orthopaedic surgery residents. Each reviewer was provided with the same set of 40 patients to review (600 questionnaires total). Of these, eight questionnaires were excluded due to incomplete answers, leaving 592 fully answered questionnaires.

Overall, the correct reaming method was chosen 64% of the time (*Figure 2*). There was no statistically significant difference in accuracy of assessment across reviewer training levels (P=0.49). The average kappa value among all 15 reviewers was 0.26 [range −0.08 to 0.70, standard error of the mean (SEM) ±0.06], indicating a poor overall ability

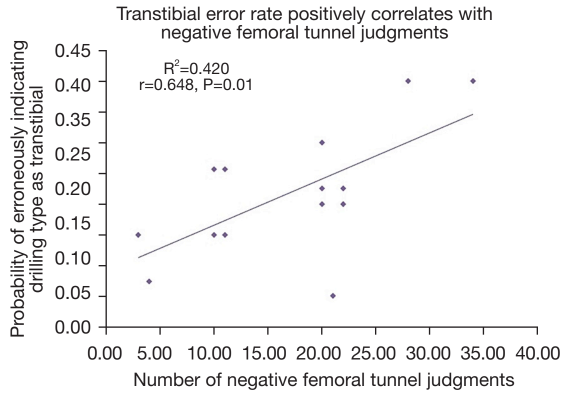


**Figure 3** Relationship between TT misclassification rates and unfavorable femoral tunnel ratings. This figure illustrates that reviewers who rated the femoral tunnel position as suboptimal on an AP radiograph were also more likely to mistakenly classify the tunnel as transtibially drilled. AP, anteroposterior; TT, transtibial.

to accurately assess FT placement with plain radiographs alone. The amount of agreement ranged from none to slight (six), fair (four), moderate (two), and substantial (two) agreement.

Pearson correlations indicated that TT error rate positively correlated with negative FT judgments on AP radiographs (r=0.648, P=0.01; *Figure 3*). Importantly, this correlation was unique to TT error rate and there was no parallel correlation between AM error rate and negative FT judgments (r=−0.005, P=0.99). Interestingly, there was no relationship present for FT judgments viewed on lateral radiographs, between either TT errors (r=−0.108, P=0.71) or AM errors (r=0.236, P=0.42).

## Discussion

Our study indicates that reaming method cannot be reliably determined using standard postoperative radiographs. FT malposition is one of the most cited reasons for failure of ACLR (23). Several methods to assess tunnel position have been described, using a range of imaging modalities from plain radiographs to 3D CT scans to magnetic resonance imaging (MRI) (4,21,34-36). Most often, plain radiographs are the sole data source used when judging the quality of tunnel placement.

Several radiographic features have been described that can differentiate the method of tunnel reaming on plain radiographs (15,24,37). Moreover, the use of plain radiographs to assess tunnel position has been shown to be accurate in many cases; however, these reports involve measuring specific angles or drawing templates over the radiographs (26,35). In contrast, other studies have raised legitimate concerns regarding the overall accuracy of radiographs when assessing tunnel position (4,37).

Many clinicians make assumptions about the reaming method used for a specific case based only on a cursory review of plain radiographs. Importantly, data from this study aligns with outcomes cited elsewhere in the literature, further validating the concern that plain radiographs, without the use of supplemental measurements or templates, may not reliably reflect the method used to ream the FT (4,37). Further, our findings demonstrate a tendency to incorrectly assume the tunnel was reamed transtibially if the FT position was judged to be poor on the AP radiograph. Our results confirmed our first hypothesis: FT reaming method could not be determined by the reviewers based on plain radiographs alone.

These results are novel, as no previous studies have examined the ability to determine reaming method from plain radiographs alone. Amis *et al.* used radiographs to evaluate tibial tunnel placement and Aglietti *et al.* calculated ratios using both the femoral and tibial tunnels (38,39). Bernard *et al.* and Harner *et al.* assessed tunnel placement by dividing the femur into quadrants (11,34). Lee *et al.* described radiographic differences in tunnels depending on their reaming method and Lintner *et al.* described good results using a combination of notch views and lateral extension views (27,40). However, other studies have demonstrated radiographic assessment of tunnel position to be difficult and unreliable (4,25,36,37). Hoser *et al.* likewise demonstrated that 3D CT is more effective in determining tunnel position than X-rays (37). Interestingly, Illingworth *et al.* have shown that a combination of the FT angle on AP radiographs and ACL inclination angle as measured on MRI can characterise the position of the FT with fidelity approaching that of 3D CT scan (35).

The results also supported our second hypothesis that the reviewers would be more likely to incorrectly assume that the FT was reamed transtibially if they judged it to be poorly positioned, specifically in the AP view. This bias has not been previously examined, and our study introduces this bias as an additional consideration into the prevailing literature.

Numerous studies have compared FT placement using TT and tibial tunnel independent reaming techniques (6,8,28,40-44). Recent studies suggest that FTs reamed independently of the tibial tunnel are positioned more anatomically than those reamed transtibially (6,42,43). However, some experts report satisfactory tunnel placement using TT techniques, and data comparing clinical outcomes between the two methods is conflicting (6,28,32,44). For instance, even though anatomic graft placement is preferable, results from a Danish registry showed that the revision rate for ACLRs with FTs reamed anteromedially is twice that of those reamed transtibially and cadaveric studies have shown that anatomically placed grafts are exposed to higher tensile forces (16,18,29,31,45). Essentially, tunnels can be placed poorly using either technique (28). Given inconclusive data on clinical outcomes, it is important that surgeons avoid associating graft failure with a certain reaming technique without appropriate evidence.

This study had several important limitations. First, it did not measure clinical outcomes or actual tunnel position, nor did it examine any relationship between outcomes, actual quality of tunnel position, reaming method, or radiographic findings. The purpose of this study was not to determine whether one surgical technique was superior to another or whether the participants could accurately assess the quality of tunnel position using radiographs. Likewise, the present study did not attempt to assess the relationship between the participants' opinion of reaming method or FT position and any outcome measures.

Second, the radiographs could not be manipulated as they would be in a standard digital PACS. This was done intentionally to more closely resemble the environment found at case presentations or in a hurried clinical setting. As previously mentioned, the radiographs were not evaluated using grids, measuring guides, or other types of template systems. The purpose of this was to differentiate our study from other studies that use supplemental tools in interpretation. Although several studies have described successful FT evaluation using grids, quadrants, and repeatable radiographic measurements, the purpose of this study was not to evaluate the efficacy of those methods (34,39,45).

All the surgeries were performed by a single surgeon, who may have tended to place the FTs in similar positions regardless of reaming method. It is possible that the surgeon strived for a consistent tunnel position across techniques, and this may theoretically limit the differences between reaming techniques. However, this limitation would not affect the reported tendency for evaluators to associate the TT method with FT positions judged to be poor subjectively. Moreover, numerous studies have demonstrated both real and radiographic differences depending on tunnel reaming technique, even with the same surgeon, further minimizing the influence of this limitation on our study (7,39,42). The operative surgeon was included in the study, and their number of correct responses was consistent with the mean number of correct responses among other attending surgeons. The order of cases was randomized and blinded, thus obscuring any clues as to the timing or other details of the surgery.

The study included a heterogeneous mix of reviewers, though all were familiar with ACLR surgery and evaluation of postoperative radiographs. These evaluators were chosen from interdisciplinary backgrounds that patients are likely to encounter. Although there were no significant differences in agreement between the different groups of reviewers, more senior reviewers tended to perform better at detecting reaming methods. It is possible that a larger sample size of senior reviewers would have different results, and it is unclear what effect this would have on our finding of TT bias.

Considering the previously described limitations, it is important to acknowledge what this study does not indicate. Our data are not intended to address clinical outcomes associated with a particular reaming method, as previously stated, but the ability of evaluators to recognize which method was utilized with plain radiographs alone. The data did suggest that our evaluators were unable to reliably determine TT versus AM femoral reaming in matched patients from a single surgeon, using standardized radiographs without assistive measuring devices. The data also demonstrated that participants were more likely to incorrectly assume that a tunnel was reamed transtibially if they also judged the tunnel placement to be poor on an AP radiograph.

## Conclusions

ACLR is an increasingly common surgical procedure with significant implications for healthcare resource utilization, especially in the case of graft failure. Failed ACLRs often result from a variety of contributing factors, with FT malposition being amongst the most common. Accurate assessment of FT position, therefore, remains crucial, particularly as the methods of reaming the FT are evolving. This study suggests that reaming method may not be reliably determined using standard postoperative radiographs, and it also identifies a bias among surgeons to assume a TT reaming approach when the overall tunnel placement is thought to be poor. Surgeons should exercise caution in evaluation of plain radiographs, being vigilant not to associate failed ACLRs with certain reaming methods in the absence of sufficient, corroborating data.

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*Ethical Statement:* The authors are accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved. This study was conducted in accordance with the Declaration of Helsinki and its subsequent amendments. The University of Kentucky Medical Center's Institutional Review Board approved this retrospective diagnostic study (No. 13-0381-P1H) and informed consent was provided for the patients or legal guardians.



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