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# Radiographic Findings in Revision Anterior Cruciate Ligament Reconstructions from the MARS Cohort

**MARS Group**

## Abstract

The Multicenter ACL (anterior cruciate ligament) Revision Study (MARS) group was developed to investigate revision ACL reconstruction outcomes. An important part of this is obtaining and reviewing radiographic studies. The goal for this radiographic analysis is to establish radiographic findings for a large revision ACL cohort to allow comparison with future studies. The study was designed as a cohort study. Various established radiographic parameters were measured by three readers. These included sagittal and coronal femoral and tibial tunnel position, joint space narrowing, and leg alignment. Inter- and intraobserver comparisons were performed. Femoral sagittal position demonstrated 42% were more than 40% anterior to the posterior cortex. On the sagittal tibia tunnel position, 49% demonstrated some impingement on full-extension lateral radiographs. Limb alignment averaged 43% medial to the medial edge of the tibial plateau. On the Rosenberg view (45-degree flexion view), the minimum joint space in the medial compartment averaged 106% of the opposite knee, but it ranged down to a minimum of 4.6%. Lateral compartment narrowing at its minimum on the Rosenberg view averaged 91.2% of the opposite knee, but it ranged down to a minimum of 0.0%. On the coronal view, verticality as measured by the angle from the center of the tibial tunnel aperture to the center of the femoral tunnel aperture measured 15.8 degree ± 6.9% from vertical. This study represents the radiographic findings in the largest revision ACL reconstruction series ever assembled. Findings were generally consistent with those previously demonstrated in the literature.

### Keywords

anterior cruciate ligament; reconstruction; revision; radiographs

Anterior cruciate ligament (ACL) reconstructions fail at a small, but not at an insignificant rate. This typically occurs in a young active population that desires a return to their previous activities. Unfortunately, for still not completely known reasons, these patients undergoing revision reconstructions do not achieve the quality of results obtained in primary reconstructions.[1–3] A careful preoperative analysis of patients undergoing revision reconstructions is necessary to determine causes of failure in an attempt to improve results.[4] An important part of this analysis is obtaining and reviewing radiographic studies.

Recently, the Multicenter ACL Revision Study (MARS) group was developed to investigate revision ACL reconstruction outcomes.[5] The goal of this group is to determine potentially modifiable predictors that can be altered to improve the outcome of ACL revision surgery. It is an 87-surgeon, 52-site prospective cohort supported by the American Orthopaedic Society of Sports Medicine (AOSSM). Our goal for this radiographic analysis is to establish



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radiographic findings for a large revision ACL cohort to allow comparison to future studies. Ultimately, when outcome has been determined for the MARS cohort, then correlation between preoperative radiographic findings and 2-, 6-, and 10-year outcomes may indicate predictors that allow counseling of patients preoperatively.

## Methods

The MARS group consists of 83 surgeons at 52 sites. It is a National Institutes of Health–funded prospective longitudinal cohort evaluating the results of revision ACL reconstruction. All members are sports medicine specialists that are AOSSM members. Radiographs were obtained in 630 patients on the basis of MARS study design. These included a full-extension lateral and standing anteroposterior (AP) of both knees. Additional recommended views included standing 45-degree bent knee posterior anterior (Rosenberg view), bilateral long leg alignment, and bilateral patellofemoral view.[6] The radiographs were obtained by the treating MARS surgeon at his or her institution. Radiographs were excluded for poor quality (inappropriate penetration), excessive obliquity for laterals (more than 5 mm lack of femoral condyle overlap), or inappropriately angled AP or Rosenberg views (femoral/tibial overlap obscuring joint space). The following radiographic measurements were made on the basis of literature description of measurement techniques. Radiographs were measured using measurement tools after opening digitized radiographs in Photoshop CS4. A minimum of two of three MARS authors who measured the radiographs measured each radiograph. Data were analyzed with SAS (Cary, NC). Interobserver agreement was obtained for the three readers and intraobserver reliability was obtained by having the readers repeat measurements more than 4 weeks following the initial measurements.

## Femoral Measurements

Femoral tunnel position on the lateral radiographs was measured by two popular techniques. The first technique measured the center of the tunnel position along Blumensaat line from the posterior cortex to the anterior edge of Blumensaat line.[7–10] This was recorded as a percentage of the distance from the posterior cortex and can be converted to a quartile classification scale. The second technique similarly measured the position, but it extended the anterior extent to the anterior edge of the lateral femoral condyle.[11]

The femoral roof angle was measured by the angle subtended by a line drawn along the posterior femoral cortex and a line drawn along Blumensaat line.[12] The knee extension angle was the angle created by lines drawn along the posterior cortex of the femur and tibia. Negative values represent hyperextension (Fig. 1).[12]

The coronal standing AP and Rosenberg views were utilized to measure the femoral tunnel–tibial tunnel verticality/obliquity (FTA) (Fig. 2). On the standing AP the midpoint of the femoral and tibial tunnels at the intercondylar notch were identified. The line connecting these two points was drawn to intersect a line parallel to the tibial plateau to create an angle of verticality. For the Rosenberg view, the line from the midpoint between the notch walls at the proximal tibial plateau and the center of the femoral tunnel at the notch was drawn to intersect a line drawn parallel to the tibial plateau (femoral tunnel coronal angle FCA) (Fig. 3). This can be converted to any of the various clock face measurements.

## Tibial Measurements

Sagittal tibial tunnel position on the lateral radiograph was obtained by measuring the line from the center of the tibial tunnel to the anterior edge of the tibia and dividing it by the distance from the anterior edge to the posterior edge of the proximal tibia and expressing it as a percentage[7,9–11,13,14] (Fig. 4). This can be expressed using a quartile quadrant system.[8]

Impingement was obtained by measuring the percentage of the tibial tunnel that was anterior to Blumensaat line extended on a full-extension X-ray[15,16] (Fig. 5). The tibial tunnel sagittal angle was measured by the angle formed by a line parallel to the tibial tunnel and a line parallel to the proximal tibial plateau.[4,17] Slope of the tibial plateau was measured by a line parallel to the posterior tibial cortex and a line parallel to the tibial plateau.

The coronal position of the tibial tunnel was measured by dividing the distance from the medial border of the tibial plateau to the midpoint of the tibial tunnel by the distance from the medial border to the lateral border of the plateau and expressing it as a percentage.[9,13] The coronal angle was measured as the angle formed by a line drawn parallel to the tibial tunnel and parallel to the tibial plateau.[4]

## Limb Alignment

Limb alignment was measured on a bilateral long leg standing X-ray. The line from the center of the femoral head to the center of the ankle tibial plafond was drawn. The point where it intersected the tibial plateau was noted. The distance from this point to the medial border of the tibial plateau divided by the total width of the tibial plateau is expressed as a percentage for both extremities.

## Joint Space

Joint space measurements were obtained on both standing AP and Rosenberg views and compared with the opposite knee and expressed as percentages for the medial and lateral compartments.[6] Reporting in this format was required because of digitalization from multiple sources with inability to obtain true distance in millimeters as has been frequently done in the past.[6,18] Two methods were used to obtain these values. The first method chose the narrowest position in the medial and lateral compartments and recorded this value.[19] The second method determined the midpoint of each compartment and recorded the joint space value there.[20,21]

## Results

The sagittal position of the center of the femoral tunnel was demonstrated to be, on average, 39.3% ± 11.1% anterior to the posterior femoral cortex along Blumensaat line. More significantly, 9% were 25% or less anterior to the posterior femoral cortex, 77% were 26 to 50% anterior to the posterior femoral cortex, 13% were 51 to 75% anterior to the posterior femoral cortex, and 1% were 76 to 100% anterior to the posterior femoral cortex (Fig. 6). Forty-two percent of the measurements were more than 40% anterior to the femoral cortex. The anterior edge of the lateral femoral condyle was 34.2% ± 18.3% anterior to the posterior femoral cortex as the second measurement from Blumensaat line. Twenty percent were 25% or less anterior to the posterior femoral cortex, 74% were 26 to 50% anterior to the posterior femoral cortex, 6% were 51 to 75% anterior to the posterior femoral cortex, and 0% were 76 to 100% anterior to the posterior femoral cortex utilizing this method.

On the sagittal view, the center of the tibial tunnel was found to be, on average, 38.2% ± 21.6% posterior to the anterior edge of the tibia. Zero percent were 0 to 10% posterior to the anterior edge of the tibia, 2% were 11 to 20%,19% were 21 to 30%, 44% were 31 to 40%, 29% were 41 to 50%, 4% were 51 to 60%, and 1% were more than 60% posterior to the anterior edge of the tibia. Impingement of the graft was evaluated by measuring the amount of the tibial tunnel that was anterior to Blumensaat line extended. This value averaged 18.8%. Fifty-one percent demonstrated no impingement. Twenty percent demonstrated 1 to 25% impingement, 15% demonstrated 26 to 50% impingement, 9% demonstrated 51 to 75% impingement, 2% demonstrated 76 to 100% impingement, and 2% demonstrated more than

100% impingement with the tunnel anterior to Blumensaat line. The sagittal tibial angle was 83.3% ± 3.7% in relation to the slope of the tibial plateau. The roof angle measured 34.1 ± 4.9 degrees.

On the coronal views, the tibial tunnel center averaged 45.4% ± 3.8% of the width of the tibial plateau, as measured from the medial edge. On the coronal AP view, the tibial tunnel angle was 69.3 ± 9.0 degrees. Sixteen percent were 60 to 64 degrees, 19% were 65 to 69 degrees, 23% were 70 to 74 degrees, 18% were 75 to 79 degrees, 5% were 80 to 84 degrees, and 3% were 85 to 89 degrees. On the AP view, the angle from the center of the tibial tunnel aperture to the center of the femoral tunnel aperture measured 15.8 ± 6.9 degrees from vertical. The angle from the center of the tibial plateau, defined as the midpoint of the walls of the notch to the femoral tunnel aperture in the notch, measured 18.8 ± 6.7 degrees.

Joint space narrowing was evaluated on the standing AP and Rosenberg views and was determined for both the medial and lateral compartments. Medial compartment measurements at the minimum joint space point on the standing AP averaged 95.6% and ranged from 100 to 36.3% as compared with the opposite knee. The percentages of joint space narrowing are shown in Table 1. Lateral compartment narrowing at its narrowest point on the standing AP view averaged 107% of the opposite compartment but ranged down to complete loss of joint space (0.0%). Midpoint joint space in the medial compartment averaged 100% of the opposite compartment on the standing AP view. Lateral compartment narrowing at its midpoint on the standing AP view averaged 108% of the opposite compartment. On the Rosenberg 45-degree view, the minimum joint space in the medial compartment averaged 106% of the opposite knee, but it ranged down to a minimum of 4.6%. The degree of joint space narrowing is shown in Table 2. Lateral compartment narrowing at its minimum on the Rosenberg view averaged 91.2% of the opposite knee, but it ranged down to a minimum of 0.0%. Midpoint joint space narrowing in the medial compartment on the Rosenberg view was 106.9% on average. Midpoint joint space narrowing in the lateral compartment on the Rosenberg view averaged 98.9%.

Alignment was measured on standing long leg films and calculated as a percentage from the medial border of the tibia. In the affected revised knees, this averaged 43.0% ± 12.2%, compared with 41.4% ± 12.5% in the unaffected limbs.

Intraclass correlation coefficients (ICC) were obtained from the readers. These demonstrated consistently high ICCs for the three readers for most measurements with more than 50% higher than 0.7. Intraobserver agreement obtained more than 4 weeks following the initial measurements demonstrated similar results with 36 of 42 measured ICCs more than 0.7. The FcA and the femoral tibial tunnel angle consistently demonstrated poor intra- and interobserver reliability. Evaluation of the data demonstrated that despite some ICCs were less than 0.7, there was no mean results between the two reviewers, which were different by more than one degree. The low ICCs thus may reflect the large amount of radiographs measured and the ability to thus develop extremely rigorous statistical analysis beyond the accuracy capable in the measurements.

## Discussion

ACL reconstructions fail for various reasons. The ability to perform a revision reconstruction that avoids the previous cause of failure requires appropriate preoperative assessment and planning. Radiographs can assist in determining risk factors for graft failure and/or poor outcome including tunnel placement, joint space narrowing, excessive varus or valgus alignment, and increased extension or hyperextension with possible graft impingement. Our study was undertaken to analyze the variety of radiographic findings in the largest revision cohort assembled to date.

Tunnel position is a critical aspect of ACL reconstruction. This has been associated with a cause of graft failure. An audit study demonstrated less than 10% of reconstructions may have appropriate tunnel placement on sagittal and coronal radiographic views.[9] Recently, the MARS cohort demonstrated that up to 53% had some degree of technical error either in isolation or in combination with trauma and/or biological issues.[5] In the patients who were felt to have technical issues contributing to their failure, 80% were believed to have femoral tunnel malposition. This is typically represented by a femoral tunnel that is too anterior or too vertical. It is believed that if the femoral tunnel is more than 40% anterior to Blumensaat line then it is located too anterior.[10] This is typically measured by a quadrant system on a lateral X-ray. Harner et al described a method to measure sagittal position of the femoral tunnel and tibial tunnel.[10] Using this system, they evaluated a series of single- and two-incision ACL reconstructions. All of their tibial tunnels were located in quartile 2. Forty-two of 50 femoral tunnels were contained in quadrant 4, and 8 of 50 tunnels were in quadrant 3.

Radiographic analysis was performed postoperatively in a series of 200 ACL reconstructions by Pinczewski et al.[22] Taking 0% as the anterior and 100% as the posterior extent, the femoral tunnel was a mean of 86% (standard deviation [SD]: 5) along Blumensaat line and the tibial tunnel was 48% (SD: 5) along the tibial plateau. Taking 0% as the medial and 100% as the lateral extent, the tibial tunnel was 46% (SD: 3) across the tibial plateau and the mean inclination of the graft in the coronal plane was 19 degrees (SD: 5.5 degrees). Khalfayan et al showed that ACL reconstructions with tunnels located at least 60% posteriorly along Blumensaat line and 20% posteriorly along the tibial plateau did well, clinically with 69% good or excellent Lysholm scores and 79% demonstrating 3 mm or less side-to-side difference on KT-1000 testing.[7] This underscores the findings of other authors who improperly placed tunnels impact outcome with anterior femoral or tibial tunnels associated with increased failure rates and inferior outcome measures.[23] Our findings demonstrated that 42% were more than 40% anterior to the posterior cortex and were not located in the most posterior quadrant.

Anterior graft impingement has been evaluated previously and found to be associated with increased effusions, lack of extension, and increased failure rates.[7,15,16,24,25] In 1993, Howell et al evaluated graft impingement in 47 knees.[16] Four grafts had their tibial tunnels anterior to Blumensaat line and all four failed. Fourteen knees demonstrated partial impingement and four of these failed. Twenty-nine had no portion of the tunnel anterior to Blumensaat line and only four of these grafts failed. The authors concluded that if full extension was obtained in a setting of anterior impingement then the knees became unstable.

A full-extension lateral radiograph is the best way to assess interior graft impingement. We obtained this view for the MARS cohort. Previous studies have also used this to assess for graft impingement postoperatively.[26] In this study, Miller and Olszewski demonstrated if the tibial tunnel was placed in the posteromedial portion of the ACL footprint then graft impingement on the intercondylar roof never occurred. Our findings in the current study demonstrated that 51% had no impingement, 47% have some form of impingement, and 2% were 100% impinged with the tibial tunnel completely anterior to Blumensaat line. Previous use of the roof angle and extension angle demonstrated that the roof angle varied from 26 to 46 degrees.[12] The MARS roof angle measured 34.1 ± 4.9 degrees, similar to the findings in this previous study. Knees with the combination of hyperextension and a vertical roof angle were unforgiving and required a posterior placement of the tibial tunnel to avoid anterior impingement.

A previous study by Howell et al defined the distance posterior to the anterior edge of the tibia that minimizes the risk of anterior graft impingement.[14] If the center of the tibial tunnel was 22 to 28 mm posterior to the anterior edge of the tibia, then no graft impingement resulted. In our cohort, we were unable to accurately measure absolute distances. A percentage posterior to the anterior edge of the tibia was derived. This was found to be 38.2% with a large SD of 21.6%, indicating variability in the tibial tunnel placement on the lateral view.

Tibial tunnel position in the coronal plane may impact anterior laxity and loss of flexion if placed too vertically. In a retrospective series, it was noted that a tibial tunnel angle greater than 75 degrees in the coronal plane resulted in loss of flexion and increased anterior laxity.[27] Morgan et al has demonstrated a sagittal tibial tunnel angle of 68 degrees in a series of ACL reconstructions utilizing defined landmarks to create the tibial tunnel.[17] In a cadaver study utilizing landmarks, the sagittal tibial tunnel angle was 75 degrees and the coronal angle was 65.7 degrees.[28] Our study demonstrated a sagittal angle of 83.3% ± 3.7% and a coronal angle of 69.3 ± 9.0 degrees including 24% that were greater than 75 degrees.

Femoral tunnel position in the coronal plane has been theorized as a contributor to outcome. A double-blinded study assessing the results of high and low femoral wall position showed improved International Knee Documentation Committee subjective scores for the low position group.[29] A “vertical” graft can allow rotational instability, whereas sagittal AP laxity is well controlled.[30] Various measurements and techniques have been used to measure the femoral tunnel position on the coronal and Rosenberg X-rays. Frequently, this has been a clock face technique, but the clock face is positioned at various places and has various sizes. We elected to use the Rosenberg view to determine the angle that the femoral tunnel center was located off the midline of the notch. This value can then be used to transform it into a clock face value depending on the size and where the clock face is located.

Previous studies have demonstrated that the surgeon’s ability to predict the femoral tunnel location is reasonable, but less so for tibial tunnel position.[31] This is an important consideration, given that in the transtibial technique, the femoral tunnel is dependent on the location of the tibial tunnel. Issues such as these have led to increased popularity of the anteromedial portal, which was used in 35% of the MARS cohort.

Plain radiographs do introduce difficulty in assessing tunnel locations. Poor technique or inadequate X-rays may preclude accurate measurements.[32] This is compounded in the multiply revised knee. These difficulties are overcome with computed tomographic scan or magnetic resonance imaging, but cost and radiation exposure makes these unreasonable options in a cohort of this size.

Assessing joint space narrowing by weight-bearing X-rays has the potential to be a valuable measure or predictor of outcome in our cohort. The progression of osteoarthritis can be followed using these methods. Narrowing that is detected over a 3-year time span has been noted to be a predictor of future surgery for osteoarthritis in the next 5 years for the patient.[33] The Rosenberg view has demonstrated increased accuracy, specificity, and sensitivity in patients with grade 3 and grade 4 chondrosis.[6,34–36] Patients undergoing revision ACL reconstructions commonly have advanced chondrosis; thus, the Rosenberg view may aid in assessing these degenerative changes. It has been previously determined that 2 mm of narrowing on a weight-bearing X-rays indicates joint space narrowing and subsequent chondrosis at the time of arthroscopy. The typical compartment in the knee will have a joint space of 5 mm. Thus, joint space narrowing of 40% compared with the similar compartment in the opposite knee would indicate at least 2 mm of narrowing. Measurements at the minimum joint space in our study found that 2% of our patients demonstrated 40% or greater narrowing in the medial compartment and 7% demonstrated similar narrowing in the lateral compartment. Measurements at the midpoint joint space found that 1% of our patients had 40% or more narrowing in the medial compartment and 3% had similar narrowing in the lateral compartment. Using percentage of narrowing rather than absolute measurements represents a potential weakness of our study, but one we cannot avoid. Radiographs were obtained in various settings and may not include sizing markers and thus we could not do absolute measurements. Most osteoarthritis classification scales use a percentage of narrowing and we believe our findings still have merit.

This study represents the radiographic findings in the largest revision ACL reconstruction series ever assembled. Findings were generally consistent with those previously demonstrated in the literature. Future studies correlating radiographic findings with patient outcome will determine whether preoperative X-rays and evaluation of these radiographic parameters can be used to counsel patients so as to predict an outcome.

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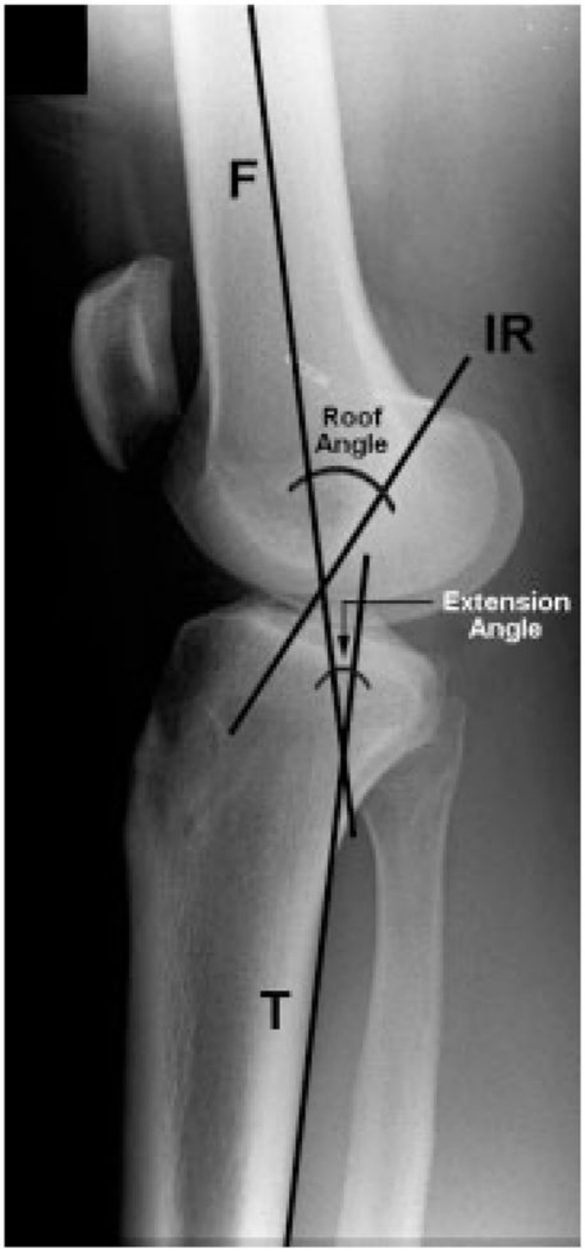


**Fig. 1.**
Knee extension angle. F, femur; IR, intercondylar roof; T, tibia.

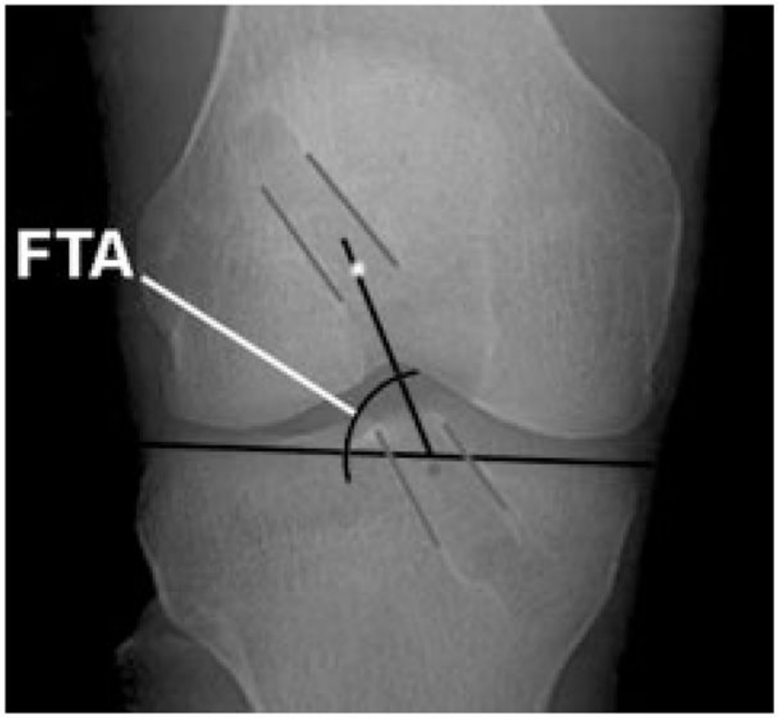


**Fig. 2.**
Femoral tunnel–tibial tunnel verticality/obliquity (FTA).

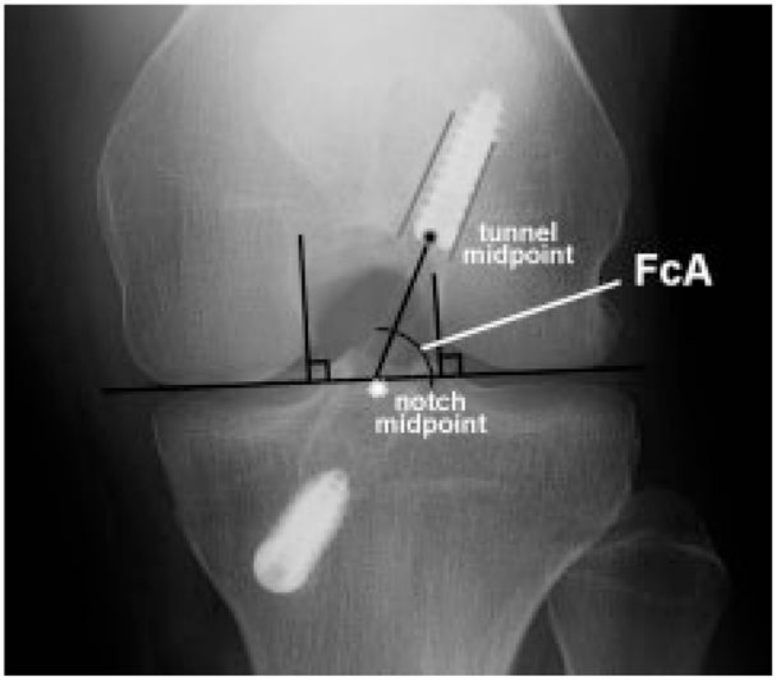


**Fig. 3.**
Femoral tunnel coronal angle (FcA).

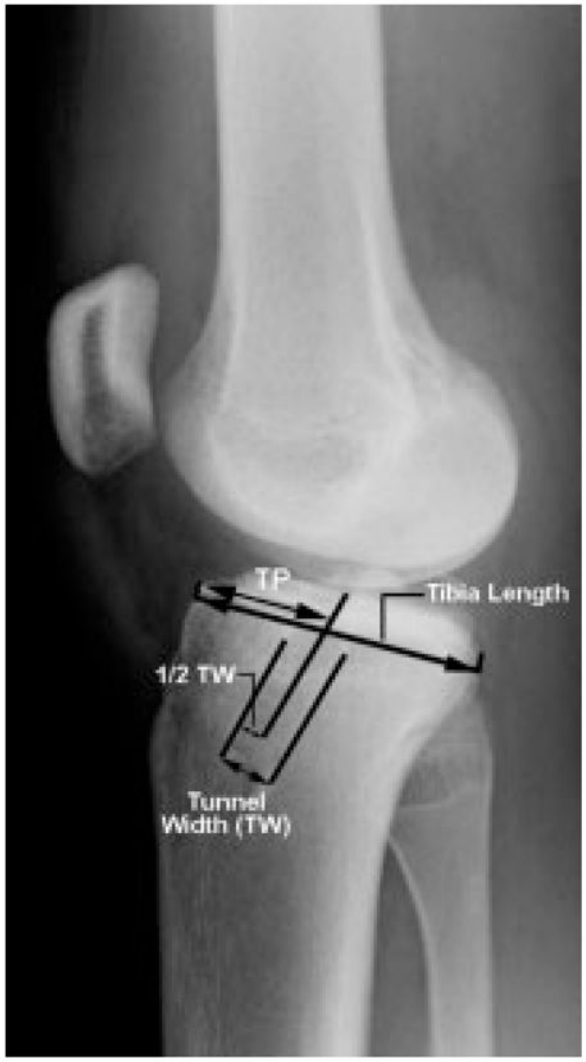


**Fig. 4.**
Tibial tunnel sagittal position. TP, tunnel position.

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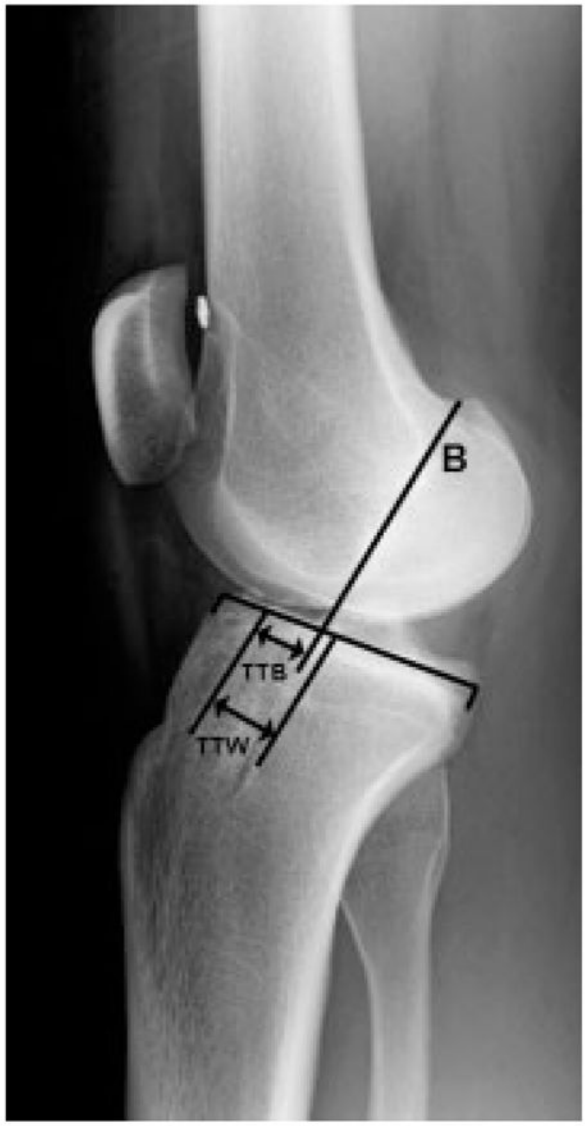


**Fig. 5.**
Tibial tunnel graft impingement. B, Blumensaat line; TTB, tunnel to Blumensaat line; TTW, total tunnel width.

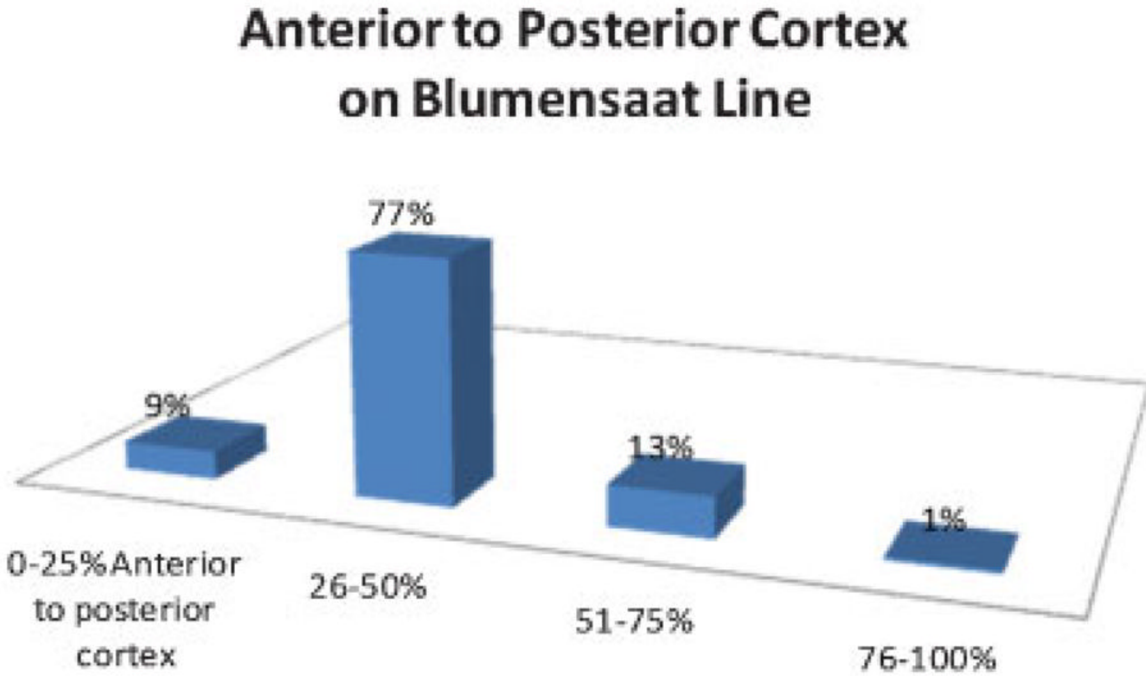


**Fig. 6.**
Results of femoral tunnel location along Blumensaat line.

## Table 1

MARS joint space narrowing on standing AP radiographs

| | **Medial minimum, %** | **Lateral minimum, %** | **Medial midpoint, %** | **Lateral midpoint, %** |
|---|---|---|---|---|
| 80 to > 100% | 83 | 88 | 95 | 93 |
| 60–79% | 12 | 10 | 5 | 7 |
| 40–59% | 4 | 1 | < 1 | < 1 |
| 20–39% | < 1 | 0 | 0 | 0 |
| 0–19% | 0 | < 1 | 0 | 0 |

Abbreviations: AP, anteroposterior; MARS, Multicenter Anterior Cruciate Ligament Revision Study.

**Table 2**

MARS joint space narrowing on Rosenberg bent knee radiographs

| | Medial minimum, % | Lateral minimum, % | Medial midpoint, % | Lateral midpoint, % |
|---|---|---|---|---|
| 80 to > 100% | 89 | 75 | 93 | 90 |
| 60–79% | 9 | 19 | 7 | 7 |
| 40–59% | 1 | 3 | 0 | 2 |
| 20–39% | 1 | 3 | < 1 | 1 |
| 0–19% | < 1 | < 1 | < 1 | < 1 |

Abbreviation: MARS, Multicenter Anterior Cruciate Ligament Revision Study.