Reliability of Early Postoperative Radiographic Assessment of Tunnel Placement After Anterior Cruciate Ligament Reconstruction

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Purpose: To evaluate the interobserver and intraobserver reliability of radiographic assessment of tunnel placement in anterior cruciate ligament reconstruction. **Methods:** Seven sports fellowship–trained orthopaedic surgeons in the Multicenter Orthopaedic Outcomes Network (MOON) group participated in the study. We prospectively enrolled 54 consecutive patients after primary anterior cruciate ligament reconstruction. Postoperative plain radiographs were obtained including a full-extension anteroposterior view of the knee, a lateral view of the knee in full extension, and a notch view at 45° of flexion (Rosenberg view). Three blinded reviewers performed 8 different radiographic measurements including those of Harner and Aglietti/Jonsson. Intraclass correlation coefficients were used to determine reliability of the measurements. Intrarater reliability was assessed by repeated measurements of a subset of 20 patient images from 1 institution, and inter-rater reliability was assessed by use of all 54 sets of films from a total of 4 institutions. **Results:** Intraobserver reliability for femoral measures ranged from none to substantial, with notch height having the worst results. Intraobserver reliability was moderate to almost perfect for tibial measures. Interobserver reliability ranged from slight to moderate for femoral measures. The Harner method for determining tunnel depth was more reliable than the Aglietti/Jonsson method. Interobserver reliability for tibial measures ranged from fair to substantial. The presence of metal interference screws did not improve reliability of measurements. **Conclusions:** Postoperative radiographs are easily obtained, but our results show that radiographic measurements are of quite variable reliability, with most of the results falling into the fair to moderate categories. **Level of Evidence:** Level III, diagnostic study.

Anterior cruciate ligament reconstruction (ACLR) is one of the most common orthopaedic procedures.[1] Although outcomes of ACLR surgery are generally very good, revision surgery in cases of ACLR failure is often much more technically challenging than the primary reconstruction. Preventing ACLR failure, therefore, is of paramount importance.

Multiple causes of ACLR failure have been de-

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Supported by a National Football League Medical Charities grant and a grant from the National Institutes of Health Mentored Clinical Research Scholar Program at Iowa (5K12RR017700-04).

The authors report the following potential conflict of interest or source of funding in relation to this article: NFL Charities.

Received May 10, 2011; accepted December 8, 2011.

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0749-8063/11291/$00.00
doi:10.1016/j.arthro.2011.12.010

scribed, including graft failure, fixation failure, secondary instability from concomitant ligamentous laxity, and surgeon technical error.[2] Inaccurate tunnel placement has been hypothesized to be one of the most common technical errors leading to ACLR failure.[3-9] Postoperative analysis of tunnel placement can be useful in predicting surgical success and in preparing for revision surgery. Furthermore, analysis of tunnel position on radiographs can assist surgeons in critiquing their surgical procedures, thereby enabling them to hone their skills and potentially improve the outcomes of future patients.[6,10]

Radiographic assessment of ACLR tunnel placement is a common and inexpensive way to analyze technical accuracy of tunnel placement.[11] Several authors have proposed methods for assessing anterior cruciate ligament (ACL) tunnels on plain films.[6,12-15] Webster et al.[16] studied measurement error and measurement reliability as they related to bone tunnel enlargement after ACLR. However, to our knowledge, there is very limited published information concentrating on the reliability of measurements of tunnel position based on plain radiographic measurements. Pinczewski et al.[10] found an overall intraclass correlation of 0.73 from all measurements of 2 orthopaedic fellow raters. However, their discussion did not go into detail about the reliability of specific measurements based on specific radiographic projections. Klos et al.[17] and Giron et al.[18] have examined the reliability of assessing femoral tunnel placement on sagittal imaging, but their studies did not address any other radiographic planes or other measurements. We aimed to measure the interobserver and intraobserver reliability of multiple postoperative radiographic measurements of tunnel placement in both the tibia and femur for ACLR. We hypothesized that the reliability of radiographic measures for ACL tunnels would be moderate.

METHODS

Seven surgeons in the Multicenter Orthopaedic Outcomes Network (MOON) performed the surgical procedures and enrolled patients in this study. A total of 54 patients from 4 sites were enrolled to participate after institutional review board approval was obtained at each site. Patients undergoing primary ACLR surgery were enrolled either preoperatively or at their first postoperative appointment. Patients with open physes, additional ligament surgery, or revision surgery; minors; and prisoners were excluded. Graft selection, surgical technique, and fixation were left to the surgeons' discretion but were documented. Of the 54 ACLRs, 12 were performed with bone–patellar tendon–bone constructs by use of aperture-based interference screw fixation and 42 were soft-tissue reconstructions (hamstring autograft or allograft) with cortically based fixation.

Digital radiographs were obtained at the first postoperative visit for the vast majority of patients and included a weight-bearing anteroposterior (AP) view of the knee, a lateral view of the knee at full extension, and a posteroanterior notch view of the knee at 45° (Rosenberg view), as performed in prior studies that have radiographically investigated postoperative ACL tunnel placement (Fig 1).[12-14,19] All films were taken within 6 weeks of surgery. At the lead investigator's home institution, 1 of the authors was responsible for personally monitoring the acquisition of the plain films to ensure that the "best possible" films were obtained. Lateral projections were retaken until there was perfect overlap of the medial and lateral femoral

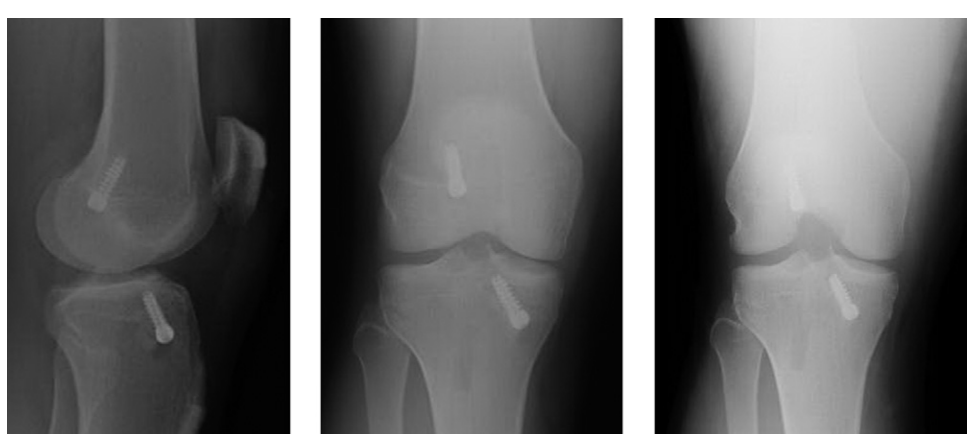

FIGURE 1. Postoperative plain film projections used for study: full-extension lateral (left), weight-bearing AP (middle), and posteroanterior notch (Rosenberg view, right).

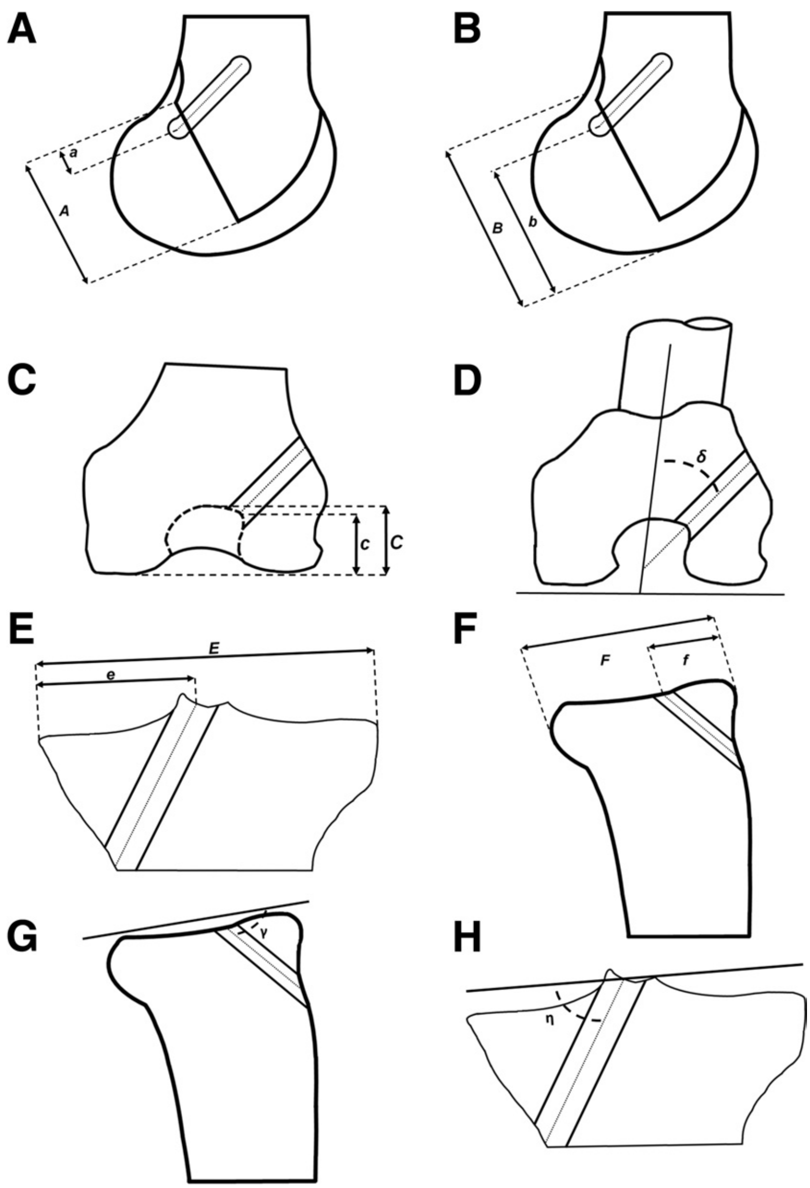

FIGURE 2. Diagrams describing each radiographic measurement: (A) percent Harner (a, distance from posterior Blumensaat's line to tunnel axis at aperture; A, total length Blumensaat's line); (B) percent Aglietti/Jonsson (b, distance from anterior lateral femoral condyle to tunnel axis at tunnel aperture; B, total measure of lateral femoral condyle measured perpendicularly to Blumensaat's line); (C) percent notch height (c, distance from tunnel axis at aperture to distal femoral articular surface; C, total height of intercondylar notch); (D) clock-face measure on Rosenberg view (angle measured from tunnel axis at aperture relative to anatomic femoral axis); (E) percent tibia medial-lateral position (e, distance from medial tibia edge to tibial tunnel axis at aperture; E, total coronal width of tibial plateau); (F) percent tibia AP position (f, distance from anterior tibia to axis of tibial tunnel at aperture; F, total sagittal width of tibial plateau); (G) tibia sagittal tunnel angle (γ, angle between tibial plateau and tibial tunnel axis in sagittal plane); and (H) tibia coronal tunnel angle (η, angle between tibial plateau and tibial tunnel axis in coronal plane).

condyles. Anterior/posterior projections were retaken until there was exactly 50% overlap of the fibular head on the lateral tibial plateau. This institution's best possible films were then used to establish the gold standard reliability for both intrarater and inter-rater analyses in our study. At the outside institutions, radiology technicians were instructed to reimage the knee as necessary to obtain adequate films and given written protocols as to appropriate radiographic studies. The AP view of the knee was deemed adequate for utilization in the study if there was between 5 and 15 mm of overlap between the fibular head and the proximal tibia.[6,13,20] The lateral radiograph of the knee was deemed adequate if there was greater than 90% overlap of the posterior femoral condyles.[21] The outside films were then used for the inter-rater analysis, and projection quality reflected what we believe is achievable at any clinic or hospital.

A total of 8 measurements were used in this study to help determine the reliability of radiographic assessment after tunnel placement and are schematically depicted in Fig 2. Measurements A and B are sagittal assessments of the femoral tunnel as previously proposed by Harner et al.[14] and by Aglietti et al.[12] and Jonsson et al.[15] The method of Harner et al. records the tunnel's aperture along the Blumensaat line as a percentage of the distance from the posterior edge (Fig 2A). Similarly, Jonsson et al. and Aglietti et al. proposed measuring the depth of the lateral femoral condyle at the level of the Blumensaat line and then describing the tunnel aperture as a percentage distance from an anterior perspective (Fig 2B), the difference being that Aglietti et al. measured to the anterior edge of the tunnel and Jonsson et al. measured to the center of the tunnel. Figure 2C shows the tunnel aperture height relative to the notch height as measured on an AP radiograph. Figure 2D depicts the clock-face angle as measured on the flexed-knee AP radiograph.[22] Figure 2E and 2F show tibial tunnel measurements on the AP and lateral radiographs.[23] Medial referencing was performed for the coronal measurement of the aperture (Fig 2E), and anterior referencing was performed for the sagittal measurement (Fig 2F). Figure 2G and 2H depict the tibial tunnel angle measurements in the sagittal and coronal planes, respectively, of lateral and AP radiographs.

Three blinded individual reviewers, all from 1 institution—consisting of an orthopaedic postgraduate year 1 resident, an orthopaedic postgraduate year 4 resident, and a sports fellowship–trained orthopaedic surgery staff—performed the measurements of all radiographs using a digital caliper, compass, and protractor (Iconico, New York, NY). The only reviewer who also performed surgery and enrolled patients in the study was the staff orthopaedic surgeon at the home institution. The other 2 reviewers did not participate in any of the included surgical procedures for which radiographs were analyzed. The protractor measured in degrees, and the caliper measured in pixels. The caliper was not calibrated to true millimeter sizes, because measurements were determined as a percentage of the width of an anatomic structure and thus had no units. An instructional meeting was performed, and an instructional packet with the measurement methods described in text and with sample images was given to each reviewer. The radiographs of 20 patients from 2 surgeons at 1 institution were blindly measured 3 separate times separated by at least 1 week by each reviewer to establish both intraobserver reliability and interobserver reliability by use of the "best attainable" radiographs for measurement collection. Then, the 34 sets of clinical radiographs from the outside institutions were blindly measured by each of the 3 reviewers to examine radiographic tunnel analysis reliability between hospitals or clinics, regardless of radiographic protocol or surgical technique. This separate analysis was performed because of concern that radiographic projectional imperfections, despite being considered of "adequate" radiographic quality, could decrease reliability of measurements. Therefore 20 sets of radiographs comprised the intrarater dataset, whereas 54 sets of images combined from all 4 institutions comprised the inter-rater dataset.

Table 1. *Reliability of ICC Values According to Landis and Koch**

ICC Value	Reliability
0.0-0.2	Slight
0.21-0.4	Fair
0.41-0.6	Moderate
0.61-0.8	Substantial
0.81-1.0	Almost perfect

*Data from reference 25.

Statistical Analysis

Measurement means and standard deviations were calculated to determine variability. $P < .05$ was used to designate statistically different mean measurements. The reliability of measurements was analyzed by use of intraclass correlation coefficients (ICCs) as described by Shrout and Fleiss.[24] In addition, inter-rater reliability was analyzed for those patients who had metallic interference screws placed to determine whether the placement of such intra-tunnel radiopaque markers improved measurement reliability. Agreement was classified according to the ICC value scaling of Landis and Koch[25] as slight, fair, moderate, substantial, or almost perfect (Table 1).

RESULTS

Measurement Means and Standard Deviations

Mean values with standard deviations for each measurement technique and rater from the single institution with the best attainable radiographs are depicted graphically in Fig 3 and listed in Table 2. Statistically significant differences in the mean measurements were found between the reviewers using the Aglietti/Jonsson method for measuring the femoral tunnel position on the lateral film ($P < .01$) (Fig 3B). For the tibia, significant differences were found for the tibial tunnel aperture medial-lateral position on the AP film ($P < .01$) (Fig 3E) and the tibial tunnel aperture AP position on the lateral film ($P < .01$) (Fig 3F). The inter-rater means and standard deviations from the outside institutions are shown graphically in Fig 4 and

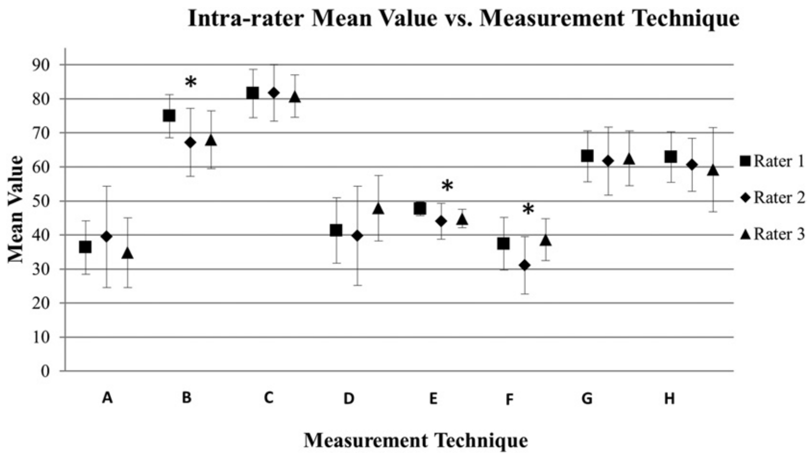

FIGURE 3. Intrarater measurement mean values with standard deviation (error bars): (A) percent Harner; (B) percent Aglietti/Jonsson; (C) percent notch height; (D) clock-face measure on Rosenberg view (in degrees); (E) percent tibia medial-lateral position; (F) percent tibia AP position; (G) tibia sagittal tunnel angle (in degrees); and (H) tibia coronal tunnel angle (in degrees). An asterisk indicates a statistically significant difference between the median values of the raters.

listed in Table 3. The means from all institutions were similar except for those measurements for which Harner's method was used, where the outside institution mean was 0.13 and the single institution mean was 0.24.

Intrarater Measurement Reliability

Intrarater and inter-rater reliability findings are displayed in Table 4. For the intrarater data, the reliability of the femoral tunnel measurements generally had moderate agreement for both the Aglietti/Jonsson and Harner methods. The clock-face measures were better, showing substantial agreement. Notch height showed the poorest intrarater reliability. In contrast to the femoral measurements, the tibial measurements had better reliability, showing substantial intrarater agreement.

Inter-rater Measurement Reliability

In comparison with the intrarater data, the inter-rater data generally showed less agreement between the measurements. The lateral-radiograph femoral tunnel measurements had only slight to fair agreement. For the subset of patients with metallic femoral tunnel screws, the Harner method showed improved reliability with moderate agreement. However, the Aglietti/Jonsson technique's reliability remained in the slight agreement range despite the radiopaque screw in the tunnel. The clock-face measurements were slightly better than the notch height measures in this measurement method, and the presence of metallic interference screws did not improve agreement. On the tibial side, the angle of the tibial tunnel in the sagittal and coronal planes had the most reliable inter-rater values, generally showing substantial agreement. Measurements of the aperture position from medial to lateral and from anterior to posterior were less reliable.

DISCUSSION

We hypothesized that early postoperative radiographs would provide moderate observer reliability for tunnel analysis. The results show that the radiographic measurements were not consistently reproducible from both intraobserver and interobserver perspectives. Ultimately, our data generally showed only fair to moderate agreement for both intrarater and inter-rater radiographic measurements of tunnel placement after ACLR. This is in contrast to the study of Pinczewski et al.[10] that reported an overall ICC of 0.73, reflecting substantial agreement for all of their measurements from 2 reviewers. Their study did not comment on the different reliabilities for specific views but rather stated that the overall agreement was substantial. The only measurements in our study that had substantial agreement were those that measured tunnel angles and not tunnel aperture position. We found that it is radiographically difficult to locate the position of tunnel apertures using postoperative radiographs, regardless of fixation method. Because all films analyzed were digital, individual raters were able to adjust contrast as needed to best visualize the location of the tunnels. Although all of the tunnels' trajectories were ultimately identifiable by adjusting the contrast of the images, it remained difficult at times to determine the exact position of the tunnel aperture. This difficulty is reflected in our results when comparing the better reliability of tunnel angle measurements versus tunnel aperture measurements.

Table 2. *Intrarater Measurement Means and Standard Deviations From 20 Subjects and at a Single Institution*

	Mean ± SD								
	Rater 1			Rater 2			Rater 3		
	First	Second	Third	First	Second	Third	First	Second	Third
Femur									
Harner (lateral)	0.287 ± 0.142	0.225 ± 0.146	0.211 ± 0.131	0.209 ± 0.089	0.187 ± 0.065	0.180 ± 0.059	0.234 ± 0.098	0.209 ± 0.084	0.212 ± 0.092
Aglietti/Jonsson (lateral)	0.672 ± 0.100	0.693 ± 0.105	0.703 ± 0.091	0.749 ± 0.064	0.754 ± 0.059	0.766 ± 0.044	0.686 ± 0.088	0.698 ± 0.069	0.716 ± 0.086
Notch height	0.817 ± 0.083	0.790 ± 0.075	0.826 ± 0.051	0.816 ± 0.071	0.843 ± 0.070	0.835 ± 0.035	0.808 ± 0.062	0.798 ± 0.038	0.843 ± 0.107
Clock-face angle (°)	39.80 ± 14.59	36.70 ± 10.78	37.65 ± 9.71	41.31 ± 9.60	37.36 ± 6.75	36.00 ± 7.72	47.95 ± 9.63	51.06 ± 10.72	54.92 ± 8.88
Tibia									
Lateral	0.311 ± 0.084	0.339 ± 0.072	0.346 ± 0.068	0.374 ± 0.077	0.414 ± 0.063	0.410 ± 0.070	0.384 ± 0.067	0.386 ± 0.065	0.403 ± 0.068
AP	0.440 ± 0.053	0.434 ± 0.039	0.427 ± 0.034	0.477 ± 0.020	0.485 ± 0.019	0.479 ± 0.025	0.448 ± 0.027	0.458 ± 0.019	0.458 ± 0.027
Lateral angle (°)	60.33 ± 7.77	60.75 ± 6.61	59.65 ± 9.10	62.86 ± 7.43	61.22 ± 7.08	62.15 ± 6.79	60.02 ± 12.56	63.91 ± 7.54	63.91 ± 8.57
AP angle (°)	61.65 ± 10.04	63.30 ± 7.20	62.80 ± 8.34	63.08 ± 7.49	61.75 ± 7.51	63.01 ± 7.18	62.51 ± 7.99	63.36 ± 8.79	62.59 ± 8.93

NOTE. Angle measurements are reported in degrees; all other measurements are proportional as described in Fig 2.

Of the various measurements analyzed, the sagittal femoral method previously described by Harner et al.[14] demonstrated better measurement reproducibility and higher reliability for both intrarater and inter-rater measures than that described by Aglietti et al.[12] and Jonsson et al.[15] In fact, the Aglietti/Jonsson method had the poorest inter-rater agreement of all measurements performed. The measurements with the poorest intrarater reliability in this study were the femoral tunnel measurements based on the AP and Rosenberg views.

Given the difficulty of determining the position of the tunnel aperture on plain films postoperatively, we predicted that the analysis method would have only fair intraobserver and interobserver reliability. Representing a 3-dimensional structure on a 2-dimensional plain film allows small rotational or angular projections to affect measurements. Furthermore, overlying anatomic structures including soft tissue and bone can obscure the visualization of the structure of interest. In an attempt to minimize the effects of imperfect radiographs on the measurements, guidelines were followed for what was considered acceptable imaging at the outside institutions. Furthermore, at the home institution, 1 of the authors (C.L.B.) personally oversaw the imaging to ensure that the best possible films were obtained. This subset of films was used to establish the intrarater reliability. Despite these efforts, there undoubtedly remained some rotational imperfections that affected the measurements. It was interesting that when the "ideal circumstance" films were analyzed for intrarater reliability, those images showed less agreement than the images from outside institutions for the femoral measurements (Table 4).

Reliability assessments for the femoral tunnel by use of sagittal images have been studied previously. Klos et al.[17] used intraoperative fluoroscopic views of drill pin or guidewire position. They determined that the method proposed by Amis et al.[13] had superior reliability compared with the techniques described by either Harner et al.[14] or Aglietti et al.[12] Whereas intraoperative fluoroscopy allows visualization of metallic markers, it adds case time to the surgery and its routine use has not been universally adopted during ACLR. Similarly, Cheng et al.[26] found in a meta-analysis and systematic review that computer navigation systems added 8 to 17 minutes to operative time. Giron et al.[18] also discussed reliability of femoral tunnel position based on sagittal radiographs. Their study included 2 reviewers, and the repeated measurements were performed either the same day or the next day. The 2 aforementioned studies did not evaluate the

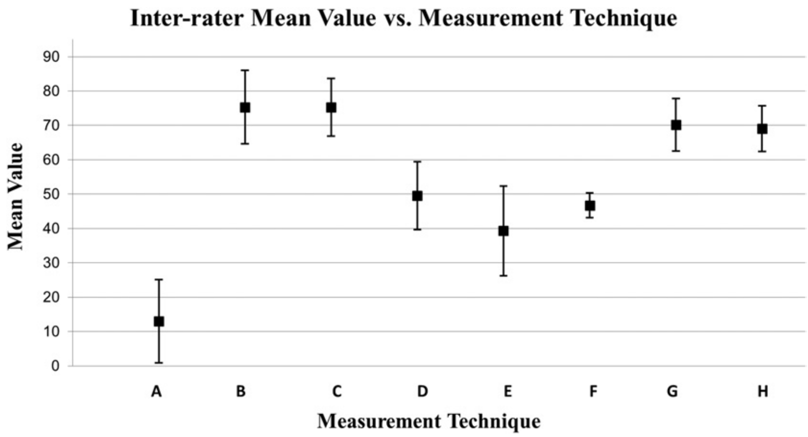

FIGURE 4. Inter-rater measurement mean values for 34 patients from outside institutions with standard deviation (error bars): (A) percent Harner; (B) percent Aglietti/Jonsson; (C) percent notch height; (D) clock-face measure on Rosenberg view (in degrees); (E) percent tibia medial-lateral position; (F) percent tibia AP position; (G) tibia sagittal tunnel angle (in degrees); and (H) tibia coronal tunnel angle (in degrees). An asterisk indicates a statistically significant difference between the median values of the raters.

reliability of other measurements from other radiographic projections. We aimed to assess the reliability of a simple yet comprehensive tunnel analysis method using 8 measurements based on 3 common X-ray projections (AP, lateral, and Rosenberg views). In this study, analysis of the femoral tunnels based on sagittal radiographs showed that the method described by Harner et al. showed higher ICC scores than the method of Aglietti et al. in both the intrarater and inter-rater analyses. Furthermore, there was also a significant difference between the mean values based on the method of Aglietti et al. measured between reviewers, suggesting that measurements were performed differently despite clear instructions on how to perform them. One possible explanation for this is occasional difficulty in correctly identifying the femoral condyles on the lateral view. In some knees the sulcus terminalis is very prominent, making distinction of the lateral condyle easier. However, this is not the case in all knees. In addition, the boundaries of the Blumensaat line, as well as the borders of the anterior femoral notch and the posterior femoral notch (the "over-the-top position"), are generally more clearly identifiable during measurements.

A quadrant method for describing the femoral tunnel aperture position on sagittal-plane radiographs has been described and used in studies performed by Bernard et al.,[27,28] Zantop et al.,[29] and Behrend et al.[30] Effectively, this method uses similar anatomic landmarks to the Harner and Aglietti/Jonsson measurement techniques, in addition to those used in this study, to create a quadrant graph overlying the lateral femoral condyle on the lateral radiograph. With this system, the location of the tunnel can be localized with respect to where the aperture falls on this graphic representation of the lateral femoral condyle. Although

TABLE 3. *Inter-rater Measurement Means and Standard Deviations From 34 Subjects From Outside Institutions*

	Mean ± SD		
	Rater 1	Rater 2	Rater 3
Femur			
Harner (lateral)	0.105 ± 0.188	0.140 ± 0.056	0.144 ± 0.120
Aglietti/Jonsson (lateral)	0.761 ± 0.095	0.784 ± 0.059	0.715 ± 0.167
Notch height	0.752 ± 0.072	0.765 ± 0.081	0.741 ± 0.099
Clock-face angle (°)	43.41 ± 10.28	46.59 ± 10.12	58.53 ± 9.26
Tibia			
Lateral	0.347 ± 0.087	0.407 ± 0.067	0.426 ± 0.239
AP	0.451 ± 0.045	0.479 ± 0.025	0.470 ± 0.038
Lateral angle (°)	68.82 ± 7.74	71.37 ± 7.65	70.23 ± 7.54
AP angle (°)	68.62 ± 6.59	69.30 ± 6.85	69.39 ± 6.58

NOTE. Angle measurements are reported in degrees; all other measurements are proportional as described in Fig 2.

TABLE 4. *Intraclass and Interclass Correlation Coefficients*

	Intrarater Reliability Calculated From Measurements on 20 Radiographs Contributed by 2 Surgeons From 1 Institution			Inter-rater Reliability Calculated From Measurements on 20 Radiographs Contributed by 2 Surgeons From 1 Institution	Inter-rater Reliability Calculated From Measurements on 34 Radiographs Contributed by 6 Surgeons From 3 Outside Institutions	Inter-rater Reliability Calculated From Measurements on 12 Radiographs From ACLRs Performed With Bone–Patellar Tendon–Bone Grafts With Aperture-Based Metal Interference Screws
	Rater 1	Rater 2	Rater 3			
Femur						
Harner (lateral)	0.39	0.57	0.53	0.12	0.38	0.54
Aglietti/Jonsson (lateral)	0.45	0.56	0.48	0.06	0.24	0.07
Notch height	0.23	0.00	0.04	0.33	0.38	0.25
Clock-face angle	0.71	0.77	0.52	0.34	0.43	0.33
Tibia						
Lateral	0.75	0.79	0.63	0.23	0.41	0.15
AP	0.66	0.60	0.47	0.43	0.25	0.08
Lateral angle	0.70	0.75	0.46	0.73	0.43	0.69
AP angle	0.71	0.88	0.77	0.76	0.63	0.75

this system does provide a visual representation that easily evaluates tunnel location, little is reported on its reliability. Furthermore, the quadrant is created by use of the same landmarks as the measurement techniques analyzed in this article, and therefore essentially the same measurements are made. Moreover, the quadrant method can restrict the surgeon or radiographic interpreter's precision of measurement to categorical data (quadrant locations) rather than a running numerical percentage position.

The technique used to measure femoral tunnel position by use of the AP and notch views showed the lowest reliability. These are the views that typically can give the reviewer an indication of the height of the tunnel on the medial wall of the lateral femoral condyle. On these radiographic views, the patella can overlie and therefore obscure visualization of the intercondylar notch. In addition, notchplasty performed at the time of surgery can potentially alter the radiographic appearance of the cortical bone along the medial side of the lateral condyle in the notch. The tunnel location on the AP view resulted in great difficulty in trying to determine where the tunnel entered the notch, especially when no metal interference screw was present. Lastly, the notch view was variable in helpfulness in determining tunnel location along the lateral condyle. Altogether, it is difficult to use radiographs to judge tunnel height in most circumstances.

We anticipated that the presence of a metallic interference screw in the tunnels would improve agreement (Table 4). Of the 54 reconstructions in this study, 12 used bone–patellar tendon–bone grafts with metallic interference screw fixation that were based at the femoral tunnel aperture. The remaining 42 grafts were fixed with cortically based devices. Our results show that only the measurements taken with the Harner technique had improved reliability scores when metallic interference screw fixation was used at the femoral tun-

FIGURE 5. Example of tunnel cortication with soft-tissue graft.

Figure 6. Example of tunnel aperture falling outside of measurement parameters of Harner et al.[14]

nel aperture. The potential difficulty in correctly identifying the lateral femoral condyle, as previously discussed, may have factored into why there was no apparent improved agreement with the Aglietti/Jonsson technique. In addition, interference screws are inherently placed eccentrically in tunnels because they are displaced to some degree by the graft for which they provide fixation. Therefore the central aperture of the drilled tunnel and the central axis of the screw do not necessarily represent the same position, and this could lead to variability in the measurements.

Another factor that we predicted would improve agreement was the presence of cortication of the tunnels (Fig 5). This phenomenon has been shown to occur with soft-tissue grafts using cortically based fixation methods.[31] In our study there were 42 soft-tissue grafts using cortically based fixation. However, few of the patients in this study had cortication of their tunnels, because images were taken at the first postoperative visit, likely well before this phenomenon can be appreciated radiographically.

Several limitations of this study should be considered when one is interpreting the results. First, the level of reviewer training may influence the accuracy of measurements. In this study 3 orthopaedists (B.R.W., B.A.W., M.C.W.) of different levels of training were used. However, we did not find a pattern that would indicate that experience level played a significant role in our outcomes. Second, the timing of the radiographs may have influenced our results. Most of the included patient radiographs were obtained at the first postoperative visit after surgery, and all radiographs were taken within 6 weeks of surgery. Tunnels with soft-tissue grafts often become more visible the further from surgery that the radiographs are taken. It is possible that our results would be altered if most films were obtained much further from the surgery date. Next, as stated previously, the quality of the radiographs likely influences the reliability of the measurements. Although radiographs were retaken if it was believed that they were rotated or angulated, it is difficult to account for small differences in the projections of each image. Images were taken at 4 different institutions, with each using a different digital system, which adds more variability but likely more generalizability to the study. It is unclear how the institutional variability impacts the reliability of measurements. Tunnel locations were occasionally very difficult to identify radiographically, as noted by prior authors.[21] However, the reviewers were not queried as to whether the tunnel was clearly identifiable or not in this study. The reviewers were asked to attempt tunnel measures for each case. In addition, only a relatively small number of ACLRs (N = 54) were analyzed. Increased numbers in the study could allow for more definitive conclusions. Lastly, the radiographic measurement systems used in the study were at times not applicable to individual cases. For example, in some cases, the tunnel aperture was believed to fall outside the radiographic parameters used in the study, despite the image satisfying the requisites of an acceptable radiograph (Fig 6). Each reviewer likely dealt with this issue in a different manner.

CONCLUSIONS

Postoperative radiographs are easily obtained, but our results show that radiographic measurements are of quite variable reliability, with most of the results falling into the fair to moderate categories.

Acknowledgment: *Contributing authors* from the Multicenter Orthopaedic Outcomes Network (MOON) Knee Group are as follows: S. Jack T. Andrish, M.D., Richard D. Parker, M.D., Eric C. McCarty, M.D., Armando F. Vidal, M.D., Rick W. Wright, M.D., Robert Brophy, M.D., Kurt P. Spindler, M.D., and Warren R. Dunn, M.D., M.P.H.

The authors thank the following members of the MOON Knee Group for their assistance with this study: James Carey, M.D., M.P.H., Charles Cox, M.D., M.P.H., Morgan H. Jones, M.D., M.P.H., Robert G. Marx, M.D., M.Sc., F.R.C.S.C., Michelle Wolcott, M.D., Matthew J. Matava, M.D., Matthew V. Smith, M.D., Christopher C. Kaeding, M.D., and David C. Flanigan, M.D. The authors also thank Nicole Grosland, Ph.D., for her bioengineering expertise and contributions to the study.

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