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What is This?
Reliability of Tunnel Measurements and the Quadrant Method Using Fluoroscopic Radiographs After Anterior Cruciate Ligament Reconstruction

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Background: Anterior cruciate ligament (ACL) reconstruction tunnel placement is often evaluated by radiographs. This study examines the interobserver reliability of various radiographic measurements of ACL tunnels.

Hypothesis: When ideal radiographic views are obtained, the interobserver reliability of the measurements among experienced surgeons would be good to excellent.

Study Design: Descriptive laboratory study.

Methods: Tunnels for single-bundle ACL reconstruction were drilled and filled with metal interference screws or a tibial reamer on 73 cadaveric knees. Ideal fluoroscopic radiographs were obtained. Three independent reviewers performed 18 measurements including a modification of the grid method. For the grid method analysis, reviewers fit a 16 × 12 grid to the lateral knee radiograph, and the center of the femoral tunnel was marked. Interobserver reliability of the measurements was performed using intraclass correlation coefficients (ICCs). A precision grouping analysis was performed for the grid measurements to calculate the mean radius and standard deviation grouping distances.

Results: The ICCs were excellent (.75) for the tibial tunnel angles and tunnel measurements, the clock face measurement, and the Aglietti et al and Jonsson et al measurements. The ICCs were good (.4-.75) for an estimation of graft impingement, Harner et al measurements, and notch height. The mean radius for grid measurements was 0.6 ± 0.4 units (range, 0-2.36 units), with each unit being 1 box in the 16 × 12 grid. When a circle was constructed with a 1.3-unit radius, 95% of the 3 surgeons’ measurements would be included in the area of that circle.

Conclusion: Reliability of ACL tunnel measurements was good to excellent under ideal circumstances for the majority of measurements. The modified grid method demonstrated very acceptable reliability.

Clinical Relevance: Measurements with good to excellent reliability can be used to evaluate ACL tunnel placement when ideal radiographic views are obtained.

Keywords: MOON; ACL reconstruction; cruciate; tunnel; reliability

Anterior cruciate ligament (ACL) reconstruction is one of the most common orthopaedic procedures.5 Rerupture rates at a minimum of 5 years’ follow-up are estimated to be 5.8%.21 Revision surgery is more difficult to perform and adds a substantial cost to health care expenditures. It is important to better understand why ACL reconstruction fails and to develop measures for prevention.

Anterior cruciate ligament reconstruction failure has been postulated to occur by various causes including graft failure, fixation failure, secondary instability of the knee, and surgical error.11 Inaccurate tunnel placement is thought to be one of the most common technical reasons for ACL reconstruction failure.12,20 Postoperative radiographs are frequently used to assess tunnel location. Multiple measurement techniques have been developed to analyze tunnel placement accuracy.1,2,8,13,14 There is limited knowledge about the reliability of some of the common tunnel radiographic measurements. Pinczewski et al17 found an overall intraclass correlation of .73 from all measurements of 2 orthopaedic fellow raters, but reliabilities were not reported about specific measurements. Klos et al15 and Giron et al19 have examined the reliability of assessing femoral tunnel placement on sagittal imaging. Overall, there is a relative paucity of data reporting the accuracy or precision of these measurements in light of how frequently ACL reconstruction is performed and analyzed. As a result, it is difficult to ascertain which

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measurements are the most relevant clinically. Our hypothesis was that when ideal radiographic views are obtained, the reliability of the various different measurement techniques among experienced surgeons would be good to excellent.

MATERIALS AND METHODS

Twelve knee surgeons in the Multicenter Orthopaedic Outcomes Network (MOON), who routinely perform arthroscopically assisted ACL reconstruction, drilled ACL tunnels in 73 cadaveric specimens and filled the femoral tunnels with 11-mm metal interference screws. Tibial tunnels were either filled with 11-mm metal interference screws, or a 10-mm tibial reamer was placed in the tunnel during imaging. The reamer was used in the tibial tunnel on 65 of the 73 cadaveric specimens because of a limited number of interference screws available. Each knee was subsequently imaged using a large digital C-arm fluoroscopy unit operated by a radiology technologist. An orthopaedic surgeon not participating in the tunnel drilling portion of the study positioned the specimens and directed the imaging. Fluoroscopic anteroposterior (AP), lateral, and notch view radiographs were taken and repeated until ideal views were obtained. The optimal AP view was defined as the lateral tibial plateau overlapping the center of the fibula. The optimal lateral view was defined by having the medial and lateral femoral condyles overlapping by at least 90%. The optimal notch view was obtained by adjusting the amount of flexion and rotation until the notch was in profile for the greatest dimension by height (adjusting flexion) and width (adjusting rotation). During the process, lateral images were not saved on 2 specimens, which left 71 specimens for the lateral radiographic measurements.

Radiographic Measurements

Three independent MOON knee surgeons then performed a series of measurements described below (including those described by Harner et al, Aglietti et al, and Jonsson et al) (Figure 1). All 3 reviewers were sports medicine fellowship–trained surgeons. They had 14, 5, and 3 years of clinical practice, respectively. All images were imported into a PowerPoint (Microsoft, Redmond, Washington) slide presentation. The surgeons individually performed measurements with an Iconico (New York, New York) digital protractor, caliper, and digital compass. All measurements demonstrated in Figure 1 result in a percentage or angle measurement that facilitates comparison by eliminating differences in magnitude when the zoom is adjusted by the surgeon before performing the measurements. The Harner et al method measures the aperture of the tunnel along the Blumensaat line as a percentage of the total distance of the Blumensaat line from posterior to anterior (Figure 1A). For the Harner et al measurements, we used the anterior edge of the tunnel aperture as well as the center of the aperture for reference points. The Aglietti et al method and the Jonsson et al method both measure the aperture of the tunnel along the Blumensaat line as a percentage of the distance from the anterior edge of the condyle (Figure 1B). Aglietti et al measured from the anterior edge of the tunnel, and Jonsson et al measured to the center of the tunnel. The tunnel aperture height was measured relative to the notch height perpendicular to a line along both distal femoral condyles as seen on an AP radiograph (Figure 1C). The “o’clock angle” was measured on the flexed knee AP radiograph. A protractor was used to draw a line across the most inferior aspect of the femoral condyles. The second limb of the protractor was positioned vertically at 83° to establish orientation to the 12-o’clock position accounting for 7° of femoral valgus. A digital compass was then used to create a circle with the upper border touching the top of the notch and the lower border tangent to the line along the inferior aspect of the femoral condyles. The digital compass was then centered in the circle, and the angle was measured from the 12-o’clock position to the center of the aperture. This angle was used for the o’clock position measurement (Figure 1D). For the coronal plane tibial tunnel measurements, the reference point used for measurements on AP radiographs was the medial plateau. The distance from the edge of the medial tibial plateau to the edge of the lateral tibial plateau was measured in comparison to the distance to the center of the tibial tunnel (Figure 1E) as well as in comparison with the lateral aspect of the tibial tunnel. The sagittal plane tibial reference point was the anterior aspect of the tibial plateau. The distance from the anterior plateau to the posterior plateau in comparison with the distance to the center of the tibial tunnel (Figure 1F) and the posterior aspect of the tibial tunnel as it enters the joint was measured. The tibial tunnel measurement angles in the sagittal and coronal planes of lateral and AP radiographs were made in comparison with the joint line (Figure 1G and 1H). Radiographic potential for graft impingement was also evaluated on the lateral radiographs as described by Howell and Taylor.

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A line was placed over the anterior aspect of the tibial tunnel and extended proximally to cross the femur. If that line projected anterior to the Blumensaat line, then it was reported that there was potential graft impingement.

Grid Analysis

Anatomic radiographic studies have published the location of the femoral footprint in terms of percentages; however, our purpose was not to identify the anatomic location of the footprint or the accuracy with which these surgeons could place the tunnels compared with the anatomic footprint. Our purpose was to identify whether surgeons using the grid method could identify and report with precision the location of the femoral tunnel.

Reviewers were given digital lateral radiographs and a 16 × 12 box grid representing a modification of the 4 × 4 box grid method described by Bernard et al. The preset grid \((x,y (16,12))\) could be expanded or collapsed in both the x-axis and y-axis and rotated as needed to be fit over the lateral femoral condyle. The surgeons were instructed to place the most superior x-axis line of the grid overlapping and parallel to the Blumensaat line. The most inferior x-axis line is tangent to the distal femoral condyle. The outermost y-axis lines are positioned so that they cross the proximal line (x-axis line along the Blumensaat line) at the point that the x-axis crosses the anterior and posterior aspects of the femoral condyles (Figure 2). The reviewers then marked the box deemed closest to the center of the femoral tunnel aperture on the grid. The subunits in the original grid method graph were increased from 4 × 4 to 16 columns × 12 rows so that there would be increased specificity for our analysis (Figure 2). If the results of the analysis demonstrated low precision, then it could be argued that the low precision may just be a result of our measurement methods. However, if the precision is good, then the question of whether the methods are precise enough is irrelevant. Ultimately, the grid that we devised was just a digital tool that the surgeons used to make the measurements. One unit is 1 box or subunit of the modified Bernard et al. grid system.

For each specimen, the center of the 3 surgeon’s measurements was calculated. We then calculated the distance of each subunit marked by the surgeon to the center of the group of subunits. This allowed us to calculate an average radius for all specimens combined, and it gives perspective of how close together the surgeons’ measurements were located.

Statistical Analysis

All measurement data were reviewed for gross errors. After data were reviewed, 14 of nearly 4000 measurements were eliminated because they were impossible based upon the description and definition of the measurements. Intraclass correlation coefficients (ICCs) were used to determine the reliability of all measurements, excluding the grid analysis, as described by Shrout and Fleiss (ICC 3.1). Agreement was classified according to the Shoukri and Pause ICC value rating scale of reliability as poor (<=.40), good (.40-.75), and excellent (> .75). This is only 1
breakdown analysis for the ICCs, and other methods have been reported with slightly more complex breakdowns for the reliability. Landis and Koch\(^{16}\) reported a scale of reliability for ICCs of slight (.0-.2), fair (.21-.4), moderate (.41-.6), substantial (.61-.8), and almost perfect (.81-1.0). Although they used this comparison for the \(k\) statistic, ICCs have been shown equivalent to the weighted \(k\) for ordinal data.\(^4\) Both methods of analyzing ICCs offer a similar interpretation, and both can be used by the reader for comparison. We elected to use the Shoukri and Pause\(^{18}\) method for our analysis to simplify categorizations, but the data stand alone for comparison by the reader.

For the grid measurements, the distance from each surgeon’s measurement to the calculated center was taken for each specimen, and total averages were obtained for all specimens combined. The standard deviation was calculated, and the distribution and frequency of measurements were reported. Because all of the measurements were done within the grid diagram, the grid results are all reported as units within the plotted diagram.

**RESULTS**

The ICCs were excellent (> .75) for the Aglietti et al\(^1\) and Jonsson et al\(^{13}\) femoral tunnel measurements, the sagittal and coronal plane measurements and angles of the tibial tunnels, and the clock face measurement. The ICCs were good (.4-.75) for an estimation of graft impingement, the Harner et al\(^{8}\) measurements, and tunnel height measurements in the notch. There were no poor (< .4) measurements (Table 1).

The mean radius for the grid measurements was 0.6 ± 0.4 units (median, 0.47 units; range, 0-2.36 units), with each unit being 1 box in the 16 × 12 grid. When a circle was constructed with a 1.3-unit radius, 95% of the 3 surgeons’ measurements would be included within the area of that circle (Figure 3).

**DISCUSSION**

This study reports on the reliability of several commonly used measurements for evaluating ACL tunnel position on ideal radiographs after reconstructive ACL surgery. The majority of the radiographic and angular measurements were excellent. There was excellent interobserver reliability, according to the ICCs, for the AP and lateral tibial tunnel angles, the clock face measurement, Aglietti et al\(^1\) and Jonsson et al\(^{13}\) tunnel measurements, the sagittal plane tibial tunnel measurements, and AP tibial tunnel measurements. The findings of our study agree with those of Pinzewskei et al,\(^{17}\) which demonstrated an overall ICC of .73 for ACL tunnel measurements. However, that study did not subdivide reliabilities of the different measurements so individual comparisons are difficult. We advocate that these measurements on ideal radiographic views of the knee can be used for analyzing tunnel positions on plain radiographs postoperatively or intraoperatively.

This study demonstrated good interobserver reliability results based upon the ICCs for the impingement measurement, the Harner et al\(^{8}\) femoral tunnel measurement, and the notch height measurement. However, the Harner et al\(^{8}\) measurements and the estimation of graft impingement were borderline to being classified as excellent, whereas the notch height is borderline to being classified as poor.

**TABLE 1**

<table>
<thead>
<tr>
<th>Measurement</th>
<th>ICC(3,1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lateral tibial tunnel angle</td>
<td>.9209</td>
</tr>
<tr>
<td>Graft impingement</td>
<td>.6836</td>
</tr>
<tr>
<td>Anteroposterior tibial tunnel angle</td>
<td>.9832</td>
</tr>
<tr>
<td>Anteroposterior clock face</td>
<td>.7760</td>
</tr>
<tr>
<td>Harner et al(^{8}) to center of tunnel</td>
<td>.6543</td>
</tr>
<tr>
<td>Harner et al(^{8}) to anterior edge of tunnel</td>
<td>.6915</td>
</tr>
<tr>
<td>Aglietti et al(^1) to center of tunnel</td>
<td>.7879</td>
</tr>
<tr>
<td>Aglietti et al(^1) to anterior edge of tunnel</td>
<td>.8279</td>
</tr>
<tr>
<td>Lateral anterior edge of tibia to center of tunnel</td>
<td>.8076</td>
</tr>
<tr>
<td>Lateral anterior edge of tibia to posterior edge of tunnel</td>
<td>.8090</td>
</tr>
<tr>
<td>Anteroposterior percentage of tibial plateau from medial to tunnel axis</td>
<td>.7455</td>
</tr>
<tr>
<td>Anteroposterior percentage of tibial plateau from medial to lateral tunnel border</td>
<td>.7768</td>
</tr>
<tr>
<td>Axis of tunnel/tunnel height</td>
<td>.4246</td>
</tr>
</tbody>
</table>

Figure 3. The black circle represents the mean radius of 0.6 units, and the gray circle represents the radius that included 95% of the surgeons’ measurements (1.3 units). The locations of the circles on the grid were chosen independent of any data from the study.
ures for ACL tunnels was done by Khalfayan et al,14 who
should be used with caution.
rent findings, we believe the notch height measurement
studies in the orthopaedic literature and in light of our cur-
were not identifiable. Because of the lack of reliability
in 92% (46/50) of their radiographs because landmarks
measure the femoral tunnel height on the AP radiograph
in the study of Hoser et al9 in which they were unable to
measure different measurements, which included a novel AP and lat-
eral femoral tunnel measurement, a notch height
measurement, and AP and lateral tibial tunnel measure-
ments. The measurements were performed on 2 separate
occasions. The authors used an analysis of variance and
reported interobserver and intraobserver variability in
terms of a P value. The only measurement that they found
to have a statistically significant amount of variability was
the interobserver notch height, suggesting that that measure-
ment is highly variable and less useful in a clinical con-
text. Because this prior study did not evaluate an ICC,
direct comparisons cannot be made about the degree of con-
sistency or reproducibility of the measurements. Also, direct
comparison with the results of the current study is difficult.
No prior study has evaluated the reliability of the grid
measurement system described by Bernard et al.3 To increase
the reviewers’ measurement accuracy, and to more defini-
tively analyze reviewer agreement, the number of boxes in
the grid was increased from the original quadrant 4 × 4
grid to a 16 × 12 grid. Increasing the number of boxes allows
for more precise analysis of rater agreement and functions as
a digital measurement tool in the study. Because there is no
standard for comparison, the results stand alone for inter-
pretation. Our impression is that there was substantial precision
with a mean radius of 0.6 units of the entire grid. If the com-
plex statistics are thrown aside, all 3 surgeons’ measurements
were within a distance of 2 of the small boxes 95% of the time.
This proximity is appreciated better visually than verbally
(Figure 3). The quadrant method is often utilized with per-
centage measurements from anterior to posterior and supe-
rior to inferior. In terms of percentages, each box would
represent 6.3% from posterior to anterior and 8.3% from supe-
rior to inferior. Hence, applying these percentages to our
mean radius analysis, the reviewers were, on average, within
0.6 boxes or 4% to 6% of each other. Similarly, 95% of the
measures were within a circle with a diameter roughly repre-
senting 12% to 16% of the superior-inferior and anterior-
posterior percentages of the lateral femoral condyle.

There are several limitations of the study that merit dis-
cussion. This study used fluoroscopic radiographs rather
than plain radiographs. These radiographs were consid-
ered ideal as they were repeated under the supervision of
an orthopaedic surgeon until deemed acceptable. It is
likely that the results would be less reliable with radi-
ographs taken in a routine clinic or hospital setting because
of rotational issues with the radiographs. An additional
weakness is that no graft was placed during these proce-
dures. As a result, the metal interference screws would
be positioned in the center of the tunnels rather than
eccentrically as would happen in clinical scenarios when
the graft would push the screw to an eccentric location.
This does not change the precision of the measurements,
which is the focus of this study, but for clinical scenarios,
it could slightly alter the location of the reconstructed
ACL, changing the accuracy of the calculated location. In
addition, a reamer was used in the tibial tunnel in most
cadaveric specimens in place of an interference screw.
We have no evidence whether the reamer would be better
or worse than the interference screw; however, it would
more clearly identify the tunnel borders and may increase
the accuracy for that small subset of the data. All
reviewers were sports medicine fellowship trained and reg-
ularly perform ACL surgery. Hence, our findings may not
be generalizable to other reviewers with different types
or levels of training. No assessment of intraobserver reli-
bility was performed, nor was there any analysis of accu-
cacy of measurements against dissection or advanced
imaging. Lastly, although several measures were per-
formed for both the tibia and femur, there are other meas-
ures that we did not evaluate for reliability, including the
femoral tunnel circle method as described by Amis et al.2
Klos et al15 later demonstrated superior ICCs with the cir-
cle method when compared with the Harner et al8 and
Giron et al6 measurements. However, because this method
is not used regularly in our clinical environment, it was not
included in the design of this study.

In conclusion, when ideal fluoroscopic imaging and metal
interference screws or markers are obtained, the majority of

Figure 4. Anteroposterior radiograph of the knee from this
study demonstrating the difficulty in clearly delineating the
radiographic landmarks for the femoral notch.

The investigators in this study believe poorly defined or
difficult to visualize radiographic landmarks led to this
result for notch height. It can be very difficult to identify
the borders of the notch in some of the radiographs that
were taken, which would lead to increased variability in
measurements (Figure 4). This finding concurs with that
in the study of Hosert al9 in which they were unable to
measure the femoral tunnel height on the AP radiograph
in 92% (46/50) of their radiographs because landmarks
were not identifiable. Because of the lack of reliability
studies in the orthopaedic literature and in light of our cur-
rent findings, we believe the notch height measurement
should be used with caution.

The most extensive prior study on radiographic meas-
ures for ACL tunnels was done by Khalfayan et al,14 who
analyzed the variability for 5 radiographic measurements
performed on 42 patients. Four reviewers performed 5 diff-
ent measurements, which included a novel AP and lat-
eral femoral tunnel measurement, a notch height
measurement, and AP and lateral tibial tunnel measure-
ments. The measurements were performed on 2 separate
occasions. The authors used an analysis of variance and
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vely analyze reviewer agreement, the number of boxes in

Figure 4. Anteroposterior radiograph of the knee from this
study demonstrating the difficulty in clearly delineating the
radiographic landmarks for the femoral notch.
the ACL tunnel measurements described are excellent. The poorest reliability was found to be with notch height measurements, where the ICC was categorized as borderline between poor and good. While there is no standard for comparison for the grid method in terms of reliability, subjectively, it demonstrates acceptable reliability.

CONTRIBUTING AUTHORS

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REFERENCES


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