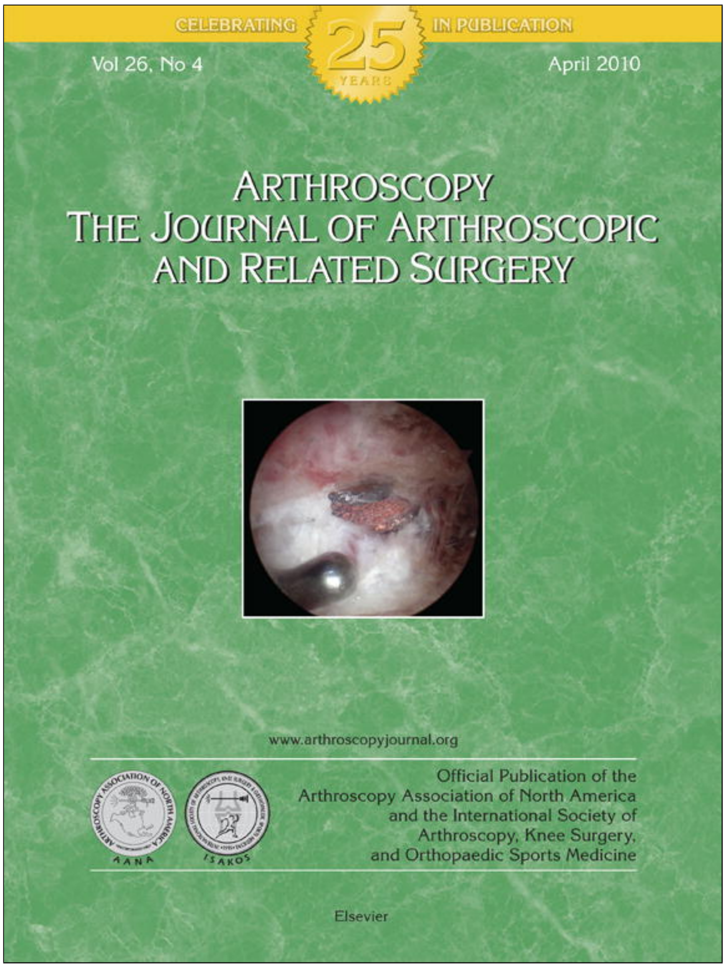
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# Anterior Cruciate Ligament Tibial Guide Pin Accuracy and Surgical Precision: Comparing 3.0-mm and 2.4-mm Guide Pins

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**Purpose:** The purpose of this study was to evaluate the accuracy of a 3.0-mm-diameter anterior cruciate ligament (ACL) tibial guide pin versus a standard, 2.4-mm drill-tipped guide pin. A secondary purpose was to evaluate surgeon precision in identifying the true (anatomic) center of the ACL tibial footprint using arthroscopic visualization. **Methods:** Five matched pairs of cadaveric knees were disarticulated, leaving a well-defined footprint of the ACL on the tibial plateau. The tibial footprint was digitally recorded by a bioengineer, and the true center of the footprint was calculated. Next, using arthroscopic visualization, a surgeon identified and marked his estimation of the true center of the ACL tibial footprint. This mark was then digitally recorded by the bioengineer and compared with the calculated center, allowing quantification of surgeon anatomic precision. Finally, under arthroscopic visualization, the surgeon was given 1 attempt to aim and drill the guide pin to his mark. Pin position was digitally recorded; the distance of the drill pin from the mark quantifies drill pin placement accuracy. **Results:** Mean accuracy for the 3.0-mm guide pin was 2.87 ± 1.19 mm versus 6.98 ± 1.29 mm for the 2.4-mm pin. The difference was significant ($P$ = .005). Surgeon anatomic precision was 3.32 ± 2.10 mm. **Conclusions:** Our results show that a 3-mm ACL tibial guide pin is significantly more accurate than a 2.4-mm-diameter pin. The 3-mm pin accuracy is within the range of surgeon precision; the 2.4-mm pin accuracy is not. **Clinical Relevance:** Pin accuracy and surgeon precision are clinically relevant measures because anatomic tunnel placement is a determinant of ACL reconstruction outcome.

Accuracy may be defined as hitting a target at which one is aiming, and in this study the target is the center of the anterior cruciate ligament (ACL) tibial footprint. Precision may be defined as selecting a target correctly, and in this study precision is defined as surgeon ability to recognize and selectively mark the anatomic center of the ACL tibial footprint using arthroscopic visualization.

Pin accuracy and surgeon precision are clinically relevant because anatomic tunnel placement is vital to clinical outcome of ACL reconstruction.[1,2] Accuracy and precision are both important for ACL tibial tunnel placement, because first, precise surgeon recognition is required to mark the ACL tibial footprint center. Second, accurate pin placement is required to hit the mark. In addition, inaccurate pin placement may be frustrating for surgeons, because pin placement correction requires inefficient or tedious, intraoperative corrective steps. Worse, sometimes tibial guide pin inaccuracy is difficult to correct because repeated pin passes tend to follow previously drilled pin tracks.[3]

The purpose of this study was to evaluate the accuracy of a standard, 2.4-mm-diameter ACL tibial tunnel guide pin versus a 3.0-mm guide pin. Our hypothesis

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was that a 3.0-mm guide pin is more accurate. A secondary purpose was to quantitate surgeon precision in identifying the true anatomic center of the ACL tibial footprint.

## METHODS

We used 5 matched pairs of cadaveric knees (mean age, 61 ± 8 years; 3 male and 2 female) for testing. The knees were disarticulated, leaving the menisci and the ACL, medial collateral ligament, posterior cruciate ligament, and lateral collateral ligament on each tibia. The ACL was then carefully dissected off of the tibial plateau by a surgeon, being sure to leave a well-defined and visible footprint of the ACL on the plateau (Fig 1). The tibia was tightly secured in a clamp.

The perimeter of each ACL tibial footprint was recorded electronically by measuring the location of circumferential points around the ACL tibial footprint by use of a MicroScribe 3-dimensional digitizer (MicroScribe G2; Immersion, San Jose, CA) calibrated with Rhinoceros software (version 3.0 SR3; Robert McNeel & Associates, Seattle, WA). A bioengineer performed the measurements (Fig 2).

Each ACL tibial footprint was measured 3 times. Surface areas, projected onto a transverse plane, were calculated by use of SolidWorks Office Premium software (version SP2.1; SolidWorks, Concord, MA). The true anatomic center of the ACL footprint was determined as the mean of 3 projected surface area measurements (and is reported on x and y coordinates on a transverse plane). The true ACL tibial footprint center is represented by the letter C.

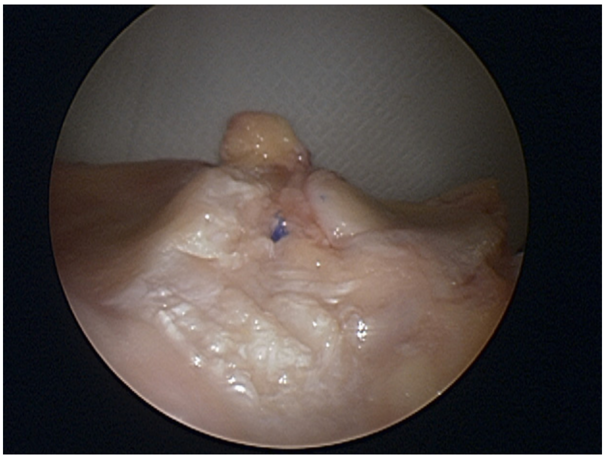

**FIGURE 1.** Simulated arthroscopic anterolateral portal view of right ACL tibial footprint after knee disarticulation. The surgeon guess (G) of the location of the footprint center was marked with a dot using a blue surgical marking pen.

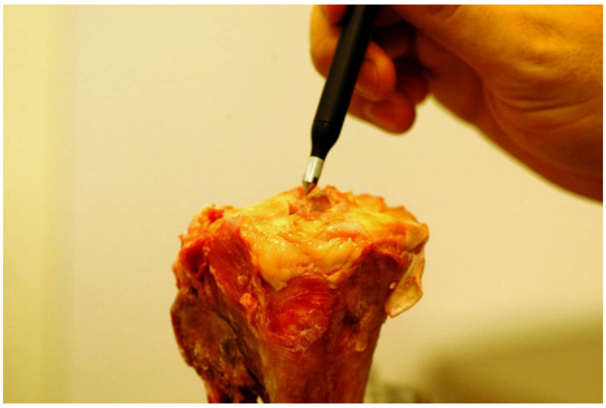

**FIGURE 2.** Right tibia viewed anterior-posterior. The bioengineer electronically measured and recorded the perimeter of the ACL tibial footprint by measuring the location of circumferential points using a MicroScribe 3-dimensional digitizer. These data were used to calculate the anatomic center (C) of the footprint.

Next, an arthroscope was steadied 1 cm superior to the anterior horn of the lateral meniscus to simulate an arthroscopic anterolateral viewing portal. Avoiding direct visualization and holding a 4.5-mm, 30° lens-angle arthroscope, the surgeon used a surgical pen to mark his most precise estimation of C (the calculated anatomic center of the ACL tibial footprint) while viewing the arthroscopic video monitor. The landmarks were the posterior aspect of the anterior horn of the lateral meniscus, the medial and lateral tibial intercondylar eminences, and the posterior cruciate ligament stump. The surgeon's estimation (or guess) of the location of the footprint center is represented by the letter G (Fig 1).

The bioengineer recorded G using the digitizer under direct visualization of all 10 specimens. The precision of the surgeon's guess (G) as compared with the calculated ACL tibial footprint center (C) was determined by use of SolidWorks (C-G).

After quantitating surgeon precision, we then compared the accuracy of a standard, 2.4-mm drill-tipped guide pin versus a 3.0-mm ACL tibial guide pin. Specifically, the specimens were divided into 5 matched pairs. The left tibia of each matched pair was used to evaluate the 2.4-mm guide pin (Arthrex, Naples, FL). The right tibia of each matched pair was used to evaluate a 3-mm guide pin (Retropin; Arthrex). Pins are manufactured for limited reuse and did not undergo deformation during testing. For each pin, ACL tibial guides were fixed at an angle of 52.5° (ACL tibial marking hook, C-ring, and 2.4-mm guide pin sleeve [Arthrex] and Retrodrill tibial guide and 3.0-mm guide pin sleeve [Arthrex]).

For each specimen, the surgeon was given 1 attempt to aim and drill the guide pin to his mark (G) through the proximal, anteromedial tibial metaphysis, using arthroscopic visualization through the simulated anterolateral arthroscopic portal.

The guide pin proximal tibial articular exit points were digitized and recorded by the bioengineer and represented by the letter P. Accuracy was determined by comparing P with G by use of SolidWorks software to project the points onto the transverse plane. The combined effects of precision (C-G) and accuracy (G-P) were calculated with SolidWorks and recorded as the distance C-P. The digital recordings and calculations are summarized in Fig 3.

### Statistical Methods

Five cadaveric pairs were originally evaluated to determine the number of samples required for a statistical power of 0.80. Significant differences were shown for the primary outcome measure, eliminating the need for further testing. Accuracy (distance of guide pin position [P] from the marked guess [G] for the 2.4-mm tibial guide pin *v* the 3.0-mm pin) was compared by use of a paired *t* test ($\alpha = .05$) with SigmaStat 3.10 software (Systat Software, San Jose, CA), after we determined the normality of the data using a Kolmogorov-Smirnov normality test. Differences in location (distance) are reported with directionality and then quantitated by use of absolute values.

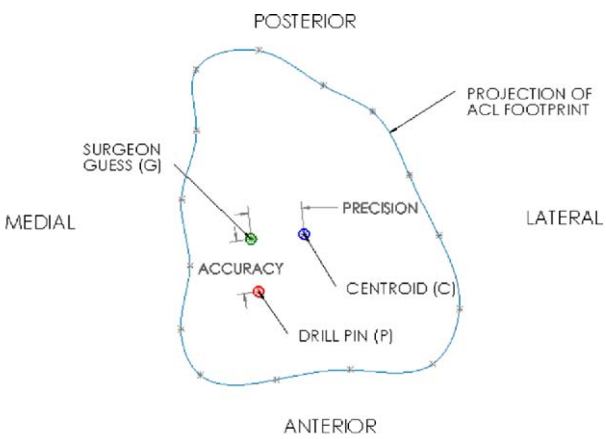


**FIGURE 3.** Left tibial superior view with digital projection of ACL tibial footprint in blue. Digital calculation of anatomic center of footprint (C) was performed. The distance from C to the surgeon guess of the footprint center (G) is precision. The distance from C to the guide pin tibial articular exit point (P) is pin accuracy.

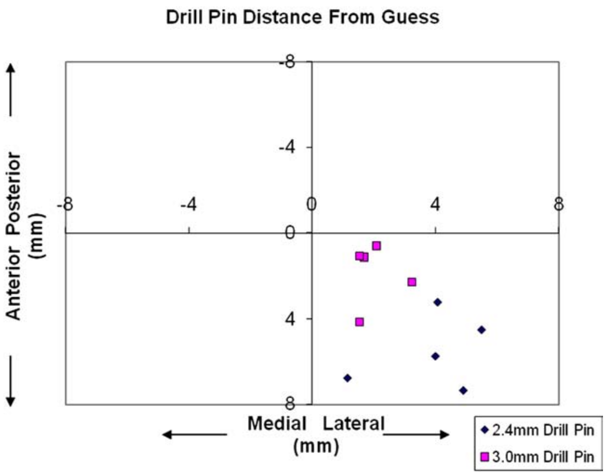


**FIGURE 4.** Pin accuracy is represented as the drill pin distance from the surgeon's guess in millimeters, where guess represents the surgeon's marked prediction of the true anatomic center of the ACL tibial footprint. Black diamonds represent the standard 2.4-mm drill-tipped guide pin. Pink squares represent the 3.0-mm guide pin. All 5 samples of the 3.0-mm pin were closer to the target than all 5 samples of the 2.4-mm pin. All samples showed anterolateral guide pin inaccuracy.

## RESULTS

Accuracy of the 2.4-mm guide pin placement was 6.98 ± 1.29 mm from the marked guess (G-P). Accuracy of the 3.0-mm guide pin was 2.87 ± 1.19 mm. The smaller distance indicates that the 3.0-mm pin came closer to the targeted mark.

Figure 4 shows that the 3.0-mm guide pin (pink squares) is more accurate than the 2.4-mm pin (black diamonds). The direction of pin inaccuracy was anterolateral for both guide pin diameters.

The complete measured distance and directionality results are shown in Table 1. The complete absolute distance results are shown in Table 2.

The 3.0-mm guide pin is significantly more accurate than the 2.4-mm pin ($P = .005$). No other differences between the absolute distances were significant.

Arthroscopic surgical precision (distance of the surgeon's marked guess from the calculated anatomic center of the tibial footprint) (distance C-G) was 3.8 ± 2.5 mm (Table 2, C-G combining all knees tested [2.4- and 3.0-mm groups]). The direction of surgeon imprecision was posterior for each sample. Precision dis-

TABLE 1. *Measured Distance Results*

| | Age (yr)/Gender | Footprint Area (mm$^2$) | C-G (mm) Medial-Lateral | C-G (mm) Anterior-Posterior | C-P (mm) Medial-Lateral | C-P (mm) Anterior-Posterior | G-P (mm) Medial-Lateral | G-P (mm) Anterior-Posterior |
|---|---|---|---|---|---|---|---|---|
| 2.4-mm Drill Guide Pin | | | | | | | | |
| Donor | | | | | | | | |
| 1 | 62/M | 157.61 | −5.10 | −6.26 | −0.21 | 1.08 | 4.89 | 7.34 |
| 2 | 67/F | 93.15 | −1.07 | −1.63 | 4.41 | 2.86 | 5.48 | 4.49 |
| 3 | 58/M | 113.75 | 1.20 | −1.73 | 5.26 | 1.47 | 4.06 | 3.20 |
| 4 | 49/F | 128.48 | 0.67 | −4.33 | 4.66 | 1.41 | 3.99 | 5.74 |
| 5 | 69/M | 132.11 | 1.89 | −2.13 | 3.04 | 4.63 | 1.15 | 6.76 |
| Mean | | 125.02 | −0.48 | −3.22 | 3.43 | 2.29 | 3.91 | 5.51 |
| SD | | 23.81 | 2.81 | 2.03 | 2.19 | 1.47 | 1.66 | 1.68 |
| 3.0-mm Drill Guide Pin | | | | | | | | |
| Donor | | | | | | | | |
| 1 | 62/M | 106.58 | −0.61 | −1.21 | 1.47 | −0.61 | 2.08 | 0.60 |
| 2 | 67/F | 89.79 | −0.86 | −2.69 | 2.37 | −0.41 | 3.23 | 2.28 |
| 3 | 58/M | 143.37 | 1.09 | −1.67 | 2.76 | −0.56 | 1.67 | 1.11 |
| 4 | 49/F | 111.15 | 1.27 | −7.07 | 2.68 | −2.93 | 1.53 | 4.14 |
| 5 | 69/M | 159.93 | −2.75 | −4.51 | −1.22 | −3.44 | 1.53 | 1.07 |
| Mean | | 122.16 | −0.37 | −3.43 | 1.61 | −1.59 | 2.01 | 1.84 |
| SD | | 28.67 | 1.64 | 2.40 | 1.66 | 1.47 | 0.72 | 1.43 |
| Total | | | | | | | | |
| Mean | | 123.59 | −0.43 | −3.32 | 2.52 | 0.35 | 2.96 | 3.67 |
| SD | | 24.89 | 2.17 | 2.10 | 2.07 | 2.47 | 1.57 | 2.43 |

NOTE. Distances between 2 measured points are expressed by use of x and y coordinates. The x values are in the medial (negative) and lateral (positive) direction; the y values are in the anterior (positive) and posterior (negative) direction.

Abbreviations: C, calculated anatomic center of ACL tibial footprint; G, surgeon's marked guess of anatomic center; P, tibial guide pin proximal articular exit point.

tance and direction data for all 10 samples are graphically represented in Fig 5.

## DISCUSSION

Our results show that a 3-mm ACL tibial guide pin is significantly more accurate than a 2.4-mm-diameter pin (Videos 1 and 2, available at www.arthroscopyjournal.org). Our hypothesis is thus supported. Secondarily, 3-mm pin accuracy (2.87 mm) is within the range of surgeon precision (3.8) but 2.4-mm pin accuracy (6.98 mm) is not.

In theory, the 3.0-mm pin is more accurate because of increased pin stiffness, which results from greater

TABLE 2. *Absolute Distance Results*

| | Absolute Distance Between Points of Interest (mm): 2.4-mm Drill Guide Pin C-G | 2.4-mm C-P | 2.4-mm G-P | 3.0-mm Drill Guide Pin C-G | 3.0-mm C-P | 3.0-mm G-P |
|---|---|---|---|---|---|---|
| Donor | | | | | | |
| 1 | 8.08 | 1.10 | 8.82 | 1.35 | 1.59 | 2.16 |
| 2 | 1.95 | 5.25 | 7.08 | 2.83 | 2.41 | 3.95 |
| 3 | 2.10 | 5.46 | 5.17 | 1.99 | 2.82 | 2.01 |
| 4 | 4.38 | 4.87 | 6.99 | 7.18 | 3.97 | 4.37 |
| 5 | 2.85 | 5.54 | 6.86 | 5.28 | 3.65 | 1.87 |
| Mean | 3.87 | 4.44 | 6.98 | 3.73 | 2.89 | 2.87 |
| SD | 2.54 | 1.89 | 1.29 | 2.44 | 0.96 | 1.19 |
| Significance | | | | $P = .937$ | $P = .065$ | $P = .005$ |

NOTE. Direct distances between 2 measured points are expressed by use of absolute values.

Abbreviations: C, calculated anatomic center of ACL tibial footprint; G, surgeon's marked guess of anatomic center; P, tibial guide pin proximal articular exit point.

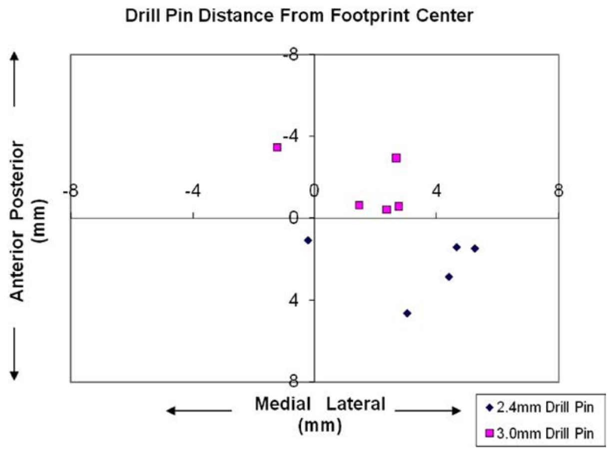


**FIGURE 5.** Surgeon precision is represented as the surgeon-marked prediction of the ACL tibial footprint (guess) distance from the true ACL tibial footprint anatomic center (centroid) in millimeters. Black diamonds represent the standard 2.4-mm drill-tipped guide pin subgroup. Pink squares represent the 3.0-mm guide pin subgroup. There were no significant differences between subgroup surgeon predictions. All samples showed posterior surgeon imprecision.

pin diameter. Decreased pin diameter may result in the pin bending in an unintended direction, which results in the pin deflecting at an unintended angle on the dense, tibial cortical bone.[4] In addition, pin direction may change as a result of bone density changes as the pin passes from the tibial cortex to the metaphysis and then back to the periarticular cortex at the tibial plateau.

With regard to previously published evaluations of the accuracy of tibial guide pin placement, a recent study of computer-navigated ACL reconstruction shows a range of variance of radiographically calculated positions of the tibial tunnel based on bony landmarks compared with manually guided and computer-navigated tunnel centers of 3.5 to 4.3 mm.[5] We show accuracy and precision in a similar range (2.87 to 6.98 mm). Robotic drilling of ACL tibial tunnels was recently reported to be inaccurate (unless the tunnels were drilled at a low feed rate of 3 to 7 minutes per pin placement).[6]

With regard to precision, a surgeon's ability to anatomically identify the true anatomic center of the ACL tibial footprint has not been previously reported. We are not certain why guide pin inaccuracy was consistently anterolateral, nor are we certain why surgeon imprecision in identifying and marking the true anatomic center of the ACL tibial footprint was consistently posterior. Nevertheless, if our results are generalizable to other surgeons in a clinical situation, arthroscopists should have an index of suspicion to avoid too posterior targeting of the ACL tibial tunnel footprint center, as well as an index of suspicion for anterolateral tibial guide pin inaccuracy. Petersen and Zantop[7] note that the ACL fibers spread far anterior below the transverse ligament; an arthroscopic surgeon should be sure to consider these anterior fibers to avoid posterior pin placement.

We speculate that surgeon imprecision is related, in part, to viewing perspective. The surgeon marked his prediction of the true center of the ACL tibial footprint under arthroscopic visualization (Fig 1). In contrast, the footprint was observed (and recorded) by the bioengineer using direct visualization (Fig 2). Graphically presented, Fig 6 digitally represents the ACL tibial footprint projected onto a transverse plane versus a frontal plane. The transverse-plane projection represents direct visualization (from a superior vantage point), whereas the frontal-plane projection pro-

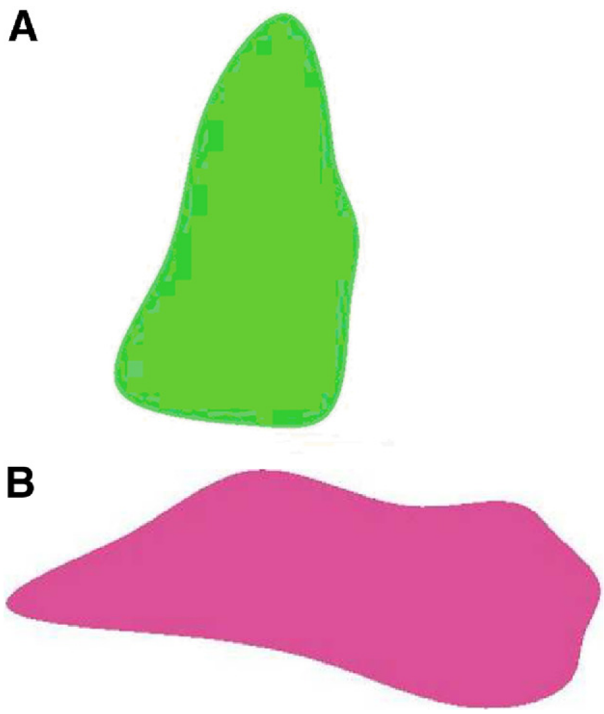


**FIGURE 6.** (A) Digital representation of right ACL tibial footprint as directly visualized by bioengineer and projected onto transverse plane to simulate superior viewing position. (Surface area projections were represented by use of SolidWorks Office Premium software [version SP2.1]. Right represents medial, inferior represents anterior, left represents lateral, and superior represents posterior.) (B) Digital representation of the same right ACL tibial footprint, but as arthroscopically visualized by the surgeon and projected onto a frontal plane to simulate anterolateral portal arthroscopic visualization. (Surface area projections were represented by use of SolidWorks Office Premium software [version SP2.1]. Right represents medial, inferior represents anterior, left represents lateral, and superior represents posterior.)

vides a gross representation of arthroscopic visualization (through a simulated anterolateral arthroscopic portal). Generally, ACL tibial footprint anatomic research is based on direct visualization from a superior vantage point,[8] yet the 2 projections provide distinctly different perspectives, and arthroscopic parallax may limit precision in predicting the true anatomic center.

Additional limitations of our study are that neither the surgeon nor the bioengineer was blinded as to study purpose. The sample size was small (10 specimens), yet statistical power was adequate to show significant difference in accuracy. Our results are unique to our method of testing, where digital projections of the articular surface were used to determine distances. Other methods used to determine the true anatomic center of the ACL tibial footprint could yield different results. Another variable is a potential difference in accuracy (tolerance) of the ACL tibial pin guides. Finally, matched-pair analysis minimized differences in bone density between the 2 groups, but cadaveric specimens may have lower bone density compared with typical ACL surgery patients, and osteoporosis may result in decreased pin accuracy.

## CONCLUSIONS

Our results show that a 3-mm ACL tibial guide pin is significantly more accurate than a 2.4-mm-diameter pin. The 3-mm pin accuracy is within the range of surgeon precision; the 2.4-mm pin accuracy is not.

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