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Arthroscopic Agreement Among Surgeons on Anterior Cruciate Ligament Tunnel Placement

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Investigation performed at The University of Iowa, Iowa City, Iowa

Background: Little is known about surgeon agreement and accuracy using arthroscopic evaluation of anterior cruciate ligament (ACL) tunnel positioning.

Purpose: To investigate agreement on ACL tunnel position evaluated arthroscopically between operating surgeons and reviewing surgeons. We hypothesized that operating and evaluating surgeons would characterize tunnel positions significantly differently.

Study Design: Controlled laboratory study.

Methods: Twelve surgeons drilled ACL tunnels on 72 cadaveric knees using transtibial (TT), medial portal (MP), or 2-incision (TI) techniques and then completed a detailed assessment form on tunnel positioning. Then, 3 independent blinded surgeon reviewers each arthroscopically evaluated tunnel position and completed the assessment form. Statistical comparisons of tunnel position evaluation between operating and reviewing surgeons were completed. Three-dimensional (3D) computed tomography (CT) scans were performed and compared with arthroscopic assessments. Arthroscopic assessments were compared with CT tunnel location criteria.

Results: Operating surgeons were significantly more likely to evaluate femoral tunnel position (92.6% vs 69.2%; $P = .0054$) and femoral back wall thickness as ''ideal'' compared with reviewing surgeons. Tunnels were judged ideal by reviewing surgeons more often when the TI technique was used compared with the MP and TT techniques. Operating surgeons were more likely to evaluate tibial tunnel position as ideal (95.5% vs 57.1%; $P < .0001$) and ''acceptable'' compared with reviewers. The ACL tunnels drilled using the TT technique were least likely to be judged as ideal on the tibia and the femur. Agreement among surgeons and observers was poor for all parameters ($\kappa = -0.0053$ to 0.2457). By 3D CT criteria, 88% of femoral tunnels and 78% of tibial tunnels were placed within applied criteria.

Conclusion: Operating surgeons are more likely to judge their tunnels favorably than observers. However, independent surgeon reviewers appear to be more critical than results of 3D CT imaging measures. When subjectively evaluated arthroscopically, the TT technique yields more subjectively poorly positioned tunnels than the TI and MP techniques. Surgeons do not agree on the ideal placement for single-bundle ACL tunnels.

Clinical Relevance: This study demonstrates that surgeons do not currently uniformly agree on ideal single-bundle tunnel placement and that the TT technique may yield more poorly placed tunnels.

Keywords: ACL; tunnel placement; anterior cruciate ligament

Anterior cruciate ligament (ACL) reconstruction is one of the most common orthopaedic surgical procedures, with satisfactory outcomes in up to 98% of patients.[19,38,47] Failure to obtain a satisfactory result can be caused by multiple factors including failure of graft incorporation, premature return to high-demand activities, repeat trauma to the knee, failure to address concomitant abnormalities, or poor operative technique.[22]

Recent articles suggested that technical errors contributed to the failure of the graft in 22% to 88%.[8,31,35,41] The most common surgical error is thought to be poor tunnel position,[1,8,46] which can lead to poor rotational stability or increased graft stress and eventual failure. Achieving optimal tunnel placement increases the likelihood of clinical success.[24,40] Anatomic dissections of the human knee have provided descriptions of the anatomy of the femoral and tibial attachments of the ACL.[10,11,15,18,50] Arthroscopic assessment relies on intra-articular landmarks, but there is some disagreement regarding optimal tunnel placement and which landmarks to use.[#] Other techniques such as the clockface method[29,36,39] of describing femoral tunnel position have been widely used but have more recently

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[#]References 5, 7, 10-12, 15, 20, 25, 36, 43, 44, 49, 50.

been met with criticism.[14] Some surgeons employ footprint guides,[3,16] intraoperative computer guidance,[4,23,42] and intraoperative fluoroscopy[6,32,45] in an attempt to target the desired tunnel location.

To our knowledge, no previous study has examined the difference in the arthroscopic assessment of tunnel position between surgeons. The purpose of this study was to evaluate the agreement of ACL tunnel placement between performing surgeons and independent evaluating surgeons using arthroscopic assessment. Our hypothesis was that the performing surgeons and evaluating surgeons would subjectively characterize the tunnel positions significantly differently.

MATERIALS AND METHODS

The study was performed on a single day in a cadaveric wet laboratory designed for arthroscopic surgery. All 12 knee surgeons participating in the study routinely perform arthroscopically assisted ACL reconstruction and are associated with the Multicenter Orthopaedic Outcomes Network (MOON) group. The surgeons were chosen such that there were 4 surgeons each who routinely perform transtibial (TT), medial portal (MP), and 2-incision (TI) techniques for femoral drilling. The experience level of each of the surgeons was recorded, and each technique had 2 surgeons with more than 9 years of clinical experience after fellowship and 2 surgeons with less than 6 years of clinical experience.

Seventy-two cadaveric knees were thawed to room temperature and tagged for future identification and association with the performing surgeons and reviewers. Surgeons were instructed to use their standard skin incisions and portals on the cadaveric knee as they would during routine ACL reconstruction in their clinical practice. Each surgeon was instructed to drill tunnels in the tibia and femur on 6 cadaveric knees using their preferred instrumentation and technique. The tunnels were drilled using a 10-mm reamer, and no graft was placed. Each surgeon was allowed a nonsurgeon assistant during the tunnel drilling.

At the completion of the ACL tunnel drilling, each operating surgeon completed a form (Figure 1) to document his or her opinion regarding the ACL tunnel placement. Each surgeon recorded the technique he or she used and several parameters of the femoral and tibial tunnels. The surgeon estimated the thickness in millimeters of the back wall and reviewed the appropriateness of the wall thickness as "ideal," "too thick," or "too thin." They were also asked to judge the position of the tunnel on the notch wall using the clockface technique in half-hour increments. The overall femoral position was judged as "ideal," "too vertical/superior," "too horizontal/inferior," "too anterior," or "too posterior." "Too anterior" and "too posterior" refer to the position of the tunnel during arthroscopic surgery in a flexed position. Finally, each surgeon deemed the femoral tunnel as either "acceptable" or "unacceptable."

Similar characteristics were recorded for the tibial tunnel, beginning with the intra-articular position of the tunnel judged as "ideal," "too anterior," "too posterior," "too medial," or "too lateral." The orientation of the tunnel was also documented by each surgeon as "ideal," "too vertical," "too horizontal," "oriented too medial-to-lateral," or "oriented too lateral-to-medial." Finally, the overall position of the tibial tunnel was judged as either "acceptable" or "unacceptable."

Each cadaveric knee was then evaluated by an independent member of the research team, and all knees, if needed, had additional incisions placed such that any of the 3 femoral drilling techniques could have been performed. All knees had a lateral-distal thigh incision compatible with the TI technique and standard tibial incisions. Three independent surgeons, who were not participants in tunnel drilling of the specimens, then independently assessed the ACL tunnels of each knee arthroscopically. The reviewers were sports fellowship–trained orthopaedic surgeons with 6 to 25 years in practice. The preferred method of tunnel drilling of the reviewers included 1 each of TT, MP, and TI. The reviewers were blinded to which surgeon performed the tunnel drilling and the technique utilized. During the reviewer's diagnostic arthroscopic procedures, a research assistant filled out the tunnel assessment form (Figure 1) to document the reviewer's opinion of the ACL tunnel placement.

A Siemens Sensation 64-slice computed tomography (CT) scanner (Munich, Germany) was used to collect 3-dimensional (3D) voxel datasets of the knee for each specimen using 0.75-mm slice thickness, and 3D surface models were generated. A novel 3D measurement system was used to identify graft tunnel position.[37] This system was designed around anatomic landmarks. Five measurements were obtained for both the femur and tibia using 3 angular measurements (α, β, γ) corresponding to the tunnel axis deviation from the x, y, and z axes of the anatomically oriented coordinate system and 2 spatial measurements. On the femur, the spatial location was measured for position on the medial wall of the lateral femoral condyle within the intercondylar notch with measures for anterior-posterior depth and superior-inferior height. The depth was calculated as a percentage of the anterior-to-posterior dimension of the lateral femoral condyle (c/C) with the posterior edge of the condyle as 0%. Tunnel height was analyzed to the maximal height of the intercondylar

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Femoral tunnel position

1. Femoral tunnel aperture position is: (select all that apply)

- [ ] Ideal
- [ ] Compromised - too anterior
- [ ] Compromised - too posterior
- [ ] Compromised - too vertical / superior
- [ ] Compromised - too horizontal / inferior

2. Using clock face terminology the femoral tunnel aperture can best be described as: (select one) (w/ knee at 90 deg flexion)

- [ ] 12 o'clock
- [ ] 12:30 / 11:30
- [ ] 1:00 / 11:00
- [ ] 1:30 / 10:30
- [ ] 2:00 / 10:00
- [ ] 2:30 / 9:30
- [ ] 3:00 / 9:00

3. The back wall thickness is _____ mm

4. The back wall thickness is: (select one)

- [ ] Ideal
- [ ] Too thick
- [ ] Too think

5. What technique do you think was used to drill this femoral tunnel? (select one)

- [ ] Transtibial
- [ ] Medial portal
- [ ] 2-incision

6. The femoral tunnel is: (select one)

- [ ] Acceptable
- [ ] Unacceptable

Tibial tunnel position

7. Tibial tunnel *aperture* is: (select all that apply)

- [ ] Ideal
- [ ] Compromised - too anterior
- [ ] Compromised - too posterior
- [ ] Compromised - too medial
- [ ] Compromised - too lateral

8. The tibial tunnel *orientation* is: (select all that apply)

- [ ] Ideal
- [ ] Compromised: tibial tunnel is too vertical
- [ ] Compromised: too horizontal
- [ ] Compromised: angulated excessively medial to lateral
- [ ] Compromised: angulated excessively lateral to medial

9. The tibial tunnel is: (select one)

- [ ] Acceptable
- [ ] Unacceptable

Figure 1. Example score sheet used by the surgeons and the observers to evaluate the tunnel placement of each specimen.

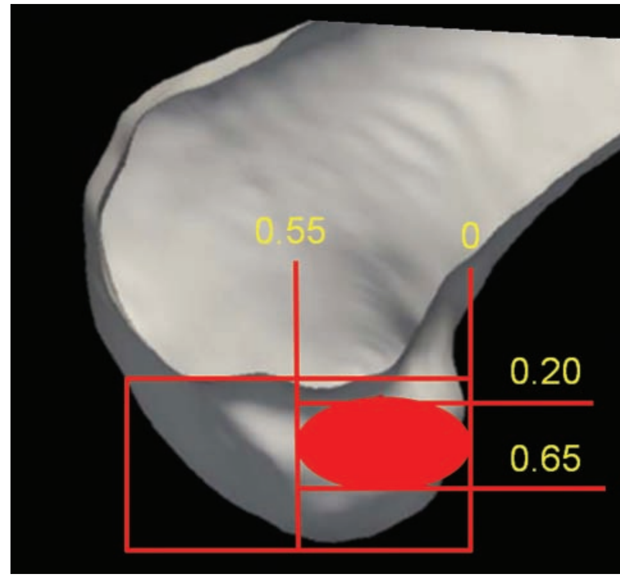

Figure 2. Acceptable femoral tunnel placement ranges for depth (c/C) of 0 to 0.55 and height (n/N) of 0.2 to 0.65.

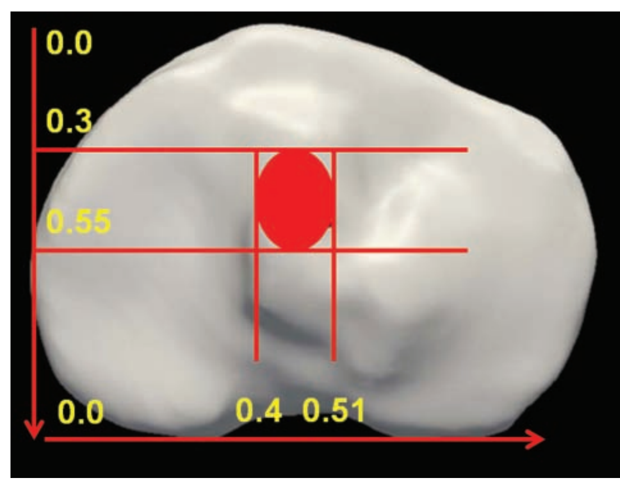

Figure 3. Acceptable tibial tunnel placement ranges for anterior to posterior (a/A) of 0.3 to 0.55 and medial to lateral (m/M) of 0.4 to 0.51.

notch with the notch apex designated as 0% (n/N). Tibial tunnel aperture location was measured as a percentage of plateau width from the medial edge of the tibia (m/M). In the sagittal plane, the centroid was measured as a percentage of the maximal sagittal depth of the tibial plateau as measured from the anterior edge and perpendicular to a reference line across the posterior tibial condyles (a/A).

Tunnel measurement criteria were applied to the tunnel measures based on a comprehensive review of the literature regarding radiographic ACL anatomy and tunnel placement on the femur[**] and the tibia.[7,9,10,28,30] These measurement criteria provide broad recommended criteria for ACL tunnel placement adapted to the imaging and measurement techniques applied in this study. The ranges

[**]References 1, 2, 7, 13, 17, 21, 30, 34, 48, 49.

TABLE 1
Comparison Between Surgeon and Observer Assessments of Femoral Tunnel Positions[a]

	Femoral Tunnel Position Assessment, n (%) Agreement				
	Ideal	Too Anterior	Too Horizontal	Too Posterior	Too Vertical
Surgeon (n = 68)	63 (92.65)	0 (0)	1 (1.47)	2 (2.94)	2 (2.94)
Observer (n = 198)	137 (69.19)	11 (5.56)	10 (5.05)	20 (10.10)	20 (10.10)

[a]P = .003 (Fisher exact test). Frequency (n) distributions among staff by femoral tunnel position are different.

TABLE 2
Comparison Between Surgeon and Observer Assessments of Acceptability of Wall Thickness[a]

	Wall Thickness Assessment, n (%) Agreement		
	Ideal	Too Thick	Too Thin
Surgeon (n = 68)	64 (94.12)	0 (0)	4 (5.88)
Observer (n = 198)	147 (74.24)	25 (12.63)	26 (13.13)

[a]P = .0002 (Fisher exact test). The κ/agreement for wall thickness between 4 surgeons is 0.0668/0.0508.

applied for the femur measurements were 0 to 0.55 for c/C and 0.2 to 0.65 for n/N (Figure 2). For the tibia, ranges of 0.30 to 0.55 for a/A and 0.4 to 0.51 for m/M were applied (Figure 3).

Statistical analysis was performed using SAS version 9.1 (SAS Institute Inc, Cary, North Carolina), and $P <$ .05 was considered significant. Fisher exact tests and χ^2 tests were used to test for differences in proportion of the categorical data. The level of agreement between the 3 observers and between the 3 observers and the surgeon was assessed and a κ value calculated for the observed parameters. The significance of each κ value was judged using the method of Landis and Koch.[27] According to Landis and Koch,[27] a κ value below 0.00 indicates poor agreement, between 0.00 and 0.20 indicates slight agreement, and between 0.21 and 0.40 indicates fair agreement. Agreement was also investigated by calculating the proportion of occasions for each parameter in which the specimen received the same response from all 3 observers and also the surgeon and the 3 observers combined.

RESULTS

Twelve surgeons performed ACL reconstructions on 72 cadaveric knees. In 4 cases, the researchers had difficulty definitively pairing the arthroscopy data sheets to the appropriate knee, and therefore, the data were discarded. In 2 cases, data from either the operating surgeon or 1 of the observers were incomplete. Therefore, analysis was done on 66 to 69 datasets depending on the variable being analyzed. Five knees were excluded from CT evaluation, as the tags identifying surgical technique and operating surgeons became detached during the freezing, shipping, and thawing process. Hence, CT data were only included for 67 knees.

There were 6 surgeons with less than 6 years in practice who averaged 31 ACL reconstructions during the year of the study and 6 surgeons with greater than 9 years in practice who averaged 101 ACL reconstructions during the year of the study. The influence of experience level on tunnel position was extensively analyzed using radiographic imaging in a separate study with only small differences found in tunnel placement based on experience level (Wolf BR, et al, unpublished observation).

Femoral Tunnel Position

It was significantly more likely that the surgeon would judge his or her tunnel as ideal compared with an observer (P = .0054) (Table 1). The observer was most likely to estimate the surgeons' tunnels as too posterior (10.1%) or too vertical/superior (10.1%). The surgeon and observers also judged wall thickness differently in that the surgeon was statistically significantly more likely to state the wall thickness was ideal compared with an observer (P = .0004) (Table 2). When asked to assess each femoral tunnel as either acceptable or unacceptable, the surgeons and observers significantly differed in their conclusions (P = .0009). The surgeons reported that 98.5% were acceptable, whereas the observers reported 82.3% as acceptable.

The observers' assessments of femoral tunnel position were analyzed based on the surgical technique of the surgeon making the tunnels (Table 3). The observers were significantly more likely to rate the tunnel position as ideal when the TI technique was used (87.0%) compared with the MP (66.7%) and TT (51.7%) techniques ($P <$ .0001). The TT technique was more likely to be rated as too posterior (21.7%) and too vertical/superior (18.3%) compared with the other 2 techniques used (Table 3).

Femoral tunnel position was judged by the surgeons and observers using the clockface method (Table 4). The surgeons' and observers' opinions significantly differed ($P <$ .0001), with the surgeons significantly more likely to judge the tunnel apertures in a "down-the-wall" position compared with observers. Surgeons stated that 98.5% of the tunnels they drilled were at the 1:30/10:30 clock positions or lower versus 66.1% for observers.

The 3D CT data showed that 59 of 67 (88.1%) femoral tunnels met all applied measurement criteria. Four (6%) femoral tunnels were too anterior, 1 (1.5%) too posterior, 2 (3%) too superior, and 1 (1.5%) too inferior using the applied criteria (Figures 4 and 5). This compares to

TABLE 3
Assessment of Femoral Tunnel Position by Independent Observers as It Relates to Femoral Tunnel Drilling Technique[a]

	Femoral Tunnel Position Assessment, n (%) Agreement				
Technique	Ideal	Too Anterior	Too Horizontal	Too Posterior	Too Vertical
2-incision (n = 69)	60 (86.96)	0 (0)	1 (1.45)	3 (4.35)	5 (7.25)
Medial portal (n = 69)	46 (66.67)	7 (10.14)	8 (11.59)	4 (5.80)	4 (5.80)
Transtibial (n = 60)	31 (51.67)	4 (6.67)	1 (1.67)	13 (21.67)	11 (18.33)

[a]$P < .0001$ (Fisher exact test).

TABLE 4
Comparison Between Surgeon and Observer Assessments of Femoral Tunnel Position Using the Clockface Method[a]

	Clockface Position Assessment, n (%) Agreement						
	12:00	12:30/11:30	1:00/11:00	1:30/10:30	2:00/10:00	2:30/9:30	3:00/9:00
Surgeon (n = 68)	0 (0)	0 (0)	1 (1.47)	25 (36.76)	25 (36.76)	14 (20.59)	3 (4.41)
Observer (n = 198)	1 (0.51)	15 (7.58)	51 (25.76)	60 (30.30)	55 (27.78)	12 (6.01)	4 (2.02)

[a]$P < .0001$ (Fisher exact test). Observers were significantly more likely to judge the tunnels as vertical or closer to 12:00.

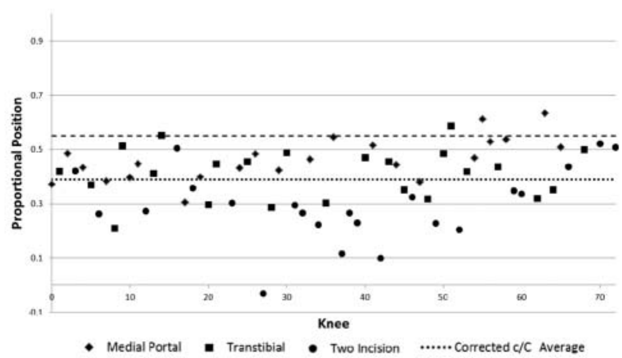

Figure 4. Scatterplot of femoral tunnel aperture position on computed tomography in relation to condyle depth from posterior to anterior per patient.

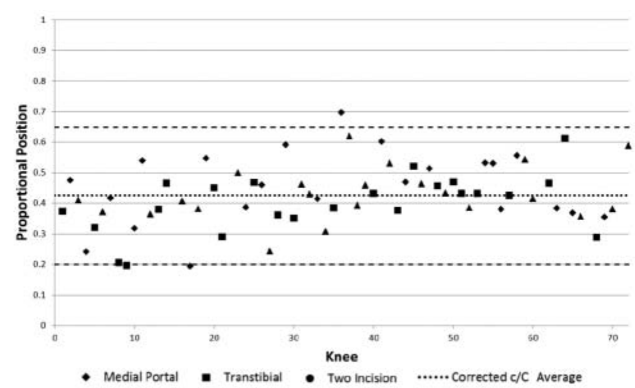

Figure 5. Scatterplot of femoral tunnel aperture position on computed tomography in relation to notch height per patient.

arthroscopic observers evaluating 5.5% of tunnels as too anterior, 10.1% as too posterior, 5.0% as too inferior, and 10.1% as too superior.

Tibial Tunnel Position

Similar to the femoral tunnel findings, the surgeon was statistically significantly more likely to judge his or her tunnel as ideal than the observers (95.6% vs 57.1%; $P <$ .0001) (Table 5). Observers judged the surgeons' tibial tunnels as too posterior in 29.8% of cases (Table 5). When asked to assess each tibial tunnel as acceptable or unacceptable, the surgeons and observers came to different conclusions as well. The surgeons rated the tibial tunnels as acceptable 100% of the time, whereas the observers concluded only 89.9% of the tunnels made were acceptable (P = .0052).

When tunnels were analyzed based on the surgical technique, tunnel positions were frequently judged less than ideal no matter which technique was used (Table 6). The TT tibial tunnels were deemed as ideal only 38.3% of the time compared with 62.3% for the TI technique and 68.1% for the MP technique (Table 6), and these values were significantly different from one another (P = .0002). The tunnels were judged as too posterior more than half the time (53.3%) when the TT technique was employed, which was significantly more often than the other techniques (P = .0002) (Table 6). Even with the TI and MP techniques, however, observers deemed the tunnel was too posterior more commonly than any other position except ideal (23.2% and 15.9%, respectively).

In the case of the 3D CT tibial tunnel data, 52 of 67 (77.6%) tunnels fell within applied measurement criteria. Eleven (16.4%) were too posterior, 2 (3.0%) were too

TABLE 5
Comparison Between Surgeon and Observer Assessments of Tibial Tunnel Positions[a]

	Tibial Tunnel Position Assessment, n (%) Agreement				
	Ideal	Too Anterior	Too Lateral	Too Medial	Too Posterior
Surgeon (n = 68)	65 (95.59)	1 (1.47)	0 (0)	1 (1.47)	1 (1.47)
Observer (n = 198)	113 (57.07)	12 (6.06)	1 (0.51)	13 (6.57)	59 (29.80)

[a] $P < .0001$ (Fisher exact test). Frequency (n) distributions among staff by tibial tunnel position are different.

TABLE 6
Assessment of Tibial Tunnel Position by Independent Observers as It Relates to Femoral Tunnel Drilling Technique[a]

	Tibial Tunnel Position Assessment, n (%) Agreement				
	Ideal	Too Anterior	Too Lateral	Too Medial	Too Posterior
2-incision (n = 69)	43 (62.32)	6 (8.70)	0 (0)	4 (5.80)	16 (23.19)
Medial portal (n = 69)	47 (68.12)	5 (7.25)	1 (1.45)	5 (7.25)	11 (15.94)
Transtibial (n = 60)	23 (38.33)	1 (1.67)	0 (0)	4 (6.67)	32 (53.33)

[a] $P = .0002$ (Fisher exact test).

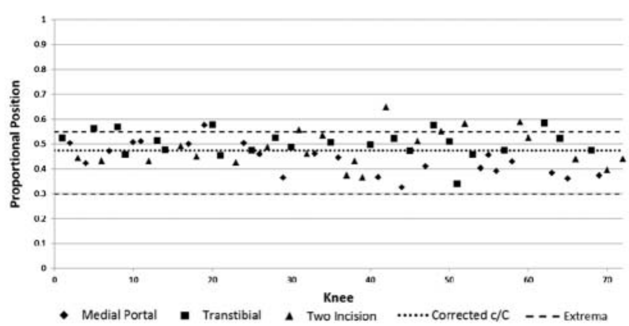

Figure 6. Scatterplot of tibial tunnel aperture position on computed tomography from anterior to posterior per patient.

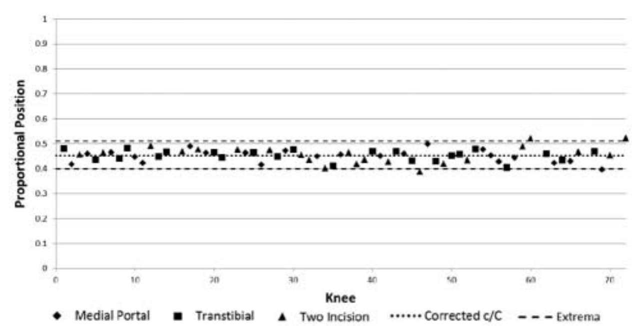

Figure 7. Scatterplot of tibial tunnel aperture position on computed tomography from medial to lateral per patient.

medial, and 2 (3.0%) were too lateral (Figures 6 and 7). In the case of the arthroscopic observers, 6.06% were judged as too anterior, 0.5% as too lateral, 6.5% as too medial, and 29.8% as too posterior.

Agreement

Agreement between surgeons and observers on each assessment of each tunnel was overall poor. Table 7 lists the κ and agreement values between all 4 observers (including the surgeon) for each specimen. It also lists the κ and agreement values between the 3 observers of each specimen with the surgeon excluded. When all 4 assessments (surgeon and 3 observers) of each specimen were analyzed, κ values generated ranged from –0.0098 to 0.1423 for the parameters tested (Table 7). This indicates a slight to poor degree of agreement according to Landis and Koch.[27] When the surgeon's assessment was removed and κ values calculated only from the data provided by the independent surgeon reviewers, the agreement remained poor. κ values ranged from –0.0053 to 0.2457, indicating a fair to poor degree of agreement according to Landis and Koch.[27] Agreement was highest for femoral tunnel review and tibial tunnel review. Otherwise, agreement was poor, especially when asked to rate the position of the femoral tunnel using the clockface method. All 4 surgeons agreed only 4.6% of the time and the 3 observers agreed only 4.3% of the time using the clockface method, indicating how poorly reproducible this estimate of femoral tunnel position is. The preferred surgical technique of the independent reviewer was analyzed, and this did not correlate with independent tunnel assessments.

DISCUSSION

This study on agreement between surgeons on arthroscopic assessment of tunnel position during ACL surgery produced

TABLE 7
Agreement Among Surgeons and Observers in Assessment of Tunnel Position Parameters[a]

	Parameter, 4 Surgeons (3 Observers)[b]				
	FT Position	FT Clockface	FT Review	TT Position	TT Review
κ	0.1345 (0.1661)	0.0298 (0.0198)	0.1423 (0.2457)	0.0429 (0.0781)	–0.0098 (–0.0053)
Agreement	0.4091 (0.4571)	0.0455 (0.0429)	0.6364 (0.6857)	0.2121 (0.2571)	0.7273 (0.7286)

[a]FT, femoral tunnel; TT, tibial tunnel.
[b]4 surgeons = agreement between the surgeon as well as the 3 observers; 3 observers = agreement between the 3 observers.

several findings that merit further discussion. First, the agreement between the surgeons for each of the parameters measured was invariably poor and was most pronounced for the clockface parameter. Second, the surgeon who drilled the femoral and tibial tunnels was more likely to judge them as ideal or acceptable than were independent observing surgeons. Finally, the likelihood of a tunnel being arthroscopically judged as ideal by an observer varied significantly with the surgical technique. Femoral and tibial tunnels drilled using the TT technique were less likely to be judged as ideal than tunnels drilled using either the MP or TI techniques. Data from the 3D CT imaging of the tunnels indicate that a very high percentage of tunnels were drilled within the applied measurement criteria in contradistinction to the assessments of the arthroscopic reviewers of a significant number of the tunnels.

The agreement on arthroscopic assessment of tunnel position was overall poor. No κ values for any of the analyzed data were above 0.25, and most were below 0.10. Our results are likely caused by a combination of factors. First, controversy remains on the optimal ACL reconstruction technique, and placement of 10-mm tunnels within the large ACL footprints can vary considerably and still be within anatomic boundaries. Second, in calculating agreement, we compared 3 or 4 surgeons with questions having up to 5 choices for each data category, allowing a large number of possible permutations. Agreement was highest for femoral tunnel review and tibial tunnel review, which makes sense because both parameters gave the observers only 2 choices (acceptable or unacceptable), allowing fewer permutations of answer combinations from the participants. κ, which controls for chance, remained poor for femoral and tibial tunnel reviews, similar to the other measured parameters. Agreement on femoral tunnel position using the clockface method was particularly poor, with a κ value of 0.0198 and agreement of 0.0429 among all 4 surgeons. Disagreement on the tunnel position between surgeons and observers was highly pronounced using the clockface method, with a distinct bias for surgeons to view the tunnels they drilled farther "down the wall." It has been noted that the clockface method is not an accurate way of describing the location of the femoral tunnel or footprint because it does not take into account knee flexion angle and it describes 3D anatomy using a 2-dimensional reference.[14] Indeed, reports differ on where the anteromedial and posterolateral bundles exist using the clockface method. Mochizuki et al[33] stated the anteromedial bundle is at the 1:40 clock position and the posterolateral bundle is at the 3:10 clock position, which contrasts significantly with Siebold et al,[43] who state that in their modified femoral clock wall model, at 102° of knee flexion, the footprints of the bundles are aligned horizontally at 11 or 1 o'clock, respectively, for right and left knees. Given the debate in the literature and the lack of agreement between experts in this study, we believe the clockface method is a less than ideal way of describing tunnel location for single- or double-bundle ACL reconstructions.

The CT data demonstrated that the surgeons were able to place the tunnels within measurement criteria derived from radiographic and anatomic studies the vast majority of the time. The 3D CT data found a total of 12% of femoral tunnels to lie outside the criteria based on ACL footprint and ACL reconstruction radiographic studies, whereas the reviewers found a total of 30.8% of the tunnels to be too superior, too posterior, too anterior, or too inferior. A similar situation exists in the case of the tibial tunnels. The 3D CT data suggest that a total of 22.4% of tunnels were drilled outside radiographic tunnel criteria, whereas reviewers took issue with the position of 42.9% of the tunnels. This comparison of imaging versus arthroscopic evaluation demonstrates the difficulty in accurately assessing the position of the ACL graft during arthroscopy. It also demonstrates the lack of agreement between surgeons on the ideal placement of a single-bundle graft. The tunnel position can be varied significantly and still be placed "anatomically."

We found large variability in the opinions of what constitutes an ideal femoral or tibial tunnel position. Over 90% of surgeons described their femoral tunnel position and wall thickness as ideal versus 69.2% and 74.2% of observers, respectively. The tibial tunnel findings were even more discrepant, with 95.6% of surgeons describing the tunnels as ideal compared with 57.1% of observers. These differences could be because of the difficulty assessing tunnel position arthroscopically or differences in opinions on what constitutes an ideal position for an ACL single-bundle graft. Interestingly, the reviewers' opinions on tunnel placement did not correlate directly with their own preferred tunnel placement technique. Ferretti et al[12] described the arthroscopic anatomy of the femoral insertion of the ACL in detail. They suggested, in the context of double-bundle ACL reconstruction, that the low anteromedial portal be used to assess the bony anatomy of the ACL footprint to position the femoral tunnels. Observation of the remnant soft tissue attachments of the ACL bundles as well as the lateral intercondylar ridge and lateral bifurcate ridge can allow the surgeon to more accurately place an ACL graft. In 2011, Ziegler et al[50] reported a cadaveric dissection of the tibial and femoral footprints of the ACL to describe the location of the tibial and femoral tunnels in relation to pertinent arthroscopic landmarks. The landmarks were described in relation to the anteromedial and posterolateral bundles on the tibial and femoral sides as well as the center of the ACL footprint on each side, allowing accurate placement of the graft in single- and double-bundle surgery. Application of the data in Ziegler et al[50] to the tunnel placement and assessment of tunnel position in our study may have led to more consistent results between the surgeon and observers. However, the data in the Ziegler et al[50] study do not provide for the arthroscopic surgeon on where, within the anatomic ACL footprint, the ideal location is to place a tunnel when employing a single-bundle ACL reconstruction technique. We suggest that one of the primary reasons for the lack of agreement between experienced surgeons on the arthroscopic assessment and acceptability of ACL tunnel position is the lack of agreement on where an ideal ACL tunnel should be drilled.

Our data indicate that femoral and tibial tunnels made with the TT technique as determined arthroscopically by independent ACL surgeons are more likely to be deemed "malpositioned." Only 51.7% of the femoral tunnels and 38.3% of the tibial tunnels drilled with the TT technique were judged as ideal by the observers. Tunnels drilled with the MP and TI techniques were much more likely to be deemed ideal. The femoral tunnels were most likely said to be too posterior or too vertical/superior, and in 53.3% of the cases, the tibial tunnels were regarded as too posterior. Our arthroscopic findings concur with a prior clinical study on failed ACL grafts requiring revision by Marchant et al.[31] These authors found that 88% of the tunnels were subjectively found to be nonanatomic, with 61% of the femoral tunnels on the intercondylar roof and 35% of the tibial tunnels placed posterior to the tibial ACL attachment.[31] In that study, 83% of the index ACL procedures were done using the TT technique.

Several additional variables likely also influence the lack of surgeon agreement. Surgeon training is varied. Some surgeons are more apt to place the femoral tunnel toward the anteromedial aspect of the femoral footprint. In recent years, there has been a shift to place the femoral tunnel more centrally within the footprint. With the advent of the TT technique, tibial tunnels often were placed a bit more posteriorly to allow more posterior femoral tunnel placement. Surgeons who use independent femoral drilling techniques may interpret tibial tunnel positioning differently than those who usually use the TT technique. Additionally, no graft was placed in the tunnels, and this may skew an independent surgeon's assessment of the tunnel location. Also, the operating surgeon had the benefit of taking down the native ACL tissue before drilling tunnels. The independent reviewer did not have the same anatomic landmarks available. Lastly, lack of agreement between surgeons is not uncommon and has been found in numerous orthopaedic studies ranging from fracture classification to arthroscopic and imaging agreement. Historically, orthopaedic surgeons have demonstrated a lack of agreement in many fields, and thus, our findings are not entirely surprising.

We can identify several limitations to this study. The study was done on cadaveric specimens, and although each surgeon was able to use his or her preferred technique, working on a cadaveric specimen can affect surgical technique. The surgeons were aware that the tunnels would be studied, and this may have induced performance bias. Only 3 independent reviewers were used, and it is possible that using more reviewers may have altered arthroscopic agreement. Our criteria for acceptable ACL tunnels based on 3D CT may be too broad. Multiple anatomic and radiographic references on ACL footprints and ACL tunnel parameters in the literature were reviewed and combined to create criteria for acceptability. Criteria for a "gold-standard" ACL tunnel placement are controversial, and 3D CT data are lacking for single-bundle reconstructions. In addition, it is noteworthy that a significant amount of variability exists between knees and ACL footprints as shown in a recent systematic review.[26] It is possible that outliers on 3D CT measurements are caused by anatomic variability rather than aberrant drilling. Although a large number of cadaveric knees were employed, there were only 12 surgeons performing the reconstructions and 4 surgeons per technique. Similarly, it is possible that the reviewers were biased by their own technique and tunnel location preferences. We intentionally had independent reviewers who utilized different techniques, but it is possible that the reviewers do not represent a generalizable assessment of ACL tunnels.

CONCLUSION

The agreement among surgeons analyzing single-bundle ACL tunnels arthroscopically is poor using κ statistics. Surgeons are significantly more likely to assess that the tunnels they drilled are in an ideal position than other independent surgeons. When judged arthroscopically, ACL tunnels are less likely to be in an ideal position when drilled using the TT technique. In contrast, 3D CT shows that the majority of ACL tunnels drilled by experienced surgeons are placed within applied radiographic criteria. Taken together, this indicates that knee surgeons do not agree on the correct position of a single-bundle ACL graft at this time and/or techniques for arthroscopic assessment of tunnel position require improvement. Given the poor agreement with arthroscopic assessment, advanced imaging may be useful in the workup of failed ACL reconstructions.

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