Graft-Tunnel Mismatch in Endoscopic ACL Reconstruction

Reliability of Measuring Tunnel Lengths and Intra-articular Distance

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Background: A continued technical challenge for surgeons performing bone–patellar tendon–bone anterior cruciate ligament (ACL) reconstruction with endoscopic techniques is graft-tunnel mismatch. If tibial tunnel and intra-articular distances could be reliably estimated, surgeons could adjust the length of the femoral tunnel to minimize graft-tunnel mismatch.

Purpose/Hypothesis: To determine whether arthroscopic measurement of the following was reliable: femoral tunnel distance (FTD), tibial tunnel distance (TTD), intra-articular distance (IAD), and total distance (TD; sum of these 3 measurements). It was hypothesized that intraoperative measurement of these distances would be reliable.

Study Design: Controlled laboratory study.

Methods: Eight sports fellowship–trained orthopedic surgeons independently performed arthroscopic measurements of the FTD, TTD, IAD, and TD in 7 cadaveric knees in which femoral and tibial tunnels had been drilled. Each surgeon performed the measurements twice using an EndoButton depth gauge. Following this, each parameter was measured open with a medial parapatellar approach. Finally, a computed tomography (CT) scan of each knee was performed, with the FTD, TTD, and IAD measured by a musculoskeletal radiologist. Inter- and intrarater reliability of the arthroscopic measurements was calculated, as well as the correlation between arthroscopic measurements and open and CT measurements.

Results: Interrater reliability for the arthroscopic measurements was 0.8 for FTD, 0.89 for TTD, 0.61 for IAD, and 0.76 (range, 0.54-0.93) for TD. Intrarater reliability was 0.94 for FTD, 0.97 for TTD, 0.83 for IAD, and 0.93 for TD. The correlation between arthroscopic and open measurements was 0.9 for FTD, 0.94 for TTD, 0.4 for IAD, and 0.84 for TD. The correlation between arthroscopic and CT measurements was 0.85 for FTD, 0.92 for TTD, and 0.71 for IAD.

Conclusion: The results of this study show that arthroscopic measurement of FTD and TTD has a high degree of intra- and interrater reliability, while that of IAD and TD demonstrates high intrarater reliability but moderate interrater reliability.

Clinical Relevance: Reliable measurement of the TTD and IAD can potentially allow adjustment of the FTD, minimizing graft-tunnel mismatch in endoscopic ACL reconstruction.

Keywords: ACL reconstruction; graft mismatch; reliability; measurement

One potential challenge for surgeons performing bone–patellar tendon–bone (BPTB) anterior cruciate ligament (ACL) reconstruction is graft-tunnel mismatch (GTM), which has been described as occurring in 10% of BPTB ACL reconstructions performed with autograft and transtibial drilling techniques.[15,17] As GTM can be associated with issues of fixation, the ability to recognize and manage this issue is important for surgeons.

GTM occurs when there is a significant disparity between the relative length of the BPTB construct and the combined length or total distance (TD) of the femoral tunnel distance (FTD), intra-articular distance (IAD), and the tibial tunnel distance (TTD).[6] A relatively long graft and short tunnel can result in a tibial bone plug that protrudes

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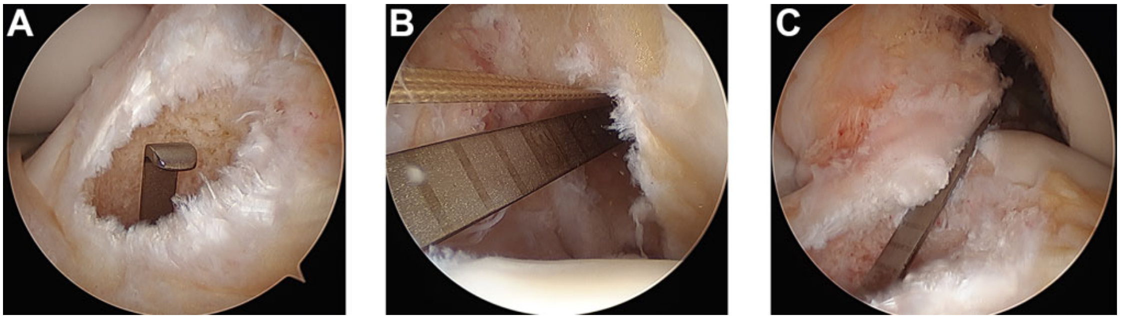

Figure 1. Arthroscopic measurement of (A) the tibial tunnel with the EndoButton depth gauge and (B) the femoral tunnel through an accessory anteromedial portal with the knee hyperflexed. (C) Intra-articular distance between the tibial and femoral tunnels, with the knee at 30° of flexion.

out of the tunnel, compromising the amount of bone fixation on the tibial side with use of an interference screw.[12,17] Relatively short grafts and long tunnels have the potential to force surgeons to blindly place the tibial interference screw, which can lead to articular penetration, screw divergence, or graft laceration.[12]

In ACL reconstruction, the lengths of the soft tissue and bony components of BPTB grafts are known to surgeons. If it were possible to accurately and reliably measure FTD, TTD, and IAD between these tunnels, it is possible that surgeons would be able to adjust the length of their femoral tunnel to minimize mismatch when performing endoscopic ACL reconstruction.

The purpose of this study was to determine if arthroscopic measurement of FTD, TTD, IAD, and TD was reliable. We hypothesized that intraoperative measurement of these distances would be reliable, allowing these measurements to be used in surgical techniques to prevent mismatch.

METHODS

Institutional research ethics board approval was obtained prior to commencing this study. A training day was held in which orthopaedic residents performed arthroscopic ACL reconstruction using BPTB in cadaveric specimens that had been donated to the university anatomy program. Residents drilled all tunnels with a diameter of 10 mm. Tibial tunnels were drilled at either 55° or 60° into the ACL footprint, with a second medial incision placed midway between the anterior border of the tibial tuberosity and the posteromedial border of the tibia. Femoral tunnels were drilled with an accessory anteromedial portal and a 7-mm offset guide, with the knee hyperflexed to a depth of 20 to 30 mm. After the training session, all BPTB grafts were removed.

Eight sports fellowship–trained orthopedic surgeons (T.D., L.B., N.B., J.A., M.L.M., D.W., D.O.-H., J.C.) were then asked to perform arthroscopic measurement of the FTD, TTD, IAD, and TD in the cadaveric knees. Using an arthroscopic camera and an EndoButton depth gauge (Smith & Nephew), the surgeons measured the length of the TTD, the length of the FTD via the anteromedial portal, the IAD between the femoral tunnel and the tibial tunnel, and the TD, with the knee positioned at 30° of flexion (Figure 1). The 30° position was chosen with a consensus among the surgeons that this was their most common knee position for performing tibial fixation of ACL grafts. Surgeons were directed to make their measurements at the estimated center of the aperture in all cases.

The surgeons performed each measurement in each knee twice, the second time approximately 30 minutes after the first time; all surgeons were blinded to their previous measurements. Following this, an open medial parapatellar approach was made to each knee, and 2 surgeons (L.B., N.B.) measured the FTD, TTD, IAD, and TD with the EndoButton depth gauge, with consensus made on each measurement.

Computed tomography (CT) of each knee was performed with 1-mm axial reconstructions. All measurements were performed with the Aquarius iNtuition Workstation (TeraRecon Inc). A single musculoskeletal radiologist (B.F.) measured the FTD, TTD, and IAD on double-oblique reformats (Figure 2).

Statistical Analysis

Intraclass correlation coefficients were calculated to determine the inter- and intrarater reliability for each measurement (FTD, TTD, IAD, TD). An intraclass correlation coefficient was also computed to determine the degree of correlation and agreement between measurements

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Ethical approval for this study was obtained from Mt Sinai Hospital Research Ethics Board (15-0269-E).

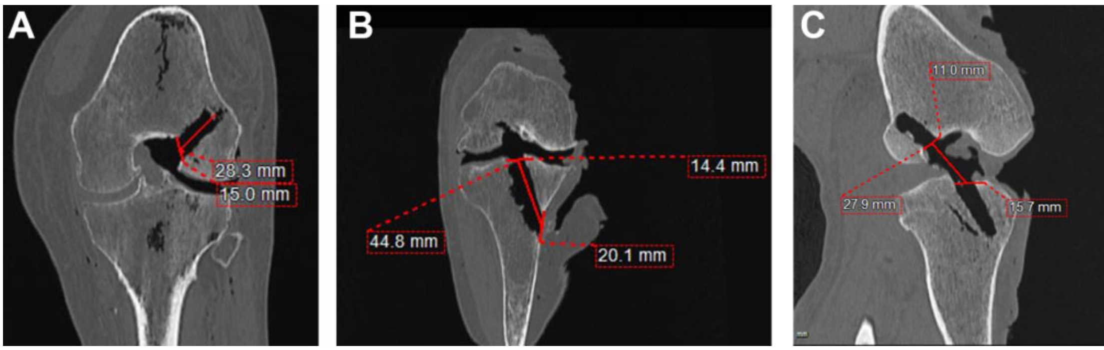

Figure 2. Coronal computed tomography demonstrating the (A) femoral tunnel and (B) tibial tunnel. (C) Sagittal oblique scan demonstrating measurement of the intra-articular distance.

TABLE 1
Measurement of the Femoral Tunnel Distance[a]

	Specimen, mm						
Measurement	1	2	3	4	5	6	7
Arthroscopic	22.4 (19.5-24.5)	25 (23.5-26)	28.1 (25.5-30)	24.4 (21-27)	21.4 (18-23.5)	25.3 (23-25.5)	23.1 (20-25.5)
Open	18	28	34	26	22	22	20
CT	21	30	31	28	20	24	18

[a]The arthroscopic measurement is the mean (range) of measurements for all 8 surgeons. CT, computed tomography.

TABLE 2
Measurement of the Tibial Tunnel Distance[a]

	Specimen, mm						
Measurement	1	2	3	4	5	6	7
Arthroscopic	43.3 (45-42)	37.5 (35-41)	37.5 (34-40)	49.5 (52-46)	50.4 (47-54)	31.9 (28-36)	41.4 (39.5-45.5)
Open	44	38	39	48	43	33	42
CT	45	35	39	53	53	31	45

[a]The arthroscopic measurement is the mean (range) of measurements for all 8 surgeons. CT, computed tomography.

obtained via arthroscopic probe (mean of all surgeons) and those via an open technique and CT scan. Reliability was deemed to be high if 0.8-1.0, moderate if 0.6–0.8, and poor if < 0.6. All analyses were conducted with SAS (v 9.4; SAS Institute) with alpha set to 0.05.

RESULTS

All results are presented in Tables 1 to 5. The interrater reliability (range) was 0.8 (0.59-0.95) for the FTD, 0.89 (0.75-0.97) for the TTD, 0.61 (0.34-0.88) for the IAD, and 0.76 (0.54-0.93) for the TD. The intrarater reliability was 0.94 for the FTD, 0.97 for the TTD, 0.83 for the IAD, and 0.93 for the TD.

With regard to the comparison between arthroscopic measurement and open measurement, the correlation (range) was 0.9 (0.56-0.98) for the FTD, 0.94 (0.74-0.99) for the TTD, 0.4 (–0.12 to 0.84) for the IAD, and 0.84 (0.33-0.97) for the TD. The correlation between the arthroscopic measurement and the CT measurement was 0.85 (0.44-0.97) for the FTD, 0.92 (0.68-0.98) for the TTD, and 0.71 (0.1-0.9) for the IAD.

DISCUSSION

The results of our study show that the arthroscopic measurement of FTD and TTD has a high degree of intra- and interrater reliability, while that of IAD and TD demonstrates high intrarater reliability and moderate interrater reliability. A good correlation was seen between arthroscopic measurements and open and CT measurements, with the exception of the measurement of IAD with an open technique.

The rate of autograft BPTB mismatch with endoscopic techniques and transtibial drilling is reported to be

TABLE 3
Measurement of the Intra-articular Distance[a]

Measurement	Specimen, mm 1	2	3	4	5	6	7
Arthroscopic	23 (21.5-26)	20.1 (18-24)	21.3 (19.5-24.5)	22.7 (19.5-25)	24.9 (22.5-26)	21.9 (19-23.5)	21.6 (19-23)
Open	20	18	20	22	23	20	16
CT	24	22	21	24	26	18	22

[a]The arthroscopic measurement is the mean (range) of measurements for all 8 surgeons. CT, computed tomography.

TABLE 4
Mean Arthroscopic Measurement of the Total Distance[a]

Measurement	Specimen, mm 1	2	3	4	5	6	7
Arthroscopic	85.6 (83-89)	80.1 (77.5-83)	84.6 (81-87)	93.1 (87-95)	94.2 (91.5-97)	78.1 (75-81)	83.5 (81-86)
FTD + IAD + TTD[b]	88.7	82.6	86.9	96.6	96.7	79.1	86.1

[a]This measurement was made with the knee at 30° of flexion and with the depth gauge placed through the tibial tunnel and into the femoral tunnel and was taken at the aperture of the tibial tunnel. The arthroscopic measurement is the mean (range) of measurements for all 8 surgeons. This distance was compared with the sum of the individual parameters. FTD, femoral tunnel distance; IAD, intra-articular distance; TTD, tibial tunnel distance.
[b]Total of FTD, IAD, and TTD measured arthroscopically.

TABLE 5
Open Measurements of the Total Distance as Measured by 2 Surgeons[a]

Measurement	Specimen, mm 1	2	3	4	5	6	7
Open	88	80	86	100	90	74	80
FTD + IAD + TTD[b]	82	84	93	96	88	75	78

[a]This measurement was made with the knee at 30° of flexion and with the depth gauge placed through the tibial tunnel and into the femoral tunnel and was taken at the aperture of the tibial tunnel. This distance was compared with the sum of the individual parameters. FTD, femoral tunnel distance; IAD, intra-articular distance; TTD, tibial tunnel distance.
[b]Total of FTD, IAD, and TTD measured open.

approximately 10%,[17] with mismatch thought to be more common with allograft than autograft.[3,17] Despite evidence that using anteromedial drilling can change the position and length of the femoral tunnel in comparison with transtibial drilling[1,7] and potentially influence mismatch,[2] the true incidence of mismatch with anteromedial drilling techniques is unknown. The results of this study will be used in a prospective cohort of patients undergoing BPTB ACL reconstruction with anteromedial drilling to determine the incidence of mismatch and the strategies to prevent it.

A minimum 10-mm bone plug has been recommended for acceptable graft fixation[14]; a protruding graft with <20 mm of tibial bone plug within the tibial tunnel is thought to compromise screw fixation.[5] Options in this setting included femoral tunnel recession,[16] graft rotation,[17] or the use of free bone blocks.[5,17] Likewise, having a graft that is too short can lead to blind placement of screws, with potential to gain inadequate distal fixation. For this reason, surgeons must have a firm understanding of ideal graft and tunnel lengths, tibial tunnel angles, and graft fixation techniques to successfully rectify the problem of GTM.

Most cases of GTM arise from the high degree of variability between tendon length and the IAD, with the incidence of graft mismatch shown to be higher when the tendinous portion of a graft is >50 mm.[15] The literature describes a mean tendon length of 40 to 50 mm and a mean intra-articular length of 20 to 25 mm.[4,15] However, a high degree of variability exists, with Denti et al[4] indicating that 25% of tendon lengths were <42 mm and Shaffer et al[15] reporting that 20% were >52 mm. The IAD has also been shown to have a high degree of variability.[4,15]

For these reasons, the IAD is a critical component of ACL mismatch. In our study, while there was moderate interrater reliability of the measurement of IAD by way of a predrilled tibial tunnel, the intrarater reliability was high, allowing surgeons to use a technique known as *femoral tunnel recession* to deal with issues of mismatch.[16] In this technique, after the tibial tunnel is drilled, the TTD and IAD can be measured and the femoral tunnel drilled accordingly to the appropriate BPTB length to avoid mismatch.[8] There has been some concern that deepening the femoral tunnel may compromise the soft tissue portion of the graft, either by a windscreen washer/abrasion effect[11] or by the interference screw potentially capturing and damaging some of the tendinous portion of the ACL graft.[9] However, in 1996, Taylor et al[16] described using femoral tunnel recession to manage GTM in 71 of 100 consecutive cases and found no evidence of increased graft failure with KT-1000 arthrometry at 12 months.

Other authors have reported methods of measuring IAD that avoid drilling the tibial tunnel first. In 1998, Denti et al[4] described using the Acufex intra-articular device to measure the IAD intraoperatively in 50 ACL reconstructions and using these measurements to determine the required tibial tunnel length. Shaffer et al[15] also used the Acufex device to measure the IAD in 12 knees; despite adjusting the tibial tunnel accordingly, the authors still encountered a mismatch in 26% of cases of transtibial drilling.

Another option for predicting and preventing GTM involves measuring the length of the BPTB autograft and adjusting the depth and length of the TTD. Numerous methods have been described for the adjustment of the tibial tunnel, including the N+7 formula—where the length of the patellar tendon in millimeters plus 7° is the suggested angle of the tibial guide[10]—and the N+10 rule.[17] Olszewski et al[12] tested the indirect N+7 method in cadavers, resulting in acceptable tibial tunnels in 89%. In contrast, Pagnano et al[13] tested the N+7 rule in a prospective study of 60 ACL reconstructions, reporting a success rate of only 50%, with grafts that were too long and too short.

Our study demonstrated decreased reliability in the arthroscopic measurement of the IAD as compared with the FTD and TTD. Factors that likely contribute to this finding include the position of the knee, difficulties in visualization, and where to measure the IAD with regard to tunnel aperture. For example, it was initially unclear whether to measure the FTD, TTD and IAD from the front, back, or center of each relevant aperture. Nearly all apertures are oblique in some manner, leading to potential differences in measurement depending on the point chosen—in this study, surgeons were directed to estimate the center of the aperture. Furthermore, the IAD was measured with the knee at 30°. While it is likely easier to measure the IAD at 90°, the ACL graft is usually never tensioned in this position.

Limitations

In this study, the reliability of the FTD may have been increased owing to the limited range of depths, with all tunnels measured at a depth of 20 to 30 mm. This is in comparison with the TTD, which had a larger range of measurements—the tibial tunnel length depends on the entry and exit points of the guide wire, the angle of the guide, and whether the guide was raised or lowered relative to the slope of the tibial plateau. All measurements were performed with a depth gauge marked with 2-mm increments, which may have contributed to some degree of error. While fellowship-trained surgeons performed all measurements, the experience of each surgeon varied, which may have affected the results.

We are unable to comment on the inter- or intrarater reliability of the open or CT measurements, as these were only performed once. While there was a good correlation between the arthroscopic and CT measurements of the IAD, it was reduced for the open measurement. The reasons why are unclear—it may be that in the ACL-deficient knee, arthrotomy alters the biomechanics of the knee and thus may change the IAD. It is also important to note that open and CT measurements will not be performed in the setting of normal clinical practice; these measurements were used to provide evidence of validity for the arthroscopic measurements. We cannot comment on the rate of GTM in this study, as the graft lengths were not measured. Finally, at this time, we are unable to say whether these arthroscopic measurements can be used to predict or prevent GTM. A prospective clinical study would be required to answer this question.

CONCLUSION

The results of our study show that the arthroscopic measurement of FTD and TTD has a high degree of intra- and interrater reliability, while that of IAD and TD demonstrates high intrarater reliability but moderate interrater reliability.

REFERENCES

1. Bedi A, Raphael B, Maderazo A, Pavlov H, Williams RJ 3rd. Transtibial versus anteromedial portal drilling for anterior cruciate ligament reconstruction: a cadaveric study of femoral tunnel length and obliquity. *Arthroscopy*. 2010;26(3):342-350.
2. Boddu CK, Arif SK, Hussain MM, Sankaranarayanan S, Hameed S, Sujir PR. Prevention of graft-tunnel mismatch during anatomical anterior cruciate ligament reconstruction using a bone–patellar tendon–bone graft. *Bone Joint J*. 2015;97(3):324-328.
3. Brown JA, Brophy RH, Franco J, et al. Avoiding allograft length mismatch during anterior cruciate ligament reconstruction: patient height as an indicator of appropriate graft length. *Am J Sports Med*. 2007;35(6):986-989.
4. Denti M, Bigoni M, Randelli P, et al. Graft-tunnel mismatch in endoscopic anterior cruciate ligament reconstruction: intraoperative and cadaver measurement of the intra-articular graft length and the length of the patellar tendon. *Knee Surg Sports Traumatol Arthrosc*. 1998;6(3):165-168.
5. Fowler BL, DiStefano VJ. Tibial tunnel bone grafting: a new technique for dealing with graft-tunnel mismatch in endoscopic anterior cruciate ligament reconstruction. *Arthroscopy*. 1998;14(2):224-228.
6. Goldstein JL, Verma N, McNickle AG, Zelazny A, Ghodadra N, Bach BR Jr. Avoiding mismatch in allograft anterior cruciate ligament reconstruction: correlation between patient height and patellar tendon length. *Arthroscopy*. 2010;26(5):643-650.
7. Golish SR, Baumfeld JA, Schoderbek RJ, Miller MD. The effect of femoral tunnel starting position on tunnel length in anterior cruciate ligament reconstruction: a cadaveric study. *Arthroscopy*. 2007;23(11):1187-1192.
8. Hartman GP, Sisto DJ. Avoiding graft-tunnel mismatch in endoscopic anterior cruciate ligament reconstruction: a new technique. *Arthroscopy*. 1999;15(3):338-340.
9. Kenna B, Simon TM, Jackson DW, Kurzweil PR. Endoscopic ACL reconstruction: a technical note on tunnel length for interference fixation. *Arthroscopy*. 1993;9(2):228-230.
10. Miller MD, Hinkin DT. The "N + 7 rule" for tibial tunnel placement in endoscopic anterior cruciate ligament reconstruction. *Arthroscopy*. 1996;12(1):124-126.

11. Morgan CD, Kalmam VR, Grawl DM. Isometry testing for anterior cruciate ligament reconstruction revisited. *Arthroscopy*. 1995;11(6):647-659.
12. Olszewski AD, Miller MD, Ritchie JR. Ideal tibial tunnel length for endoscopic anterior cruciate ligament reconstruction. *Arthroscopy*. 1998;14(1):9-14.
13. Pagnano MW, Kim CW, Huie G, Scott WN. Difficulties with the "N + 7 rule" in endoscopic anterior cruciate ligament reconstruction. *Arthroscopy*. 1997;13(5):597-599.
14. Pomeroy G, Baltz M, Pierz K, Nowak M, Post W, Fulkerson JP. The effects of bone plug length and screw diameter on the holding strength of bone-tendon-bone grafts. *Arthroscopy*. 1998;14(2):148-152.
15. Shaffer B, Gow W, Tibone JE. Graft-tunnel mismatch in endoscopic anterior cruciate ligament reconstruction: a new technique of intraarticular measurement and modified graft harvesting. *Arthroscopy*. 1993;9(6):633-646.
16. Taylor DE, Dervin GF, Keene GC. Femoral bone plug recession in endoscopic anterior cruciate ligament reconstruction. *Arthroscopy*. 1996;12(4):513-515.
17. Verma NN, Dennis MG, Carreira DS, Bojchuk J, Hayden JK, Bach BR Jr. Preliminary clinical results of two techniques for addressing graft tunnel mismatch in endoscopic anterior cruciate ligament reconstruction. *J Knee Surg*. 2005;18(3):183-191.