Radiographic Landmarks for Femoral Tunnel Positioning in Lateral Extra-articular Tenodesis Procedures

Vera Jaecker,* MD, Jan-Hendrik Naendrup,* BS, Thomas R. Pfeiffer,* MD, Bertil Bouillon,* MD, and Sven Shafizadeh,†‡ MD
Investigation performed at Department of Trauma and Orthopaedic Surgery, Witten/Herdecke University, Cologne Merheim Medical Center, Cologne, Germany

Background: Lateral extra-articular tenodesis (LET) is being increasingly performed as an additional procedure in both primary and revision anterior cruciate ligament reconstruction in patients with excessive anterolateral rotatory instability. Consistent guidelines for femoral tunnel placement would aid in intraoperative reproducible graft placement and postoperative evaluation of LET procedures.

Purpose: To determine radiographic landmarks of a recently described isometric femoral attachment area in LET procedures with reference to consistent radiographic reference lines.

Study Design: Descriptive laboratory study.

Methods: Ten fresh-frozen cadaveric knees were dissected. The footprints of the lateral femoral epicondyle (LFE) apex and the deep aspects of the iliotibial tract, with its Kaplan fiber attachments (KFAs) on the distal femur, were marked with a 2.5-mm steel ball. True lateral radiographic images were taken. Mean absolute LFE and KFA distances were measured from the posterior cortex line (anterior-posterior direction) and from the perpendicular line intersecting the contact of the posterior femoral condyle (proximal-distal direction), respectively. Furthermore, positions were measured relative to the femur width. Finally, radiographic descriptions of an isometric femoral attachment area were developed.

Results: The mean LFE and KFA positions were found to be 4 ± 4 mm posterior and 4 ± 3 mm anterior to the posterior cortex line, and 6 ± 4 mm distal and 20 ± 5 mm proximal to the perpendicular line intersecting the posterior femoral condyle, respectively. The mean LFE and KFA locations, relative to the femur width, were found at –12% and 11% (anterior-posterior) and –17% and 59% (proximal-distal), respectively. Femoral tunnel placement on or posterior to the femoral cortex line and proximal to the posterior femoral condyle within a 10-mm distance ensures that the tunnel remains safely located in the isometric zone.

Conclusion: Radiographic landmarks for an isometric femoral tunnel placement in LET procedures were described.

Clinical Relevance: These findings may help to intraoperatively guide surgeons for an accurate, reproducible femoral tunnel placement and to reduce the potential risk of tunnel misplacement, as well as to aid in the postoperative evaluation of LET procedures in patients with residual complaints.

Keywords: lateral extra-articular tenodesis (LET); radiographic landmarks; femoral tunnel position

While lateral extra-articular tenodesis (LET) procedures have historically been performed in isolated anterior cruciate ligament (ACL) injuries,[3,5,10] the use of these procedures has experienced a recent resurgence in interest as concomitant-modified procedures in improving the outcome of ACL reconstruction in primary cases displaying excessive anterolateral rotatory instability, as well as in ACL revision surgeries.[2,7,16,21,22] Numerous LET techniques have been described and commonly include the attachment of a redirected strip of the iliotibial tract to the lateral femur.[20]

Although LET procedures are inherently nonanatomic as they do not re-create a specific anatomic structure, they have been shown to provide favorable effects in controlling anterolateral rotatory instability compared with the use of isolated intra-articular reconstruction techniques.[3,6,8,23]

‡Address correspondence to Sven Shafizadeh, MD, Department of Orthopaedic Surgery and Sports Traumatology, Witten/Herdecke University, Sana Medical Centre Cologne, Aachener Str. 445-449, 50933 Cologne, Germany (email: sven.shafizadeh@me.com).

*Department of Trauma and Orthopaedic Surgery, Witten/Herdecke University, Cologne Merheim Medical Centre, Cologne, Germany.

†Department of Orthopaedic Surgery and Sports Traumatology, Witten/Herdecke University, Sana Medical Centre Cologne, Cologne, Germany.

The authors declared that they have no conflicts of interest in the authorship and publication of this contribution. AOSSM checks author disclosures against the Open Payments Database (OPD). AOSSM has not conducted an independent investigation on the OPD and disclaims any liability or responsibility relating thereto.

The American Journal of Sports Medicine
1–5
DOI: 10.1177/0363546519864580

However, there is an ongoing debate regarding LET procedures, as several other biomechanical studies have displayed controversial results, including the overconstraint of internal tibial rotation or a failure to restore normal joint kinematics.[4,9,15,20]

Recently, Kittl et al[11] compared the femoral attachment sites of several previously described LET techniques in a biomechanical study and described a femoral isometric attachment area (IAA) for LET procedures. Thus, any LET reconstruction combination that had a femoral insertion site located proximal to the lateral femoral epicondyle (LFE) and that coursed deep to the lateral collateral ligament (LCL) displayed steady length change patterns during knee motion and showed a significantly lower total strain range compared with reconstructions that were located anterior and distal to the LFE. While the femoral tunnel position of the Lemaire reconstruction[14] constituted the most distal femoral insertion point within the IAA, being just proximal and posterior to the LFE, the femoral tunnel position of the MacIntosh reconstruction technique represented the most proximally edged insertion within the IAA, being posterior to the femoral cortex and to the distal insertion of the Kaplan fiber attachment (KFA) of the distal femur.[10] Accordingly, it can be assumed that any femoral tunnel position located between the LFE and the distal insertion of the KFA results in isometric graft behavior.

In the absence of definite anatomic and radiographic landmarks for guiding the tunnel placement in LET procedures, there is a certain risk of tunnel misplacement and consequent nonisometric graft biomechanics. Although limited evidence exists regarding the influence of tunnel misplacement on clinical outcomes and failure rates in LET procedures, it is likely that, as in other orthopaedic reconstructive procedures, notable deviations from an isometric attachment site can compromise clinical outcomes, including potential overconstraint of the knee, abnormal joint kinematics, or a failure to restore rotational stability. Therefore, reproducible surgical techniques for an accurate tunnel positioning within the IAA are desirable.

The aim of this study was, first, to define the recently described IAA on a lateral radiograph and, second, to establish radiographic landmarks to assist in intraoperative femoral tunnel placement and aid in the postoperative evaluation of LET procedures.

Furthermore, an additional purpose was to assess the reproducibility of the identification of these landmarks by using intra- and interclass correlation coefficients (ICCs).

We hypothesized that definable anatomic landmarks containing the IAA could be consistently identified on a lateral radiograph and, further, that a standardized radiographic protocol could reproducibly describe the radiographic positions of the IAA in relation to defined reference lines.

METHODS

Ten nonpaired, fresh-frozen cadaveric knees from donors with a mean age of 68.5 ± 7.5 years (7 left knees and 3 right knees) were obtained.

One experienced orthopaedic knee surgeon (S.S.) performed all of the dissections. The skin and subcutaneous fat were removed. Then, the iliotibial tract was dissected and the deep aspects of the iliotibial tract, with its KFAs on the distal femur, were exposed. A 2.4-mm drill guide was positioned just distal of the femoral attachment of the Kaplan fibers.

The knees were then completely dissected. The apex of the LFE was detected and another drill guide was positioned there. The drill guides were then removed and both tunnel entries were marked with a 2.5-mm steel ball.

Standardized true lateral radiographs were taken by using an image intensifier (Ziehm vision R, Ziehm Imaging GmbH), which showed overlapping condyles. A ruler was positioned in the radiograph, which allowed for a correction for magnification.

Radiological Measurement

Measurements of the LFE and KFA positions were performed with a professional computer-aided drawing and measurement software (Canvas 9.0, ACD Systems).

For absolute measurement, in relation to the defined reference lines, an extension of the posterior femoral cortex was drawn distally (line 1) (Figure 1), and the distance between line 1 and the marked position was measured, to determine the anterior-posterior direction (a', positive value, if the point was anterior to line 1). Then, 1 line perpendicular to this extension line was drawn by intersecting the contact of the posterior femoral condyle with the posterior cortex (line 2). The distance between line 2 and the marked position was measured to determine the proximal-distal direction (b', positive value, if the point was proximal to line 2).

Furthermore, for the comparable measurements of the LFE and KFA positions in relation to the knee size, an additional extension of the anterior femoral cortex was drawn distally (line 3) (Figure 1) and parallel to line 1, and the distance between line 1 and line 3 was measured and defined as 100% (a). The length of a was then laid on line 1 to create a square (b). The relative anterior-posterior and proximal-distal distances from the marked position in relation to a, relative to b, were measured and expressed as a percentage (a'/a, b'/b) (Figure 1).

Statistical Analysis

Two independent observers (V.J. and S.S.) measured each of the distances on all of the radiographs on 2 different occasions, to determine the interobserver and intraobserver ICCs by using SPSS Statistics Software version 21 (IBM Corp.). To qualify the ICC, the following commonly used guidelines were set: <0.2, slight agreement; 0.21-0.40, fair agreement; 0.41-0.60, moderate agreement; 0.61-0.80, substantial agreement; and 0.81-1.00, almost perfect agreement.[13]

Measurement results were analyzed using a statistical analysis software (GraphPad Prism Software version 7 for Mac). Mean positions, SDs, and ranges were calculated to determine the variability of the LFE and KFA locations.

Figure 1. Measurements of the lateral femoral epicondyle and Kaplan fiber attachment positions. An extension of the posterior femoral cortex (line 1) and 1 perpendicular line intersecting the contact of the posterior femoral condyle with the posterior cortex were drawn (line 2). An additional extension of the anterior femoral cortex was drawn parallel to line 1 (line 3). The absolute (*a*′, *b*′; mm) and relative (*a*′/*a, b*′/*b*; %) anterior-posterior and proximal-distal distances of the marked positions from line 1, relative to line 2, were measured.

Ethical Approval

Ethical approval was obtained from the ethics committee of Witten/Herdecke University, Germany (IRB 164/2018).

RESULTS

Location of the Lateral Femoral Epicondyle

The LFE was located posterior to the posterior cortical extension (line 1) in 8 specimens, and on the line and anterior to the posterior cortical extension (line 1) in 1 specimen each. In the proximal-distal direction, the LFE was found distal to the posterior femoral condyle (line 2) in all 10 specimens.

The mean anterior-posterior and proximal-distal positions were found –4 ± 4 mm away (posteriorly) from line 1 and –6 ± 4 mm away (distally) from line 2, respectively (Table 1, Figure 2).

The mean anterior-posterior and proximal-distal positions relative to line *a* were found at –12% and –17%, respectively (Table 1).

Location of the Kaplan Fiber Attachments on the Distal Femur

The KFA was located anterior to line 1 in 9 cases and posterior to line 1 in another specimen. In all 10 specimens, the KFAs were located proximal to line 2.

TABLE 1
Measurement Results of the LFE and KFA Positions in the Anterior-Posterior and Proximal-Distal Directions[a]

	LFE		KFAs	
	ap (%)	pd (%)	ap (%)	pd (%)
Mean	–12	–17	11	59
Min	–34	–29	–5	36
Max	5	–3	21	91
SD	12	9	7	17
	ap (mm)	pd (mm)	ap (mm)	pd (mm)
Mean	–4	–6	4	20
Min	–14	–12	–2	14
Max	2	–1	7	26
SD	4	4	3	5

[a]Values are expressed as percentages relative to the width of the femur, as distances from the posterior cortex line (ap) and as distances from the perpendicular line intersecting the contact of the posterior femoral condyle with the posterior cortex (pd). ap, anterior-posterior; KFA, Kaplan fiber attachment; LFE, lateral femoral epicondyle; pd, proximal-distal.

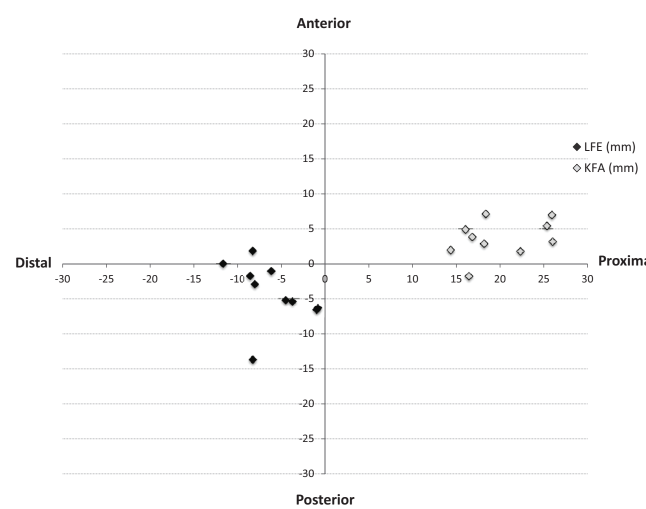

Figure 2. Measurement results of the lateral femoral epicondyle (LFE) and the Kaplan fiber attachment (KFA) positions in the anterior-posterior and proximal-distal directions. The zero point represents the intersection of the posterior cortex line and the perpendicular line of the posterior femoral condyle.

The mean anterior-posterior and proximal-distal locations were found 4 ± 3 mm away (anteriorly) from line 1 and 20 ± 5 mm away (proximally) from line 2, respectively (Table 1, Figure 2).

The mean anterior-posterior and proximal-distal positions relative to line *a* were found at 11% and 59%, respectively (Table 1).

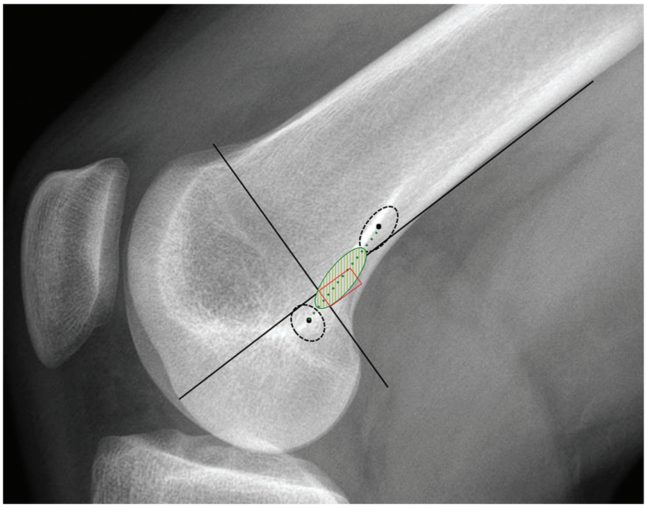

Figure 3. A lateral radiograph containing the radiographic description of the isometric femoral lateral extra-articular tenodesis attachment (green ellipse) between the lateral femoral epicondyle (LFE; distal position) and the Kaplan fiber attachment (KFA; proximal position). The black points represent the mean locations of the LFE and the KFA origins within a 95% CI (black circles). The red square displays the recommended area for a safe isometric femoral tunnel position.

The variability of the LFE and KFA positions on a lateral radiograph, relative to the size of the femur, is depicted in Figure 3. Given that the isometric femoral attachment site has been described both proximal and posterior to any LFE, as well as distal to any KFA position (green ellipse), the placement of the femoral tunnel proximal to the posterior femoral condyle line (line 2) within a 10-mm distance and orientating the tunnel on or below the posterior cortex line (line 1) ensures the safe placement of the femoral tunnel within the isometric area (red square).

The interobserver ICCs were 0.878 and 0.935, and the intraobserver ICCs were 0.913 and 0.954, at the time of the first and second measurements, respectively, thus indicating almost perfect agreement.

DISCUSSION

In this study, radiographic landmarks for femoral tunnel placement in LET procedures were established, in relation to a previously defined isometric femoral attachment site. Based on the radiographic location of the lateral epicondyle and the femoral attachment of the Kaplan fibers, the placement of the femoral tunnel on or posterior to the femoral cortex line and proximal to the posterior femoral condyle within a 10-mm distance ensures that the tunnel remains safely located in the isometric zone. Furthermore, a method of determining the femoral tunnel position on a lateral radiograph has been described, with reference to fixed radiographic reference points. These findings may help to intraoperatively guide surgeons for an accurate, reproducible femoral tunnel placement and to aid in the postoperative evaluation of LET procedures in patients with postoperative persistent complaints. In addition, high intra- and interclass correlation coefficients indicate a reliable identification of these landmarks.

As LET procedures do not reconstruct a particular anatomic structure, an intraoperative evaluation of whether femoral tunnel positioning allows for isometric graft behavior constitutes a major challenge, especially as no anatomic landmarks exist to identify an exact position. Therefore, Kittl et al[11] examined length change patterns of several previously described femoral attachment positions in a biomechanical cadaveric study and identified an IAA for a safe tunnel placement. According to this study, grafts that were attached between the LFE and the distal insertion of the KFA and that ran deep to the LCL displayed steady length change patterns and did not sustain excessive tightening or slackening during knee motion. Intraoperatively, the method of palpating these anatomic landmarks may, however, lead to a high variability of tunnel placement, and consequent nonisometric graft biomechanics can be assumed.

Given that the LFE on a lateral radiograph was located distal to the posterior femoral condyle in all specimens and, on average, 4 mm posterior to the posterior cortex line, staying proximal to the posterior femoral condyle and further orienting on the femoral cortex line regarding the anterior-posterior direction may serve as a feasible intraoperative guidance maneuver for femoral tunnel placement. The range of isometric tunnel positioning in the proximal direction (particularly in larger knee sizes) may be larger; however, by remaining within a 10-mm distance proximal to the posterior femoral condyle, the isometric placement of the femoral tunnel distal to any KFA is ensured.

Although limited evidence exists regarding the influence of tunnel misplacement in a clinical setting, biomechanical studies have demonstrated that a nonisometric femoral attachment in LET procedures can lead to the overconstraint of internal tibial rotation or a failure to restore normal joint kinematics.[4,9,15,20] Therefore, it may be assumed that notable deviations from an isometric tunnel position may similarly affect the clinical outcome.

There has been a recent increase of cadaveric studies that have identified radiographic landmarks of anatomic structures in various other orthopaedic surgical procedures, such as medial patellofemoral ligament, ACL, or LCL reconstructions, because the use of fluoroscopy has been shown to reduce the variability of tunnel positions.[12,17,19] Therefore, radiographic landmarks in LET procedures may similarly be useful in reducing the risk of tunnel misplacements, as well as in creating consistent results.

In addition, these landmarks may help in comparing postoperative tunnel positions in LET procedures with clinical results, as well as in evaluating tunnel positions in patients with recurrent rotatory instability or persisting pain. In contrast to other studies describing radiographic landmarks by using only absolute distances,[17,18] the recommendations of this study can be used in a clinical setting independent of the size of the femur because landmarks have been defined as absolute millimeter values, as well as distances relative to the height of the femur.

Limitations

There are several limitations to this study. The radiographic reference points represent the variability of 10 specimens, which naturally includes anatomic interspecimen variations. However, measurements were normalized in relation to the sizes of the knees. Furthermore, the sample size is comparable with those in other radiographic studies that have been previously performed.[1,18] In addition, as definite anatomic landmarks in LET procedures do not exist, the radiographic references described in this study are based on the biomechanical results of 1 cadaveric study. Therefore, future research may involve the performance of biomechanical studies of fluoroscopic controlled femoral tunnel placements in LET procedures to compare which reconstructions optimally reduce anterolateral rotatory instability, without providing nonisometric overconstraint of the knee.

CONCLUSION

Radiographic landmarks for an isometric femoral tunnel placement in LET procedures were described. These findings may help to intraoperatively guide surgeons for an accurate, reproducible femoral tunnel placement and to reduce the potential risk of tunnel misplacement, as well as to aid in the postoperative evaluation of LET procedures in patients with residual complaints.

REFERENCES

1. Barnett AJ, Howells NR, Burston BJ, Ansari A, Clark D, Eldridge JD. Radiographic landmarks for tunnel placement in reconstruction of the medial patellofemoral ligament. *Knee Surg Sports Traumatol Arthrosc*. 2012;20(12):2380-2384.
2. Devitt BM, Bouguennec N, Barfod KW, Porter T, Webster KE, Feller JA. Combined anterior cruciate ligament reconstruction and lateral extra-articular tenodesis does not result in an increased rate of osteoarthritis: a systematic review and best evidence synthesis. *Knee Surg Sports Traumatol Arthrosc*. 2017;25(4):1149-1160.
3. Dodds AL, Gupte CM, Neyret P, Williams AM, Amis AA. Extra-articular techniques in anterior cruciate ligament reconstruction: a literature review. *J Bone Joint Surg Br*. 2011;93(11):1440-1448.
4. Draganich LF, Reider B, Ling M, Samuelson M. An in vitro study of an intraarticular and extraarticular reconstruction in the anterior cruciate ligament deficient knee. *Am J Sports Med*. 1990;18(3):262-266.
5. Engebretsen L, Lew WD, Lewis JL, Hunter RE. The effect of an iliotibial tenodesis on intraarticular graft forces and knee joint motion. *Am J Sports Med*. 1990;18(2):169-176.
6. Ferretti A, Monaco E, Ponzo A, et al. Combined intra-articular and extra-articular reconstruction in anterior cruciate ligament-deficient knee: 25 years later. *Arthroscopy*. 2016;32(10):2039-2047.
7. Guzzini M, Mazza D, Fabbri M, et al. Extra-articular tenodesis combined with an anterior cruciate ligament reconstruction in acute anterior cruciate ligament tear in elite female football players. *Int Orthop*. 2016;40(10):2091-2096.
8. Hewison CE, Tran MN, Kaniki N, Remtulla A, Bryant D, Getgood AM. Lateral extra-articular tenodesis reduces rotational laxity when combined with anterior cruciate ligament reconstruction: a systematic review of the literature. *Arthroscopy*. 2015;31(10):2022-2034.
9. Inderhaug E, Stephen JM, El-Daou H, Williams A, Amis AA. The effects of anterolateral tenodesis on tibiofemoral contact pressures and kinematics. *Am J Sports Med*. 2017;45(13):3081-3088.
10. Ireland J, Trickey EL. Macintosh tenodesis for anterolateral instability of the knee. *J Bone Joint Surg Br*. 1980;62(3):340-345.
11. Kittl C, Halewood C, Stephen JM, et al. Length change patterns in the lateral extra-articular structures of the knee and related reconstructions. *Am J Sports Med*. 2015;43(2):354-362.
12. Koenen P, Shafizadeh S, Pfeiffer TR, et al. Intraoperative fluoroscopy during MPFL reconstruction improves the accuracy of the femoral tunnel position. *Knee Surg Sports Traumatol Arthrosc*. 2018;26(12):3547-3552.
13. Landis JR, Koch GG. The measurement of observer agreement for categorical data. *Biometrics*. 1977;33(1):159-174.
14. Lemaire M, Combelles F. [Plastic repair with fascia lata for old tears of the anterior cruciate ligament (author's transl)]. *Rev Chir Orthop Reparatrice Appar Mot*. 1980;66(8):523-525.
15. Matsumoto H, Seedhom BB. Treatment of the pivot-shift intraarticular versus extraarticular or combined reconstruction procedures. A biomechanical study. *Clin Orthop Relat Res*. 1994;299:298-304.
16. Monaco E, Labianca L, Conteduca F, De Carli A, Ferretti A. Double bundle or single bundle plus extraarticular tenodesis in ACL reconstruction? A CAOS study. *Knee Surg Sports Traumatol Arthrosc*. 2007;15(10):1168-1174.
17. Pfeiffer TR, Herbst E, Kanakamedala AC, Naendrup JH, Debski RE, Musahl V. The use of fluoroscopy leads to improved identification of the femoral lateral collateral ligament origin site when compared with traditional tactile techniques. *Arthroscopy*. 2018;34(8):2487-2493.e1.
18. Schöttle PB, Schmeling A, Rosenstiel N, Weiler A. Radiographic landmarks for femoral tunnel placement in medial patellofemoral ligament reconstruction. *Am J Sports Med*. 2007;35(5):801-804.
19. Shafizadeh S, Balke M, Hagn U, Hoeher J, Banerjee M. Variability of tunnel positioning in ACL reconstruction. *Arch Orthop Trauma Surg*. 2014;134(10):1429-1436.
20. Slette EL, Mikula JD, Schon JM, et al. Biomechanical results of lateral extra-articular tenodesis procedures of the knee: a systematic review. *Arthroscopy*. 2016;32(12):2592-2611.
21. Sonnery-Cottet B, Daggett M, Fayard JM, et al. Anterolateral Ligament Expert Group consensus paper on the management of internal rotation and instability of the anterior cruciate ligament—deficient knee. *J Orthop Traumatol*. 2017;18(2):91-106.
22. Trojani C, Beaufils P, Burdin G, et al. Revision ACL reconstruction: influence of a lateral tenodesis. *Knee Surg Sports Traumatol Arthrosc*. 2012;20(8):1565-1570.
23. Vadala AP, Iorio R, De Carli A, et al. An extra-articular procedure improves the clinical outcome in anterior cruciate ligament reconstruction with hamstrings in female athletes. *Int Orthop*. 2013;37(2):187-192.