THIEME OPEN ACCESS

Bone Tunnel Enlargement after ACL Reconstruction with Hamstring Autograft Is Dependent on Original Bone Tunnel Diameter

Steffen Sauer, MD[1] Martin Lind, MD, PhD[1]

[1] Department of Orthopaedic Surgery and Sports Medicine, Arhus University Hospital, Aarhus, Denmark

Address for correspondence Steffen Sauer, MD, Department of Orthopaedic Surgery and Sports Medicine, Arhus University Hospital, Norrebrogade 44, DK-8000 Aarhus, Denmark (e-mail: stefsaue@rm.dk).

Surg J 2017;3:e96–e100.

Abstract

Background Bone tunnel enlargement is a well-established phenomenon following anterior cruciate ligament (ACL) reconstruction, and is related to soft tissue grafts, suspension fixation devices, and absorbable implants. Severe tunnel enlargement can lead to reconstruction failure. The correlation between bone tunnel enlargement following ACL reconstruction and original bone tunnel diameter has not been elucidated.

Purpose To determine whether bone tunnel enlargement after ACL reconstruction with hamstring autograft is dependent on original tunnel diameter established during primary ACL reconstruction.

Materials and Methods A retrospective review was conducted on 56 patients scheduled for ACL revision surgery who had undergone computed tomography (CT) scanning as part of their preoperative evaluation. All patients had undergone previous hamstring ACL reconstruction. Original femoral and tibial bone tunnel diameters were extracted from operative reports, and femoral and tibial bone tunnel enlargement was assessed on CT serial sections. The correlation between original tunnel diameter and bone tunnel enlargement was investigated using regression analysis.

Results Mean tibial bone tunnel enlargement was significantly and inversely dependent on the original tibial bone tunnel diameter with a correlation coefficient of −0.55 per unit (7 mm = +1.93 mm, 8 mm = +1.43 mm, 9 mm = 0.83 mm, $p = 0.007$). Thus, every additional increase (mm) in diameter of the original tibial bone tunnel reduces the extend of tunnel widening by 0.55 mm.

Conclusions The results of this study indicate that tibial bone tunnel enlargement following ACL reconstruction is dependent on original tibial bone tunnel diameter with smaller diameter tunnels developing more tunnel enlargement than larger tunnels. The contributing factors remain unclear and need to be further investigated.

Keywords
- ACL
- tunnel widening
- tunnel enlargement

Bone tunnel enlargement is a well-established phenomenon occurring predominantly within the first 3 months following anterior cruciate ligament (ACL) reconstruction surgery.[1,2] The highest percentage of change in femoral and tibial tunnel size occurs within the first 6 weeks after surgery.[1] However, tunnel enlargement has been reported up to 2 years post-operatively.[1,3,4] The incidence of tunnel enlargement is particularly related to hamstring autografts with large

received
February 4, 2017
accepted after revision
May 3, 2017

DOI https://doi.org/10.1055/s-0037-1603950.
ISSN 2378-5128.

reported variability ranging from 25 to 100% in femoral tunnels and 29 to 100% in tibial tunnels.[5–8] First attributed to allografts[3,9] and bone-tendon-bone (BTB) grafts,[10,11] tunnel enlargement related to hamstring autografts was first described by ĹInsalata and Harner in the late nineties.[2] Clatworthy et al proposed a multifactorial etiology of tunnel enlargement with a biochemical component after performing suspensory fixation in both hamstring and BTB grafts, finding a higher incidence of tunnel enlargement in hamstring grafts.[12] Faunoe and Kaalund reported more distinct tunnel enlargement in cortical fixation compared with transverse pin fixation of hamstring grafts, concluding that the graft fixation site in relation to the joint is crucial in the development of tunnel enlargement.[13] The exact etiology of tunnel enlargement however remains unclear and is believed to be a multifactorial process including both mechanical and biological factors.[10,12,14–19] Mechanical factors include graft tunnel-motion, especially in tunnel malposition; drill-related bone necrosis; and aggressive rehabilitation.[7,9,10,20–24] Biochemical factors include synovial fluid propagation and cytokine-induced osteolysis, eventually aggravated by absorbable fixation implants.[3,9,10,23] The clinical relevance of tunnel enlargement is uncertain. Although the majority of studies did not reveal a correlation between tunnel enlargement and clinical outcome,[2,3,8,9,12,17,20,23,25–27] some studies have recognized tunnel enlargement to be an early sign of graft failure.[28] However, a clinically *important* issue is that revision surgery is complicated by severe tunnel enlargement, eventually making the two-stage ACL revision surgery necessary.[29] Previous studies have *focused* on the correlation between bone tunnel enlargement and surgical technique, graft choice, and rehabilitation.[2,8,10,17] To our knowledge, the correlation between bone tunnel enlargement and original bone tunnel diameter has not been elucidated.

Purpose and Hypothesis

The purpose of this study was to determine whether bone tunnel enlargement after ACL reconstruction with hamstring autograft measured on computed tomography (CT) is dependent on original tunnel diameter established during primary ACL reconstruction surgery. As both mechanical and biological causes of tunnel enlargement may theoretically be dependent on graft-tunnel contact area and bone–tendon interface, we hypothesized that smaller diameter tunnels are more susceptible to tunnel enlargement than larger tunnels.

Methods

Patients

All patients with accessible CT scanning of femoral and tibial bone tunnels after ACL reconstruction were identified. As CT is used as a part of preoperative revision evaluation, a cohort of 122 consecutive patients, who were scheduled for ACL revision surgery at the Aarhus University Hospital between 2013 and 2016, was identified. Of these patients, the study included 56 patients with primary ACL reconstruction using hamstring autograft and accessible primary operative reports and a new CT scan of femoral and tibial bone tunnels as part of the preoperative ACL revision evaluation. These inclusion criteria enabled CT-based evaluation of tunnel enlargement after hamstring autograft ACL reconstruction. Medical records including operative reports were assessed to identify original femoral and tibial bone tunnel diameter established during primary ACL reconstruction (range: 6–9 mm). Furthermore, patient demographics and graft fixation methods were recorded (►**Table 1**).

CT Assessment

Femoral and tibial bone tunnel enlargement was assessed by CT scanning (mean time from ACL reconstruction to CT tunnel measurement = 40.8 months) using the traditional two-dimensional (2D) CT method.[30] The transosseus diameter of femoral and tibial tunnels was measured at each tunnel midpoint in coronal, sagittal, and axial CT image planes using a linear measuring tool (►**Fig. 1**).

Table 1 Graft fixation methods in relation to original bone tunnel diameter established during primary ACL reconstruction (range: 6–9 mm)

Original bone tunnel diameter (mm)	6	6.5	7	7.5	8	8.5	9
Number of patients (*n*)	1	2	15	3	16	1	17
Primary femoral ACL graft fixation							
Cortical suspension	1	2	13	3	14	1	14
Transverse pin fixation	0	0	2	0	2	0	2
Interference screw	0	0	0	0	0	0	1
Primary tibial ACL graft fixation							
Nonabsorbable screw	1	2	15	3	5	1	9
Absorbable screw	0	0	0	0	3	0	3
Nonspecified screw	0	0	0	0	8	0	5

Abbreviation: ACL, anterior cruciate ligament.

Fig. 1 Two-dimensional (2D) computed tomography (CT) measuring method.[30] Bone tunnels are assessed in coronal, sagittal, and axial CT image planes.

Statistics

Mean tunnel diameter values were calculated and analysis of the correlation between original tunnel diameter and bone tunnel enlargement was investigated using regression analysis.

Results

Tunnel enlargement from the original tunnel diameter to CT measured, follow-up diameter for both femoral and tibial bone tunnels is presented in ►**Table 2**. For femoral tunnels, original 7-mm bone tunnels showed a mean tunnel enlargement of +0.15 mm ($p = 0.576$). Original 8-mm bone tunnels showed a mean tunnel enlargement of −0.003 mm ($p = 0.987$), while 9-mm original bone tunnels showed a mean tunnel enlargement of −0.16 mm ($p = 0.574$). For tibial tunnels, original 7-mm tibial bone tunnels showed a mean tunnel enlargement of +1.93 mm ($p = 0.0001$). Original 8-mm bone tunnels showed a mean tunnel enlargement of +1.38 mm ($p = 0.0001$), while original 9-mm bone tunnels showed a mean tunnel enlargement of +0.83 mm ($p = 0.002$). As seen in ►**Fig. 2**, mean tibial bone tunnel enlargement is significantly and inversely dependent on the original tibial bone tunnel diameter with a correlation coefficient of −0.55 ($p = 0.007$). Thus, every additional increase (mm) in diameter regarding the original tibial bone tunnel reduces the extend of tibial tunnel widening by 0.55 mm. There was no significant correlation between tunnel enlargement and the elapsed time from primary ACL reconstruction to CT follow-up measurement (mean = 40.8 months; range = 7–139 months; femoral tunnels, $p = 0.2$; tibial tunnels, $p = 0.06$). There was no significant correlation between tunnel enlargement and patient age.

Discussion

The primary finding of the this study was that tunnel enlargement of tibial bone tunnels after hamstring ACL reconstruction was inversely correlated to the original tunnel diameter, with small diameter tunnels showing more excessive tunnel enlargement than larger tunnels. Second, femoral bone tunnels did not demonstrate any significant tunnel enlargement. The dependency of bone tunnel enlargement on original bone tunnel diameter has not been described before. Clatworthy et al proposed a multifactorial etiology of tunnel enlargement with a biochemical component after performing suspensory fixation in both hamstring and BTB grafts and finding a higher incidence of tunnel enlargement in hamstring grafts.[12] Interestingly, the authors mentioned an evident difference in graft size distribution with hamstrings ranging from 6 to 10 mm and BTB grafts ranging from 9 to 13 mm. Considering the results of this study, it seems possible that the differences in original tunnel diameter *might* have contributed to the finding of more tunnel enlargement for hamstring grafts in the study of Clatworthy et al, as hamstring grafts classically have the smallest original tunnel diameters in comparison to grafts with bone blocks. The fact that femoral tunnels in

Table 2 Tunnel enlargement presented as change in original bone tunnel diameter

Original tunnel diameter	Femoral mean bone tunnel enlargement (CI, *p*-value)	Tibial mean bone tunnel enlargement (CI, *p*-value)
7 mm	+0.15 mm; (CI: −0.4–0.7, $p = 0.576$)	+1.93 mm (CI: 1.4–2.4, $p = 0.0001$)
8 mm	−0.003 mm (CI: −0.42–0.3, $p = 0.987$)	+1.38 mm (CI: 1.1–1.7, $p = 0.0001$)
9 mm	−0.16 mm (CI: −0.7–0.4, $p = 0.574$)	+0.83 mm (CI: 0.3–1.3, $p = 0.002$)

Abbreviation: CI, confidence interval.

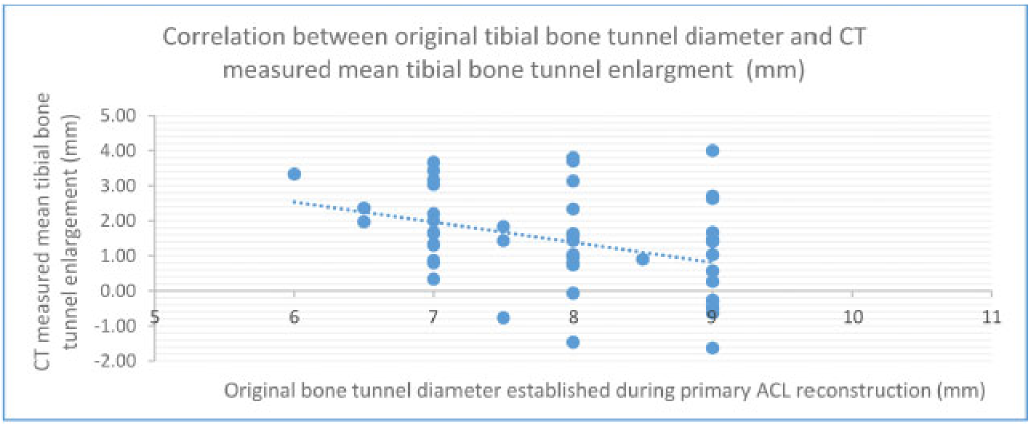

Fig. 2 Regression analysis of the correlation between mean tibial bone tunnel enlargement and original tibial bone tunnel diameter (coefficient correlation: −0.55; confidence interval [CI]: −0.944–156; $p = 0.007$).

comparison to tibial tunnels do not show significant tunnel enlargement has been reported before.[12] A possible explanation could be drill-related bone necrosis, which theoretically is less marked at the femoral site, as the femoral bone-reamer contact area is irrigated with arthroscopic fluid in contrast to the tibial site. Also, the femoral condylar bone has a higher density than proximal tibial bone, which could make femoral bone more resistant to tunnel enlargement after ACL reconstruction. Furthermore, tibial tunnel enlargement may be related to the biomechanical stress caused by the interference screw, which theoretically may be more distinct in smaller bone–tendon interfaces. However, a multifactorial etiology of tunnel enlargement must be assumed. The majority of studies regarding tunnel enlargement after ACL reconstruction surgery have focused on the correlation between bone tunnel enlargement and surgical technique, graft choice, fixation method, and aggressiveness of rehabilitation.[2,8,10,17,31,32] Considerably fewer studies have focused on the potential biochemical causes of tunnel enlargement including the interaction of synovial fluid with the bone–tendon interface.[33] The graft-tunnel contact area may represent a key point in the etiology of tunnel enlargement. Small diameter tunnels with less bone–tendon interface may be more susceptible for drill-related bone necrosis and biomechanical stress, especially in tunnel malposition. In addition, inflammatory cytokines in the synovial fluid may affect the tibial bone–tendon interface more excessively than femoral tunnels, as gravity tends to direct synovial fluid into the tibial bone tunnel. This could explain why femoral tunnels did not show significant tunnel enlargement. ACL reconstruction with graft diameters less than 8 mm in diameter has been shown to be associated with higher revision rates.[29,34] Insufficient graft material has been proposed as a potential cause. The results from this study suggest an additional cause for these clinical findings, as small diameter ACL reconstructions will have a higher proportion of tunnel enlargement that could result in graft fixation failure. The small and inhomogeneous patient cohort comprising different graft fixation methods represents a limitation of this study. Furthermore, all accessible CT scans represented patients who had failure of their ACL reconstruction, and therefore, could represent a population with altered biomechanics. Studies with larger cohorts are needed to investigate the correlation between original bone tunnel diameter and bone tunnel enlargement. The results of this study present a new perspective on bone tunnel enlargement etiology, as small diameter bone tunnel diameter may represent an unrecognized factor favoring bone tunnel enlargement. However, further studies are needed to revise the findings of this study.

Conclusion

The results of this study indicate that tibial bone tunnel enlargement following ACL reconstruction is significantly and inversely dependent on the original tibial bone tunnel diameter. Every additional increase (mm) in diameter regarding the original tibial bone tunnel reduces the extend of tibial tunnel widening with 0.55 mm. The contributing factors remain unclear and need to be further investigated.

References

1 Buck DC, Simonian PT, Larson RV, Borrow J, Nathanson DA. Timeline of tibial tunnel expansion after single-incision hamstring anterior cruciate ligament reconstruction. Arthroscopy 2004;20(01):34–36
2 L'Insalata JC, Klatt B, Fu FH, Harner CD. Tunnel expansion following anterior cruciate ligament reconstruction: a comparison of hamstring and patellar tendon autografts. Knee Surg Sports Traumatol Arthrosc 1997;5(04):234–238
3 Jackson DW, Windler GE, Simon TM. Intraarticular reaction associated with the use of freeze-dried, ethylene oxide-sterilized bone-patella tendon-bone allografts in the reconstruction of the anterior cruciate ligament. Am J Sports Med 1990;18(01):1–10; discussion 10–11
4 Sgaglione NA, Douglas JA. Allograft bone augmentation in anterior cruciate ligament reconstruction. Arthroscopy 2004; 20(Suppl 2):171–177
5 Fules PJ, Madhav RT, Goddard RK, Newman-Sanders A, Mowbray MA. Evaluation of tibial bone tunnel enlargement using MRI scan

cross-sectional area measurement after autologous hamstring tendon ACL replacement. Knee 2003;10(01):87–91
6 Jansson KA, Harilainen A, Sandelin J, Karjalainen PT, Aronen HJ, Tallroth K. Bone tunnel enlargement after anterior cruciate ligament reconstruction with the hamstring autograft and endobutton fixation technique. A clinical, radiographic and magnetic resonance imaging study with 2 years follow-up. Knee Surg Sports Traumatol Arthrosc 1999;7(05):290–295
7 Nebelung W, Becker R, Merkel M, Röpke M. Bone tunnel enlargement after anterior cruciate ligament reconstruction with semitendinosus tendon using Endobutton fixation on the femoral side. Arthroscopy 1998;14(08):810–815
8 Segawa H, Omori G, Tomita S, Koga Y. Bone tunnel enlargement after anterior cruciate ligament reconstruction using hamstring tendons. Knee Surg Sports Traumatol Arthrosc 2001;9(04):206–210
9 Roberts TS, Drez D Jr, McCarthy W, Paine R. Anterior cruciate ligament reconstruction using freeze-dried, ethylene oxide-sterilized, bone-patellar tendon-bone allografts. Two year results in thirty-six patients. Am J Sports Med 1991;19(01):35–41
10 Fahey M, Indelicato PA. Bone tunnel enlargement after anterior cruciate ligament replacement. Am J Sports Med 1994;22(03):410–414
11 Peyrache MD, Djian P, Christel P, Witvoet J. Tibial tunnel enlargement after anterior cruciate ligament reconstruction by autogenous bone-patellar tendon-bone graft. Knee Surg Sports Traumatol Arthrosc 1996;4(01):2–8
12 Clatworthy MG, Annear P, Bulow JU, Bartlett RJ. Tunnel widening in anterior cruciate ligament reconstruction: a prospective evaluation of hamstring and patella tendon grafts. Knee Surg Sports Traumatol Arthrosc 1999;7(03):138–145
13 Fauno P, Kaalund S. Tunnel widening after hamstring anterior cruciate ligament reconstruction is influenced by the type of graft fixation used: a prospective randomized study. Arthroscopy 2005;21(11):1337–1341
14 Clatworthy MG, Bartelett J, Howell S, et al. The effect of graft fixation techniques on tunnel widening in hamstring ACL reconstruction. Arthroscopy 1999;15(Suppl):5
15 Harris NL, Indelicato PA, Bloomberg MS, Meister K, Wheeler DL. Radiographic and histologic analysis of the tibial tunnel after allograft anterior cruciate ligament reconstruction in goats. Am J Sports Med 2002;30(03):368–373
16 Hersekli MA, Akpinar S, Ozalay M, et al. Tunnel enlargement after arthroscopic anterior cruciate ligament reconstruction: comparison of bone-patellar tendon-bone and hamstring autografts. Adv Ther 2004;21(02):123–131
17 Höher J, Möller HD, Fu FH. Bone tunnel enlargement after anterior cruciate ligament reconstruction: fact or fiction? Knee Surg Sports Traumatol Arthrosc 1998;6(04):231–240
18 Wilson TC, Kantaras A, Atay A, Johnson DL. Tunnel enlargement after anterior cruciate ligament surgery. Am J Sports Med 2004;32(02):543–549
19 Wright RW, Dunn WR, Amendola A, et al. Risk of tearing the intact anterior cruciate ligament in the contralateral knee and rupturing the anterior cruciate ligament graft during the first 2 years after anterior cruciate ligament reconstruction. Am J Sports Med 2007;35(07):1131–1134
20 Linn RM, Fischer DA, Smith JP, Burstein DB, Quick DC. Achilles tendon allograft reconstruction of the anterior cruciate ligament-deficient knee. Am J Sports Med 1993;21(06):825–831
21 Otsuka H, Ishibashi Y, Tsuda E, Sasaki K, Toh S. Comparison of three techniques of anterior cruciate ligament reconstruction with bone-patellar tendon-bone graft. Differences in anterior tibial translation and tunnel enlargement with each technique. Am J Sports Med 2003;31(02):282–288
22 Sakai H, Yajima H, Hiraoka H, et al. The influence of tibial fixation on tunnel enlargement after hamstring tendon anterior cruciate ligament reconstruction. Knee Surg Sports Traumatol Arthrosc 2004;12(05):364–370
23 Schulte K, Majewski M, Irrgang JJ, et al. Radiographic tunnel changes following arthroscopical reconstruction: autograft versus allograft. Arthroscopy 1995;11:372–373
24 Simonian PT, Erickson MS, Larson RV, O'kane JW. Tunnel expansion after hamstring anterior cruciate ligament reconstruction with 1-incision EndoButton femoral fixation. Arthroscopy 2000;16(07):707–714
25 Fink C, Zapp M, Benedetto KP, Hackl W, Hoser C, Rieger M. Tibial tunnel enlargement following anterior cruciate ligament reconstruction with patellar tendon autograft. Arthroscopy 2001;17(02):138–143
26 Lind M, Feller J, Webster KE. Bone tunnel widening after anterior cruciate ligament reconstruction using EndoButton or EndoButton continuous loop. Arthroscopy 2009;25(11):1275–1280
27 Webster KE, Feller JA, Hameister KA. Bone tunnel enlargement following anterior cruciate ligament reconstruction: a randomised comparison of hamstring and patellar tendon grafts with 2-year follow-up. Knee Surg Sports Traumatol Arthrosc 2001;9(02):86–91
28 Siebold R, Kiss ZS, Morris HG. Effect of compaction drilling during ACL reconstruction with hamstrings on postoperative tunnel widening. Arch Orthop Trauma Surg 2008;128(05):461–468
29 Rizer M, Foremny GB, Rush A III, et al. Anterior cruciate ligament reconstruction tunnel size: causes of tunnel enlargement and implications for single versus two-stage revision reconstruction. Skeletal Radiol 2017;46(02):161–169
30 Crespo B, Aga C, Wilson KJ, et al. Measurements of bone tunnel size in anterior cruciate ligament reconstruction: 2D versus 3D computed tomography model. J Exp Orthop 2014;1(01):2
31 Hantes ME, Mastrokalos DS, Yu J, Paessler HH. The effect of early motion on tibial tunnel widening after anterior cruciate ligament replacement using hamstring tendon grafts. Arthroscopy 2004;20(06):572–580
32 Iorio R, Vadalà A, Argento G, Sanzo VD, Ferretti A. Bone tunnel enlargement after ACL reconstruction using autologous hamstring tendons: a CT study. Int Orthop 2007;31(01):49–55
33 Zysk SP, Fraunberger P, Veihelmann A, et al. Tunnel enlargement and changes in synovial fluid cytokine profile following anterior cruciate ligament reconstruction with patellar tendon and hamstring tendon autografts. Knee Surg Sports Traumatol Arthrosc 2004;12(02):98–103
34 Spragg L, Chen J, Mirzayan R, Love R, Maletis G. The effect of autologous hamstring graft diameter on the likelihood for revision of anterior cruciate ligament reconstruction. Am J Sports Med 2016;44(06):1475–1481