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

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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 postoperatively.[1,3,4] The incidence of tunnel enlargement is particularly related to hamstring autografts with large

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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 ÍInsalata 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.

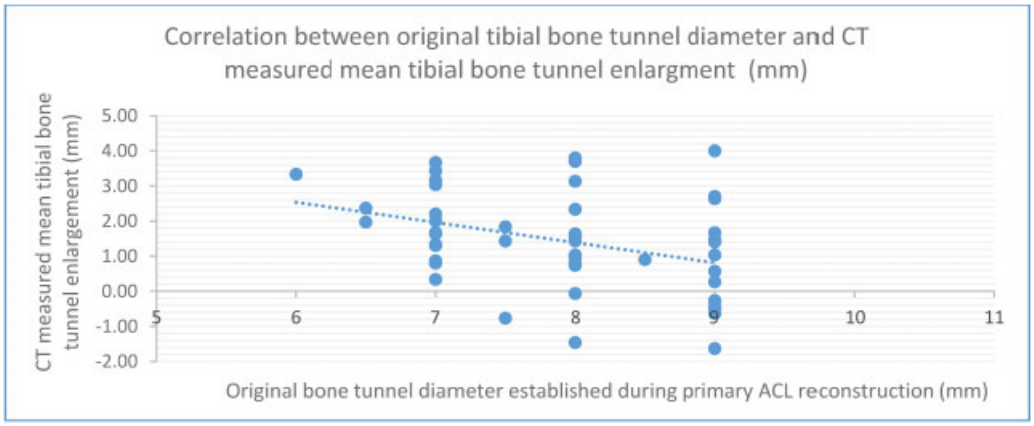

Fig. 2 Regression analysis of the correlation between mean tibial bone tunnel enlargement and original tibial bone tunnel diameter (coefficient correlation: −0.55; confidence interval [CI]: −0.944–156; $p = 0.007$).

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.

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