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ORIGINAL ARTICLE

Tunnel enlargement 5 years after anterior cruciate ligament reconstruction: a radiographic and functional evaluation

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Abstract

Purpose The aetiology and clinical significance of enlargement of bone tunnels following anterior cruciate ligament (ACL) reconstruction remains controversial. This phenomenon has been attributed to biological factors and mechanical factors.

We wanted to study the amount of femoral and tibial tunnel enlargement 5 years post-ACL reconstruction. By standardizing the type of femoral fixation, we also wanted to determine whether the type of tibial fixation had any bearing to the amount of tibial tunnel enlargement.

Methods All patients who underwent arthroscopic hamstring autograft ACL reconstruction between January 2000 and December 2000 were identified. All grafts were fixed with close-looped endobutton proximally. The grafts were fixed on the tibial side with staples or bioabsorbable interference screws.

At a minimum of 5 years after surgery, these patients were recalled. They were assessed with Lysholm knee, Tegner activity and the IKDC Subjective and Objective forms and a KT-1000 arthrometer. The diameter of the bone tunnels and tunnel positions in the anterior–posterior and lateral radiographs were measured using digital callipers by a two blinded researchers.

Results We found that the femoral tunnel enlarged more than the tibial tunnel. At 5 years, the mean tibial tunnel enlargement was 2.46 mm and the mean femoral tunnel enlargement was 3.23 mm. All 54 patients had endobutton femoral fixation. Of them, 34 patients had tibial graft fixation with staples (extracortical fixation) and 20 patients had tibial graft fixation with bioabsorbable interference screws (aperture fixation). The mean enlargement as measured by the two independent observers in the extra-cortical group was 1.98 mm (24.7 %)* and 1.51 mm (18.2 %)**compared to 3.27 mm (40.4 %)* and 2.92 mm (30.0 %)** in the aperture fixation group. This difference in tibial tunnel enlargement between the groups was significant ($p < 0.001$, mean difference 1.29 mm). However, this was not correlated with any significant difference in clinical outcome at 5 years.

Conclusion We, like some authors, have shown that the use of interference screws in tibial fixation despite being aperture fixation actually has a greater amount of tibial enlargement. This lends weight to the biological theory to tunnel enlargement.

Keywords ACL reconstruction · Tunnel enlargement · Tibial fixation

Introduction

Tunnel enlargement after anterior cruciate ligament (ACL) surgery has been established since the 1990s [1]. Hamstring grafts have been shown to have more tunnel enlargement than bone–patellar tendon–bone (BTB) grafts [2, 3]. The aetiology of this phenomenon is controversial and unclear. Tunnel enlargement has been attributed to both biological and mechanical factors and suggested to be affected by the type of fixation used [1, 4–7].

For biological factors, three main theories have been put forth [1]. The immune response to the allograft antigens

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and ethylene oxide used in graft sterilization has been identified as potential causes of tunnel enlargement in allograft ACL reconstruction [6, 8, 9]. The localized bone resorption around titanium or bioabsorbable interference screws is suggested to be facilitated by macrophages releasing cytokines and stimulating osteoclastic activity [10]. ACL graft incorporation has also been suggested as a separate trigger for bone resorption [11].

The mechanical theory of tunnel enlargement is attributed to graft tunnel motion. The 'Bungee effect' is caused by excessive graft tunnel motion secondary to suspensory fixation devices. The second theory is the 'windshield wiper theory' that explains the graft oscillating from distant point of fixation, resulting in enlarged cone-shaped tunnels. Hoher et al. [1] found that fixation further away from the joint had more motion at the entrance of the tunnel. It has been suggested by various authors that tunnel enlargement may be prevented by aperture graft fixation to reduce graft tunnel motion [1, 3, 12, 13].

In our study, we wanted to study the amount of femoral and tibial tunnel enlargement at 5 years post-ACL reconstruction. We also wanted to determine whether the type of tibial fixation influenced the amount of tibial tunnel enlargement.

Methods

All patients who underwent primary ACL reconstruction in our hospital between January 2000 and December 2000 were identified. All patients who underwent revision ACL surgery or knee multi-ligament reconstructions were excluded. Following approval by the hospital ethics committee, 63 patients were successfully recalled. After reviewing these patients based on our inclusion criteria, 54 patients were included in our study.

All patients had undergone an arthroscopic single-incision transtibial ACL reconstruction with double-looped autogenous semitendinosus and gracilis tendons. All grafts were fixed with close-looped endobutton (Smith & Nephew, MA, USA) in the femur. The grafts were fixed on the tibial side with staples (Smith & Nephew, MA, USA) or bioabsorbable interference screws (Smith & Nephew, MA, USA).

For the cases that were fixed with bioabsorbable interference screw, the screw size used was equal to the size of the tibial tunnel drilled. Screw sizes between 7 and 9 mm were used. Meniscal tears were either meniscectomized or repaired depending on the arthroscopic findings during surgery.

Post-operatively, all patients were kept on knee brace till functional return of quadriceps control, and all the knees were immediately mobilized with full weight bearing. All patients underwent a standard post-ACL reconstruction physiotherapy protocol.

The mean age of our patients was 24.8 years (range of 18–40). There were 60 males (95.3 %) and 3 females (4.7 %). There were 43 (68.5 %) recreational athletes and 20 (31.5 %) competitive athletes. Our patients had surgery at an average of 8.7 months (range 1–48 months) after their injury.

Clinical evaluation at 5 years

The patients completed the Lysholm knee, Tegner activity and the Subjective International Knee Documentation Committee (IKDC) questionnaires. Clinical examination of the operated knee was performed according to the Objective International Knee Documentation Committee (IKDC) evaluation form. The operated and non-operated knees were assessed with KT-1000 arthrometer at 134 N and at 30° knee flexion. The difference in millimetres for the anterior displacement between the two knees was calculated.

Radiographic evaluation at 5 years

Knee radiographs (anterior–posterior and lateral in 30° flexion) were performed. A radiographic marker was placed to allow for correction of the magnification factor.

The diameter of the bone tunnels in the anterior–posterior and lateral radiographs was measured using digital callipers by two blinded researchers. The larger of the two diameters (AP and lateral) were taken as amount of tunnel enlargement. We expressed the tunnel enlargement as a percentage value, the amount of enlargement over the perioperative drill size in both the femur and tibia. Interobserver and intraobserver variability in the radiographic measurements were also noted. Figure 1 shows how these tunnels were studied.

Tunnel placements were studied on the true lateral view of the knee using the method described by Segawa et al. [14]. On Blumensaat's line, the distance from the posterior aspect of the femur to the posterior aspect of the femoral tunnel was measured. This was presented as a percentage value to the entire femoral sagittal width (length of Blumensaat's line). The distance of the tibial tunnel from the anterior aspect of the tibial plateau was measured. This was presented as a percentage value with the sagittal width of tibial plateau. The femoral tunnel angle, angle between the femoral tunnel and Blumensaat's line, was also documented. Figure 2 shows how these tunnel placement and femoral tunnel angles were studied.

Statistical analysis

Statistical analysis was performed with SPSS version 11. 0. The amount of tibial tunnel enlargement and percentage

Fig. 1 The amount of tunnel enlargement and how the tunnels are measured. The tunnel enlargement was expressed as a percentage value; the amount of enlargement over the perioperative drill size in both the femur and tibia

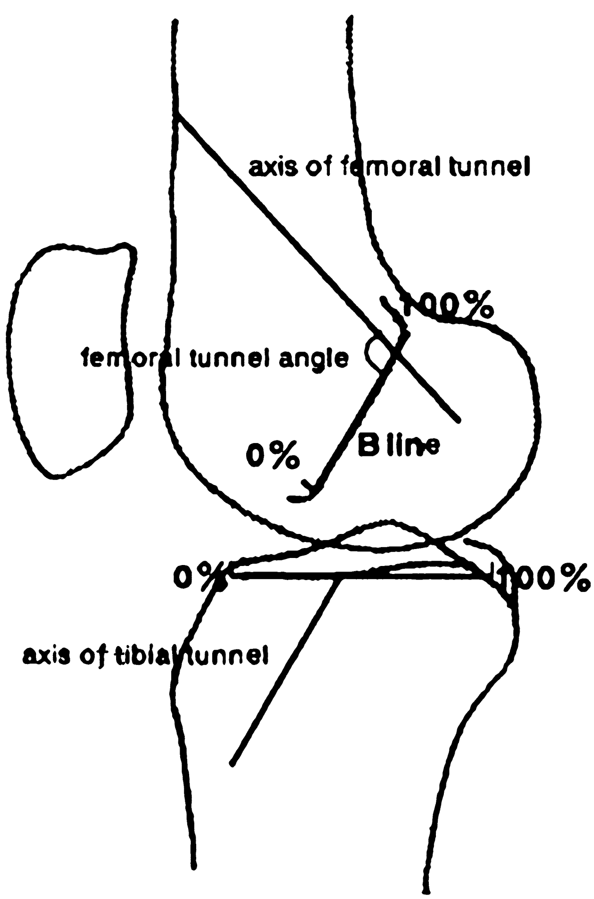

Fig. 2 How these tunnel placement and femoral tunnel angles were studied

enlargement between the two groups, aperture fixation and extracortical fixation, was compared using the independent sample *t* test. One-way ANOVA tests were used to determine whether tibial and femoral tunnel enlargement has any correlation with Lysholm, IKDC scores and KT-1000 measurements.

Results

Tunnel enlargement

At 5 years, based on the measurement from two independent observers, the mean tibial tunnel enlargement was 2.46 and 2.03 mm (average ICC 0.82, 95 % CI 0.66–0.90). The mean tibial tunnel percentage enlargement was 30.5 and 22.6 %.

The mean femoral tunnel enlargement was 3.23 and 2.33 mm (average ICC, 0.55 95 % CI 0.52–0.77). The mean femoral tunnel percentage enlargement was 41.2 and 26.9 %. We found that at 5 years, the femoral tunnel enlarged more than the tibial tunnel in both absolute (millimetres) and percentage terms.

All 54 patients had endobutton femoral fixation. Thirty-four patients had tibial graft fixation with staples (extracortical fixation) and 20 patients had tibial graft fixation with bioabsorbable interference screws (aperture fixation).

When comparing the amount of tibial tunnel enlargement in these two groups, the mean enlargement in the extracortical group was 1.98 and 1.51 mm (average ICC

Table 1 Tibial fixation and tunnel enlargement

Distal fixation	No	Observer	Mean tibial enlarge (mm)	Mean tibial enlarge per cent (%)	Mean femoral enlarge (mm)	Mean femoral enlarge per cent (%)
Extracortical fixation—staples	34	1	1.98	24.68	3.22	40.57
		2	1.51	18.20	2.18	20.08
Aperture fixation—bioabsorbable screw	20	1	3.27	40.43	3.24	42.33
		2	2.92	30.10	2.59	30.03

Table 2 Tibial fixation and tunnel placement

Distal fixation	No	Femoral tunnel placement on lateral view (%)	Tibial tunnel placement on lateral view (%)	Femoral tunnel angle on femoral lateral view (°)
Extracortical fixation—staples	34	25.37	36.34	98.83
Aperture fixation—bioabsorbable screw	20	22.27	32.73	99.95

0.80, 95 % CI 0.62–0.91) compared to 3.27 and 2.92 mm (average ICC 0.69, 95 % CI 0.24–0.88) in the aperture fixation group. Table 1 tabulates these values.

Using the independent *t* test, this difference in tibial tunnel enlargement in millimetres and in percentage terms between the groups with different two tibial fixation was found to be significant ($p < 0.001$, mean difference 1.29 mm) Thus, we found that using aperture fixation with a bioabsorbable screw led to a significantly larger amount of tibial tunnel enlargement.

The amount of femoral tunnel enlargement in both groups was 3.22 and 2.18 mm (average ICC* 0.66, 95 % CI** 0.14–0.88) for the extracortical and 3.24 mm and 2.59 mm (average ICC 0.56, 95 % CI 0.32–0.72) for the aperture group. Using the independent *t* test, we found that the difference between the two groups was not significant ($p = 0.973$). Keeping in mind that all proximal femoral fixation was with the endobutton, we found that the type of tibial fixation had no bearing on the amount of femoral tunnel widening.

Tunnel placement

We compared the tunnel placement between the extracortical and aperture fixation groups and found that they were similar. Table 2 tabulates the differences. The difference between the two groups was not statistically significant ($p = 0.114$; $p = 0.152$). This indicates that tunnel placement between the two groups was similar and was not a confounder in data analysis.

Clinical results

At 5 years, the mean Lysholm score was 86.2 (SD ± 10.6) and the mean subjective IKDC score was 80.4 (SD ± 14.5); 79.7 % of our[1] patients had normal or nearly normal knees (IKDC A or B) with remaining 20.3 % at IKDC Grade C.

The mean side–side difference for anterior displacement using the KT-1000 arthrometer at 134 N of traction at 30° flexion was 1.1 mm (SD ± 1.4 mm). The median pre-injury Tegner activity level was 7 (SD ± 1.6), and the median 5-year post-surgery Tegner activity level was 6 (SD ± 1.7).

We found that the amount of tibial and femoral tunnel enlargement in absolute and percentage terms had no bearing on Lysholm and subjective IKDC at 5 years, that is, correlational analysis did not show that having a larger tunnel enlargement led to poorer outcome scores.

We also found that the Lysholm, subjective IKDC, objective IKDC grades and KT side-to-side differences were similar between the two types of tibial fixation. Despite a larger amount of tibial tunnel enlargement in the aperture group, it did not affect the clinical outcome scores for these patients at 5 years. Table 3 tabulates these results.

Discussion

Tunnel enlargement occurs in both tibia and femur. The amount of enlargement is often greater in the femur than in the tibia [2, 3, 7, 13, 15, 16]. The results from our study concur with these findings. This may be because with transtibial femoral drilling performed during that period time (2000), the femoral tunnels were vertical and longer than the tibial tunnels. This accounts for why longitudinal graft motion is more pronounced in the femur. In anatomical ACL reconstructions with the femoral tunnels

1 * ICC refers to intraclass correlation coefficient
** CI refers to confidence interval.

Table 3 Tibial fixation and outcome scores

Fixation method	No	Lysholm	Subjective IKDC	Objective IKDC	Side-to-side KT (mm)
Extracortical fixation—staples	34	86.3	81.8	26 Grade A and B 8 Grade C	1.00
Aperture fixation—bioabsorbable screw	20	86.1	78.1	17 Grade A and B 3 Grade C	1.21

drilled from the anteromedial portal, the femoral tunnels are shorter and we feel that the amount of tunnel enlargement in the tibia and femur will be comparable.

Various authors have put forward evidence to support the theories for tunnel enlargement in ACL reconstruction. The role of intratunnel graft movement is proposed and studied by various authors [17–19]. Jagodzinski et al. [17] reported that the force magnitude at the entrance of the ACL tunnel was significantly higher at the femoral tunnel than the tibial tunnel and higher in the sagittal plane than the coronal plane. These findings were consistent with the results in our study as well as what other authors have reported [20, 21]. These provide evidence that biomechanical forces play a role in post-operative tunnel enlargement. We feel that the biomechanical forces play a more important role in the longer femoral tunnel than the tibial tunnel.

Both Weiler et al. [18] and Fauno et al. [19] reported that using an interference screw for hamstring aperture graft fixation could prevent tunnel widening.

However, three other authors studied the morphology of femoral and tibial tunnel enlargement. They reported that most of the femoral and tibial tunnels enlarged to a fusiform shape with significantly more enlargement in the midportion of the tunnel. They concluded that this did not support the importance of aperture fixation, and biological factors instead explain better these findings [20–22].

Buelow et al. [23] found that despite achieving aperture fixation with interference screw, there were greater amounts of tunnel enlargement in the tibia. Similarly, we also found that the tibial interference screw had more tunnel widening than the cortical post-group. This suggests that in the tibia, the biological factors possibly play a more important role than the mechanical factors in tunnel widening, especially when bioabsorbable interference screws are used.

Two other studies have looked at the role of bioabsorbable screws in tibial tunnel enlargement on radiographs after ACL reconstruction [24, 25]. Laxdal et al. [24] found that the poly-L-lactic acid/hydroxyapatite (PLLA) group displayed greater tunnel enlargement, compared to metal screws which affected the post-operative outcome scores. Robinson et al. [25] reported that hydroxyapetite (HA) interference screws for tibial fixation in hamstring ACL reconstruction reduced post-operative tunnel widening when compared with the use of PLLA screws.

Zysk studied synovial fluid samples from patients collected after ACL surgery and reported that patients with bone tunnel enlargement had higher concentrations of TNF-alpha, IL-6 and NO, indicating the involvement of these mediators in the tunnel enlargement [26].

Segawa et al. [14] had shown that a more anterior tibial tunnel had more tunnel enlargement. Xu et al. [27] also reported that femoral and tibial tunnel enlargements were greater with more anterior and more vertical femoral tunnels. This adds support to the mechanical theory for tunnel enlargement. By showing that our groups had similar tunnel placements, we want to remove it as a confounder in our data analysis.

Neddermann et al. [28] have shown that despite significant tunnel widening, there were no increased anterior–posterior laxity measurements. Quatman et al. [29] reported a case of severe tibial and femoral tunnel enlargement after ACL revision surgery; however, clinical examination showed minimal anterior knee laxity, and arthroscopic inspection revealed graft integrity. We also have not found any clinical significance to tunnel enlargement based on clinical outcome scores and instrumented laxity testing [7, 16, 19, 20, 30].

Marked tunnel widening is a concern in ACL revision surgery. There has been a case of tibial plateau fracture through the ACL tibial tunnel, secondary to extensive tunnel widening and osteolysis around the interference screw [31]. This reminds us that tunnel enlargement is not a benign entity.

From the literature, tunnel enlargement can occur up to 1–3 years after surgery, and most studies look at tunnel enlargement up to 2 years [4–6]. The strength of this study is that when we have looked at tunnel enlargement at 5 years there is only one other study that has studied this with a similar length of follow-up [12].

We have kept the other variables constant to allow for comparison of our tibial tunnel results. Ma et al. in their study of 2 groups of hamstring ACL reconstruction—one group with bioabsorbable screws in the femur and tibia and the other group with endobutton in the femur and post-fixation in the tibia—reported equal amounts of tunnel enlargements in the tibia in both study groups [7]. Unlike the study by Ma et al., we have kept the femoral fixation unchanged in both groups to compare the effect of tibial fixation on tunnel enlargement.

We believe that this is the only tunnel enlargement that has analysed femoral and tibial tunnel positions and removed it as a possible confounder before comparison. It is suggested that bone tunnel enlargement after ACL reconstruction can be increased by accelerated rehabilitation [32]. We have also used a standard rehabilitation protocol so that rehabilitation does not become a confounder.

The weakness of this study is that it is a retrospective review. However, we were able to obtain the functional scores and radiographs of all these patients at 5 years after surgery. Computer tomography (CT) and magnetic resonance imaging (MRI) have been suggested to be better at evaluating post-operative tunnel enlargements. However, various authors have used CTs and MRIs to validate the accuracy of plain radiographs in measurements of tunnel enlargement [2, 3, 32–34]. We did not want to subject our patients to further imaging, and it would not have been possible for us to obtain ethical board approval for the use of follow-up CT scan in these patients.

Conclusion

Graft tunnel enlargement in ACL reconstruction is recognized, but the aetiology is still controversial. We have shown that there is a significant biological component to tunnel enlargement. This results in greater tibial tunnel enlargement with the use of interference screws despite the ACL being fixed closer to the joint.

Conflict of interest We the authors hereby declare that we do not have any conflict of interest with the contents of this article submitted.

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