Time-Related Changes in the Cross-Sectional Area of the Tibial Tunnel After Compaction of an Autograft Bone Dowel Alongside a Hamstring Graft

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Purpose: Extensive tunnel expansion in hamstring anterior cruciate ligament (ACL) reconstruction can complicate revision surgery. The purpose of this study was to examine our hypothesis that compaction of a bone dowel into the tibial tunnel reduces the cross-sectional area of the tunnel on the day of surgery and limits tunnel expansion to that of the cross-sectional area of the reamer at 4 months and 1 to 2 years. **Methods:** A bone dowel averaging 23 mm in length and 7 mm in diameter was harvested from the tibial tunnel in 10 patients undergoing hamstring ACL reconstruction. The tibial tunnel was dilated, and the bone dowel was compacted anterior to the tendon graft. The cross-sectional area of the tibial tunnel was calculated on the day of surgery and at 4 months and 1 to 2 years postoperatively from computed tomography scans. **Results:** On the day of surgery, the cross-sectional area of the tibial tunnel was 34% smaller than the 50-mm^2 cross-sectional area of the 8-mm reamer used to drill the tunnel ($P < .001$). At 1 to 2 years, the cross-sectional area of the tibial tunnel was smaller than that of the reamer in 6 subjects, was slightly larger (53 to 56 mm^2) in 3 subjects, and was substantially larger (80 mm^2) in 1 subject. **Conclusions:** A surgeon who compacts an autogenous bone dowel into the tibial tunnel alongside a hamstring graft can expect little to no tunnel expansion in 90% of patients at 1 to 2 years. To our knowledge, the limitation of tunnel expansion to that of the cross-sectional area of the reamer has not been shown with other tibial fixation techniques. **Level of Evidence:** Level IV, therapeutic case series. **Key Words:** Anterior cruciate ligament reconstruction—Bone dowel—Tibial tunnel—Tunnel expansion—Computed tomography—Hamstring.

Tunnel expansion in anterior cruciate ligament (ACL) reconstruction is greater with a hamstring autograft than with a bone–patellar tendon–bone autograft[1-3] and occurs with a variety of hamstring fixation devices.[2-6] To date, we were unable to find a published study of a hamstring fixation technique in which tunnel expansion was limited to that of the cross-sectional area of the reamer at 1 to 2 years after ACL reconstruction.

The clinical consequences of the common phenomenon of tunnel expansion are being defined. Extensive tunnel expansion can complicate revision surgery.[7,8] Therefore a technique for fixing a hamstring graft that limits tunnel expansion to the cross-sectional area of the reamer might have the clinical benefit of simplifying revision surgery.

One technique that might limit tunnel expansion is the compaction of a bone dowel into the tibial tunnel alongside a hamstring ACL graft.[9] In this study we chose the WasherLoc (Arthrotek, Warsaw, IN) as the tibial fixation device because a previous study showed significant expansion of the tibial tunnel with the WasherLoc at 1 to 3 years[10] and because the WasherLoc affords access for compacting a bone dowel anterior to a tendon ACL graft.[9] The purpose of this study was to measure the cross-sectional area of the

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tibial tunnel by use of computed tomography (CT) on the day of surgery and at 4 months and 1 to 2 years postoperatively. We hypothesized that compaction of a bone dowel into the tibial tunnel reduces the cross-sectional area of the tunnel on the day of surgery and limits tunnel expansion to that of the cross-sectional area of the reamer at 4 months and 1 to 2 years postoperatively.

METHODS

Subjects

In this study, 10 patients (7 male and 3 female) were treated with an arthroscopic assisted ACL reconstruction by use of a double-looped semitendinosus and gracilis (DLSTG) graft by the senior author. The radiation exposure associated with 3 CT scans spread over a 1- to 2-year interval and confined to the knee with shielding of the gonads and thyroid was considered within reasonable levels based on 3 previous studies.[4,7,11] Patients were advised that there was radiation exposure confined to the knee, and each gave informed consent. Because some subjects declined to participate in the study, the selection of the subjects was not consecutive. The mean age at the time of surgery was 35 ± 8 years (range, 17 to 42 years).

Surgical Technique

The surgical technique of arthroscopic, transtibial ACL reconstruction by use of the DLSTG graft, as well as harvesting and compacting of the bone dowel into the tibial tunnel, has been previously described.[9,12,13] In brief, the guidewire for the tibial tunnel was placed. The cortex at the distal end of the guidewire was removed with a cannulated reamer that matched the diameter of the DLSTG graft. A cancellous bone dowel was harvested with an 8.0-mm outside diameter and 7.0-mm inside diameter harvest tube. A cannulated plunger was inserted into a harvest tube, which was attached to a handle. The harvest tube and plunger were impacted over the guidewire to the subchondral bone of the tibial plateau. The harvest tube was rotated clockwise and counterclockwise several times to break the tip of the cancellous dowel from the subchondral bone. The harvest tube and bone dowel were removed from the tibial tunnel. The handle was removed, and the length of the bone dowel was measured by use of the length markings on the plunger. After passing and securing of the DLSTG graft in the femur, the free ends of the graft were fixed inside the distal end of the tibial tunnel with a WasherLoc device (Arthrotek). A cone-shaped dilator, which tapers from 3 to 8 mm, was driven 30 mm into the tibial tunnel anterior to the graft to the level of the joint line. A plastic sleeve was placed over the cutting tip of the harvest tube to protect the DLSTG graft. The plastic sleeve was centered over the dilated opening. The plunger inside the harvest tube was struck with a mallet, which compacted the bone dowel into the dilated space until the bone plug was flush with the distal end of the tunnel (Fig 1).[9] No braces were used in the postoperative rehabilitation. Weight-bearing and range of motion of the knee through a full arc were allowed immediately, with crutches being discarded as tolerated. A return to unrestricted sports activities was allowed at 4 months postoperatively based on a previously described protocol.[14,15]

CT Measurement of Cross-Sectional Area

CT scanning was performed 3 times on each knee on the day of surgery and at 4 months and between 1

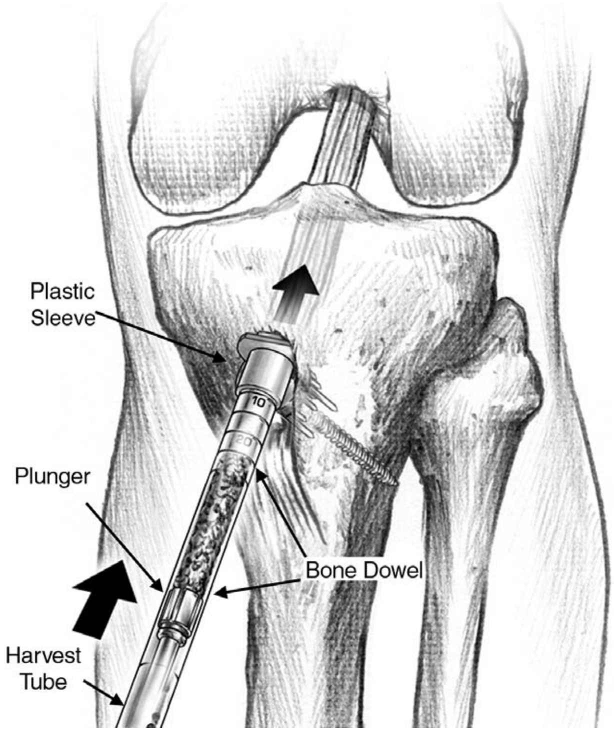

FIGURE 1. Relation of plastic sleeve, bone dowel, plunger, and harvest tube. The plastic sleeve, which covers the sharp tip of the harvest tube, is centered over the dilated opening at the distal end of the tibial tunnel anterior and proximal to the WasherLoc tibial fixation device. A mallet is used to drive the plunger in the direction of the arrows to compact the 7-mm-diameter bone dowel into the tibial tunnel anterior to the tendon graft.

and 2 years postoperatively by use of a Picker (Marconi) PQ 2000 helical scanner (Philips Medical Systems, Amsterdam, The Netherlands). Scanning was performed axially in the craniocaudal direction from the level of the intercondylar notch of the distal femur to the proximal end of the WasherLoc tibial fixation device. The scans were obtained by use of 3-mm collimation and 2-mm table increments producing a 1-mm overlap between images. The axial images were reconstructed in a bone algorithm and reformatted on a Picker (Marconi) voxel Q workstation (Philips Medical Systems). Oblique multiplanar reconstructions were performed perpendicular to the longitudinal axis of the tibial tunnel in 1-mm increments. The inclination of the oblique multiplanar reconstruction was selected by iterative adjustments until the shape of the tibial tunnel at the level of the tibial tunnel became a circle. The cross-sectional area of the tibial tunnel was measured every 1 to 1.5 mm along the length of the tibial tunnel from the joint line to the proximal end of the tibial fixation device. On each slice, the drawing tool was used to outline the margin of the tibial tunnel, and the region-of-interest tool was used to calculate the cross-sectional area within the tracing. The cross-sectional area within the tracing was the cross-sectional area of the tibial tunnel (Fig 2).

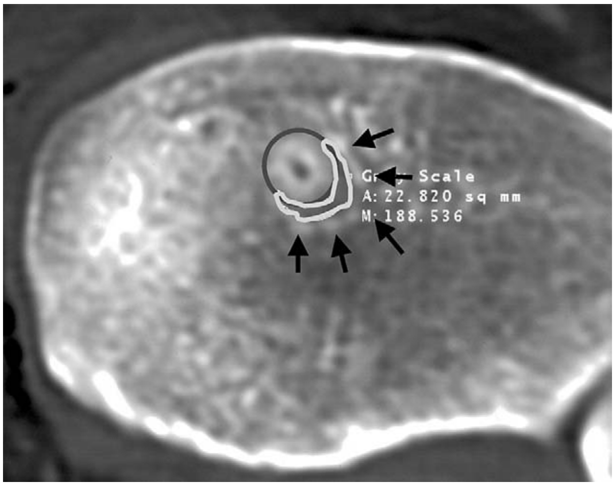

FIGURE 2. Oblique multiplanar CT reconstruction performed perpendicular to the longitudinal axis of the tibial tunnel on the day of surgery. The CT slice shows the bone dowel (dark circle), the tibial tunnel containing the tendon graft (white irregular tracing), and the posterolateral wall of the tibial tunnel (arrows). The increased density of the posterolateral wall is caused by the impaction of the dilator and the compaction of the bone dowel. The tibial guidewire created the small 2.3-mm hole in the center of the bone dowel. The outline of the margin of the tibial tunnel was traced with the drawing tool (white irregular tracing), and the cross-sectional area of the tibial tunnel within the tracing was calculated with the region-of-interest tool (A). In this example the cross-sectional area of the tibial tunnel was 22.820 mm^2.

Data Reduction and Statistical Analysis

For each CT scan, the mean cross-sectional area of the tibial tunnel was computed by averaging all of the measurements made from the joint line to the proximal level of the tibial fixation device. The percentage of reduction (+) or expansion (−) of the cross-sectional area of the tibial tunnel was calculated with respect to the cross-sectional area of the reamer used to drill the tunnel as follows: ([Cross-sectional area of reamer used to drill tunnel − Cross-sectional area of tunnel]/Cross-sectional area of reamer used to drill tunnel) × 100. Because either an 8- or 9-mm reamer (with a 50- or 64-mm^2 cross-sectional area, respectively) was used to drill the tibial tunnel, the cross-sectional area of each tibial tunnel was normalized to an 8-mm reamer to allow comparisons. Normalization was performed by use of the following: 50 mm^2 − Percentage of tunnel shrinkage or expansion × 50 mm^2.

A paired *t* test was used to determine whether the cross-sectional area of the tibial tunnel on the day of surgery and at 4 months and 1 to 2 years postoperatively was different than the cross-sectional area of the 8-mm reamer. A 1-factor, repeated-measures analysis of variance and a Tukey post hoc test were used to determine whether there was a significant change in the normalized cross-sectional area of the tibial tunnel between the day of surgery, 4 months postoperatively, and 1 to 2 years postoperatively. Statistical software and a personal computer were used to make the comparisons (SAS software, version 8.0; SAS Institute, Cary, NC). Results were expressed as mean ± 95% confidence interval. The level of significance was set at $P < .05$.

RESULTS

The tibial tunnel was drilled with an 8-mm reamer in 5 knees and a 9-mm reamer in 5 knees. The mean length of the bone dowel was 23 ± 6 mm (range, 15 to 30 mm). The mean time from the day of surgery to final follow-up was 21 ± 5 months (range, 15 to 29 months).

The distribution of the bone plug along the length of the tibial tunnel was determined on the day of surgery by computation of the mean reduction in the cross-sectional area of the tibial tunnel in 5-mm sections from the joint line to the proximal end of the WasherLoc device. The mean reduction in the cross-sectional area of

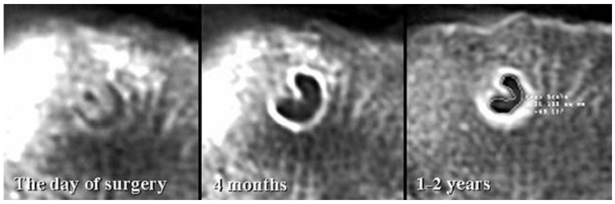

FIGURE 3. Series of 3 CT scans from subject 1 showing the cross-sectional area and shape of the tibial tunnel at a distance of 1 cm from the joint line. The cross-sectional areas of 22 mm^2 on the day of surgery, 42 mm^2 at 4 months postoperatively, and 24 mm^2 at 1 to 2 years postoperatively were all smaller than the 50-mm^2 cross-sectional area of the 8-mm reamer used to drill the tibial tunnel. On the day of surgery, the bone dowel caused the indentation in the anteromedial side of the tibial tunnel. Between the day of surgery and 4 months postoperatively, the indentation diminished, indicating that some of the bone dowel resorbed. Between 4 months and 1 to 2 years postoperatively, the walls of the tunnel became more sclerotic.

the tibial tunnel was 15% ± 21% at 0 to 4 mm from the joint line, 21% ± 20% at 5 to 9 mm from the joint line, 34% ± 24% at 10 to 14 mm from the joint line, 48% ± 16% at 15 to 19 mm from the joint line, and 56% ± 4% at 20 to 24 mm from the joint line. Therefore the bone dowel extended to the joint line and reduced the cross-sectional area distally more than proximally.

An example of a CT scan from subject 1 shows the location and size of the effect of the bone dowel on the cross section of the tibial tunnel 1 cm distal to the joint line on the day of surgery and 4 months and 1 to 2 years postoperatively (Fig 3).

A column graph shows the normalized cross-sectional area of the tibial tunnel for each subject on the day of surgery and 4 months and 1 to 2 years postoperatively (Fig 4). On the day of surgery, the bone dowel reduced the cross-sectional area of the tibial tunnel in all subjects. At 1 to 2 years, the cross-sectional area of the tibial tunnel was either smaller or slightly smaller than the cross-sectional area of the 8-mm reamer in 9 of 10 subjects.

A column graph shows the mean normalized cross-sectional area of the tibial tunnel on the day of surgery and 4 months and 1 to 2 years postoperatively (Fig 5). On the day of surgery, the mean normalized cross-sectional area of the tibial tunnel of 33 ± 3 mm^2 was smaller than the 50-mm^2 cross-sectional area of the 8-mm reamer ($P < .001$). At 4 months postoperatively, the mean normalized cross-sectional area of the tibial tunnel of 53 ± 3 mm^2 was not different from the 50-mm^2 cross-sectional area of the 8-mm reamer ($P = .340$). At 1 to 2 years postoperatively, the mean normalized cross-sectional area of the tibial tunnel of 47 ± 10 mm^2 was not significantly different from the 50-mm^2 cross-sectional area of the 8-mm reamer ($P = .423$). There was a significant expansion of the tibial tunnel between the day of surgery and 4 months postoperatively ($P < .05$) but not between 4 months and 1 to 2 years postoperatively ($P > .05$).

One male subject, aged 35 years, had a substantial enlargement of the tibial tunnel at 1 to 2 years postoperatively, which was greater than that in the other subjects. The normalized diameter of the tibial tunnel expanded from 30 to 80 mm from the day of surgery and 1 to 2 years postoperatively (Fig 4). The length of the bone dowel was 20 mm.

DISCUSSION

The most important findings of this study are that compaction of a bone dowel reduced the cross-sectional area of the tibial tunnel on the day of surgery and that the mean cross-sectional area of the tibial tunnel at 4 months and 1 to 2 years postoperatively was not larger than the cross-sectional area of the reamer that was used to drill the tunnel in 9 of 10 subjects. In this study the use of a bone dowel limited tunnel expansion better than the use of a periosteal flap[16] or the use of an interference screw[5] reported in other studies. The use of a periosteal flap sewed to a soft-tissue graft in the femoral tunnel was shown to

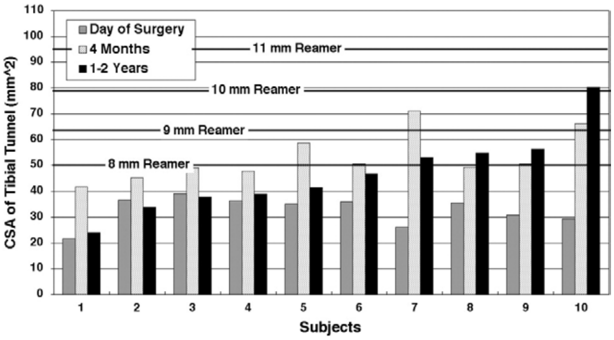

FIGURE 4. Cross-sectional area (CSA) of the tibial tunnel of each subject normalized to an 8-mm reamer on the day of surgery and at 4 months and 1 to 2 years postoperatively. To assist in the clinical interpretation of the graph, a series of transverse lines are drawn for the 8-mm (50 mm^2), 9-mm (64 mm^2), 10-mm (79 mm^2), and 11-mm (94 mm^2) reamers, which correspond to their respective cross-sectional areas. Columns below the 8-mm line indicate a reduction in the cross-sectional area of the tibial tunnel. Columns above the line indicate tunnel expansion. On the day of surgery, the bone dowel reduced the cross-sectional area of the tibial tunnel in all subjects. At 1 to 2 years postoperatively, the cross-sectional area of the tibial tunnel was smaller than that of the 8-mm reamer in 6 subjects (subjects 1-6), was slightly larger (53 to 56 mm^2) in 3 subjects (subjects 7-9), and was substantially larger (80 mm^2) in only 1 subject (subject 10).

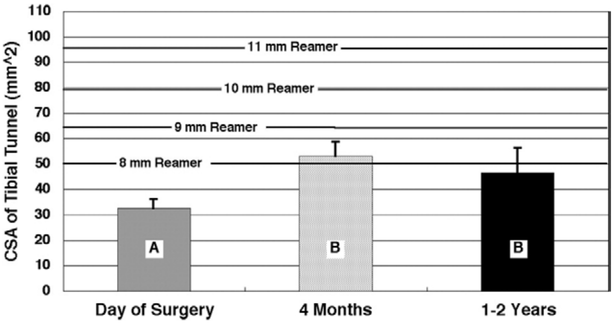

FIGURE 5. Mean normalized cross-sectional area (CSA) of the tibial tunnel on the day of surgery and at 4 months and 1 to 2 years postoperatively. On the day of surgery, the mean cross-sectional area of the tibial tunnel was smaller than that of the 8-mm reamer ($P < .001$). At 4 months and 1 to 2 years postoperatively, the mean cross-sectional area of the tibial tunnel was not significantly different from that of the 8-mm reamer ($P = .340$ and $P = .423$, respectively). Over time, the tibial tunnel expanded between the day of surgery (A) and 4 months postoperatively (B) ($P < .05$) but did not change between 4 months and 1 to 2 years postoperatively (B) ($P > .05$). Error bars represent 95% confidence intervals.

reduce but not prevent tunnel expansion at 3 and 6 months after reconstruction.[16] The use of a bioresorbable interference screw caused a 75% tunnel expansion on the day of surgery that further expanded by another 31% at 6 months postoperatively.[5]

The time-related results from our study agree with the finding in other studies that tunnel expansion occurs in the first 3 to 6 months but does not increase thereafter.[3,5,6] This early tunnel expansion may be obligatory with a soft-tissue graft because it has been observed with many types of soft-tissue fixation methods, including suspensory, interference screw, and distal fixation.[2-6,17] We were unable to find any published studies that evaluated tunnel widening with the Intrafix (Depuy Mitek, Raynham, MA), retrograde screw, and EndoPearl (Conmed, Largo, FL). There is no reason to suspect that tunnel widening does not occur with the intrafix and retrograde screw because it occurs with the interference screw.[4,5]

A mechanical advantage of the compaction of a bone dowel is that the stiffness of the graft construct is increased. The bone dowel functions as a joint line fixation device in series with the WasherLoc and increases the stiffness of the graft–fixation device–bone complex by 58 N/mm on the day of surgery.[9] The additional stiffness from the bone dowel lowers the initial tension that is applied to the graft to restore stability and might prevent the recurrence of instability.[18]

A biologic advantage of the compaction of a bone dowel is that the rate of healing of the tendon to the tunnel might be increased. The biologic attachment of a tendon graft is stronger in a snug tunnel,[19,20] in a tunnel that circumferentially makes contact with the tendon graft,[21] and when biologically active substances are added to the tunnel.[22] The compaction of the bone dowel reduces the tunnel, allows circumferential contact, and adds biologically active substances that might enhance healing of the tendon graft to the bone.

One issue that was not addressed in our study and has not yet been clarified in any study is the identification of specific factors that cause tunnel expansion. Several factors hypothesized to cause tunnel expansion include early motion,[23] distal fixation,[2] micromotion,[6] and biologic factors.[7,24] In our study the subjects had 2 of these factors—distal fixation and micromotion[25]—because the knees were treated with early motion and full weight-bearing. Despite these factors, the bone dowel was still effective at limiting tunnel expansion to that of the cross-sectional area of the reamer at 4 months and 1 to 2 years postoperatively in 9 of 10 subjects. This finding in our study is different from findings with tibial fixation with an interference screw, sutures tied to a post, and double staples in other studies, which showed that tibial tunnel expansion is greater than that of the reamer at an intermediate time interval of 3 to 6 months and 1 to 2 years after surgery.[1,3,5]

Another issue that was not addressed is whether an allograft bone dowel is as effective as an autogenous bone dowel in limiting tunnel expansion to that of the cross-sectional area of the reamer. There are several disadvantages to the use of an allograft bone dowel, which include slow incorporation,[26] disease transmission,[27,28] and higher cost. Further studies are required to determine whether an allograft bone dowel limits the cross-sectional area of the tibial tunnel.

A limitation of our study is whether the study design supports the assumption that the bone dowel caused the limitation of tunnel expansion at 4 months and 1 to 2 years postoperatively. In this study the control was the cross-sectional area of the reamer used to drill the tibial tunnel. The hypothesis was that tunnel expansion at 4 months and 1 to 2 years postoperatively is limited to that of the cross-sectional area of the reamer. It is generally understood that tunnel expansion occurs with the WasherLoc device, because a previous study showed expansion of the tibial tunnel at 16 months postoperatively.[10] Because our study showed that the mean cross-sectional area of the tibial tunnel at 4 months and 1 to 2 years postoperatively with compaction of the autogenous bone dowel was not significantly different from the reamer and given that the previous study by Sakai et al.[10] showed tunnel expansion with the WasherLoc device, the assumption that compaction of an autogenous bone dowel alongside a hamstring graft limited tunnel expansion at 4 months and 1 to 2 years postoperatively is not unreasonable.

CONCLUSIONS

A surgeon who compacts an autogenous bone dowel into the tibial tunnel alongside a hamstring graft can expect little to no tunnel expansion in 90% of patients at 1 to 2 years. Limiting tunnel expansion to that of the cross-sectional area of the reamer should simplify revision surgery. To our knowledge, the limitation of tunnel expansion to that of the cross-sectional area of the reamer has not been shown with other tibial fixation techniques.

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