Serial Magnetic Resonance Study Assessing the Effects of Impingement on the MR Image of the Patellar Tendon Graft

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Summary: This study was designed to serially analyze the magnetic resonance (MR) appearance of patella tendon grafts during the first year of implantation, and to determine if the sagittal location of the tibial tunnel affects the MR appearance of the graft. An additional goal was to analyze the effect of the sagittal placement of the tibial tunnel placement on knee extension and stability. Two groups were defined by comparing the sagittal relationship of the tibial, tunnel to the slope of the intercondylar roof from a lateral roentgenogram of the knee in full extension. The roof impinged group consisted of nine patients who had the tibial tunnel placed anterior to the tibial intersection of the slope of the intercondylar roof. The unimpinged group was composed of eleven patients who had the tibial tunnel placed posterior and parallel to the slope of the intercondylar roof. MR scans were obtained at 0-2, 12, 24, 36, and >48 weeks postoperatively. The signal intensities of grafts in both groups were identical at 1 week, but increased in the impinged group by 3 months and remained increased at 12 months postoperatively (p < 0.01). In contrast, the MR signal of grafts in the unimpinged group remained unchanged during the first year. Knees with impinged grafts had extension deficits but remained stable. Roof impingement was impossible to view directly with the knee in full extension. Positioning the tibial tunnel posterior and parallel to the slope of the intercondylar roof in the extended knee and using an impingement rod to indirectly assess roof impingement avoided the extension deficits and MR signal increases characteristic of an impinged graft. The clinical relevance is that the surgeon controls the MR appearance of the graft and the severity of extension deficits by deciding where to place the tibial tunnel and when to perform a roofplasty. Key Words: Patellar tendon grafts-Knee-Graft-Magnetic resonance-Impingement.

Magnetic resonance (MR) scanning has recently been used to study the appearance of autogenous fascia lata (1), hamstring (2,3), and patellar-tendon-bone (PTB) (4,5), anterior cruciate ligament (ACL) grafts. Grafts may appear well defined, partially defined, or indiscernible (1-5). Knee instability has been associated with grafts with high MR signal intensities (2-5). Identifying the cause of the MR signal increase in the graft may improve the success rate of ACL reconstructions.

The sagittal location of the tibial tunnel is the variable that affects the MR appearance of double-looped hamstring grafts. Hamstring grafts placed in tibial tunnels anterior to the slope of the intercondylar roof acquire a signal increase by 3 months post-implantation that persists for 3 years. Grafts placed in tibial tunnels posterior...
and parallel to the slope of the intercondylar roof retain a low signal intensity in the graft throughout the first year of implantation. Roof impingement has been identified as the cause of signal increase in hamstring grafts (3).

The cause of the signal increase in PTB reconstructions has not been determined. One purpose of this study was to serially analyze the MR appearance of PTB grafts during the first year of implantation and to determine if the sagittal location of the tibial tunnel affects the MR appearance of the graft. A second purpose was to analyze the effect of sagittal location of tibial tunnel placement on knee extension and stability.

METHODS AND MATERIALS

Twenty consecutive patients with ACL reconstructions were divided into two groups based on the roentgenographic relationship of the tibial tunnel to the slope of the intercondylar roof on a lateral roentgenogram, exposed with the knee in maximal extension (3,4). The roof impinged group consisted of those knees in which the tibial tunnel was at least partially anterior to the slope of the intercondylar roof on a lateral roentgenogram of the maximally extended knee (Fig. 1A). In the unimpinged group, the tibial tunnel was located entirely posterior and parallel to the slope of the intercondylar roof (Fig. 2A).

The impinged group was composed of nine patients (eight men, one woman), with an average age of 27 (range 20-37) years, two with an acute ACL tear and the other seven with chronic instability. The left knee was reconstructed in six and the right in three patients. The knees in the impinged group were reconstructed by centering the tibial tunnel 5 mm anterior and medial to the center of the old ACL insertion (eccentric position) (6).

Impingement was assessed arthroscopically in the roof impinged group by directly viewing the intraarticular course of the graft while flexing and extending the knee. Any side-wall impingement that was observed was corrected by local bone removal. The relationship of the graft to the intercondylar roof was difficult to visualize during the final 10° of extension. The trochlea began to articulate with the tibial articular surface obscuring the view of the anterior surface of the graft (7). The tip of a nerve hook probe was placed between the roof and the graft as the knee was extended to palpate the clearance in an attempt to provide an indirect measurement of roof impingement. Bone was removed from the intercondylar roof when impingement was believed to be present. The tibial tunnel-intercondylar roof relationship on the lateral roentgenogram confirmed that the amount of bone removal was insufficient to prevent roof impingement in each case (3).

The unimpinged group differed from the roof impinged group in that the tibial tunnel was purposely placed more posterior on the tibia. A prototype tibial drill guide system was used in nine of the reconstructions to place a guide pin 4-5 mm posterior and parallel to the slope of the intercondylar roof with the knee in maximum extension (3). The unimpinged group was composed of 11 men, with an average age of 26 (range 17-36) years, two with an acute ACL tear and the other nine with chronic instability. The left knee was reconstructed in seven and the right in four patients.

Because of the difficulty in directly visualizing roof impingement, a sizing rod was used to indirectly detect and determine successful correction of impingement before inserting the graft in nine of the reconstructions in the unimpinged group (Fig. 3). A 9 mm diameter, stainless steel impingement rod was placed within the tibial tunnel. An attempt was made to insert the impingement rod into the intercondylar notch with the knee fully extended. Insertion was blocked by bone in each case. The knee was then slowly flexed until the rod freely passed into the notch. The difference in motion provided an estimate of the flexion contracture that would result if bone was not removed from the intercondylar roof. A roofplasty was performed until the impingement rod could be freely pistoned within the intercondylar notch with the knee maximally extended. Sculpturing of the intercondylar roof was required in all the knees in the unimpinged group (3).

Reconstructions in both groups were performed using a 9-10 mm wide autogenous PTB graft. The femoral hole was placed using a rear-entry guide (Acufex Microsurgical, Norwood, MA, U.S.A.). A tensiometer (Acufex) was used to assess the excursion profile of the pilot holes. Adjustments in femoral tunnel placement were performed to insure that the femoral-tibial separation distance was <3 mm in both treatment groups.

Postoperatively, knees were placed in a continuous passive motion machine for 4 days until 90° of flexion was regained. A long-leg, hinged brace with an extension stop at 35° of flexion was worn full-time for the first 5 weeks. Bracing was discontinued for walking and activities of daily living, and full weight-bearing was
begun as tolerated after 5 weeks. A derotation brace with an extension stop at 35° of flexion was used only during strengthening exercises (1/2 h per day) for the first 4.5 months. At 6 months, the extension stop was removed from the derotation brace and progressive return to athletics was permitted.

**Postoperative data collection**

One year postoperatively, a lateral roentgenogram was obtained with the knee in maximal extension to determine the presence and amount of intercondylar roof impingement. Rotation was controlled by assuring that there was <6 mm of femoral condyle offset on the lateral film. One of the radiologists (T.E.F.) read each roentgenogram without knowing the clinical outcome. Four lines were constructed and four measurements were made on each lateral radiograph to calculate the amount of impingement and to determine the location of the center of the tibial tunnel (Figs. 1A, 2A). The first line was drawn parallel to the intercondylar shelf (Blumensaat’s line) extending to the tibial articular surface. The second line was drawn to overlay the sclerotic subchondral margin of the concave medial tibial plateau. The third and fourth lines, outlining the anterior and posterior limits of the tibial tunnel, were drawn parallel to the sclerotic tunnel edges. Lastly, the center of the tibial tunnel was marked. Four measurements were made: (a) The sagittal depth of the medial tibial plateau (SAGTIBDEP) was measured between the anterior bone-cartilage junction and the posterior cortex of the medial plateau. (b) the dis-
tance from the anterior edge of the tibia to the center of the tibial tunnel (CTT) was determined. (c) The distance between the anterior wall of the tibial tunnel and the tibial intersection of Blumensaat’s line (X) was measured. (d) The width of the tibial tunnel orifice (W) was measured. The following two ratios were constructed: (a) sagittal location of the CTT was determined by dividing its location by the SAGTIBDEP (CTTSAG TIB DEP x 100) and (b) the amount of intercondylar roof impingement was determined by taking the X located either anterior (+ impingement) or posterior (- impingement) to Blumensaat’s line and dividing by the width of the tibial tunnel (X/W x 100) (3).

Grafts were studied over time by obtaining limited, sagittal MR scans at 0-2, 12, 24, 36, and >48 weeks postoperatively. During the first portion of the study, MR scans were performed using an 0.35 Tesla (T) superconducting magnet with a dedicated quadrature detection knee coil (Diasonics, San Francisco, CA, U.S.A.). Part way through the study, the MR system was upgraded to a 1.5 T superconducting magnet (Philips, Amsterdam, Holland).

The 1.5 T images were superior in clarity and signal-to-noise ratio, but were otherwise comparable. A T1 weighted scout film (TR = 443, TE = 15) was obtained in the coronal plane to provide the orientation of the ACL graft. The one coronal slice that simultaneously demonstrated the femoral tunnel, and tibial tunnel or ACL graft was used. An oblique sagittal imaging place was selected so that the slice overlaid the lateral-medial trajectory of the ACL graft. This technique permitted the entire graft to be visible from origin to insertion on one slice by customizing the orientation of the scan to the trajectory of the graft. Imaging was confined to ten, 3.0...
mm thick sagittal sections (0.625 mm² pixels) centered about the intercondylar region of the knee. Image acquisition was performed with the standard spin-echo technique using a 1500 msec TR and 50 msec TE (0.35 T) or 1,200 msec TR and 40 msec TE (1.5 T) (24).

A four-level grading system based on the MR signal of the graft was developed to analyze four distinct regions of the graft. A Grade 1 signal ("normal") was awarded when the entire segment of graft had a homogeneous, low intensity signal indistinguishable from that of the patellar ligament (PCL). A Grade 2 image was recorded if the segment of graft retained at least 50% of "normal" ligament signal intermixed with portions of the graft that had become edematous, as indicated by areas of increased signal intensity. A Grade 3 image was documented when a segment of graft had <50% of its area exhibiting a normal appearing ligament signal. A Grade 4 graft consisted of a diffuse increase in signal intensity with no normal-looking strands of ligament (100% edematous). Signal artifact induced by the fixation hardware did not interfere with interpretation of the graft signal (2,4).

The intraarticular pathway of the ACL autograft was divided into thirds for signal analysis. Zone P consisted of the proximal 1/3 of the graft after it exited the femoral tunnel. Zone M corresponded to the middle third of

FIG. 3. A A notch view of a right knee is shown with the lateral femoral condyle (L), posterior cruciate ligament (P), medial femoral condyle (M), and anterior cruciate insertion stump (I) labeled for orientation. The impingement rod can be seen entering through the tibial tunnel into the intercondylar notch. A wallplasty has already been performed by removing bone from the medial edge of the lateral femoral condyle (arrow). B: Roof impingement was detected when the rigid sizer could not be passed into the notch with the knee in maximum extension. Four millimeters of bone was removed from the intercondylar roof to correct for the roof impingement. The curved arrow identifies the location and amount of bone removal from the intercondylar roof. After the roofplasty the impingement rod could be freely passed in and out of the notch with the knee in maximum extension confirming complete elimination of roof impingement. C: The ACL graft has been secured in place and the probe demonstrates that the graft has taken-up tension. Direct viewing demonstrates that there was no contact between the graft and the lateral femoral condyle indicating that the wallplasty was successful in eliminating side-wall impingement (arrow). D: Roof impingement was undercorrected in this study because the graft-roof relationship could not be seen with the knee fully extended (curved arrow). In this example, the graft-roof relationship could not be directly seen even when the knee was held in 5 degrees of flexion. Probing the graft-roof relationship to assess roof impingement was ineffective in determining the adequacy of the roofplasty.

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the graft coursing under the intercondylar roof. Zone D was the distal third of the graft from the aperture of the intercondylar notch to the entrance into the tibial tunnel (2-4).

One of the radiologists (J.A.C.) read each MR scan without knowing the clinical outcome (86 scans, 4,3/knees). A composite grade for each zone was made based on the average signal obtained from the 3-4 sagittal images that depicted the ACL graft. These ordinal measurements were used for statistical comparison of the MR signal by zone between the impinged and unimpinged knees at each time interval, using the non-parametric Mann-Whitney-U Test. A comparison of the MR signal appearance between the proximal, middle, and distal zones was made at each scanning interval using the nonparametric Kruskal-Wallis test to detect any regional signal changes. A Friedman Test for repeated measures was used to determine if the MR signal increase was time related and whether the signal increase improved during the first year of graft implantation (2). A significant difference existed when p < 0.05.

At final follow-up, surgical results from the two groups were compared using the Student’s t test. Parameters measured were difference in knee extension between normal and reconstructed knee, Lysholm scoring scale, single-leg hop ratio (reconstructed/normal), and instrumented laxity testing during a manual maximum drawer test (MMT), using the KT-1000 (MEDmetric Corp., San Diego, CA, U.S.A.) (8,9). The one unstable knee in the unimpinged group was excluded from statistical analysis of KT-1000 laxity measurements. Regression analysis was used to compare location of the CTT on the lateral roentgenogram to the difference in knee extension.

RESULTS

Analysis of the lateral roentgenograms obtained with the knee in maximal extension revealed that the sagittal position of the CTT was significantly different between the roof impinged and unimpinged groups (Figs. 1 A, 2A and Table I) (p < 0.0001, Student t test). The CTT in the roof impinged group was located 6-7 mm anterior to the CTT in the unimpinged group (based on a 60 mm sagittal tibial depth).

The MR signal analysis of the ACL graft by zones revealed that there was no difference in the MR appearance of the grafts between the two groups at the time of implantation (Figs. 1B, 2B, 4A, 4B). However, there was a difference in the relationship of the graft to the intercondylar roof within the first week between the groups. Postoperative knee effusions prevented the knees in both groups from fully extending in the MR scanner at 1 week. The grafts in the impinged knees were all contacting the inter-condylar roof on the MR scan with the knees in 10-20˚ of flexion. There was no contact between the roof and the graft at 1 week in the unimpigned

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Impinged group</th>
<th>Unimpinged group</th>
<th>p-value</th>
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<tbody>
<tr>
<td>Months postop</td>
<td>17.3 ± 6 mo</td>
<td>17.1 ± 7 mo</td>
<td>NS p = 0.94</td>
</tr>
<tr>
<td>Center of tibial tunnel*</td>
<td>30.7 ± 3.6%</td>
<td>44.2 ± 4.3%</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td>Amount of impingement*</td>
<td>53 ± 21%</td>
<td>-20 ± 14%</td>
<td>&lt; 0.0001</td>
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<tr>
<td>Difference in passive knee extension</td>
<td>5 ± 3˚</td>
<td>1 ± 2˚</td>
<td>&lt; 0.0008</td>
</tr>
<tr>
<td>Single Leg Hop Test (I/N x 100)</td>
<td>96 ± 8%</td>
<td>9.5 ± 7%</td>
<td>NS p = 0.89</td>
</tr>
<tr>
<td>Lysholm score</td>
<td>96 ± 4%</td>
<td>94 ± 3%</td>
<td>NS p = 0.16</td>
</tr>
<tr>
<td>Difference in MMT (N - I)c</td>
<td>1.0 ± 1.6 mm</td>
<td>0.8 ± 0.8 mm</td>
<td>NS p = 0.71</td>
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\* The sagittal location of the center of the tibial tunnel was determined from a lateral roentgenogram of the extended knee by dividing the distance from the anterior edge of the tibia to the center of the tibial tunnel by the sagittal depth of the tibia.

\* The amount of impingement was determined by measuring the distance the anterior edge of the tibial tunnel was anterior (+) or posterior (-) to the slope of the intercondylar roof and dividing by the sagittal width of the tibial tunnel.

\* Comparison excludes the instrumented laxity data from the one unstable knee in the unimpinged group.

MMT, manual maximum drawer test; NS, not significant; N, number.
knees.

From 3-12 months, the roof impinged group had a significant increase in the MR signal of the middle and distal thirds of the graft when compared to that of the unimpinged group (p < 0.05-0.01, Mann-Whitney) (Fig. 4B). This increase in the MR signal of impinged grafts was regionalized and spared the proximal third within each time period (p < 0.02-< 0.001, Kruskal-Wallis) (Fig. 4A). The MR signal increase occurred during the first 12 weeks of implantation in the impinged grafts (p < 0.004, Friedman). There was no improvement in the grafts in the roof impinged group during the first 9 months of implantation (p < 0.12, Friedman) (Fig. 1B-D). In contrast, the signal in the unimpinged grafts remained low and unchanged during the first year of implantation (Figs. 2B-D, 4B).

Regaining knee extension was a consistent problem in the roof impinged group. Three patients required a second arthroscopic procedure to relieve intercondylar roof impingement. Two knees were operated on at 3 months for persistent 10-15° flexion contractures and painful effusions. A delayed roofplasty was performed by arthroscopically removing -8 mm of bone from the intercondylar roof. A manipulation was not performed. In both, knees extension improved, the effusion disap-
Instability resulting from roof impingement is fortunately relatively infrequent with an incidence of instability ranging from 9-23% (1,5).

An extension deficit has been the best clinical sign of persistent roof impingement (3,4). A lateral roentgenogram of the maximally extended knee can be used to detect roof impingement. Roof impingement should be suspected when the knee has a flexion contracture and the anterior edge of the tibial tunnel is in line with the intercondylar roof or when the tibial tunnel is partially anterior to the slope of the intercondylar. Several studies have shown that flexion contractures are common following ACL reconstructions (3,4,8,12,13). Many of these extension deficits can be prevented by an adequately performed roofplasty (3,4).

An association between extension deficits and acute ACL reconstructions has recently been proposed by several authors (14). This study did not determine whether the ACL grafts were impinged. There were two acute ACL reconstructions in both the impinged and unimpinged groups in our study. Extension deficits were observed in only the impinged knees. The acutely reconstructed knees with unimpinged grafts had no difficulty in regaining extension. The cause of extension deficits following acute ACL reconstructions is probably multifactorial, with the timing of surgery and the presence or absence of roof impingement being two possible variables that may cause flexion contractures.

Graft excursion profiles were determined by the use of a tensiometer for the anterior tibial tunnels in the impinged group and the posterior tunnels in the unimpinged group. There was no difference in the excursion profile between the two groups (4). A cadaver study has confirmed that an excursion profile of <2 mm can be achieved for any fiber within the broad ACL tibial insertion stump (15). All of the graft fibers in the posterior tibial tunnels were anatomic and entirely within the pathway of the original ACL (7). Therefore, the cadaver findings support our clinical observations that isometric tibial tunnel placement was achieved for both groups. Surgeons should not rely on isometry to control the sagittal placement of the tibial tunnel, because large variations can be expected which can result in severe roof impingement (4).

The high incidence of MR signal increases in fascia lata grafts (69%) (1), hamstring grafts (91%) (2), and patella tendon grafts (20%) (4) indicates that roof impingement has been difficult to recognize by many surgeons using both open and arthroscopic techniques.
The relationship between the graft and the intercondylar roof cannot be directly visualized as the knee nears terminal extension (Fig. 3) (7). In that study, the use of a probe to palpate the graft-roof relationship was ineffective in determining when roof impingement was present and when it was successfully corrected. Theoretically, grafts could be placed in anterior tibial tunnels without roof impingement if a sufficient roofplasty is performed. However, results from the previously cited MR studies indicate that a precise, reproducible, direct technique for determining the adequacy of a roofplasty has not yet been developed.

In the present study, the indirect technique of determining roof impingement with an impingement rod effectively detected and eliminated roof impingement before the graft was implanted. Bone removal from the roof was customized for the sagittal position of the tibial tunnel and hyperextension of the knee. Complete bone removal was achieved when the impingement rod could be passed into the notch through the tibial tunnel with the knee in full extension. This technique has also been effective in eliminating roof impingement and MR signal increase in hamstring grafts (3).

In summary, MR scanning of ACL grafts is effective in detecting roof impingement. The signal increase in impinged grafts is time dependent and well established after 3 months of implantation. Knees with roof impingement have a high incidence of extension deficits. Those surgeons that place the graft anteriorly and attempt to directly view the graft-roof relationship will have a tendency to incompletely correct for roof impingement. Roof impingement is best avoided by placing the tibial tunnel posterior and parallel to the slope of the intercondylar roof within the anatomic pathway of the original ACL. Roof impingement can be analyzed by passing a rigid sizer into the notch through the tibial tunnel with the knee fully extended. Indirect evaluation of roof impingement permits a precise, conservative, customized roofplasty, which allows the knee to regain full extension and protects and graft from impingement trauma.

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**REFERENCES**