Serial magnetic resonance imaging of hamstring anterior cruciate ligament autografts during the first year of implantation

A preliminary study

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ABSTRACT
A prospective, observational study was performed to document the serial changes in the magnetic resonance signal of devascularized, hamstring ACL autografts during the 1st year of implantation.

Twenty-one ACL deficient knees (14 chronic, 7 acute) were reconstructed. Instability developed in five knees within the first 6 months of graft implantation (24%). Magnetic resonance examinations were performed at 1, 6, 12, 24, 36, and >48 weeks postoperatively (repetition time 1500, echo delay time = 50). A total of 104 scans were reviewed (average, five per knee). The ACL graft was divided into four unequal size zones for analysis. The proximal, middle, and distal thirds of the intraarticular portion of the graft and the portion of the graft within the tibial tunnel were independently analyzed. The magnetic resonance signal in each portion of the graft was graded on a scale with (I) being a normal signal, (II) >50% of the total volume of the graft having a normal signal, (III) <50% of the graft having a normal signal, and (IV) 100% of the graft having an increased signal.

The increased magnetic resonance signal of the ACL graft was observed to be regionalized and confined to the distal two-thirds of the intraarticular portion of the graft. The portion of the graft exiting the femoral tunnel and within the tibial tunnel retained a normal magnetic resonance signal. The increases in magnetic resonance graft signal were time-dependent, became well established by 3 months, and remained unchanged at 1 year. The clinical outcome could not be predicted based on the magnetic resonance signal of the graft.

Magnetic resonance (MR) imaging of the knee has become an accepted diagnostic tool for evaluating the integrity of the ACL. MR scanning permits visualization of the entire sagittal anatomy of the ACL from the femoral origin to tibial insertion. The diagnosis of an ACL injury has been based on changes in signal intensity, lack of continuity, and distorted relationships within its intraarticular pathway. The increase signal in the traumatized ACL is considered to be secondary to increases in water concentration representing, edema or hemorrhage. This extensive visualization of the ACL cannot be achieved in vivo by any other imaging modality. To date, imaging of reconstructed ligaments has been limited to only a few isolated cases.

The purpose of this prospective, observational study was to use serial MR images to study the fate of combined semitendinosus-gracilis human autografts during the 1st year of implantation. The MR data were analyzed in an attempt to answer the following five questions: 1) Do MR signal changes of an implanted graft occur within localized regions along the intraarticular and transosseous pathway of the graft? 2) Are some regions of the graft resistant to the MR signal increase? 3) Does an increase in the MR signal occur in every graft?
Serial MRI of Hamstring ACL Autografts

From December 1986 to December 1987 26 consecutive arthroscopically assisted ACL reconstructions were performed for anterior instability of the knee. Autografts consisting of three or four strands of double-looped semitendinosus and gracilis tendons were used. Of this group, 23 patients had intraoperative testing of the placement of the femoral and tibial pilot holes (2.4 mm in diameter) with a transarticular suture and tensiometer. All patients had 2 mm or less change in the tibial-femoral separation distance when the knee was ranged from maximal extension to 90° of flexion. Twenty-one of these 23 patients completed all of the study requirements, including a minimum of at least four serial MR studies of the autograft. The study group consisted of these 21 patients (18 males, 3 females), with a mean age 24 years (range, 16 to 36 years). Surgery was performed for chronic knee instability in 14 patients and for an acute ACL rupture in 7.

Surgical technique

An arthroscopically assisted, double-looped, hamstring and semitendinosus ACL reconstruction was performed on each knee. A side wallplasty was performed to remove acquired osteophytes from the medial wall of the lateral femoral condyle in order to enlarge the aperture of the anterior notch to a normal width of at least 23 mm.7 A rear-entry guide (Acufex Microsurgical, Inc., Norwood, MA) was inserted through an anterolateral femoral incision to place a guide pin 5 to 7 mm anterior to the roof position at either the 11:00 or 1:00 o’clock position (right or left knee, respectively). The tibial pin was placed by drilling through a front-entry guide (Acufex Microsurgical, Inc.) with the knee in 90° of flexion. The tibial landmark for placing the tip of the guide was 5 mm anterior and medial to the center of the ACL insertion stump (eccentric position). A tensiometer Acufex Microsurgical, Inc.) was attached to a transarticular suture and passed through the provisional pilot holes. Adjustments in femoral tunnel placement were performed to ensure that the femoral-tibial separation distance was 2 mm or less with passive motion from 0° to 90° of flexion.

The semitendinosus and gracilis tendons were harvested through a 4 cm incision. The two grafts were double-looped over an umbilical tape and the combined cross-section of the four strands was measured by drawing the graft through a hollow, cylindrical sizers (Acufex Microsurgical, Inc.). Occasionally, the gracilis graft was too short to permit double looping and a three-stranded graft had to be used. A cannulated reamer, sized to the combined diameter of the double-looped graft, was used to create snug-fitting femoral and tibial tunnels (the average tunnel diameter was 7 to 8 mm). The intraarticular tunnel margins were smoothed with a rasp to prevent abrasion by sharp bony edges. The looped end of the two grafts were passed around a 6.5 mm screw and ceramic ligament washer. The screw was then inserted through a 12 mm wide strip of the iliotibial band and secured to the lateral femoral cortex as an extraarticular tenodesis. Soft-tissue staples were used to secure the grafts to the tibia with the knee in maximal extension and external rotation. A hinged, long leg brace was applied, allowing full flexion but limiting extension at 35° of flexion.

Postoperatively the knees were placed on a continuous passive motion (CPM) machine permitting motion from 0° to 90°/直到 the knee regained 90° of flexion. The brace was worn out of bed. Patients were discharged in their brace and wore it continuously for 4 weeks. Prone extension exercises were begun out of the brace at 4 weeks to regain extension. Full weightbearing was permitted at 6 weeks and the long leg brace was discarded. A derotation brace with an extension stop at 35° of flexion was used during strengthening exercises for the next 41/2 months. At 6 months, the extension stop was removed from the derotation brace and progressive return to athletics was permitted.

POSTOPERATIVE DATA COLLECTION

Patients were scheduled to have a limited sagittal MR study of the graft at approximately 1, 6, 12, 24, 36, and > 48 weeks postoperatively. Scheduling conflicts occasionally made strict adherence to these time intervals impossible. A minimum of four scans per knee were required for inclusion in the study.

The MR scans were performed using a 0.35 Tesla superconducting magnet with a dedicated quadrature detection knee coil (Diasonics, San Francisco, CA). Imaging was confined to 10, 2.5 mm thick sagittal sections (0.625 mm2 pixels) centered about the intercondylar region of the knee. The knee was externally rotated 10° to 15° to optimally align the graft in the sagittal plane. Image acquisition was performed with the standard spin-echo technique using a 1500 msec repetition time and 50 msec echo delay time. Encoding and reconstruction was performed with the standard two-dimensional Fourier transformation technique, using 256 phase encoding steps and two excitations (15 minute acquisition time).

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 I signal (‘normal’) was awarded when the zone was filled with a graft that had a homogeneous, low intensity signal indistinguishable from that of the PCL or patellar ligament. A Grade II image was recorded if the volume of graft analyzed on multiple slices retained at least 50% of normal ligament signal intermixed with portions of the graft that had acquired an increased signal intensity. A Grade III image was documented when a graft within a zone had less than 50% of its volume exhibiting a normal-appearing ligament signal. A Grade IV graft consisted of a diffuse increase in signal intensity with no normal-appearing strands of ligament. The appearance of cancellous bone within the ligament in the tibial tunnel was recorded. Signal artifact induced by the fixation hardware did not interfere with the interpretation of the graft signal.

The intraarticular pathway of the ACL autograft was
divided into thirds for signal analysis. Zone P consisted of the proximal third of the graft as it exited from the femoral tunnel. Zone M corresponded to the middle third of 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. The fourth zone consisted of the segment of graft within the tibial tunnel.

The radiologist (JAC) read each MR scan without knowing the clinical outcome. The graft appeared on three to four contiguous slices because the sagittal sections were 2.5 mm wide and the ACL graft averaged 8 mm in diameter. Representative grading of the graft signal required that all images containing the ACL graft be analyzed. A composite grade for each zone was made based on the average signal obtained from the three to four images that displayed the entire volume of the ACL graft. These measurements were used for statistical comparison of the MR signal between zones, clinical outcome, and time periods, using the Kruskal-Wallis and Friedman analysis of variance (ANOVA) tests for ordinal data and the unpaired Student’s t-test for interval data. One of the orthopaedic surgeons (SMH) independently read each of the three intraarticular graft zones using the MR grading scheme for the 6 week and 9 month scans. The interobserver variability for interpreting the MR scans was determined by calculating the Wilcoxon signed-rank test. The number of zones that scored identical, greater, or less were recorded for each zone within each time interval.

At final followup (> 48 weeks) the knees were classified as either stable or unstable. A stable knee had to have all of the following findings: extension to at least 0˚, a solid endpoint to the Lachman and anterior drawer tests, an absent pivot shift and flexion rotation drawer, single-leg hop test within 95% of the distance of the uninvolved leg,10 and KT-1000 instrument (MEDmetric Corp., San Diego, CA) laxity testing at 67 N, 89 N, and maximal manual test (MMT) with less than or equal to 2.5 mm of difference when compared to the intact knee.

RESULTS

Five of the 21 knees became unstable during the 1st year as defined by the presence of a positive pivot shift, and a significantly increased excursion during ligamentous laxity testing (Table 1). Three patients with unstable knees had a Grade I pivot shift and were subjectively improved. The other two patients had Grade II pivot shifts and were not improved. The remaining 16 knees (76%) were clinically stable. The ligament laxity in these stable knees was essentially equal to the normal knee for the 67 N, 89 N, and MMT tests. These knees all had a negative pivot shift, normal Lachman test, full extension (at least 0˚), and a single-leg hop test within 95% of the normal leg.

A total of 104 MR scans were reviewed by the radiologist; there was an average of five and a minimum of four scans per knee. MR analysis of the grafts by zone revealed that the increased signal was regionalized (Fig. 1). The signal increase was observed to be confined to the middle and distal intraarticular zones, with the proximal intraarticular zone and the portion of the graft within the tibial tunnel retaining a normal MR graft signal. The regionalized signal increase,

![Figure 1](image-url)  
Figure 1. The MR signal grade for each of the three intraarticular zones was compared at each time period after implantation. Significant regionalized increases in MR signal were observed between intraarticular zones at all time intervals beginning at 6 weeks. The MR signal was increased in the middle and distal zones. The MR signal of the graft in the proximal intraarticular zone did not increase over time. The median MR signal was plotted for each zone. (Statistical analysis: Kruskal-Wallis.)

![Figure 2](image-url)  
Figure 2. The combined MR signal of the intraarticular portion of the graft significantly increased from 0 to 12 weeks [proximal (P), middle (M), and distal (D) zones]. After 3 months the combined MR signal remained elevated and showed no sign of improvement. The data was plotted as the median MR signal grade, the error bars represent the 50% range. (Statistical analysis: Friedman’s ANOVA.)
within the distal two-thirds of the intraarticular pathway of the graft, was significantly different from the proximal third from 6 to 48 weeks postimplantation (Kruskal-Wallis test). The regionalized signal increase did not develop until after the extension stop brace was removed and the knee began to regain extension.

The combined MR signal for the intraarticular portion of the graft (proximal, middle, and distal zones) was analyzed to determine if there was any statistical change in the graft signal between scanning intervals during the first year (Fig. 2). There was a significant increase in the signal between 0 and 12 weeks, but the signal remained increased and unchanged from 12 to 48 weeks (Friedman’s ANOVA). There was no statistical difference in the MR grading between the stable and unstable groups.

The MR scans of a stable knee at 1 week, 12 weeks, and 1 year demonstrate the observed changes in the MR signal noted during the 1st year of graft implantation (Fig. 3). The

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<th>Zones scored</th>
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*Wilcoxon signed-ranked test.

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A, at 1 week postimplantation the entire graft at normal MR signal (Grade I). The soft-tissue trauma associated with harvesting, devascularizing, preparing, and inserting the hamstring graft did not cause an increase in the MR signal of the graft. B, by 3 months, the graft exiting from the femoral tunnel in the proximal intraarticular zone (1) has remained unchanged (Grade I); the middle intraarticular zone (2) had acquired an increased signal involving approximately 50% of the width of the graft (Grade II); the distal intraarticular zone (3) had only a few strands of normal-appearing ligament with more than 50% of the ligament having an increased signal (Grade III). The portion of the graft within the tibial tunnel (4) was normal in appearance (Grade I). C, the increase in the MR signal of the graft persisted at 1 year with no evidence of returning to normal. The MR appearance of the proximal (1) and middle (2) intraarticular portion of the graft remained unchanged (Grades I and II, respectively); the MR signal of the distal (3) segment of the graft had progressed to Grade IV with no normal-appearing signal. At 1 year the tibial tunnel (4) had begun to fill in with cancellous bone (*). Pixel signal intensity measurements of the material in the tunnel was identical to the signal of the surrounding medullary bone. The black, linearly oriented MR signal that frames the cancellous bone anteriorly and posteriorly represents remodeled cortical bone that has become sclerotic over time. The sclerotic tunnel margins are also clearly visible on roentgenograms after 4 months. Although the graft appears discontinuous, this patient’s knee has remained stable at 3 year followup.
ACL graft was wider than the 2.5 mm sagittal slices, resulting in the ACL graft being displayed on more than one image. For this reason grading of the graft signal in these knees required that three to four images be reviewed to assess the total volume of the graft before arriving at a composite grade. These additional images have not been included, but were used by the reviewers to assist in the grading of the ligament. The graft at 1 week had a uniform low, homogeneous signal (Grade I, normal) in all four zones. By 3 months, the graft in the proximal zone (Grade I) exiting from the femoral tunnel has remained unchanged the middle zone (Grade II) had acquired an increased signal involving approximately 50% of the width of the graft; the distal zone (Grade III) had only a few strands of normal-appearing ligament, with more than 50% of the ligament having an increased signal; the graft within the tibial tunnel (Grade I) was normal in appearance. The increased ligament signal persisted at 1 year with no evidence of returning to normal. The portion of the graft in the proximal and middle zones had remained unchanged; the distal zone had progressed to Grade IV with no normal-appearing signal; the portion of graft in the tibial tunnel had acquired bony ingrowth.

Two of the 16 stable knees displayed a normal MR signal of the graft throughout the 1st year of implantation. These knees retained a constant, homogeneous MR signal similar to the signal of the PCL.

The portion of the graft within the osseous tibial tunnel never acquired an increase in graft signal. By 6 months 20% of the knees had evidence of bone ingrowth, and by 1 year 35% of the knees had cancellous bone replacing a portion of the graft (Fig. 3C).

The interobserver variability confirmed that the grading scheme was reproducible for both the radiologist, skilled in MR analysis, and the orthopaedic surgeon (Table 2). There was no significant difference in the grading of the proximal, middle, and distal zones at 6 weeks and the middle and distal zones at 9 months (five of six zones). Between 10 and 13 zones were graded identically by the two independent reviewers out of 16 zones per time interval. Only the 9 month grading of the proximal zone was significantly different. The radiologist consistently scored the proximal zone as having an increased MR signal. A “worst-case analysis” was made by using the radiologist’s elevated scoring tendency for the proximal zone to determine if a regionalized signal increase occurred in each time period. Analysis of the radiologist’s MR signal scores confirmed that the increase in MR graft signal was regionalized over time (Fig. 1).

**DISCUSSION**

This prospective study was the first to study serially the MR appearance of ACL autografts during the 1st year of implantation. This new technology, applied to a reconstructed knee, permits noninvasive, serial, in vivo study of the entire sagittal anatomy of a human ACL graft. The relationship of the graft to the intercondylar roof, the orientation and sagittal location of the tibial tunnel, and the location of the femoral tunnel can be determined as well as serial changes in the signal appearance of the ACL graft.

The MR signal increase of the graft was regionalized and did not occur throughout the entire length of the graft. The signal increase was confined to the distal two-thirds of the intraarticular portion of the graft (the middle and distal zones). The proximal one-third of the graft exiting the femoral tunnel and the portion in the tibial tunnel appeared to be resistant from developing increased signal changes. The cause of these regionalized changes are unknown at this time.

The causes of the time-dependent, regionalized increase in the MR signal of the grafts remains unclear. The grafts in this study were placed with <2.0 mm of excursion as determined by a tensiometer. Graft elongation, due to improper tunnel selection, would be expected to cause an increase in MR signal that effected the entire length of the intraarticular portion of the ligament instead of a limited section of the graft. Some other possible causes of the regionalized increases in MR signal could be graft impingement and/or unknown nutritional factors.

Comparison of the combined MR signal of all three intraarticular zones with respect to time of implantation revealed that the MR signal significantly increased during the first 12 weeks of implantation. The increase in graft signal corresponded temporally to the removal of the extension stop long leg brace and the return to full weightbearing on the reconstructed limb. After 3 months of implantation the MR signal of the graft remained increased. The MR appearance of the graft was no better at 48 weeks than at 12 weeks. Nine months of graft adaptation and remodeling within the intraarticular environment did not improve the MR signal of the graft.

Comparison of the MR signal observed in the stable and unstable knees failed to show any statistically significant difference. The MR signal of the graft could not be used to predict which graft would ultimately fail within the 1st year of implantation.

The increase in MR signal did not occur in every reconstruction. Two reconstructions did not develop an increase in graft signal. The MR signal of the graft was the same at 48 weeks and at the time of implantation in these two knees. Although the significance of the preservation of a normal MR graft signal cannot be determined based on the small number of patients in this study, a speculation can be made. The increased MR signal has been thought to be related to an increase in water concentration representing graft edema. In dogs, graft edema has been shown to be a proven marker for following changes in graft strength. Thus, there may be an inverse relationship with an increase in graft signal indicating a decrease in graft strength over time.

Determination of whether the increase in MR graft signal is obligatory or controlled by some unforeseen variable will require further study. Human studies involving a larger number of knees and animal studies will be required to correlate the changing MR signal with graft strength and clinical outcome.
CONCLUSIONS

1. Increases in magnetic resonance graft signal were time-dependent, becoming well established by 3 months and remaining unchanged at 1 year.

2. Increases in the magnetic resonance signal of an ACL graft are regionalized and confined to the distal two-thirds of the intraarticular portion of the graft.

3. The portion of the graft exiting the femoral tunnel and within the tibial tunnel have an unchanging magnetic resonance signal during the 1st year of implantation.

4. Some grafts retain a normal magnetic resonance signal throughout the 1st year of implantation.

REFERENCES


