Unimpinged and Impinged Anterior Cruciate Ligament Grafts: MR Signal Intensity Measurements

Regionalized magnetic resonance (MR) signal intensities were quantitatively measured in impinged and unimpinged anterior cruciate ligament (ACL) grafts. Images were obtained with a 1.5-T imager, and signal intensity was measured in the proximal, middle, and distal thirds of the graft. In 15 unimpinged ACL grafts, the signal intensity remained low and did not vary during the first year of implantation (45 images). In contrast, 17 impinged ACL grafts showed an increase in signal intensity in the distal two-thirds of the graft that persisted 1-3 years after implantation (P < .001). Unimpinged grafts were placed in tibial tunnels posterior and parallel to the slope of the intercondylar roof. Reconstructions with anterior tibial tunnels resulted in graft impingement that caused increases in graft signal intensity. This increase demonstrates a clear association between surgical technique and the subsequent MR appearance of the graft.

Index terms: Grafts, 4526.458,4526.4857 • Knee, ligaments and menisci, 4526.458, 4526.4857 • Ligaments, MR studies, 4526.1214

Radiology 1991; 179:639-643

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The anterior cruciate ligament (ACL) is commonly injured by athletes. The resulting knee instability often prevents athletes from returning to and excelling at their sport. Reconstruction of the ACL has been effective in the storing stability and confidence in the knee (1). Grafts are inserted into 8-10-mm-diameter holes that have been drilled in the femur and tibia. The placement of these bone tunnels is critical to the success of the reconstruction (2-4).

We have used serial magnetic resonance (MR) images to study the appearance of human ACL grafts during the first year of implantation. We subjectively noted that ACL grafts with the tibial tunnel positioned anterior to the slope of the intercondylar roof developed areas of high signal intensity 6-12 weeks after implantation. These grafts were thought to be impinged because of the intercondylar roof impinging on the anterior surface of the graft during knee extension. In contrast, reconstructions in which the tibia tunnel was posterior to the intercondylar roof remained low in signal intensity (5).

The current study was designed to quantitatively measure regionalized MR signal intensities in impinged and unimpinged ACL grafts. One aim of the study was to determine if the signal intensity of the graft was controlled by the location of the tibial tunnel. Another goal was to determine if the signal intensity of unimpinged grafts remained constant during the first year of implantation.

MATERIALS AND METHODS

Prospective Study: Unimpinged Grafts

The prospective study involved 20 consecutively seen patients who had an ACL reconstruction without roof impingement November 1988 through September 1989. The tibial tunnel was placed by means of a prototype drill guide that positioned the tibial tunnel posterior and parallel to the slope of the intercondylar roof with the knee in maximal extension. Impingement of the graft was avoided by removal of bone from the intercondylar roof until a rigid sizer could be passed through the tibial tunnel and into the intercondylar notch with the knee in maximal extension (Fig 1).

Retrospective Review: Impinged Grafts

The retrospective study involved 19 of 21 patients in whom an ACL reconstruction was unknowingly performed with graft impingement (January 1987 through October 1988). The tibial tunnel was intentionally placed anteriorly according to accepted reconstruction techniques for that period (1). The lateral radiograph obtained with the knee in maximal extension revealed that the tibial tunnel was anterior to the slope of the intercondylar roof in each case (Fig 2).

All patients had a double-looped gracilis and semitendinosus hamstring autograft inserted arthroscopically. Data collection consisted of lateral radiography of the knee in maximal extension at 1 year, a measurement of the difference in knee extension between the knee that was operated on and normal knee at 1 year, clinical testing of stability based on the presence or absence of a pivot shift, and instrumented laxity testing with an arthrometer (KT1000; Medmetric, San Diego) (6).

The sagittal location of the center of the tibial tunnel was determined in both the impinged and unimpinged grafts with lateral radiographs. The sagittal depth of the tibia was measured and divided by the distance from the anterior tibial edge to the center of the tibial tunnel (Fig 2).

The prospective study group under-went MR imaging (1.5 T) of the unimpinged grafts three times: at 3,6, and greater than 12 months. The retrospectively reviewed knees had undergone MR imaging (1.5 T) of the impinged grafts once: 12-36 months after implantation.

Abbreviations: ACL = anterior cruciate ligament, ANOVA = analysis of variance, TE = echo time, TR = repetition time.
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Figure 1. Intraoperatively obtained lateral radiograph of the knee in maximal extension demonstrates the unimpinged position for the tibial tunnel. The tibial tunnel was posterior and parallel to the slope of the intercondylar roof in the extended knee. Bone has been removed from the intercondylar roof to allow free passage of the rigid metal sizer into the joint. Three months after surgery, this knee regained full extension equal to that of the unoperated knee.

MR Technique

MR imaging was performed with a 1.5-T superconducting magnet (Philips Medical Systems International, Da Best, Netherlands) and a dedicated knee coil. The knee was externally rotated 10°-15° to align the graft in the sagittal plane. A T1 weighted scout image (repetition time [TR] = 443 msec, echo time [TE] = 15 msec [443/15]) was obtained in the coronal plane to provide the orientation of the ACL graft. An oblique sagittal imaging plane was selected so that the section overlay the lateromedial trajectory of the ACL graft (Fig 3). This technique permitted the entire graft to be visible from origin to insertion in one section.

Images were acquired with a standard spin-echo technique involving a 1,200-msec TR and a 40-msec TE. Eleven 3.0-mm-thick sagittal sections (0.625-mm² in pixels) were imaged in each graft (5,7). The computer software enabled a round or oval cursor to be placed over sections of the ACL graft on the viewing screen. Signal intensities of the proximal, middle, and distal thirds of the graft were measured by one of the authors (G.S.B.) (Fig 4).

Use of Phantoms to Normalize Signal Intensity

A separate study was performed to determine the repeatability of signal intensity measurements in the same person and among people. Eight patients with asymptomatic knees underwent imaging on three occasions by means of the previously described MR techniques. Five test-tube phantoms of varying concentrations of MnCl² solution were placed posterior to the joint within the knee coil. A total of 55 images were analyzed.

Data Analysis

A one-factor analysis of variance (ANOVA) for repeated measures was used to determine if the signal intensity measurements in each zone of the unimpinged grafts changed among the 3-, 6-, and 12-month measuring times. This test has advantages over a Student t test because it allows a statistical comparison to be made among three or more groups. Similarly, a multiple group comparison of the signal intensities in the proximal, middle, and distal zones of the unimpinged and impinged grafts was performed by means of a one-factor ANOVA of the final MR image. The remaining comparisons between the impinged and unimpinged grafts were made by means of an unpaired Student t test and χ² analysis. Significance was based on P < .05. One standard deviation was used to describe the variability of the means.

RESULTS

Fifteen patients with unimpinging grafts completed all the requirements for the study (average age, 25 years; 13 male, two female patients). Five patients did not return for the 6- or 12-month session of MR imaging and were deleted from the study. The lateral radiograph confirmed that the tibial tunnels were posterior to the slope of the intercondylar roof. The center of the tibial tunnel was located 42% ± 2.4 of the entire sagittal depth of the tibial plateau from the anterior edge of the tibia. A total of 45 MR images were analyzed.

The appearance on MR images of the impinging free ACL grafts did not change in signal intensity during the 1st year of implantation (Fig 4). The signal intensity of the proximal (P > .55), middle (P > .21), and distal (P > .14) zones of the unimpinged ACL graft did not vary among measurements made at 3.6, and 12 months (Fig 5). The 12-month images were obtained an average of 377 days ± 52 (range, 327-491) after surgery. There was no regional difference in the signal intensity of the unimpinged grafts among the proximal, middle, and distal zones on the final images (P > .62).
Seventeen of 19 patients with roof impingement of the ACL graft returned for follow-up MR imaging (1.5 T) an average of 819 days ± 270 (range, 360-1,154) after surgery (average age, 23 years; 15 male, two female patients). The lateral radiograph confirmed that the tibial tunnels were at least partially anterior to the slope of the intercondylar roof.

The center of the tibial tunnel was located 30% ± 5.4 of the entire sagittal depth of the tibial plateau from the anterior edge of the tibia. These impinged grafts often appeared discontinuous. The proximal (p) one-third and the portion within the tibial tunnel (t) remained low in signal intensity. The anterior tibial tunnel forced the graft to angulate around the distal edge of the intercondylar roof. This sagittal oblique MR image was obtained 3 years after graft implantation (1,200/40). The patient has fully returned to active athletics, and the knee has remained stable in spite of the marked increase in signal intensity of the graft. This knee lacked 5° of extension.

Comparison of the signal intensity of each zone on the final MR images between the unimpinged and impinged grafts revealed that there was a highly significant increase in the signal intensity in the distal two-thirds of the intraarticular pathway of the graft. These impinged grafts often appeared discontinuous. The proximal (p) one-third and the portion within the tibial tunnel (t) remained low in signal intensity. The anterior tibial tunnel forced the graft to angulate around the distal edge of the intercondylar roof. This sagittal oblique MR image was obtained 3 years after graft implantation (1,200/40). The patient has fully returned to active athletics, and the knee has remained stable in spite of the marked increase in signal intensity of the graft. This knee lacked 5° of extension.
impinged ACL in all three zones ($P < .0001$) (Fig 7). Impinged grafts were associated with a signal intensity increase in the entire graft, with the most pronounced changes occurring in the distal two-thirds. The signal intensity increases in impinged grafts persisted 3 years after surgery.

Radiographically, the impinged knees had tibial tunnels placed more anteriorly than the unimpinged knees had ($P < .0001$). The posterior tunnel placement avoided premature impingement of the graft by the intercondylar roof before the knee reached terminal extension (Table).

Clinically, impinged knees had less extension at 1 year ($P < .0001$) and were more likely to be unstable (Table). Twenty-four percent of the impinged grafts had instability ($P < .05$), whereas no instability existed in the unimpinged knees.

The coefficient of variation of the phantoms across all subjects ranged from 16.0% to 19.7%. When one phantom was used to normalize the rest, the coefficient of variation remained nearly the same, ranging from 12.6% to 17.8%. Normalization did not significantly change the intra- or intersubject variation in signal intensity (ANOVA). Unnormalized signal intensity measurements were accurate to within 15%-20%. The increase in signal intensity from roof impingement greatly exceeded the intrasubject and intersubject variation when a TR of 1,200 msec and a TE of 40 msec were used. Comparisons of unnormalized signal intensity measurements among people and within a person over time were not compromised by excessive scaling differences because of the relatively low coefficient of variation.

**DISCUSSION**

The use of signal intensity measurements to quantitate regional variations in the MR signal intensity of unimpinged and impinged ACL grafts is a new application of an accepted technique. In fact, signal intensity measurements have been shown to be superior to T1 and T2 determinations for detecting and quantitating liver disease (8).

Unimpinged grafts retained a low MR signal intensity when they were placed in a tibial tunnel that was posterior to the slope of the intercondylar roof. Enlargement of the notch to prevent graft impingement allowed these grafts to remain low in signal intensity throughout the 1st year of implantation (5).

Impinged grafts acquired a regionalized increase in MR signal intensity when placed in anterior tibial tunnels (7). This signal intensity change occurred because of premature impaction of the graft by the intercondylar roof during knee extension. The distal two-thirds of the impinged grafts retained this signal increase for up to 3 years after graft implantation. The MR appearance of the graft appeared to be determined on the basis of the surgical technique.

Signal averaging from adjacent soft tissues theoretically could have falsely elevated the signal intensity of the graft. Volume averaging was minimized by use of an odd number of 3-mm-wide oblique sagittal images centered on grafts 8 mm in diameter. The center section was framed by 2-3 mm of ligament. The significant differences in signal intensity between the impinged and unimpinged grafts cannot be explained by random, minor variations in section location.

Impinged grafts were clinically observed to have a higher incidence of instability and associated with more difficulty in regaining complete knee extension than unimpinged grafts were (5). However, most impinged grafts had an acceptable clinical result. In this study, 75% of the knees with graft impingement were clinically stable but lacked 3°-5° of knee extension.

A graft that is severely impinged may be so high in signal intensity that it is difficult to see at MR imaging (Fig 7). The increased signal intensity could represent...
replacement of the ligament by synovium. The graft could also be atrophied or ruptured. Although part of this study protocol, three knees with impinged (high-signal-intensity) grafts have undergone repeated arthroscopy, each showing mildly swollen, continuous grafts covered by a thin layer of synovium. These knees were stable.

It is clear that impinged grafts may have marked increases in signal intensity that do not result in instability of the knee. For this reason, the integrity of an impinged graft should be determined on the basis of clinical stability testing and not on the MR appearance of the graft.

It is not known whether a relationship exists between the impingement-induced increases in MR signal intensity and the strength of the graft. In a dog study, an increase in the water content of the graft correlated with a decrease in graft strength (9). MR signal intensity is known to increase as the water content of the tissue increases. The edematous MR appearance of the impinged grafts may reflect a significant deterioration in the strength of the graft.

This study has provided some guidelines for interpretation of the MR image of an ACL graft. A graft that is low in signal intensity is free from roof impingement. Unimpinged grafts do not angulate around the distal edge of the intercondylar roof. Knees with unimpinged grafts regain full extension and are stable, and the grafts maintain their strength. A graft with an increase in signal intensity predominantly in the distal two-thirds of the ligament has impingement. This signal intensity increase is caused by an anteriorly placed tibial tunnel that permits the intercondylar roof to impact the graft during knee extension. The graft directly contacts the intercondylar roof and may be seen to angulate about its distal edge. Knees with impinged grafts were associated with a greater incidence of instability and persistent flexion contractures. The signal intensity increase suggests that impinged grafts may be weaker.

Acknowledgments: The authors thank Karen Lindfors, MD, and Goeff Patrissi, MA, for their review of the manuscript and assistance in the statistical analysis of the data.

References