Comparison of Sagittal Obliquity of the Reconstructed Anterior Cruciate Ligament With Native Anterior Cruciate Ligament Using Magnetic Resonance Imaging

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Purpose: This study was conducted to compare the obliquity of asymptomatic anterior cruciate ligament (ACL) grafts with normal controls using sagittal magnetic resonance imaging (MRI). **Type of Study:** Case control study. **Methods:** Sagittal MRIs from 30 patients with a reconstructed ACL graft and from 30 individuals with an intact ACL were reviewed. Reconstructed patients were operated on with a 2-incision technique using a patellar tendon autograft. These selected patients had a normal or nearly normal IKDC score with a 3 mm or less anterior posterior translation on KT-1000 arthrometer testing compared with the intact knee. MRI showed a continuous and homogeneous graft without evidence of roof impingement. Obliquity of the grafted ACL was determined on each lateral MRI by measuring the intersection of the graft line with the tibial plateau plane. These figures were compared with data similarly obtained from 30 individuals with a stable knee and an intact ACL determined by history and physical examination. **Results:** Graft obliquity in reconstructed patients averaged 67° with a range between 55° and 81°. In normal controls, intact ACL obliquity averaged 51° with a range between 45° and 55°. The difference between the two groups was statistically significant ($P < .0001$). **Conclusions:** MRIs of patients with an appropriate tibial tunnel placement in order to avoid notch impingement showed a continuous and homogeneous graft similar to the native ACL, but with a more vertical graft that does not recreate the normal sagittal obliquity. However, according to arthrometer testing, these more vertical grafts can control anterior posterior knee displacement. **Key Words:** ACL reconstruction—MRI evaluation—Sagittal obliquity—Functional anatomy.

Roof impingement of a reconstructed anterior cruciate ligament (ACL) can be evaluated with magnetic resonance imaging (MRI) studies, which show an increased signal in the distal two thirds of the graft. This appearance on MRI may reflect deterioration in the strength of the graft and is generally associated with a greater incidence of instability.[1-3]

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It has been extensively reported in the literature that, to avoid this complication, the tibial tunnel must be placed slightly posterior to previous parameters.[4-7] However, this tibial tunnel placed posterior and parallel to the slope of the intercondylar roof may alter the intention to reproduce the native ACL, particularly its obliquity in the sagittal plane with potential biomechanical implications. This study was conducted to compare the obliquity of asymptomatic ACL grafts with a group of normal controls, using sagittal MRI scans.

METHODS

Sagittal MRIs from 30 patients with a reconstructed unimpinged ACL graft and from 30 patients with an intact ACL determined by history and physical examination were retrospectively reviewed. All reconstructed patients were operated on between August 1986 and December 1992 using a 2-incision technique and patellar tendon autograft. During that period of time, 312 patients underwent reconstruction with that technique at the authors' institution. Postoperative MRI studies were obtained from 75 patients and images were evaluated to assess the anatomic placement, continuity, and appearance of the graft. According to this evaluation, images from 30 patients were selected only if the entire graft was black and homogeneous with low signal intensity from origin to insertion and without evidence of roof impingement.

Each patient was clinically evaluated according to the IKDC knee ligament standard evaluation form and measured with an instrumented laxity test with an arthrometer (KT-1000; MedMetric, San Diego, CA). Patient selection for this study included only those with a normal or nearly normal IKDC score with a solid end point to the Lachman test, an absent pivot-shift test, and a 3mm or less anterior posterior translation measured with a KT-1000 arthrometer when compared with the intact knee (manual-maximum test).

According to these imaging and clinical parameters, 30 patients with a continuous and homogeneous graft without evidence of roof impingement and with a stable knee were selected for this study. The mean age of this group was 32 years with a range between 19 and 54 years. The mean time between ACL reconstruction and MRI evaluation was 28 months with a range between 12 and 100 months.

Imaging studies were performed at our institution with either a 1.0-Tesla or 1.5-Tesla super-conducting magnet. In all patients, coronal and sagittal imaging of contiguous sections 5 mm thick were performed with repetition time of 500 msec and echo time of 20 msec, a 16-cm field of view, a 256 × 128 matrix, and one excitation. The knee was placed at 10° of flexion and externally rotated 10° to 15° in an attempt to optimally align the ACL in the sagittal plane that was magnified to 135% of actual size (magnification factor of 1.35).

ACL grafts showed decreased signal intensity on T1-weighted images, and measurements were performed on a single image that depicted the complete sagittal dimensions of the graft from origin to insertion. The relationship of the ACL graft to the tibial plateau was studied according to the following landmarks (Fig 1). A tibial plateau line (A) was drawn perpendicular to the long axis of the tibia at the level of the anterior edge of the ACL graft insertion. The anterior-most portion of the ACL graft was marked at line A and at the midpoint between the origin and insertion. The posterior edge of the ACL graft was also marked at the line A and again, at the midpoint between the origin and insertion. A second line (B) was drawn following the mid distance between these anterior and posterior ACL graft landmarks. Obliquity of the grafted ACL was determined by measuring the intersection between lines A and B (Fig 1).

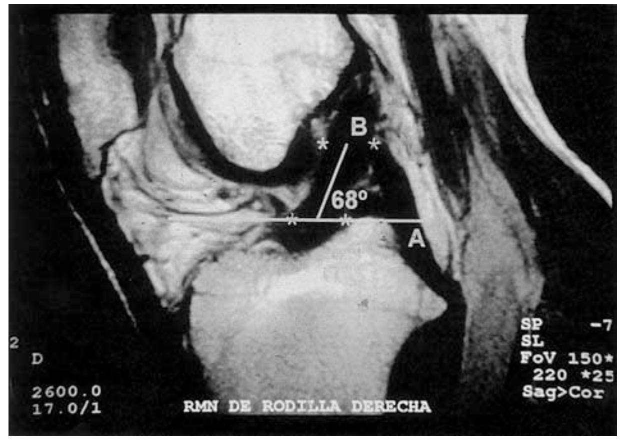

FIGURE 1. Sagittal MRI from case number 19 at 36 months after reconstruction. The relationship of the ACL graft to the tibial plateau was studied according to the following landmarks: A tibial plateau line (A) was drawn perpendicular to the long axis of the tibia at the level of the anterior edge of the ACL graft insertion. The anterior-most portion of the ACL graft was marked at line A and at the midpoint between the origin and insertion. The posterior edge of the ACL graft was also marked at the line A and again, at the midpoint between the origin and insertion. Second line (B) was drawn following the mid distance between these anterior and posterior ACL graft landmarks. Obliquity of the grafted ACL was determined by measuring the intersection between lines A and B.

These figures were compared with data similarly obtained from 30 normal individuals with a stable knee and an intact ACL, determined by history and physical examination. The mean age of normal controls was 29 years with a range between 16 and 51 years. Statistical analysis was undertaken using the Kruskal-Wallis test, and differences between these 2 groups were determined with the χ-square test.

RESULTS

A more vertical placement of the graft was observed in reconstructed patients with unimpinged patellar tendon grafts than in normal controls with an intact ACL (Fig 2). Graft obliquity in reconstructed patients averaged 67° with a range between 55° and 81°. In normal controls, intact ACL obliquity averaged 51° with a range between 45° and 55°. These results showed a statistically significant difference in ACL

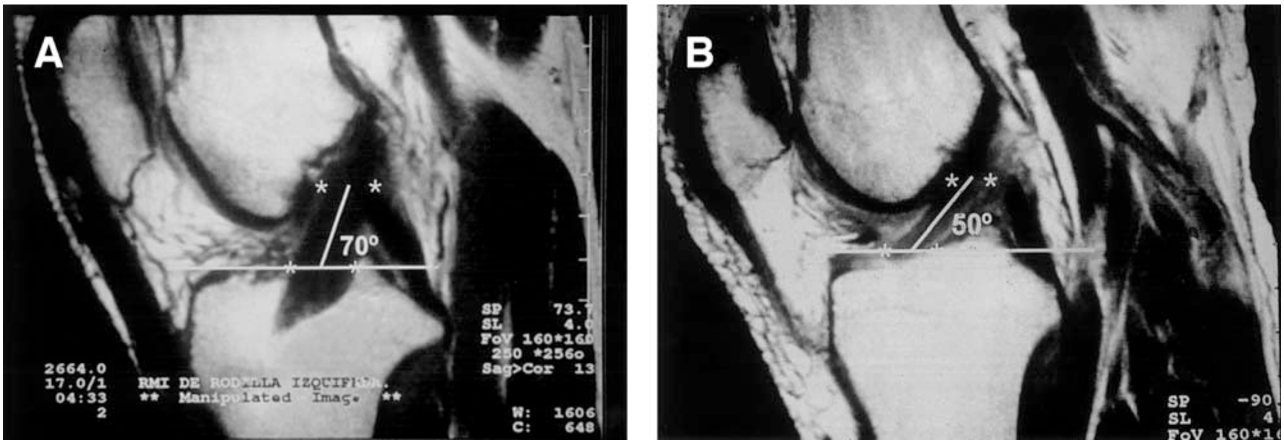

FIGURE 2. Comparison of sagittal obliquity between a reconstructed patient and a normal control. (A) Sagittal MRI from case number 2 at 28 months after reconstruction showing 70° of sagittal obliquity. (B) Sagittal MRI from normal control number 3 with 50° of sagittal obliquity.

obliquity between grafted and normal ACLs ($P < .0001$).

One half of normal controls ranged between 46° and 50° of sagittal obliquity and the other half between 51° and 55°. Only 1 patient in the reconstructed group showed a normal graft obliquity of 55°. The remaining 29 patients showed a more vertical graft that did not duplicate normal ACL obliquity (Fig 3).

Reconstructed patients had a mean manual-maximum KT-1000 displacement of 1.4 mm with a range between 0 and 3 mm. The differences in graft sagittal obliquity observed in these patients did not correlate with the amount of anterior posterior translation (Table 1).

DISCUSSION

An ideal ACL graft is one that restores normal anatomy and reproduces the complete function of the original ACL. However, limitations for that objective arise from the fact that present surgical techniques utilize a uniform tubular graft that cannot reproduce proximal or distal normal insertions. Anatomic studies of normal knees confirmed that the ACL is not uniform in diameter from origin to insertion.[8,9] The tibial insertion is nearly 2 times wider in the sagittal plane than the proximal fibers of the ligament. This anterior insertion originates the twisting of these fibers and this configuration seems to accommodate to the contour of the intercondylar roof, allowing full extension without notch impingement.[10] The parallel collagen fibers of patellar or hamstring tendons cannot duplicate this twisting of a native ACL. Because of these differences in shape and size of the graft, selecting the location for the tibial tunnel in the sagittal plane is a demanding decision for the surgeon. If the center of the ACL tibial footprint is selected as the central site for tibial tunnel placement, the position will be too anterior in relation to the intercondylar roof ending with an impinged graft. Knees with a severe impingement of the graft uniformly fail and are more likely to become unstable.[11] One way to avoid this complication is to perform an extensive bone removal from the intercondylar roof.[12] However, there is evidence that, with time, bony regrowth of the removed area may occur, ending with graft impingement. MRI studies of the intercondylar roof after notchplasty showed that a thin layer of cortical bone forms in most patients within 6 months of surgery.[13,14] Another alternative is to place the tibial tunnel more posterior, centering the graft so that it is aligned with the bulk of the ACL fibers, as presently recommended by many authors.[1,4-6] This

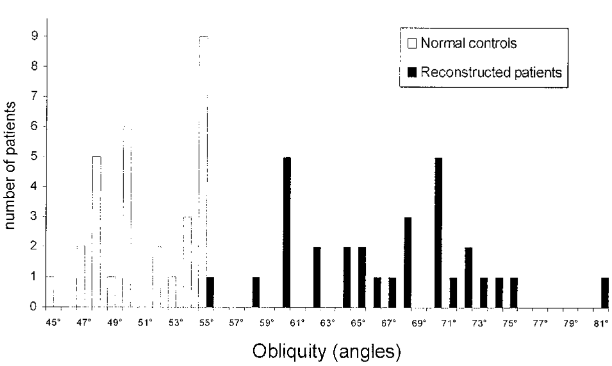

FIGURE 3. Distribution of sagittal obliquity measurements between reconstructed patients and normal controls.

Table 1. *Demographic Data*

Case	Reconstruction Patients				Normal Controls	
	Age (yr)	Follow-up (mo)*	Arthrometer KT-1000†	Sagittal Graft Obliquity	Age (yr)	Sagittal ACL Obliquity
1	26	100	2 mm	60°	21	55°
2	31	28	2 mm	70°	21	50°
3	28	65	1 mm	60°	25	50°
4	23	12	0 mm	60°	51	54°
5	26	12	2 mm	65°	39	48°
6	36	27	1 mm	60°	30	55°
7	34	16	3 mm	62°	48	52°
8	31	26	1 mm	66°	22	48°
9	23	13	2 mm	70°	21	55°
10	40	15	0 mm	73°	43	54°
11	40	28	0 mm	65°	33	55°
12	28	54	2 mm	62°	32	49°
13	31	24	1 mm	60°	31	45°
14	22	18	3 mm	58°	25	47°
15	29	36	2 mm	68°	26	55°
16	27	12	1 mm	68°	31	48°
17	32	12	2 mm	64°	16	48°
18	45	27	0 mm	70°	35	55°
19	39	36	2 mm	70°	28	55°
20	31	30	2 mm	81°	38	52°
21	24	36	3 mm	74°	22	53°
22	19	24	2 mm	75°	20	54°
23	35	28	1 mm	72°	39	50°
24	54	36	0 mm	55°	26	48°
25	28	12	1 mm	70°	34	50°
26	46	39	2 mm	71°	35	55°
27	20	24	2 mm	64°	18	55°
28	50	12	0 mm	72°	34	47°
29	38	39	1 mm	68°	29	50°
30	33	12	0 mm	67°	29	50°
Average	32	28	1.4 mm	67°	29	51°

*Follow-up between ACL reconstruction and MRI study.
†Manual-maximum anterior-posterior displacement compared with the intact knee.

type of reconstruction may result in a functional graft without roof impingement, but it does not recreate the anatomy of the native ACL according to the presently reported data.

In our study, 30 selected patients with an asymptomatic properly performed ACL reconstruction had MRIs showing a more vertical graft than normal controls. The difference in sagittal obliquity between these 2 groups was statistically significant. According to arthrometer testing, these nonanatomic grafts can control anterior-posterior knee displacement. However, it is possible that such sagittal abnormality may influence other biomechanical ACL functions, like knee rotation, that presently are not clinically measured.

A surgeon performing an ACL reconstruction with presently available type of grafts faces the following dilemma: To place the tibial tunnel in its anatomic insertion trying to reproduce the original ACL sagittal obliquity with high risk of roof impingement, or to place the tunnel slightly more posterior, obtaining an unimpinged but more vertical nonanatomic graft. Potential biomechanical implications of this increased obliquity, aside from anterior-posterior static stability, remain to be determined.

REFERENCES

1. Howell SM, Clark JA. Tibial tunnel placement in anterior cruciate ligament reconstruction and graft impingement. *Clin Orthop* 1992;283:187-195.
2. Howell SM, Berns GS, Farley TE. Signal intensity measure-

ments of unimpinged and impinged anterior cruciate ligament grafts. *Radiology* 1991;179:639-643.
3. Howell SM, Taylor MA. Failure for reconstruction of the anterior cruciate ligament due to impingement by the intercondylar roof. *J Bone Joint Surg Am* 1993;75:1044-1055.
4. Morgan CD, Kalman VR, Grawl DM. Definitive landmarks for reproducible tibial tunnel placement in anterior cruciate ligament reconstruction. *Arthroscopy* 1995;11:275-288.
5. Jackson DW, Gasser SI. Tibial tunnel placement in ACL reconstruction. *Arthroscopy* 1994;10:124-131.
6. Tomczak RJ, Hehl G, Mergo PJ, Merkle E, Rieber A, Brambs HJ. Tunnel placement in anterior cruciate ligament reconstruction: MRI analysis as an important factor in the radiological report. *Skeletal Radiol* 1997;26:409-413.
7. Clancy W, Nelson D, Reider B, Narechania R. Anterior cruciate ligament reconstruction using one-third patellar ligament, augmented by extra-articular tendon transfers. *J Bone Joint Surg Am* 1982;64:352-359.
8. Harner CD, Baek GH, Vogrin TM, Carlin GJ, Kashiwaguchi S, Woo SLY. Quantitative analysis of human cruciate ligament insertions. *Arthroscopy* 1999;15:741-751.
9. Odensten M, Gillquist J. Functional anatomy of the anterior cruciate ligament and a rationale for reconstruction. *J Bone Joint Surg Am* 1985;67:257-262.
10. Sidles JA, Larson RV, Garbini JL, Downey DJ, Matsen FA. Ligament Length Relationships in the Moving Knee. *J Orthop Res* 1988;6:593-610.
11. Howell SM, Clark JA, Farley TE. Serial magnetic resonance study assessing the effects of impingement on the MR image of the patellar tendon graft. *Arthroscopy* 1992;8:350-358.
12. Howell SM, Clark JA, Farley TE. A rationale for predicting anterior cruciate graft impingement by the intercondylar roof. A magnetic resonance imaging study. *Am J Sports Med* 1991; 19:276-282.
13. Bents RT, Jones RC, May DA, Snearly WS. Intercondylar notch encroachment following anterior cruciate ligament reconstruction: A prospective study. *Am J Knee Surg* 1998;11: 81-88.
14. May DA, Snearly WN, Bents R, Jones R. MR imaging findings in anterior cruciate ligament reconstruction: Evaluation of notchplasty. *AJR Am J Roentgenol* 1977;169:217-222.