Brace-Free Rehabilitation, with Early Return to Activity, for Knees Reconstructed with a Double-Looped Semitendinosus and Gracilis Graft*†‡

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Abstract: Forty-one patients in whom operative reconstruction of a torn anterior cruciate ligament had been performed by one surgeon with use of a double-looped semitendinosus and gracilis hamstring graft were studied to determine (1) if a brace-free rehabilitation program compromised the early & ability of the knee; (2) if the stability of the knee deteriorated between four months, when the patient returned to unrestricted activities, and two years; and (3) if the function of the treated knee was completely restored by four months after the operation. The graft was placed arthroscopically, without impingement by the intercondylar roof, and was fixed within the tibial tunnel to conserve the length of the graft. The stability and function of thirty-seven of the knees were assessed at four months as part of a larger prospective study. Four patients chose not to return for the four-month evaluation. The patients returned to unrestricted sports and work activities after the four-month evaluation. At two years, all forty-one patients were evaluated.

At four months, after completion of the brace-free rehabilitation program, thirty-three (82 per cent) of the thirty-seven patients had an absent pivot shift and a normal Lachman test. Twenty-eight (88 per cent) of thirty-four knees had less than three millimeters of difference in laxity compared with the contralateral knee, as determined by testing at the maximum manual force with use of a KT-1000 arthrometer. Stability remained unchanged at two years, justifying the early return to vigorous activities at four months. The girth of the thigh, the extension of the knee, and the Lysholm and Gillquist score were the same at four months as at two years, verifying the success of the brace-free intensive rehabilitation program in the restoration of early function to the treated knee. However, some continued improvement was observed in the performance of the one-leg-hop for distance test between four months and two years.

The two structures that are most commonly used for autogenous grafts in the reconstruction of a torn anterior cruciate ligament are the patellar ligament and the hamstring tendons. Most surgeons prefer the patellar ligament because it is readily procured, can be fixed firmly, and tolerates the loads produced by an intensive rehabilitation program. Patients who have a patellar ligament autogenous graft can return to vigorous activities two to six months after the operation without affecting the stability of the knee at two years after the operation. However, there are concerns that the same rapid rehabilitation may not be successful with the use of other graft materials. To our knowledge, the outcome of an intensive rehabilitation program and an early return to sports and work activities for patients who have had a reconstruction of the knee with the use of hamstring tendons has not been reported.

This observational study was designed to measure the function and stability of knees that had been reconstructed with a double-looped semitendinosus and gracilis hamstring graft. A functional assessment and arthrometric measurements of stability were made at four months, after completion of a brace-free, intensive rehabilitation program, and at two years after the operation. The objectives of the study were to determine (1) if the rehabilitation program compromised the early stability of the knee, (2) if the stability of the knee deteriorated after the patients returned to unrestricted activities at four months, and (3) if the function of the knee was completely restored by four months after the operation.

Materials and Methods

Patients

Forty-nine consecutive operations were performed by the senior one of us (S. M. H.), from February 1991 to May 1992, with the use of a four-bundle graft consisting
of a loop of the semitendinosus and a loop of the gracilis tendon to replace a torn anterior cruciate ligament. Only knees that were available for follow-up after two years were included in the study. Eight patients were excluded because they did not return for the two-year evaluation (Table I). The most recent stability measurements for four of these patients were recorded four to thirteen months after the operation; one of the four died fourteen months after the operation; and one was lost to follow-up.

The most recent stability measurements for three other patients were recorded two months postoperatively, two were re-evaluated by telephone three years after the operation, and one was lost to follow-up. The remaining patient was lost to follow-up after one month.

Therefore, the present study consisted of forty-one patients; twenty-eight were male and thirteen were female. The mean age at the time of the index operation was thirty-three years (range, fifteen to forty-eight years). All patients were athletically active before the injury, and thirty-eight (93 per cent) injured the knee during a sports activity. The mode of injury was a non-contact, deceleration maneuver on a planted foot for twenty-six (63 per cent) of the forty-one patients and a fall from a height or a collision for fifteen (37 per cent).

Thirty-four patients had had no operation on the knee before the index procedure. Six patients had had one previous operation. Four of them had had an arthroscopic partial medial meniscectomy; one, an arthroscopic medial and lateral meniscectomy; and one, an arthroscopic debridement. One patient had had two previous operations: an open repair of the medial collateral ligament and an arthroscopic debridement. Twenty-five index procedures were performed within six months after the injury, and sixteen were performed after six months. Two patients had a tear of the medial collateral ligament.

All of the patients had a torn anterior cruciate ligament diagnosed preoperatively and confirmed intraoperatively. Preoperatively, stability was determined objectively with a KT-1000 arthrometer (Med-Metric, San Diego, California) at an applied anterior load of eighty-nine newtons and with a maximum manual anterior force. The difference in anterior displacement between the injured and contralateral knees was calculated. All of the injured knees had at least three millimeters more anterior laxity than the contralateral knee, which is diagnostic of an attenuated anterior cruciate ligament. Subjectively, the end point on Lachman testing was soft in all injured knees that were available for follow-up after two years.

### TABLE I

<table>
<thead>
<tr>
<th>Variable</th>
<th>Case 1</th>
<th>Case 2</th>
<th>Case 3</th>
<th>Case 4</th>
<th>Case 5</th>
<th>Case 6</th>
<th>Case 7</th>
<th>Case 8†</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reason patient was not evaluated at 2 yrs.</td>
<td>Could not be located</td>
<td>Moved out of state</td>
<td>Moved out of area</td>
<td>Moved out of state</td>
<td>Died 14 mos. postop.</td>
<td>Moved out of state</td>
<td>Moved out of state</td>
<td>Moved out of area</td>
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<tr>
<td>Last objective evaluation (mos. postop.)</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>4</td>
<td>7</td>
<td>13</td>
<td>13</td>
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<tr>
<td>Girth of thigh (cm)</td>
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<td>-0.5</td>
<td>-1</td>
<td>0</td>
<td>1</td>
<td>0</td>
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<tr>
<td>5 cm proximal to superior pole of patella</td>
<td>NA</td>
<td>0.5</td>
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<td>-3</td>
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<td>0</td>
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<td>2</td>
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<td>15 cm proximal to superior pole of patella</td>
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<td>3 loss§</td>
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<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>4 loss§</td>
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<td>Extension of knee (degrees)</td>
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<td>0</td>
<td>0</td>
<td>0</td>
<td>0.5</td>
<td>-7</td>
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<tr>
<td>Manual maximum test (mm)</td>
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<td>0</td>
<td>4</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0.5</td>
<td>-7</td>
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<tr>
<td>End point on Lachman testing</td>
<td>Firm</td>
<td>Firm</td>
<td>Soft</td>
<td>Firm</td>
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<td>Firm</td>
<td>Firm</td>
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<tr>
<td>Pivot shift</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Lysholm and Gillquist score (points)</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>97</td>
<td>100</td>
<td>95</td>
<td>100</td>
</tr>
<tr>
<td>Hop index (per cent)</td>
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<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>100</td>
<td>102</td>
<td>85</td>
<td>100</td>
</tr>
<tr>
<td>Re-evaluated by telephone (mos. postop.)</td>
<td>NA</td>
<td>49</td>
<td>24</td>
<td>45</td>
<td>14</td>
<td>NA</td>
<td>43</td>
<td>40</td>
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<tr>
<td>Level of athletic activity‡</td>
<td>NA</td>
<td>Strenuous</td>
<td>Moderate</td>
<td>Strenuous</td>
<td>Strenuous</td>
<td>Strenuous</td>
<td>Strenuous</td>
<td>Strenuous</td>
</tr>
<tr>
<td>Reconstructed knee stable at last contact</td>
<td>NA</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Reoperation</td>
<td>NA</td>
<td>Hardware removed</td>
<td>None</td>
<td>None</td>
<td>None</td>
<td>None</td>
<td>NA</td>
<td>None</td>
</tr>
</tbody>
</table>

*NA = not available.

†The patient had a bilateral tear of the anterior cruciate ligament.

‡The values are given as the difference between the treated and the contralateral limb.

§The treated knee had hyperextension but it did not equal that of the contralateral knee.

¶The values are given as the difference in anterior laxity between the treated and the contralateral knee.

#The hop index was the mean distance hopped by the treated limb divided by that hopped by the contralateral limb, with the result multiplied by 100. A hop index of 85 per cent or more was considered normal.
knees. Intraoperatively, thirty-nine knees had a fully positive pivot shift and, during arthroscopy, all of the anterior cruciate ligaments were observed to be attenuated or absent.

The forty-one patients returned for evaluation at a mean of twenty-six months (range, twenty-four to thirty-two months) after the index operation. To control for examiner bias, the one of us who did not perform the operations (M. A. T.) independently examined thirty-seven patients at the most recent evaluation. Because of scheduling conflicts, the senior one of us evaluated the remaining four patients. Stability and functional data were also available for thirty-seven patients at four months postoperatively. These data were obtained from a larger prospective study in which information was collected preoperatively and at one, two, and four months after the procedure by the senior one of us.

Functional Assessment

The patients categorized their level of activity before the injury, after the injury but before the operation, and two years after the operation. They chose one of four categories. Strenuous activities included sports that required jumping, pivoting, and hard cutting maneuvers, such as football, soccer, and basketball; moderate activities included those that required strenuous manual work, such as skiing, tennis, baseball, and volleyball light activities included those that required light manual work, such as jogging, running, and cycling; and sedentary activities included housework and desk jobs with no participation in sports.

The girth of the thigh five and fifteen centimeters proximal to the superior pole of the patella as well as the extension of the knee were measured on the treated and contralateral sides. The difference between the girth of the thigh of the treated limb and that of the contralateral limb was calculated, and the girth of the thigh of the treated limb was assigned to one of four categories: (1) at least two centimeters greater than that of the contralateral limb, (2) within one centimeter of that of the contralateral limb, (3) two centimeters less than that of the contralateral limb, or (4) more than two centimeters less than that of the contralateral limb. The difference in extension of the knee was also calculated and the extension of the treated knee was assigned to one of three categories: (1) hyperextension equal to that of the contralateral knee, (2) hyperextension not equal to that of the contralateral knee, and (3) extension to 0 degrees.

The patients performed a one-leg-hop for distance test by standing on one limb, hopping as far as possible, and landing on the same limb. The distance was measured and recorded. Alternating between the treated and the contralateral limb, each limb was tested three times. The hop index was the mean distance hopped by the treated limb divided by the mean distance hopped by the contralateral limb, with the result multiplied by 100. A hop index of 8.5 per cent or more was considered normal.

The Lysholm and Gillquist score was used to assess the subjective function of the knee, with the help of the patient. Points were assigned for the level of function within several categories: degree of limp; level of weight-bearing; ability to climb stairs and to squat; degree of atrophy of the thigh; and sensation of instability, pain, or swelling during walking, running, or jumping. The score for a normal knee is 100 points.

The International Knee Documentation Committee form was used to evaluate the function of the knee at the most recent follow-up examination.7 Knees were graded as normal (A), nearly normal (B), abnormal (C), or severely abnormal (D) in seven categories: the patient’s assessment of the function of the knee, symptoms (such as pain, swelling, and giving-way), motion, stability, crepitus in each knee compartment, morbidity at the donor site, and the one-leg-hop for distance test. The lowest grade in any category was used as the final result for that knee. The grade for a normal knee is A.

Assessment of Stability

Three tests were used to evaluate the stability of the reconstructed knee. The result of the Lachman test for the treated knee was graded as having either a firm or a soft end point. The result of the pivot-shift test was assessed by comparison of the degree of rotatory subluxation in the treated knee with that in the contralateral knee. The difference in the KT-1000 displacement values between the treated and the contralateral knee was calculated. Anterior displacement was recorded to the nearest 0.5 millimeter with the knee in 20 to 30 degrees of flexion at two different loads. An eighty-nine-newton load was applied with use of the force handle on the arthrometer, and a maximum manual anterior translation was measured by manual application of a high anterior force to the proximal aspect of the calf just distal to the knee joint line.

Stability was determined with the combined results of the Lachman test, the pivot-shift test, and the arthrometric laxity measurements. A stable knee had three findings: a firm end point, no pivot shift or a subtle pivot glide equal to that of the contralateral knee, and a difference of less than three millimeters between the anterior displacement of the treated knee and that of the contralateral knee during a maximum manual force. An unstable knee had a soft end point, an increased pivot shift compared with that of the contralateral knee, or an increase in anterior displacement of three millimeters or more.

Roentgenographic Assessment

We previously described a measurement technique to determine the percentage of impingement by the intercondylar roof, the location of the central axis of the tibial tunnel, and the slope of the intercondylar roof.11-13 These measurements were performed on a lateral roentgenogram of the fully extended knee, made at the most recent follow-up examination (Fig. 1).

Impingement by the roof was assessed by study of the relationship of the tibial tunnel to the point of intersec-
tion of the line of the slope of the intercondylar roof with the plane of the articular surface of the tibial plateau. The plane of the tibial plateau was defined by a line between the most superior points of the anterior and posterior margins of the proximal end of the tibia. The percentage of impingement by the roof was calculated by measurement of the distance on the line of the tibial plateau from the point where the line of the anterior edge of the tibial tunnel intersected the plateau to the point where the line of the slope of the intercondylar roof intersected the plateau. This distance was then divided by the width of the tibial tunnel, and the result was expressed as a percentage.\textsuperscript{11,13,16}

The location of the central axis of the tibial tunnel was calculated by extension of the line of the central axis of the tibial tunnel to its intersection with the line of the tibial plateau; the distance from this intersection to the anterior end of the line of the tibial plateau was then measured. This distance was divided by the length of the line of the tibial plateau, and the result was expressed as a percentage.\textsuperscript{11,13,16}

The slope of the intercondylar roof was measured as the angle subtended by the line of the slope of the intercondylar roof and the long axis of the femur.\textsuperscript{11,13,16}

Complications

A review of the chart and consultation with the patient at the most recent follow-up examination were used to determine the occurrence of complications. Complications were divided into those associated with procurement of the graft and those related to the intraarticular portion of the operation. The potential morbidity that is associated with procurement of the graft includes wound infection, superficial phlebitis, deep vein thrombosis, loss of sensation in the skin overlying the proximal-lateral aspect of the tibia due to injury to the infrapatellar branch of the saphenous nerve, and weakness during flexion of the knee. The potential morbidity associated with the intraarticular portion of the operation includes infection, arthrofibrosis, prominence of the hardware, and the need for an additional operation.

Operative Technique

The senior one of us previously described the intraarticular, arthroscopically assisted reconstruction of the anterior cruciate ligament with use of a double-looped semitendinosus and gracilis autogenous graft by means of a two-incision technique.\textsuperscript{9}

Briefly, the semitendinosus and gracilis tendons were procured with a tendon-stripper (Acufex Micro-surgical, Norwood, Massachusetts). Retained muscle was removed; and sutures were sewn to each end of each tendon. The midpoint of each tendon was looped over a single suture. The suture was used to pull the four-bundle graft through a series of calibrated cylinders (Arthrotek, Ontario, California). The diameter of the snuggest-fitting cylinder defined the diameter of the four-bundle graft and was used to select the diameter of the cannulated reamer to drill the tibial and femoral tunnels. The four-bundle graft was seven, eight, or nine millimeters in diameter. Four knees (10 per cent) were treated with a seven-millimeter graft; twenty-eight knees (68 per cent), an eight-millimeter graft; and nine knees (22 per cent), a nine-millimeter graft.

Of the thirty-six knees that had not had a previous operation on the medial meniscus, nine had a partial excision of that structure and five had an arthroscopic suture repair; three knees had an incomplete tear that was left alone. Eight of the forty knees that had not had a previous operation on the lateral meniscus had a partial excision of that structure; an incomplete tear was left alone in three other knees.

\textbf{Fig. 1}

The percentage of impingement by the intercondylar roof, the location of the center of the tibial tunnel, and the slope of the intercondylar roof were determined from several landmarks on the lateral roentgenogram of the fully extended knee. The plane of the tibial plateau was defined by line AB. The center of the tibial tunnel (CTT, arrow) bisected the distance from the anterior edge of the tibial tunnel (AETT) to the posterior edge of the tibial tunnel (PETT). The slope of the intercondylar roof was defined as the angle subtended by the line of the slope of the intercondylar roof (IR, dotted line) and the long axis of the femur.
A previously described technique\textsuperscript{6,10,13,14} was used to customize the placement of the tibial tunnel to account for variability in extension of the knee and the slope of the intercondylar roof among the knee\textsuperscript{11} and to avoid impingement by the roof. With use of a guide system (Impingement-Free Tibial Guide System; Arthrotek), the center of the tibial tunnel was positioned four to five millimeters posterior and parallel to the slope of the intercondylar roof with the knee in maximum extension within the posterior half of the insertion of the anterior cruciate ligament. The tibial tunnel was drilled, and bone was removed from the intercondylar roof and wall. Elimination of impingement by the roof was confirmed when a metal rod (Impingement-Free Tibial Guide System), the same diameter as the graft, could be advanced freely through the tibial tunnel into the intercondylar notch with the knee in full extension (Fig. 2). The center of the femoral tunnel was positioned five to seven millimeters distal to the proximal edge of the intercondylar roof, at the eleven o’clock orientation for the right knee or the one o’clock orientation for the left knee, with use of a rear-entry or front-entry femoral guide system (Acufex Microsurgical). The femoral tunnel was drilled through the lateral incision.

In our experience, the fixation method that we used in previous studies\textsuperscript{13-15} did not achieve consistent fixation of the graft directly to bone in approximately 20 per cent of the knees because the gracilis tendon was too short. In the patients in whom this was the case, a suture bridge had to be used to link the short tendon to a fixation post. There were voids between the tapered ends of the tendon and the wall of the bone tunnel. We were concerned that the conversion from mechanical to biological fixation would be protracted if the tunnel was not filled with tendon, and we were reluctant to use this method of fixation in conjunction with intensive rehabilitation.

To satisfy our concerns regarding fixation, we devised a method to anchor short grafts as well as longer grafts consistently without a suture bridge. The length of the graft was conserved by looping the midpoint of each tendon around a fixation post (a 4.0-millimeter-diameter small-fragment cancellous-bone screw; Synthes, Paoli, Pennsylvania) countersunk inside the tibial tunnel. A drilling device (Tibial Fixation Device; Arthrotek) positioned the fixation post twenty millimeters inside the tibial tunnel, as measured from the distal end of the tunnel\textsuperscript{9} (Fig. 3). The smooth section of the screw spanned the bore of the tibial tunnel while the threaded section gained purchase in the cancellous metaphysis and the posterior cortex of the tibia (Fig. 4). The graft was inserted so that the free ends of each tendon extended outside the femoral tunnel while the midpoint of each tendon was looped around the recessed screw. With the knee in full extension, an unmeasured tension was applied manually to the free ends of the tendons exiting the femoral tunnel. The graft was secured to the lateral femoral cortex in thirty-nine knees with one or

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**Fig. 2**
Illustration demonstrating how bone was removed from the wall and roof of the intercondylar notch until a metal rod of the same diameter as the graft could be freely advanced into the notch with the knee in maximum extension. The elimination of impingement by the roof was confirmed before the tendon graft was inserted into the knee.

**Fig. 3**
Illustration demonstrating how a drilling device was inserted into the tibial tunnel to drill a 2.7-millimeter-diameter hole perpendicular to the long axis of the tibia. The drill-hole bisected the cross section of the tibial tunnel and was located twenty millimeters inside the tunnel, as measured from the distal end of the tunnel. This allowed the graft to be fixed within the tibial tunnel, which conserved the length of the graft.
two 6.5-millimeter cancellous-bonescrews and ligament washers (Synthes). In two knees, two soft-tissue staples (Stryker, Kalamazoo, Michigan) were used because the ligament washers were unavailable. Fragments produced by the reaming of the bone were impacted into the tibial tunnel with an impingement rod to fill any voids between the tendon, screw, and tunnel wall.

Rehabilitation Program

The postoperative regimen included application of a soft dressing which was kept on for forty-eight hours; continuous passive motion for the first twenty-four to forty-eight hours after the operation; toe-touch weight-bearing for three weeks followed by walking without crutches after three weeks; unrestricted closed and open-chain knee-extension exercises beginning at four weeks resumption of running in a straight line at eight to ten weeks; and an unrestricted return to sports and work activities at four months. No braces were used.

Analysis of the Data

A paired Student t test was used to compare continuous data at the four-month and two-year follow-up examinations. The Wilcoxon signed-rank test was used when repeated comparisons of ordinal data were required. The Fisher exact test was used when 2 x 2 comparison of nominal data we’re appropriate. To determine the percentage of knees that had improved or worsened between four months and two years, paired differences were calculated for the girth of the thigh, the extension of the knee, and the instrumented laxity measurements.

The interobserver analysis of the instrumented laxity measurements was performed with use of the contralateral knee because its anterior laxity was assumed to remain constant over time. This is in contrast to the anterior laxity of the treated knee, which could have increased over time as a result of remodeling of the graft. A paired Student t test was used to compare the maximum manual anterior translation measured in the contralateral knee by the senior one of us at four months with that measured by the other one of us at two years. The four knees examined by the senior one of us at two years were excluded from this analysis.

Results

Functional Assessment

The level of sports activity was significantly improved by the operation (p = 0.009) but was not restored to the pre-injury level (p = 0.01) (Table II). Thirty-eight (93 percent) of the forty-one patients had returned to either strenuous (twenty-five patients; 61 per cent) or moderate (thirteen patients; 32 per cent) activities by two years after the operation.

With the numbers available, we could detect no significant improvement in the girth of the thigh, as measured either five centimeters (p = 0.20) or fifteen centimeters (p = 0.12) proximal to the superior pole of the patella within two centimeters of each other for thirty-six (97 per cent), and they were within two centimeters of each other for thirty-six (97 per cent) (Fig. 5). The two-year measurement at fifteen centimeters was equal to the four-month measurement for nine (24 per cent) of the thirty-seven treated limbs, was within one centimeter of each other for twenty-nine limbs (78 per cent), and they were within two centimeters of each other for thirty-six (97 per cent) (Table III). The two-year measurement of the girth of the thigh at five centimeters was equal to the four-month measurement for sixteen (45 per cent) of the thirty-seven treated limbs that were examined at both four months and two years. The measurements were within one centimeter of each other for twenty-nine limbs (78 per cent), and they were within two centimeters of each other for thirty-six (97 per cent) (Fig. 5). The two-year measurement at fifteen centimeters was equal to the four-month measurement for nine (24 per cent) of the thirty-seven treated limbs, was within one centimeter of it for twenty-seven (73 per cent); was within two centimeters of it for thirty-eight (81 per cent), and was within three centimeters of it for thirty-five (94 per cent).

By four months, all patients had regained extension of the knee to at least 0 degrees, with thirty-five (95 per cent) of the thirty-seven knees that were examined at both four months and two years having some measure of hyperextension. With the numbers available, there was no significant improvement in extension between four months and two years (p = 0.79) (Table III). The measurement of extension at two years was equal to that at four months for twenty-one knees (57 per cent), was within 3 degrees of it for thirty-three (89 per cent), and was within 6 degrees of it for thirty-six (97 per cent) (Fig. 6). Only twenty-nine of the thirty-seven patients who were seen at both four months and two years completed the one-leg-hop for distance test.

### Table II

**Comparison of Levels of Athletic Participation Before the Injury of the Knee, Preoperatively and Two Years After the Operation.**

<table>
<thead>
<tr>
<th>Level of Activity</th>
<th>Pre-Injury</th>
<th>Preop.</th>
<th>Two Years Postop.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sustained (activities involving jumping, pivoting, and hard cutting, such as football, soccer, and basketball)</td>
<td>32 (78%)</td>
<td>2 (5%)</td>
<td>25 (61%)</td>
</tr>
<tr>
<td>Moderate (activities involving strenuous manual work, such as skiing, tennis, baseball and volleyball)</td>
<td>9 (22%)</td>
<td>9 (22%)</td>
<td>13 (32%)</td>
</tr>
<tr>
<td>Light (activities involving light manual work, such as jogging, running, and cycling)</td>
<td>—</td>
<td>11 (27%)</td>
<td>1 (2%)</td>
</tr>
<tr>
<td>Sedentary (activities such as housework and desk job; no sports)</td>
<td>—</td>
<td>19 (46%)</td>
<td>2 (5%)</td>
</tr>
</tbody>
</table>

*The values are given as the number of patients.
†International Knee Documentation Committee’s categories for level of athletic participation.
‡The level of sports activity was significantly improved by the operation (p = 0.009) but was not restored to the pre-injury level (p = 0.01) (Wilcoxon signed-rank test).
at four months. Eight patients had not regained enough confidence in the treated knee to complete the test. Of the twenty-nine who completed the test, eighteen (62 per cent) achieved a hop index of 85 per cent or more for the treated limb (Table III). The hop index continued to improve significantly between four months and two years ($p = 0.0007$). At two years, thirty-three (85 per cent) of the thirty-nine patients who completed the test had a hop index of 85 per cent or more. The Lysholm and Gillquist score for the treated knee was virtually the same at four months as it was at two years ($p = 0.71$). Thirty-seven (90 per cent) of the forty-one patients gave the treated knee a score of 90 points or more.

With the use of the International Knee Documentation Committee form, twenty-six (63 percent) of the treated knees were rated as normal (A); eleven (27 per cent), as nearly normal (B); and four (10 per cent), as abnormal (C) at the time of the most recent follow-up.

### Table III

<table>
<thead>
<tr>
<th>Variable</th>
<th>4 Mos.*</th>
<th>2 Yrs.*</th>
<th>P Value‡</th>
</tr>
</thead>
<tbody>
<tr>
<td>Girth of thigh§</td>
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<td></td>
<td>0.20</td>
</tr>
<tr>
<td>5 cm proximal to superior pole of patella</td>
<td></td>
<td></td>
<td>0.12</td>
</tr>
<tr>
<td>2 cm greater</td>
<td>4 (10%)</td>
<td>29 (78%)</td>
<td>29 (70%)</td>
</tr>
<tr>
<td>Within 1 cm</td>
<td>29 (78%)</td>
<td>29 (70%)</td>
<td>6 (16%)</td>
</tr>
<tr>
<td>2 cm less</td>
<td>6 (16%)</td>
<td>5 (12%)</td>
<td>&gt;2 cm less</td>
</tr>
<tr>
<td>2 cm greater</td>
<td>0</td>
<td>4 (10%)</td>
<td>22 cm greater</td>
</tr>
<tr>
<td>Within 1 cm</td>
<td>19 (51%)</td>
<td>23 (56%)</td>
<td>2 cm less</td>
</tr>
<tr>
<td>&gt;2 cm less</td>
<td>7 (19%)</td>
<td>7 (17%)</td>
<td>Extension of treated knee</td>
</tr>
<tr>
<td>Hyperextends same as contralateral knee</td>
<td>26 (70%)</td>
<td>28 (68%)</td>
<td>9 (24%)</td>
</tr>
<tr>
<td>Hyperextends but not same as contralateral knee</td>
<td>9 (24%)</td>
<td>11 (27%)</td>
<td>Extends to 0 degrees</td>
</tr>
<tr>
<td>Completed one-leg-hop for distance test</td>
<td>29</td>
<td>39</td>
<td></td>
</tr>
<tr>
<td>Hop index</td>
<td></td>
<td></td>
<td>0.0007</td>
</tr>
<tr>
<td>&gt;105%</td>
<td>0</td>
<td>3 (8%)</td>
<td>100 points</td>
</tr>
<tr>
<td>95-105%</td>
<td>9 (31%)</td>
<td>24 (62%)</td>
<td>95 to 99 points</td>
</tr>
<tr>
<td>85-94%</td>
<td>9 (31%)</td>
<td>6 (15%)</td>
<td>90 to 94 points</td>
</tr>
<tr>
<td>75-84%</td>
<td>4 (14%)</td>
<td>4 (10%)</td>
<td>79 to 89 points</td>
</tr>
<tr>
<td>65-74%</td>
<td>2 (7%)</td>
<td>1 (3%)</td>
<td>Lysholm and Gillquist score</td>
</tr>
<tr>
<td>55-64%</td>
<td>2 (7%)</td>
<td>1 (3%)</td>
<td>100 points</td>
</tr>
<tr>
<td>&lt;55%</td>
<td>3 (10%)</td>
<td>0</td>
<td>95 to 99 points</td>
</tr>
<tr>
<td>90 to 94 points</td>
<td>8 (22%)</td>
<td>9 (22%)</td>
<td>89 to 89 points</td>
</tr>
</tbody>
</table>

*The values are given as the number of patients.
†Four patients did not return for the four-month evaluation.
‡According to the paired Student t test.
§Compared with the contralateral limb.
¶The hop index was the mean distance hopped by the treated limb divided by that hopped by the contralateral limb, with the result multiplied by 100. A hop index of 85 per cent or more was considered normal.

### Assessment of Stability

The interobserver analysis of the instrumented laxity measurements was performed with use of the results of the maximum manual test on the contralateral, uninjured knee. With the numbers available, we could detect no significant difference between the measurements made at four months (by the senior one of us) (average [and standard deviation], 10.4 ± 1.9 millimeters) and those made at two years (by the other one of us) (average [and standard deviation], 10.2 ± 2.1 millimeters) ($p = 0.50$). The anterior laxity measured at two years was equal to that measured at four months for sixteen (43 per cent) of the thirty-seven knees examined at both four months and two years, was within one millimeter for thirty (81 per cent), and was within two millimeters for thirty-four (92 per cent).
Graph of the percentage of thirty-seven knees with a change in the girth of the thigh between four months and two years. A positive difference indicates that the measurement of girth was larger at two years than at four months. A negative difference indicates that the measurement was larger at four months than at two years. The measurements were made at five and fifteen centimeters proximal to the superior pole of the patella. The four-month and two-year measurements made five centimeters were within one centimeter of each other for 78 per cent (twenty-nine) of the knees and those made at fifteen centimeters were within one centimeter of each other for 73 per cent (twenty-seven) of the knees.

Graph of the percentage of thirty-seven knees with a change in extension between four months and two years. A positive difference indicates that more extension was measured at two years than at four months. A negative difference indicates that more extension was measured at four months than at two years. The four-month and two-year measurements were equal for 57 per cent (twenty-one) of the knees, were within 3 degrees of each other for 89 per cent (thirty-three), and were within 6 degrees of each other for 97 per cent (thirty-six).

Graph of the results of the interobserver analysis of the instrumented laxity measurements. The anterior translation measured, with the maximum manual test, in the contralateral knee at four months (by the senior one of us) was compared with that measured at two years (by the other one of us). Measurements were made in the contralateral knee because its anterior laxity was assumed to remain constant over time. A positive difference indicates that more laxity was measured at two years than at four months. A negative difference indicates that more laxity was measured at four months than at two years. The four-month and two-year measurements were identical for 43 per cent (sixteen) of the knees, were within one millimeter of each other for 81 per cent (thirty), and were within two millimeters for 92 per cent (thirty-four).
The anterior laxity measured at two years with the eighty-nine-newton test was equal to that measured at four months for ten (27 per cent) of the treated knees, was within one millimeter of it for thirty-one (84 per cent), and was within two millimeters of it for thirty-five (95 per cent). The anterior laxity measured at two years with the maximum manual test was equal to that measured at four months for twelve (32 per cent) of the treated knees, was within one millimeter of it for twenty-seven (73 per cent), and was within two millimeters of it for thirty-four (92 per cent) (Fig. 8).

At four months, thirty-three (89 per cent) of the thirty-seven treated knees had an absent pivot shift and a firm end point on Lachman testing (Table IV). Three patients who had a bilateral tear of the anterior cruciate ligament were excluded from the analysis of the instrumented laxity measurements. Twenty-eight (82 per cent) of the thirty-four patients in whom the contralateral knee was uninjured had either no increase (two patients) or less than a three-millimeter increase in anterior laxity in the treated knee, as determined by the maximum manual test, and the knees were considered stable. The treated knee in two patients who had a three-millimeter increase in anterior laxity was classified as unstable on the basis of the arthroscopic data, even though they had an absent pivot shift and a firm end point on Lachman testing. The remaining four patients who had an increase in laxity of at least three millimeters, as determined by the maximum manual test, also had a positive pivot shift, and the knees were classified as unstable.

With the numbers available, there was no significant deterioration in the stability of the knee between four months postoperatively, when the patients returned to unrestricted sports and work activities, and two years ($p = 0.23$ to 0.88) (Table IV). At two years, thirty-seven (90 per cent) of the forty-one treated knees had an absent pivot shift and a firm end point on Lachman testing. Thirty-

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**FIG. 8**

Graph of the percentage of thirty-seven knees with a change in anterior laxity between four months and two years. A positive difference indicates that more anterior laxity was measured, with the eighty-nine-newton or maximum manual test, at two years than at four months. A negative difference indicates that more anterior laxity was measured at four months than at two years. The four-month and two-year measurements were identical for 32 per cent (twelve) of the knees, were within one millimeter of each other for 73 per cent (twenty-seven), and were within two millimeters of each other for 92 per cent (thirty-four) when the maximum manual test was used.
Four patients had superficial phlebitis involving the saphenous vein that presented within two weeks after the index operation. Treatment consisted of local application of heat and oral administration of a non-steroidal anti-inflammatory agent. Almost all patients had anesthesia in a several-square-centimeter area of the skin overlying the proximal-lateral aspect of the tibia due to injury of the infrapatellar branch of the saphenous nerve. There were no symptomatic neuromas. One patient had weakness during flexion of the knee. Seven of the forty-one patients had an additional operation: five had removal of all screws and the washer, one had partial excision of the medial meniscus after a failed repair, and one had a lateral release because of pain in the anterior aspect of the knee. No patient needed a manipulation for stiffness. There were no cases of arthrofibrosis or intra-articular infection.

**Discussion**

This study was designed to determine if knees reconstructed with a four-bundle graft, composed of a loop of semitendinosus and gracilis tendon could be safely and effectively rehabilitated without a brace and with the patient returning to vigorous activities four months after the operation. A high rate of instability and poor clinical function at four months would have indicated that the operative technique and rehabilitation program had been poorly designed. An increase in instability between four months and two years would have implied that the composite hamstring graft was not mature enough to tolerate the early return to sports and work activities. An improvement in the functional assessment of the knee between four months and two years would have shown that the rehabilitation ineffectively restored early function to the knee. A high rate of failure at two years would have suggested that a four-bundle hamstring graft was ineffective for replacement of a torn anterior cruciate ligament.

Thirty-seven (90 per cent) of the forty-one treated knees in this study were stable and functional at two years. The knees that were unstable were detected at the four-month follow-up examination.

An analysis of the possible causes for the early failure of the graft in the four patients was not revealing. The rate of failure was higher in the female patients (two of thirteen) than in the male patients (two of twenty-eight); however, because of the low rate of instability, this difference was not significant. The timing of the operation and the condition of the menisci were not implicated; two operations were performed early and the menisci were intact, and two operations were performed later with one meniscus in each knee being partially excised. The operative procedure was consistent; impingement by the roof was avoided in each knee, and there were no intraoperative difficulties. Each patient complied with the postoperative regimen, and none had a reinjury during the rehabilitation phase. Other possible causes for early failure of the graft that were not measured include variability in the preten- sioning of the graft; geometric differences between knees, which may have affected kinematics; and subtle variability in placement of the femoral tunnel, which may have
affected the tension of the graft. We were unable to determine a specific cause for the early instability.

The stability of the treated knees did not deteriorate between four months and two years, implying that the grafts were mature enough at four months to stabilize the knees effectively. Studies in which an autogenous patellar ligament graft was used as a replacement for the anterior cruciate ligament have also shown that stability is not affected by a return to vigorous activities as early as two to six months or four to six months after the reconstruction. Collectively, these studies provide substantial clinical evidence that autogenous graft material used to reconstruct the anterior cruciate ligament in humans is strong and mature enough at four months for the patient to return to sports and work activities safely.

The rate of stability of the knees that had been reconstructed with a double-looped hamstring graft in the present study matched the rate of stability reported in two studies and exceeded that reported in five studies in which an autogenous patellar ligament graft was used to replace the anterior cruciate ligament. Therefore, the double-looped hamstring graft can be used instead of a patellar ligament graft when the goal is an early return to vigorous activities.

The operation involved two principles that may have been important to its success. First, impingement of the graft by the intercondylar roof was avoided, which allowed the knees to regain extension easily without the roof abrading and injuring the graft.

One explanation for the success of the double-looped hamstring graft is that it has superior mechanical properties compared with a ten-millimeter-wide patellar ligament graft. The average diameter of the double-looped hamstring graft in our study was eight millimeters, which provides a circular graft with a cross-sectional area of fifty square millimeters. The patellar ligament graft is 3.5 to 4.0 millimeters thick and rectangular. A ten-millimeter-wide patellar ligament graft has a cross-sectional area of only thirty-five to forty square millimeters. Normal anterior cruciate ligaments are an average of five millimeters thick and ten millimeters wide and have an average cross-sectional area of fifty square millimeters, which is identical to that of the double-looped hamstring graft. The failure strength of the double-looped graft, as calculated from data reported by Noyes et al., is 238 per cent that of the normal anterior cruciate ligament. The failure strength of a ten-millimeter-wide patellar ligament graft is only 138 per cent that of the normal anterior cruciate ligament. The cross-sectional area of the double-looped hamstring graft more closely approximates that of a normal anterior cruciate ligament, and the hamstring graft has a greater margin of strength than the patellar ligament graft. Thus, it is an excellent autogenous graft for reconstruction.

The technique for prevention of impingement by the roof required that the position of the tibial tunnel be customized to account for the variability, among the knees, in the slope of the intercondylar roof and the extension of the knee. The slope of the intercondylar roof in the patients in the present study ranged from 26 to 44 degrees, with the center of the tibial tunnel ranging accordingly from 30 to 54 per cent of the sagittal depth of the tibia. The adequacy of the so-called roofplasty and wallplasty was determined before the graft was implanted by insertion of a metal rod, the same diameter as the graft, through the tibial tunnel and into the intercondylar notch with the knee in maximum extension.

The second principle was that firm fixation should be achieved in every knee by conservation of the length of the graft through fixation of the graft within the tibial tunnel. This technique of countersinking the graft was developed because, in our experience, approximately 20 per cent of the gracilis tendons were too short to be directly fixed to bone outside both tunnels. In the present study, the graft was looped around a fixation post within the tibial tunnel, shifting the point of fixation on the tibia four to five centimeters proximally. In every knee, a long, thick piece of the graft exited the femoral tunnel, allowing firm fixation of the graft directly to the lateral femoral cortex with a cancellous-bone screw and washer.

In summary: the results of this study support the use of a double-looped semitendinosus and gracilis hamstring graft as an alternative to an autogenous patellar ligament graft when intensive rehabilitation of the knee without a brace and a return to sports or work activities four months after the operation are desired.

References


