0363-5465/103/3131-0002$02.00/0
THE AMERICAN JOURNAL OF SPORTS MEDICINE, Vol. 31, No. 1

Arthroscopic Anterior Cruciate Ligament Reconstruction: A Metaanalysis Comparing Patellar Tendon and Hamstring Tendon Autografts

Kevin B. Freedman, MD, MSCE, Michael J. D'Amato, MD, David D. Nedeff, MD, Ari Kaz, MS, and Bernard R. Bach, Jr.,* MD

From the Sports Medicine Section, Department of Orthopaedic Surgery, Rush Medical College, Rush-Presbyterian-St. Luke's Medical Center, Chicago, Illinois

Background: The best choice of graft tissue for use in anterior cruciate ligament reconstruction has been the subject of debate.
Hypothesis: Anterior cruciate ligament reconstruction with patellar tendon autograft leads to greater knee stability than reconstruction with hamstring tendon autograft.
Study Design: Metaanalysis.
Methods: A Medline search identified articles published from January 1966 to May 2000 describing arthroscopic anterior cruciate ligament reconstruction with either patellar tendon or hamstring tendon autograft and with a minimum patient follow-up of 24 months.
Results: There were 1348 patients in the patellar tendon group (21 studies) and 628 patients in the hamstring tendon group (13 studies). The rate of graft failure in the patellar tendon group was significantly lower (1.9% versus 4.9%) and a significantly higher proportion of patients in the patellar tendon group had a side-to-side difference of less than 3 mm on KT-1000 arthrometer testing than in the hamstring tendon group (79% versus 73.8%). There was a higher rate of manipulation under anesthesia or lysis of adhesions (6.3% versus 3.3%) and of anterior knee pain in the patellar tendon group (17.4% versus 11.5%) and a higher incidence of hardware removal in the hamstring tendon group (5.5% versus 3.1%).
Conclusions: Patellar tendon autografts had a significantly lower rate of graft failure and resulted in better static knee stability and increased patient satisfaction compared with hamstring tendon autografts. However, patellar tendon autograft reconstructions resulted in an increased rate of anterior knee pain.

Tears of the ACL have been estimated to occur in 1 in 3000 people in the United States each year.[28] As a result, more than 100,000 ACL reconstructions are performed annually in the United States.[9] Authors of several series of ACL reconstructions have reported good or excellent outcomes in 90% or more of patients.[11,27,32,33] The best choice of graft tissue for use in ACL reconstruction, however, has been the subject of ongoing debate. The majority of reconstructions performed today use either central-third patellar tendon or semitendinosus-gracilis tendon autograft constructs.[21] Proponents of each graft choice make claims of superiority of one over the other, yet there remain little data published to support these claims.

The primary goal of ACL reconstruction is to provide a functionally stable knee. In obtaining this goal, however, the surgeon wishes to minimize the complications of graft harvest to the patient. Disadvantages of central-third patellar tendon grafts include patellofemoral pain, weakness of the quadriceps muscle, possible rupture of the patellar tendon, and patellar fracture.[37] The disadvantages of hamstring tendon autografts include potential hamstring muscle weakness and prominence or pain from the hardware used for fixation. Despite an abundance of literature on ACL reconstruction and its outcome, there are little data directly comparing patellar tendon autograft and hamstring tendon autograft to aid the patient and surgeon in selecting the

* Address correspondence and reprint requests to Bernard R. Bach, Jr., MD, c/o Midwest Orthopaedics, 1725 West Harrison Street, Suite 1063, Chicago, IL 60612.
No author or related institution has received any financial benefit from research in this study.

appropriate graft. There are several published articles describing trials that directly compared patellar tendon and hamstring tendon autografts,[4,11,27,32,33] but each individual study is limited in its ability to make statistically strong conclusions because of limited sample size.

Metaanalysis is a technique to statistically combine or integrate the results of several independent clinical trials to increase statistical power.[12] Metaanalysis is an attractive alternative to assist in answering clinically important questions when a large, expensive, and logistically difficult trial would otherwise be necessary. In the case of graft choice for ACL reconstruction, the technique allows the combination of smaller trials of patellar tendon and hamstring tendon autografts to increase sample size and make statistically valid conclusions.

The purpose of this study was to compare the results of patellar tendon and hamstring tendon autograft constructs used in ACL reconstruction. Specifically, we performed a metaanalysis of the published literature on arthroscopic ACL reconstruction with a minimum of 24 months of follow-up on all patients.

MATERIALS AND METHODS

Identification and Selection of Studies

Before performing our literature search, we established the general protocol for our study. The inclusion criteria for our metaanalysis were use of an arthroscopic ACL reconstruction technique in adult patients and a minimum follow-up of 24 months for each subject. Exclusion criteria were use of an arthrotomy or miniarthrotomy approach, a combined extraarticular or intraarticular augmentation, or surgery on patients with open physes. Studies of more than one technique for ACL reconstruction were included if the data for each technique could be extracted for the analysis. Our intention was to perform a comprehensive review of the results of these studies, including patient demographic data, surgical and rehabilitation protocols, objective and subjective outcome measurements, and complications. An outcome variable was excluded only if the reporting between studies contained such heterogeneity as to preclude meaningful statistical analysis.

Our literature search began with a Medline search of the January 1966 to 1996 and 1997 to 2000 (May) databases. Our search protocol was designed to minimize the possibility of missing a relevant article. We began by searching specific phrase groups as "textwords" throughout the database, such as *ACL, anterior cruciate ligament, reconstruction, patella, hamstring, gracilis,* and *semitendinosus*, to identify all relevant articles.

The results were then limited to human subjects and English language articles only. All resulting articles were then reviewed to determine whether they fit the inclusion or exclusion criteria as previously established. To ensure that no relevant studies were missed by the Medline search, we then performed a manual cross-reference review of the citations of each relevant article to determine whether there were any further studies that might fit our search criteria.

Several studies were excluded for marginal violations of the inclusion criteria, such as the inclusion of data from patients with 23 months or less of follow-up, despite an overall mean follow-up of greater than 24 months. For example, the article by Aglietti et al.[4] was excluded from the analysis because it has a range of follow-up from 22 to 39 months, despite an average follow-up of 28 months.

Data Abstraction

The data were abstracted separately from each included study by two individual reviewers. Any discrepancies in results between the two reviews were corrected through reexamination of the data by the senior author (BRB). We collected demographic data, such as the total number of subjects, the final number of subjects evaluated, sex and mean age of subjects, the mean follow-up interval, and whether any of the patients had had previous knee surgery. The surgical protocols, including surgical approach and femoral and tibial fixation methods, were noted. The rehabilitation protocol, including weightbearing status and postoperative immobilization, the use of continuous passive motion, and the time to return to unrestricted sports activity, was identified in each study. The outcome measurements evaluated from each study included total graft failure, KT-1000 arthrometer (Medmetric Corp., San Diego, California) side-to-side differences in laxity, the results of pivot shift examinations, loss of motion, subjective patient satisfaction, and return to previous level of sports. Complications evaluated in each study included total reoperation rate, lysis of adhesions or manipulation under anesthesia, subsequent meniscectomy or meniscal repair, infection, need for subsequent hardware removal, and anterior knee pain. Additional information was collected from each study when appropriate, such as pre- and postoperative knee scores. However, in many cases, outcome variables (such as knee scores) were collected in such a different manner within each study that it precluded any meaningful combination or analysis.

Appropriateness of Pooling

The studies within each treatment group, patellar tendon autograft or hamstring tendon autograft, were reviewed to determine whether they could be combined. The combination of trials in each treatment arm was based on the premise that the treatment groups were clinically homogeneous in composition; this method has been used previously in several studies.[14,20,29] The similarity among treatment groups was determined by patient inclusion and exclusion criteria, patient age and sex, and follow-up interval. For each outcome event (for example, graft failure), we constructed a contingency table of study by outcome. The purpose of this table was to test whether the proportion of patients experiencing an outcome event varied significantly across studies. For two-level outcomes, the Fisher-Freeman-Halton exact test was used. For three-level outcomes, methods appropriate for a singly ordered R × 3 table were used.

Statistical Analysis

The absolute risk for each outcome event was determined for the patellar tendon autograft (PT) and hamstring tendon autograft (HS) groups. The point estimate of absolute risk was determined by adding the number of events that occurred through all studies and dividing by the number of patients at risk. In any study, if one of the outcomes was not specifically defined, the patients were not considered at risk for that particular outcome and were therefore eliminated from the denominator. A pooled analysis was then performed.

Chi-square testing was performed for all proportions, and the Student's *t*-test was used for all means. The significance level was set at $P < 0.05$. All statistical analysis was performed with Intercooled Stata 5.0 software (Stata Co., College Station, Texas).

RESULTS

Literature Search

A Medline search using textword phrase groups related to ACL reconstruction was performed and yielded 973 articles. This search was then limited to English language articles on human subjects, which yielded 735 articles. These 735 articles represented the pool of studies subjected to our inclusion and exclusion criteria. After thorough review of each article, 21 patellar tendon studies[1,2,5–8,10,11,13,15,17,22,25,27,32–35,40,42,43] and 13 hamstring tendon studies[3,11,18,23,26,27,30–33,38,39,44] met the inclusion criteria for this metaanalysis.

Appropriateness of Pooling

The included trials had similar study populations and inclusion criteria. All patients were athletically active before injury and had a preoperative diagnosis of an ACL-deficient knee that was confirmed intraoperatively. The mean age (25.9 years for the PT group and 25.4 years for the HS group) and mean length of follow-up (46.3 months for the PT group and 34.2 months for the HS group) were similar, with a minimum of 24 months of follow-up for all patients. Meaningful statistical analysis could not be performed on these data because of the method of presentation in the original studies. In addition, the PT group had a significantly higher proportion of male patients (66.8%) than did the HS group (62.1%) ($P = 0.04$).

When the heterogeneity across studies was examined, stratified by PT and HS group, there were several outcomes with significant heterogeneity. These outcomes included graft failure (PT), pivot shift testing (HS), side-to-side laxity (PT and HS), motion loss (PT), manipulation or lysis of adhesions (PT and HS), infection (HS), hardware removal (PT and HS), anterior knee pain (PT and HS), return to previous level of activity (PT and HS), and patient satisfaction (HS). Because of the large degree of heterogeneity across outcomes and the number of studies affected, it was determined that all studies that met the inclusion criteria should be retained in the analysis.

Data Analysis

The summaries of portions of the data abstracted from each individual study are presented in Appendix A1 through A4 for the PT group and in Appendix B1 through B4 for the HS group.

Graft Failure and Postoperative Laxity

There was a significantly lower rate of graft failure in the PT group (1.9%) than in the HS group (4.9%) ($P < 0.001$) (Table 1). There was also a significantly higher proportion of patients in the PT group (79%) with a side-to-side difference of less than 3 mm on KT-1000 arthrometer testing compared with the HS group (73.8%) ($P = 0.017$). There was a higher proportion of patients with a grade 2 or higher pivot shift result in the HS group (4.5%) than in the PT group (3.3%); however, this difference was not statistically significant ($P = 0.126$).

Patient Satisfaction and Return to Sports

The PT group had a higher patient satisfaction rate (95%) than the HS group (87%) ($P < 0.001$). Patient satisfaction was determined by subjective questioning in each study included. Of note, only 10 of the 21 patellar tendon studies and 6 of the 13 hamstring tendon studies included patient satisfaction as an outcome. There was no significant difference in return to previous level of sporting activity between the PT group (67.2%) and the HS group (65.6%) ($P = 0.48$).

Range of Motion

Motion loss was measured as a loss of extension of more than 5° compared with the contralateral limb to standardize across studies (Table 2). The results were similar between the two groups, with 1.9% of patients in the PT

TABLE 1
Graft Failure and Laxity Results of Patellar Tendon and Hamstring Tendon Autografts

Graft source	Graft failure	Pivot shift test results			KT-1000 arthrometer laxity testing		
		Grade 0	Grade 1	>Grade 1	<3 mm[a]	3–5 mm	>5 mm
Patellar tendon	1.9% (25/1318)	82.2% (964/1173)	14.5% (170/1173)	3.3% (39/1173)	79.0% (911/1153)	15.4% (178/1153)	5.6% (64/1153)
Hamstring tendon	4.9% (23/468)	81.8% (256/313)	13.7% (43/313)	4.5% (14/313)	73.8% (415/562)	19.4% (109/562)	6.8% (38/562)

[a] Statistically significant difference between patellar tendon and hamstring tendon groups ($P < 0.05$).

TABLE 2
Comparison of Complications of ACL Reconstructions

Graft source	Motion loss (>5° extension)	Meniscectomy or meniscal repair	MUA[a] or lysis of adhesions	Hardware removal	Anterior knee pain[b]	Infection
Patellar tendon	1.9% (20/1078)	3.0% (37/1226)	6.3% (81/1281)	3.1% (40/1281)	17.4% (169/972)	0.5% (6/1318)
Hamstring tendon	0.7% (3/417)	4.3% (21/487)	3.3% (17/523)	5.5% (27/487)	11.5% (45/390)	0.4% (2/558)

[a] Manipulation under anesthesia.
[b] Statistically significant difference between groups ($P < 0.05$).

group and 0.7% of patients in the HS group ($P = 0.11$) sustaining an extension loss of 5° or more postoperatively.

Complications

The number of patients requiring subsequent meniscal surgery, hardware removal, and lysis of adhesions or manipulation under anesthesia is presented in Table 2. No significant difference was seen between the PT and HS groups in the rate of subjects requiring subsequent meniscal surgery ($P = 0.18$). However, the PT group had a significantly higher rate of subjects requiring lysis of adhesions or manipulation under anesthesia to regain motion after their procedure ($P = 0.009$), and the HS group had a significantly higher rate of hardware removal after the reconstruction procedure ($P = 0.017$). The PT group demonstrated a higher rate of postoperative anterior knee pain than was seen in the HS group ($P = 0.007$). Infection rates between the two groups were not significantly different ($P = 0.77$).

DISCUSSION

The appropriate graft choice for ACL reconstruction remains controversial. There are many clinical studies documenting high success rates with use of both central-third patellar tendon autografts,[1,2,5–8,10,11,13,15,17,22,25,27,32–35,40,42,43] and autologous semitendinosus and gracilis tendon autografts.[3,11,18,23,26,27,30–33,38,39,44] The results of this study confirm that both patellar tendon and hamstring tendon autografts result in a functionally stable knee in more than 95% of patients at a minimum of 24 months of follow-up. However, several significant differences were found when patellar tendon and hamstring tendon autografts were compared, both in terms of knee stability and resulting complications.

Overall, there was a significantly higher rate of graft failure in the HS group (4.9%) than the PT group (1.9%). Laxity was also measured clinically with the KT-1000 arthrometer and with pivot shift testing. The results showed that a significantly higher proportion of patients in the PT group (79%) had a side-to-side difference of less than 3 mm on KT-1000 arthrometer testing, compared with the HS group (73.8%). In addition, when pivot shift testing was evaluated, there was a higher proportion of patients with a grade 2 pivot shift or higher in the HS group (4.5%) than in the PT group (3.3%), although this difference was not statistically significant. These additional objective measures further support the conclusion that patellar tendon autograft may provide a functionally stable knee more often than hamstring tendon autograft.

When complications from each of the graft sources were evaluated, significant differences were found, including the need for subsequent lysis of adhesions or manipulation under anesthesia, the incidence of anterior knee pain, and the need for hardware removal. There was a higher incidence of need for subsequent lysis of adhesions or manipulation under anesthesia in the PT group than in the HS group. Complications associated with the harvest of part of the extensor mechanism may be one reason for this difference between the two groups. Differences in rehabilitation between patients with patellar tendon and with hamstring tendon autografts may also contribute to this difference. We looked for associations among the differences in rehabilitation protocols, the use of continuous passive motion devices, or immobilization techniques and the development of motion loss, but with the format of the data as presented in the studies, no associations or trends were noted.

The incidence of anterior knee pain was higher in the PT group than in the HS group as well. Surgical violation of the extensor mechanism during graft harvest is the most likely explanation for this difference. However, the development of anterior knee pain has been associated with less aggressive rehabilitation methods, the use of open kinetic chain extension exercises, and the development of motion loss.[24,37,41] It will be useful to look at future studies that use current rehabilitation methods to determine whether a lower incidence of anterior knee pain is achieved despite use of patellar tendon autografts.

The HS group more frequently required removal of hardware after ACL reconstruction; the increased incidence of hardware removal most likely reflects the increased use of staples or screw-and-washer constructs on the tibial side to provide soft tissue fixation, as opposed to the use of interference screw fixation with patellar tendon autografts.

Motion loss was not significantly different between the two groups, although a trend was seen for a higher incidence of extension loss in the PT group (1.9%) compared with the HS group (0.7%). The data pool for flexion loss contained too much heterogeneity to allow for meaningful analysis.

Evaluation of the demographics of the two patient groups revealed a similar mean age; however, differences were noted in the mean follow-up period and in the sex ratios between the two groups. The mean follow-up period for the PT group was over 12 months longer than that of the HS group. Because of the data presentation methods used in the articles, statistical analysis of this difference was precluded. However, it should be noted that a longer follow-up period allows for a greater opportunity to develop a complication or a failure. Although the longer follow-up period may have contributed to the increase in anterior knee pain reported in the PT group, it provided further support for the conclusion that a patellar tendon autograft is more likely to result in a functionally stable knee.

There was a statistically significant difference in the sex ratios between the two groups, with a greater percentage of male patients included in the PT group. This difference in sex ratios may have contributed to the increased laxity and graft failure seen in the HS group. There have been several studies of the effect of sex differences in ACL reconstruction, with greater ACL laxity found in women.[11,16,19,36]

There are many strengths of this metaanalysis. A comprehensive literature search was performed to identify eligible studies. In addition, strict inclusion criteria were established, including the requirement of a minimum 24-month follow-up on all patients in all included studies. Ultimately, 30 studies, comprising 1976 patients, were included in this metaanalysis. In addition, several important variables considered in ACL reconstruction, including graft stability, range of motion, return to sports, and complications, were analyzed.

There are several potential limitations of this study. Like all metaanalyses, it is dependent on the scientific validity of the studies that were incorporated in the analysis. During our analysis of the data, we found a wide heterogeneity in the surgical techniques, rehabilitation protocols, and the presentation of results, all of which affect the comparison of patient populations. Despite our strict criteria regarding surgical technique (limiting our analysis to only those series in which arthroscopic techniques were used), a variety of fixation methods were used among both groups (Appendix A-2 and B-2). Although the majority of the patellar tendon studies used interference screw fixation methods, the hamstring tendon studies used a variety of methods, including screw and washers, suture posts, staples, buttons, and interference screws. These differences can affect subsequent laxity measurements as well as complication rates. In addition, among the hamstring tendon studies, a variety of tissue constructs were used. Some used a combination of semitendinosus and gracilis tendons, while others used the semitendinosus tendon alone. Various combinations of doubling, tripling, or quadrupling the tendons were also used. These differences could have contributed to the results and affected our ability to combine the studies.

When the heterogeneity across studies was analyzed statistically, there were significant differences found within each study group for many of the outcomes evaluated. For example, a closer examination of each individual study can be performed for the rate of hardware removal for each group, which exhibited significant heterogeneity ($P < 0.0001$). The rate of hardware removal in the HS group ranged from 29% (8 of 28 patients)[39] to 0% (0 of 69 patients)[3] ($P = 0.0001$). Similarly, for the PT group, the rate of hardware removal ranged from 31% (8 of 26 patients)[25] to 0% (0 of 103)[7] ($P = 0.0004$). Rather than exclude studies with data points at the extreme for each outcome, it seemed more appropriate to retain these data for the analysis. By including all studies, the data were a more appropriate reflection of the overall results in the literature. This inclusion increased the variability in the analysis but decreased any bias that may have occurred from deleting studies. However, there may be clinical reasons for this heterogeneity, including unrecognized differences in the patient populations, surgical techniques, fixation methods, or rehabilitation protocols. This heterogeneity across studies for many outcomes illustrates the limitations of combining studies in the form of a metaanalysis and the value of performing a large cohort study that can stratify patients by risk factors.

The variations in rehabilitation techniques may have also affected the results. Recent advances in rehabilitation techniques have led to findings that early, aggressive rehabilitation protocols are both safe and decrease the rate of complications such as motion loss, the development of arthrofibrosis, and even the development of anterior knee pain.[41]

The heterogeneity in the reporting of data resulted in our inability to analyze several variables, including loss of knee flexion, knee scores, and functional testing. Many articles failed to list the individual data of their subjects, instead presenting only the combined results. This limited our ability to look for associations among certain outcome variables. It also serves to highlight the importance of developing standardized data presentation methods in the future. Fortunately, we were able to analyze several important outcome variables, including laxity, pivot shift test results, loss of extension, subjective patient satisfaction, return to previous level of activity, subsequent surgery, and several complications.

Another metaanalysis comparing patellar tendon and hamstring tendon autografts used in ACL reconstruction was recently published.[45] This study included only trials that directly compared patellar tendon and hamstring tendon autografts within the same study.[4,11,27,32] There is a significant advantage, in theory, to using only randomized clinical trials that compare the two techniques directly. The randomization process is designed to equally distribute all other factors related to the outcome of ACL reconstruction, other than graft selection. This process improves the ability to combine studies in a metaanalysis, since it is hoped that these other factors will remain randomized between study groups. However, three of the four studies were not completely *randomized* control trials because two were performed by alternating sequence[4,27] and one was performed by consecutive series.[11] Therefore, the advantage of using only clinical trials that directly compare patellar and hamstring tendon autografts was compromised. For this reason, in this metaanalysis we included any clinical study in which an arthroscopic technique for ACL reconstruction was performed with a minimum of 24 months of follow-up. In addition, our results are consistent with those of the metaanalysis of Yunes et al.,[45] which found that patellar tendon autografts led to greater static stability than hamstring tendon reconstructions.

SUMMARY

Patellar tendon ACL reconstructions tend to show modest advantages in providing improved static stability, with lower rates of graft failure and improved patient satisfaction, compared with hamstring tendon autografts. However, this increased stability may come at the cost of greater complication rates, including a higher rate of motion problems requiring surgical intervention and an increased likelihood of anterior knee pain. Overall, both graft sources appeared to provide excellent return of function at a high rate of success. The absolute difference in graft failure between the two groups was 3% (1.9% in the PT group and 4.9% in the HS group). A future randomized control trial designed to detect this difference would require nearly 1200 total patients. The feasibility of such a study, even on a multicenter level, is questionable. In addition, constant improvements in surgical fixation and rehabilitation techniques may make the differences between graft choices even less apparent.

REFERENCES

1. Aglietti P, Buzzi R, D'Andria S, et al: Arthroscopic anterior cruciate ligament reconstruction with patellar tendon. *Arthroscopy 8:* 510–516, 1992
2. Aglietti P, Buzzi R, Giron F, et al: Arthroscopic-assisted anterior cruciate ligament reconstruction with central third patellar tendon. A 5–8-year follow-up. *Knee Surg Sports Traumatol Arthrosc 5:* 138–144, 1997
3. Aglietti P, Buzzi R, Menchetti PPM, et al: Arthroscopically assisted semitendinosus and gracilis tendon graft in reconstruction for acute anterior cruciate ligament injuries in athletes. *Am J Sports Med 24:* 726–731, 1996
4. Aglietti P, Buzzi R, Zaccherotti G, et al: Patellar tendon versus doubled semitendinosus and gracilis tendons for anterior cruciate ligament reconstruction. *Am J Sports Med 22:* 211–218, 1994
5. Arciero RA, Scoville CR, Snyder RJ, et al: Single versus two-incision arthroscopic anterior cruciate ligament reconstruction. *Arthroscopy 12:* 462–469, 1996
6. Bach BR Jr, Jones GT, Sweet FA, et al: Arthroscopy-assisted anterior cruciate ligament reconstruction using patellar tendon substitute: Two- to four-year follow-up results. *Am J Sports Med 22:* 758–767, 1994
7. Bach BR Jr, Levy ME, Bojchuk J, et al: Single-incision endoscopic anterior cruciate ligament reconstruction using patellar tendon autograft. Minimum two-year follow-up evaluation. *Am J Sports Med 26:* 30–40, 1998
8. Bach BR Jr, Tradonsky S, Bojchuk J, et al: Arthroscopically assisted anterior cruciate ligament reconstruction using patellar tendon autograft. Five- to nine-year follow-up evaluation. *Am J Sports Med 26:* 20–29, 1998
9. Brown CH Jr, Carson EW: Revision anterior cruciate ligament surgery. *Clin Sports Med 18:* 109–171, 1999
10. Buss DD, Warren RF, Wickiewicz TL, et al: Arthroscopically assisted reconstruction of the anterior cruciate ligament with use of autogenous patellar-ligament grafts. Results after twenty-four to forty-two months. *J Bone Joint Surg 75A:* 1346–1355, 1993
11. Corry IS, Webb JM, Clingeleffer AJ, et al: Arthroscopic reconstruction of the anterior cruciate ligament: A comparison of patellar tendon autograft and four-strand hamstring tendon autograft. *Am J Sports Med 27:* 444–454, 1999
12. DerSimonian R, Laird N: Meta-analysis in clinical trials. *Control Clin Trials 7:* 177–188, 1986
13. Engebretsen L, Benum P, Fasting O, et al: A prospective, randomized study of three surgical techniques for treatment of acute ruptures of the anterior cruciate ligament. *Am J Sports Med 18:* 585–590, 1990
14. Freedman KB, Brookenthal KR, Fitzgerald RH, et al: A meta-analysis of thromboembolic prophylaxis following elective total hip arthroplasty. *J Bone Joint Surg 82A:* 929–938, 2000
15. Grontvedt T, Engebretsen L, Bredland T: Arthroscopic reconstruction of the anterior cruciate ligament using bone-patellar tendon-bone grafts with and without augmentation. A prospective randomised study. *J Bone Joint Surg 78B:* 817–822, 1996
16. Harmon KG, Ireland ML: Gender differences in noncontact anterior cruciate ligament injuries. *Clin Sports Med 19:* 287–302, 2000
17. Heier KA, Mack DR, Moseley JB, et al: An analysis of anterior cruciate ligament reconstruction in middle-aged patients. *Am J Sports Med 25:* 527–532, 1997
18. Howell SM, Taylor MA: Brace-free rehabilitation, with early return to activity, for knees reconstructed with a double-looped semitendinosus and gracilis graft. *J Bone Joint Surg 78A:* 814–825, 1996
19. Huston LJ, Wojtys EM: Neuromuscular performance characteristics in elite female athletes. *Am J Sports Med 24:* 427–436, 1996
20. Imperiale TF, Speroff T: A meta-analysis of methods to prevent venous thromboembolism following total hip replacement. *JAMA 271:* 1780–1785, 1994
21. Johnson RJ, Beynnon BD, Nichols CE: The treatment of injuries of the anterior cruciate ligament [current concepts review]. *J Bone Joint Surg 74A:* 140–151, 1992
22. Jomha NM, Pinczewski LA, Clingeleffer A, et al: Arthroscopic reconstruction of the anterior cruciate ligament with patellar-tendon autograft and interference screw fixation. The results at seven years. *J Bone Joint Surg 81B:* 775–779, 1999
23. Karlson JA, Steiner ME, Brown CH, et al: Anterior cruciate ligament reconstruction using gracilis and semitendinosus tendons. Comparison of through-the-condyle and over-the-top graft placements. *Am J Sports Med 22:* 659–666, 1994
24. Kartus J, Magnusson L, Stener S, et al: Complications following arthroscopic anterior cruciate ligament reconstruction. A 2–5-year follow-up of 604 patients with special emphasis on anterior knee pain. *Knee Surg Sports Traumatol Arthrosc 7:* 2–8, 1999
25. Kleipool AEB, Zijl JAC, Willems WJ: Arthroscopic anterior cruciate ligament reconstruction with bone-patellar tendon-bone allograft or autograft. A prospective study with an average follow up of 4 years. *Knee Surg Sports Traumatol Arthrosc 6:* 224–230, 1998
26. Maeda A, Shino K, Horibe S, et al: Anterior cruciate ligament reconstruction with multistranded autogenous semitendinosus tendon. *Am J Sports Med 24:* 504–509, 1996
27. Marder RA, Raskind JR, Carroll M: Prospective evaluation of arthroscopically assisted anterior cruciate ligament reconstruction: Patellar tendon versus semitendinosus and gracilis tendons. *Am J Sports Med 19:* 478–484, 1991
28. Miyasaka KC, Daniel DM, Stone ML, et al: The incidence of knee ligament injuries in the general population. *Am J Knee Surg 4:* 3–8, 1991
29. Mohr DN, Silverstein MD, Murtaugh PA, et al: Prophylactic agents for venous thrombosis in elective hip surgery. Meta-analysis of studies using venographic assessment. *Arch Intern Med 153:* 2221–2228, 1993
30. Muneta T, Sekiya I, Yagishita K, et al: Two-bundle reconstruction of the anterior cruciate ligament using semitendinosus tendon with Endobuttons: Operative technique and preliminary results. *Arthroscopy 15:* 618–624, 1999
31. Nebelung W, Becker R, Merkel M, et al: Bone tunnel enlargement after anterior cruciate ligament reconstruction with semitendinosus tendon using Endobutton fixation on the femoral side. *Arthroscopy 14:* 810–815, 1998
32. O'Neill DB: Arthroscopically assisted reconstruction of the anterior cruciate ligament: A prospective randomized analysis of three techniques. *J Bone Joint Surg 78A:* 803–813, 1996
33. Otero AL, Hutcheson L: A comparison of the doubled semitendinosus/gracilis and central third of the patellar tendon autografts in arthroscopic anterior cruciate ligament reconstruction. *Arthroscopy 9:* 143–148, 1993
34. Otto D, Pinczewski LA, Clingeleffer A, et al: Five-year results of single-incision arthroscopic anterior cruciate ligament reconstruction with patellar tendon autograft. *Am J Sports Med 26:* 181–188, 1998
35. Patel JV, Church JS, Hall AJ: Central third bone-patellar tendon-bone anterior cruciate ligament reconstruction: A 5-year follow-up. *Arthroscopy 16:* 67–70, 2000
36. Rozzi SL, Lephart SM, Gear WS, et al: Knee joint laxity and neuromuscular characteristics of male and female soccer and basketball players. *Am J Sports Med 27:* 312–319, 1999
37. Sachs RA, Daniel DM, Stone ML, et al: Patellofemoral problems after anterior cruciate ligament reconstruction. *Am J Sports Med 17:* 760–765, 1989
38. Sgaglione NA, Del Pizzo W, Fox JM, et al: Arthroscopically assisted anterior cruciate ligament reconstruction with the pes anserine tendons: Comparison of results in acute and chronic ligament deficiency. *Am J Sports Med 21:* 249–256, 1993
39. Sgaglione NA, Del Pizzo W, Fox JM, et al: Arthroscopic-assisted anterior cruciate ligament reconstruction with the semitendinosus tendon: Comparison of results with and without braided polypropylene augmentation. *Arthroscopy 8:* 65–77, 1992

40. Sgaglione NA, Schwartz RE: Arthroscopically assisted reconstruction of the anterior cruciate ligament: Initial clinical experience and minimal 2-year follow-up comparing endoscopic transtibial and two-incision techniques. *Arthroscopy 13:* 156–165, 1997
41. Shelbourne KD, Nitz P: Accelerated rehabilitation after anterior cruciate ligament reconstruction. *Am J Sports Med 18:* 292–299, 1990
42. Shelton WR, Papendick L, Dukes AD: Autograft versus allograft anterior cruciate ligament reconstruction. *Arthroscopy 13:* 446–449, 1997
43. Webb JM, Corry IS, Clingeleffer AJ, et al: Endoscopic reconstruction for isolated anterior cruciate ligament rupture. *J Bone Joint Surg 80B:* 288–294, 1998
44. Yasuda K, Tsujino J, Tanabe Y, et al: Effects of initial graft tension on clinical outcome after anterior cruciate ligament reconstruction. Autogenous doubled hamstring tendons connected in series with polyester tapes. *Am J Sports Med 25:* 99–106, 1997
45. Yunes M, Richmond JC, Engels EA, et al: Patellar versus hamstring tendons in anterior cruciate ligament reconstruction: A meta-analysis. *Arthroscopy 17:* 248–257, 2001

APPENDIX A1
Demographic Information on Patients Included in the Patellar Tendon Group

Author and year published	Total number of patients	Number of patients evaluated	Effective follow-up (%)	Mean age at surgery (years)	Mean follow-up (months)	Percentage of patients that are male
Engebretsen et al.[13] 1990	50	50	100	29	24	58
Marder et al.[27] 1991	40	37	93	22	29	65
Aglietti et al.[1] 1992	73	69	95	23	96	77
Buss et al.[10] 1993	69	67	97	24	32	66
Otero and Hutcheson[33] 1993	N/A[a]	55	N/A	26	36	76
Bach et al.[6] 1994	75	62	83	27	37	71
Arciero et al.[5] 1996	82	82	100	20	31	88
Grondvedt et al.[15] 1996	51	47	92	26	24	45
O'Neill[32] 1996	87	85	98	27	44	64
Aglietti et al.[2] 1997	101	89	88	23	84	81
Heier et al.[17] 1997	53	45	85	45	37	38
Sgaglione and Schwartz[40] 1997	90	86	96	25	36	73
Shelton et al.[42] 1997	30	30	100	25	24	53
Bach et al.[7] 1998	128	103	81	25	26	63
Bach et al.[8] 1998	147	97	66	26	79	74
Kleipool et al.[25] 1998	29	26	90	28	52	35
Otto et al.[34] 1998	80	68	85	27	60	72
Webb et al.[43] 1998	90	82	91	25	24	53
Jomha et al.[22] 1999	80	59	74	26	84	73
Corry et al.[11] 1999	90	82	91	25	24	53
Patel et al.[35] 2000	44	32	73	33	70	75

[a] Data not available.

APPENDIX A2
Surgical Protocol for the Patellar Tendon Group

Author and year published	Technique	Femoral graft fixation	Tibial graft fixation
Engebretsen et al.[13] 1990	Single incision	IS[a] and screw and washer	Staples or IS & screw and washer
Marder et al.[27] 1991	Double incision	Screw and washer	Screw and washer
Aglietti et al.[1] 1992	Double incision	Ligament button	IS and ligament button
Buss et al.[10] 1993	Double incision	Ligament button	IS and ligament button
Otero and Hutcheson[33] 1993	Double incision	IS	IS
Bach et al.[6] 1994	Double incision	IS	IS
Arciero et al.[5] 1996	Both	IS	IS
Grondvedt et al.[15] 1996	Double incision	IS	IS
O'Neill[32] 1996	Both	IS	IS
Aglietti et al.[2] 1997	Double incision	Ligament button	IS and ligament button
Heier et al.[17] 1997	Double incision	Screw and washer	Screw and washer
Sgaglione and Schwartz[40] 1997	Both	IS	IS
Shelton et al.[42] 1997	Single incision	IS	IS
Bach et al.[7] 1998	Single incision	IS	IS
Bach et al.[8] 1998	Double incision	IS	IS
Kleipool et al.[25] 1998	Single incision	IS	IS
Otto et al.[34] 1998	Single incision	IS	IS
Webb et al.[43] 1998	Single incision	IS	IS
Jomha et al.[22] 1999	Single incision	IS	IS
Corry et al.[11] 1999	Single incision	IS	IS
Patel et al.[35] 2000	Single incision	IS	IS

[a] Interference screw.

APPENDIX A3
Results of Postoperative Laxity Testing for the Patellar Tendon Group

Author and year published	KT-1000 arthrometer side-to-side difference (% of patients)			Pivot shift grade (% of patients)			
	<3 mm	3–5 mm	>5 mm	0	1+	2+	3+ or 4+
Engebretsen et al.[13] 1990	79	21	0	89	11	0	0
Marder et al.[27] 1991	86	14	0	78	16	6	2
Aglietti et al.[1] 1992	56	32	12	87	10	3	0
Buss et al.[10] 1993	84	16	0	89	3	8	0
Otero and Hutcheson[33] 1993	N/A[a]	N/A	N/A	N/A	N/A	N/A	N/A
Bach et al.[6] 1994	92	4	4	92	5	3	0
Arciero et al.[5] 1996	70	22	8	74	22	4	0
Grondvedt et al.[15] 1996	98	2	0	68	32	0	0
O'Neill[32] 1996	89	7	4	N/A	N/A	N/A	N/A
Aglietti et al.[2] 1997	48	38	13	70	19	11	0
Heier et al.[17] 1997	78	10	12	36	47	15	2
Sgaglione and Schwartz[40] 1997	77	16	7	91	6	3	0
Shelton et al.[42] 1997	72	23	5	87	13	0	0
Bach et al.[7] 1998	83	14	3	91	9	0	0
Bach et al.[8] 1998	70	26	4	84	16	0	0
Kleipool et al.[25] 1998	73	21	6	76	18	6	0
Otto et al.[34] 1998	N/A	N/A	N/A	65	34	1	0
Webb et al.[43] 1998	90	7	3	91	9	0	0
Jomha et al.[22] 1999	65	33	2	76	22	2	0
Corry et al.[11] 1999	91	1	8	91	9	0	0
Patel et al.[35] 2000	88	12	0	91	N/A[b]	N/A	N/A

[a] Data not available.
[b] 9% of patients tested were reported as positive.

APPENDIX A4
Postoperative Knee Scores for the Patellar Tendon Group

Author and year published	Tegner[a]	Lysholm (mean)	Noyes (mean)	HSS[b] (mean)	IKDC[c] (%)
Engebretsen et al.[13] 1990		94			
Marder et al.[27] 1991					
Aglietti et al.[1] 1992					
Buss et al.[10] 1993				88	
Otero and Hutcheson[33] 1993		85			
Bach et al.[6] 1994	7.6/2.1/6.3	88	86	88	
Arciero et al.[5] 1996		90			85
Grondvedt et al.[15] 1996		96			
O'Neill[32] 1996		92%>90			92
Aglietti et al.[2] 1997					77
Heier et al.[17] 1997		91			64
Sgaglione and Schwartz[40] 1997					94
Shelton et al.[42] 1997					
Bach et al.[7] 1998	7.3/3.5/6.5	90	88	90	
Bach et al.[8] 1998	7.1/3.5/6.3	87	87	89	
Kleipool et al.[25] 1998	8/3/6	95			70
Otto et al.[34] 1998		91			80
Webb et al.[43] 1998		93			86
Jomha et al.[22] 1999		94			76
Corry et al.[11] 1999					80
Patel et al.[35] 2000	6.3/3.1/5.1	89			

[a] Results given as preinjury/preoperative/postoperative.
[b] Hospital for Special Surgery.
[c] International Knee Documentation Committee.

APPENDIX B1
Demographic Information on Patients Included in the Hamstring Tendon Group

Author and year published	Total number of patients	Number of patients evaluated	Effective follow-up (%)	Mean age at surgery (years)	Mean follow-up (months)	Percentage of patients that are male
Marder et al.[27] 1991	40	35	88	24	32	74
Sgaglione et al.[39] 1992	29	28	97	25	34	71
Sgaglione et al.[38] 1993	51	50	98	24	37	74
Otero and Hutcheson[33] 1993	N/A[a]	36	N/A	25	36	81
Karlson et al.[23] 1994	87	64	74	28	34	66
Howell and Taylor[18] 1996	49	41	84	33	26	68
Maeda et al.[26] 1996	42	41	98	24	27	54
Aglietti et al.[3] 1996	77	69	90	23	60	63
O'Neill[32] 1996	40	40	100	27	38	68
Yasuda et al.[44] 1997	70	64	91	24	30	52
Nebelung et al.[31] 1998	34	29	85	N/A	N/A	76
Corry et al.[11] 1999	90	85	94	25	24	52
Muneta et al.[30] 1999	62	54	87	24	27	39

[a] Data not available.

APPENDIX B2
Surgical Protocol for the Hamstring Tendon Group

Author and year published	Technique	Graft construct[a]	Femoral graft fixation	Tibial graft fixation
Marder et al.[27] 1991	Double incision	Doubled ST/G	Screw/washer	Screw/washer
Sgaglione et al.[39] 1992	Double incision	Doubled ST or single ST/G	Staples ×2 or screw/washer	Staples ×2 or screw washer
Sgaglione et al.[38] 1993	Double incision	Doubled ST or single ST/G	N/A[b]	N/A
Otero and Hutcheson[33] 1993	Double incision	Doubled ST/G	Suture post	Screw/washer
Karlson et al.[23] 1994	Double incision	Single ST/G	Screw/washer ×2	Screw/washer
Howell and Taylor[18] 1996	Double incision	Doubled ST/G	Screw/washer or staples	Screw/washer or staples
Maeda et al.[26] 1996	Double incision	Multiple combinations of ST/G	Buttons or suture post	Buttons or suture post
Aglietti et al.[3] 1996	Double incision	Single ST/G	Spiked staples ×2	N/A
O'Neill[32] 1996	Double incision	Single ST/G	Spiked staples ×2	Spiked staples ×2
Yasuda et al.[44] 1997	Double incision	Doubled ST/G	Spiked staples ×2	Spiked staples ×2
Nebelung et al.[31] 1998	Single incision	Doubled ST	Endobutton	Staples ×2
Corry et al.[11] 1999	Double incision	Doubled ST/G	Interference screw	Interference screw
Muneta et al.[30] 1999	Single incision	Multistrand ST or Multistrand ST/G	Acufex button or Endobutton	Suture post

[a] ST, semitendinosus tendon; G, gracilis tendon.
[b] Data not available.

APPENDIX B3
Results of Postoperative Laxity Testing for the Hamstring Tendon Group

Author and year published	KT-1000 arthrometer side-to-side difference (% of patients)			Pivot shift grade (% of patients)			
	<3 mm	3–5 mm	>5 mm	0	1+	2+	3+
Marder et al.[27] 1991	74	N/A[a]	N/A	69	14	11	6
Sgaglione et al.[39] 1992	61	21	18	82	14	4	0
Sgaglione et al.[38] 1993	71	16	13	88	8	4	0
Otero and Hutcheson[33] 1993	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Karlson et al.[23] 1994	66	25	9	N/A	N/A	N/A	N/A
Howell and Taylor[18] 1996	89	3	8	90	N/A[b]	N/A	N/A
Maeda et al.[26] 1996	73	17	10	N/A	N/A	N/A	N/A
Aglietti et al.[3] 1996	51	39	10	86	9	1	4
O'Neill[32] 1996	83	10	7	N/A	N/A	N/A	N/A
Yasuda et al.[44] 1997	75	22	3	N/A	N/A	N/A	N/A
Nebelung et al.[31] 1998	55	35	10	N/A	N/A	N/A	N/A
Corry et al.[11] 1999	79	15	6	82	18	0	0
Muneta et al.[30] 1999	81	15	4	80	18	2	0

[a] Data not available.
[b] 39 of 41 patients reported as positive.

APPENDIX B4
Postoperative Knee Scores for the Hamstring Tendon Group

Author and year published	Tegner[a] (mean)	Lysholm (mean)	Noyes (mean)	HSS[b] (mean)	IKDC[c] (%)
Marder et al.[27] 1991					
Sgaglione et al.[39] 1992	6.0/2.0/5.3	87		89	
Sgaglione et al.[38] 1993	6.3/2.0/5.4	90		90	
Otero and Hutcheson[33] 1993		88			
Karlson et al.[23] 1994		92	92	90	75
Howell and Taylor[18] 1996		90%>90			90
Maeda et al.[26] 1996					
Aglietti et al.[3] 1996					86
O'Neill[32] 1996		88%>90			88
Yasuda et al.[44] 1997					
Nebelung et al.[31] 1998	NA/NA/5.7				66
Corry et al.[11] 1999		86%>84			89
Muneta et al.[30] 1999		95			

[a] Results given as preinjury/preoperative/postoperative.
[b] Hospital for Special Surgery.
[c] International Knee Documentation Committee.