0363-5465/93/2105-0738$02.00/0
THE AMERICAN JOURNAL OF SPORTS MEDICINE, Vol. 21, No. 5

Quadriceps strength and functional capacity after anterior cruciate ligament reconstruction

Patellar tendon autograft versus allograft*

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ABSTRACT

Harvesting the central third of the patellar tendon for autograft anterior cruciate ligament reconstruction is thought to compromise quadriceps strength and functional capacity. We compared objective measurements of quadriceps strength and functional capacity in athletes after patellar tendon autograft or allograft anterior cruciate ligament reconstruction. We looked at 33 active male patients (mean age, 24.3 years) who had anterior cruciate ligament reconstructions 12 to 24 months earlier using patellar tendon autograft ($N = 15$) or allograft ($N = 18$) techniques. All patients underwent an intensive rehabilitation program. Quadriceps strength and power were assessed by measuring peak torque at 60 and 240 deg/sec, torque acceleration energy at 240 deg/sec, and the quadriceps index using a Cybex II isokinetic testing device. Functional capacity was evaluated based on the results of 3 specially designed functional performance tests and the hop test. Results revealed no significant difference between autograft and allograft groups with respect to any of these parameters. These findings indicate that harvesting the central third of the patellar tendon for autograft anterior cruciate ligament reconstruction does not diminish quadriceps strength or functional capacity in highly active patients who have intensive rehabilitation. Thus, the recommendation to avoid patellar tendon autograft anterior cruciate ligament reconstruction to preserve quadriceps strength and functional capacity may be unnecessary.

Disruption of the ACL is a common injury that can lead to significant functional impairment. The treatment of complete ACL ruptures remains controversial. Because of the poor outcome associated with the untreated ACL-deficient knee[18,19,37] and the primarily repaired knee,[8,14,43] ACL reconstruction has become the treatment of choice in the active patient. The goal of ACL reconstruction is to restore functional capacity by effectively approximating the complex structure and function of the normal ACL. Graft options for ACL reconstruction include autogenous tissue, allogenic tissue, and synthetic materials. The choice of reconstructive procedure depends on the inherent advantages and disadvantages of the technique and the functional demands of the patient.

The bone-patellar tendon-bone autograft technique pioneered by Campbell[9] and Jones[28] is the most common procedure for ACL reconstruction (J. Campbell, et al., unpublished data). Long-term follow-up studies of this technique generally have revealed good results in terms of objective clinical measures and subjective assessment scores.[20,26,27,38,44] Advantages of the patellar tendon autograft include its high tensile strength,[7,36] ability to revascularize,[1,2] and bony plug insertions.[15] The morbidity reportedly associated with patellar tendon harvesting includes patellar fracture,[32] patellar tendinitis,[31] patellar tendon rupture,[4] quadriceps tendon rupture,[13] patellofemoral dysfunction,[16,22,41] flexion contracture,[16,39,41] and diminished structural properties of the remaining patellar tendon.[6]

Allogenic material has been used successfully for ACL

* Presented at the annual meeting of the AOSSM, Orlando, Florida, July, 1991.
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reconstruction in animal studies where researchers used patellar tendon,[3,46] fascia lata,[10] or ACL.[24,34] Clinical results of allograft reconstruction also have been encouraging.[23,35,45] Patellar tendon allografts share the mechanical advantages of the patellar tendon autograft and have a more abundant supply of tissue, require less operative time, have superior cosmetic results, and avoid the morbidity associated with autograft harvesting. Disadvantages of allograft ACL reconstruction include the possibility of disease transmission[5] and stimulation of an immune response.[40]

Because patellar tendon autograft harvesting disrupts the extensor mechanism, deficits in quadriceps strength and functional status are thought to be associated with this procedure[6,21,41,48] and are cited as reasons to prefer patellar tendon allograft reconstruction in active persons.[25,33,45,49] The purpose of this study was to determine, retrospectively, if harvesting the central third of the patellar tendon for ACL reconstruction compromises quadriceps strength and functional capacity of the knee in athletes. Specifically, our aim was to objectively compare quadriceps strength and functional capacity of athletes after patellar tendon autograft or allograft ACL reconstruction.

MATERIALS AND METHODS

Subjects

Thirty-three active (mean actual Tegner score, 7.4) male patients (mean age, 24.3 years) who had their ACL reconstructed 12 to 24 months (mean, 18.6) earlier participated in this study. Fifteen subjects had undergone patellar tendon autograft reconstruction and 18 subjects had undergone patellar tendon allograft reconstruction. There was no significant difference between groups relative to their age or the length of followup. One of the criteria for inclusion in this study was the absence of significant (i.e., grade III) injury to either the medial or lateral collateral ligaments. Meniscal injuries varied in each group and treatment ranged from partial meniscectomy to meniscal repair. The distribution of meniscal injuries was similar in each group. Preoperative flexion weightbearing views and intraoperative assessment of articular cartilage were available for each patient and no significant articular cartilage damage was noted at the time of surgery. No subsequent surgical procedures had been performed on any subjects at the time this study was conducted. Operative procedures were performed by one of two surgeons (FHF or CDH). They used essentially the same arthroscopically assisted technique. A two-incision technique was used and the patellar tendon allograft or autograft was secured using a standard interference screw technique on both the femur and tibia. The lateral thigh incision was approximately 3 to 5 cm long in all patients, but the tibial incision varied depending on graft selection. In the allograft patients, the tibial incision ranged from 3 to 5 cm in length, and in the autograft population, it was between 8 and 14 cm in length. In both groups, the central third portion of the patellar tendon, along with its bone blocks, was harvested, and grafts ranged from 10 to 11 mm in width. Both of the surgeons tried to place the grafts in the center of the insertion sites on both the femur and tibia. Tunnels were drilled to equal size of the grafts harvested and ranged from 10 to 11 mm in size. Standard precautions were taken during drilling, preparation of the tunnels, and notchplasty. The peritenon was closed in the autograft group using 0 Vicryl suture. The central third defect of the tendon was not closed, rather the peritenon was approximated.

Postoperatively, all subjects underwent a rehabilitation protocol at the same institution. The protocol emphasized strength and functional training. It consisted of use of a range of motion brace from 0° to 90° for the first 6 weeks, partial weightbearing during Weeks 6 to 12, full weightbearing as tolerated from the 8th week, running beginning at 6 months, and return to sports at 8 months.

Quadriceps strength and power

Quadriceps strength and power were assessed using a Cybex II isokinetic testing device (Lumex Inc., Ronkonkoma, NY). Quadriceps peak torque (PT) and torque acceleration energy (TAE) were tested for both the involved and uninvolved limbs using standard stabilization with the patient seated. Torque acceleration energy was measured at a velocity of 240 deg/sec, and PT was measured at velocities of both 60 and 240 deg/sec. Peak torque is defined as the highest level of torque produced during a given isokinetic contraction and thus is a measure of muscle strength (force). Torque acceleration energy, defined as the work (force × distance) produced in a unit of time, is a measure of muscle power. The quadriceps index was calculated as the ratio of the PT in the involved knee to the PT in the uninvolved knee. In addition, the circumference of both thighs was measured at 10 and 23 cm above the medial joint line with the patient in the supine position. The thigh circumference index was calculated as the ratio of the involved leg thigh circumference to the uninvolved leg thigh circumference.

Functional assessment

Knee function was assessed using three previously established functional performance tests and the hop test. The functional performance tests (cocontraction test, Carioca test, and shuttle run) were used to obtain an objective measurement of knee function by reproducing the activities required to perform common sport skills.[29,30] Test-retest reliability values for these tests range from $r = 0.92$ to $r = 0.96$.[30]

The cocontraction test (Fig. 1) was performed by securing a VELCRO (VELCRO USA Inc., Manchester, NH) belt attached to a heavy, 1.2-m long piece of rubber tubing with an outer diameter of 2.5 cm (Rehab Tubing, Pro Orthopedic Devices, Inc., Tucson, AZ) around the patient's waist. The tubing was anchored to a metal loop secured to a wall at a point 1.5 m above the floor. A semicircle was painted on the floor with a 2.5 m radius about the metal loop. The subject stood facing the wall with toes on the line; this stretched the tubing 1.2 m beyond its original length. This functional

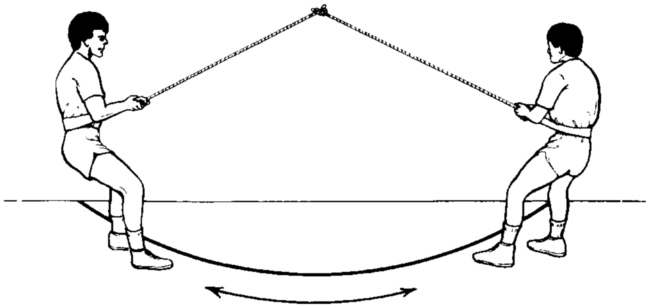

Figure 1. Cocontraction test. The patient moves in a side-step or shuffle fashion around the periphery of a 2.5-m radius semicircle. The test is complete when five semicircle lengths have been performed.

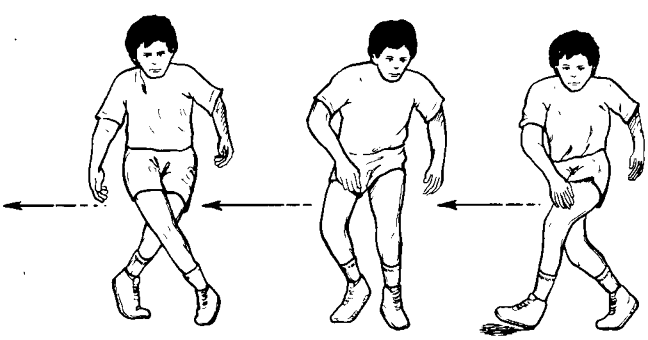

Figure 2. Carioca test. Using an alternating crossover step, the subject moves laterally to the right 12.2 m, then reverses direction to return to the starting position.

performance test required each subject to complete five semicircles with constant tension applied to the over-stretched rubber tubing. The subject began the test on the right side of the semicircle and moved in a side-step or shuffle fashion, to complete five circuits (three to the left and two to the right) in the minimum time possible.

The Carioca test (Fig. 2) required the subject to move laterally with a crossover step. This functional performance test was performed over two 12.2-m lengths. The subject began by moving from left to right and then reversed direction, completing a total distance of 24.4 m in the minimum possible time.

In the third functional performance test, the shuttle run test (Fig. 3), subjects ran four lengths of 6.1 m each. At the end of one length, the subject touched a line on the floor with his foot, reversed direction, returned to the starting point, touched the starting line, and repeated the process. The complete test covered 24.4 m with three changes in direction.

The measurement for all three tests was elapsed time, which was determined using a hand-held chronograph. Each subject performed three trials of each test. The shortest time for each test was the total functional performance test score.

The hop test, developed by Daniel et al.,[12] was designed to assess both strength and confidence in the injured leg. Standing on one leg, the subject hops as far as possible,

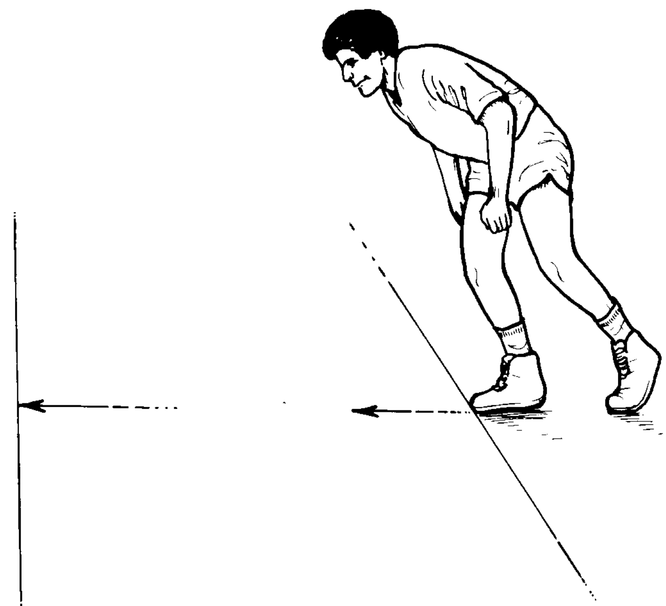

Figure 3. Shuttle run test. The athlete performs four lengths of 6.1 m each to complete 24.4 m in the shortest amount of time possible, reversing direction after the completion of each length.

landing on the same leg. A complete test comprised three trials on both the involved and the uninvolved legs. The mean distance for all three trials on each leg was recorded. The hop index was then calculated as the ratio of the mean distance hopped on the involved leg to that of the uninvolved leg.

Statistical analysis

A one-way analysis of variance was used to determine between-group differences for all variables. Significance level was set at $P < 0.05$.

RESULTS

There was no significant difference in thigh circumference index between autograft (95% ± 1.06%; mean ± SE) and allograft (96% ± 0.75%) patients. With regard to quadriceps strength and power assessment, there were no significant differences in PT (Fig. 4), torque acceleration energy (Fig. 4), or quadriceps index (Fig. 5) between autograft and allograft groups. With regard to functional assessment, there were no significant differences in individual functional performance tests (Fig. 6), total functional performance test (Fig. 6), or hop index (Fig. 7) between autograft and allograft groups. Raw values for each of these variables are in Table 1.

DISCUSSION

The choice of procedure for ACL reconstruction depends on the functional demands of the patient and the benefits and

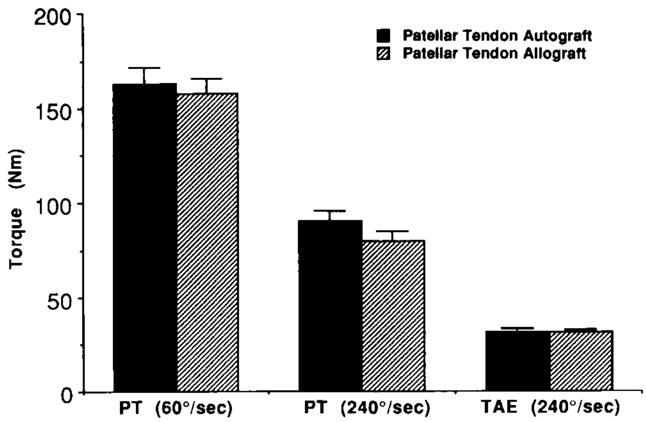

Figure 4. Peak torque (PT) (at 60 and 240 deg/sec) and torque acceleration energy (TAE) (at 240 deg/sec) values for patellar tendon autograft and allograft groups. Horizontal lines represent SE ($P > 0.05$).

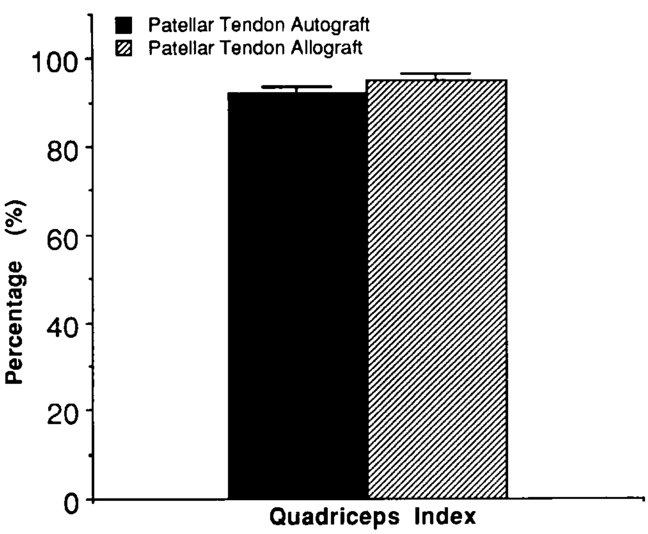

Figure 5. Quadriceps index (involved leg PT/uninvolved leg PT at 60 deg/sec) for patellar tendon autograft and allograft groups. Horizontal lines represent SE ($P > 0.05$).

complications associated with each procedure. For most competitive athletes, quadriceps strength and knee function are of paramount importance. Several authors have stated that the patellar tendon autograft technique significantly disrupts the extensor mechanism and results in diminished quadriceps strength and knee function.[6,21,41,48] Consequently, others have cited this deficit in quadriceps strength as a rationale to prefer the patellar tendon allograft technique.[33,45,49] However, the issue of quadriceps strength and functional capacity after patellar tendon autograft reconstruction had not been adequately studied using objective strength and functional criteria in a highly active population.

Using such criteria in a highly active group of patients who underwent intensive rehabilitation, the present study

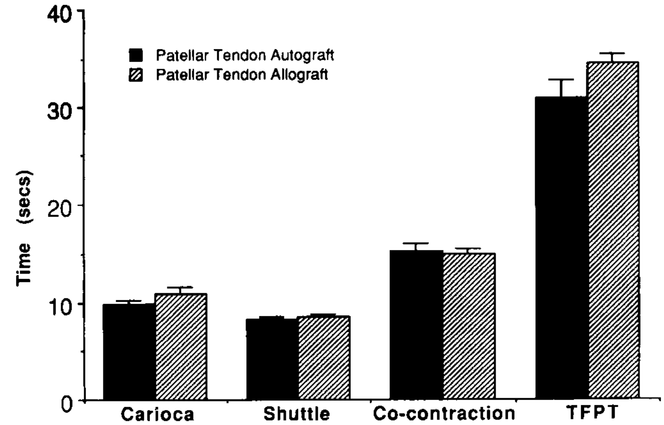

Figure 6. Functional performance tests for patellar tendon autograft and allograft groups. Horizontal lines represent SE ($P > 0.05$). TFPT, total functional performance test.

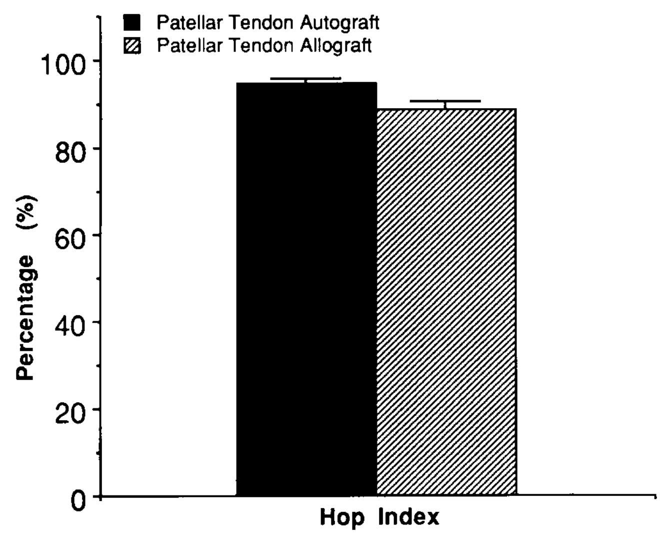

Figure 7. Hop index (involved leg hop/uninvolved leg hop) for patellar tendon autograft and allograft groups. Horizontal lines represent SE ($P > 0.05$).

TABLE 1
Quadriceps strength, power, and girth values

Variable	Allograft	Autograft
Peak torque 60 deg/sec (N-m)	163.3 ± 45.3	158.2 ± 45.2
Peak torque 240 deg/sec (N-m)	90.0 ± 26.2	79.5 ± 45.2
Torque acceleration energy 240 deg/sec (N-m)	31.5 ± 9.2	31.1 ± 11.0
Quadriceps index (%)[a]	92 ± 6.2	95 ± 4.2
Thigh circumference index (%)[a]	96 ± 0.75	95 ± 1.06

[a] Expressed as percentage of involved to uninvolved.

showed no difference in quadriceps strength, quadriceps power, or functional capacity between patellar tendon autograft and allograft reconstructed subjects. In addition, both the autograft and allograft subjects reestablished strength and power in their involved knees exceeding 90% of their uninvolved knees. The quadriceps index values in these subjects are similar to the mean quadriceps index of 90.5% reported by Daniel and coworkers[11] in 94 subjects, aged 15 to 45 years, who had no history of knee injury.

In contrast, other investigators have reported significant deficits in quadriceps strength after ACL reconstruction, especially in patients with patellar tendon autograft. Huegel and Indelicato[21] found good quadriceps strength in subjects with allograft reconstructions; 68% of these patients possessed an 80% quadriceps index 6 months postoperatively. However, only 20% of patients who had patellar tendon autograft reconstructions had an 80% quadriceps index at 6 months. Sachs and colleagues[41] prospectively studied 126 patients who had autograft ACL reconstruction using patellar tendon, hamstring tendon, or iliotibial band tissue. At a 1-year followup, these authors found their patients had an overall mean quadriceps index of 66.2% with significantly weaker quadriceps in the patients who had patellar tendon autografts (mean quadriceps index, 60.8%) as compared with those with hamstring tendon autografts (mean quadriceps index, 71.2%). In addition, these investigators found a strong correlation between flexion contracture, patellar irritability, and quadriceps weakness. The San Diego Kaiser series[42] also demonstrated an effect of graft source on quadriceps weakness when patients with hamstring tendon autografts were compared with patients with patellar tendon autografts 1 year after ACL reconstruction. Although those with hamstring tendon autografts had a higher quadriceps index (81% versus 74%), they had a lower flexion index (88% versus 97%).

Plausible explanations for the disparately high quadriceps strength demonstrated by our subjects with patellar tendon autografts as compared with those in the aforementioned studies include patient characteristics, postoperative time elapsed, and rehabilitative approach. The subjects participating in the present study were relatively young and very active (mean Tegner score, 7.4). In addition, many were competitive collegiate athletes. Their youth, combined with their athletic goals, may have led to a stronger commitment to regain strength and functional capacity. Furthermore, these subjects were tested 1 to 2 years (mean, 18.6 months) after ACL reconstruction. Whereas Huegel and Indelicato found a marked difference in quadriceps strength between patellar tendon autograft and allograft patients, their subjects were examined 6 months after reconstruction. The studies conducted 1 and 2 years postoperatively (San Diego Kaiser series[42] and Tibone and Antioch,[48] respectively) noted higher overall quadriceps index and less difference between groups. Thus, it may be that the return of quadriceps strength after autograft ACL reconstruction requires 1 to 2 years.

Finally, more aggressive rehabilitation may account for the high quadriceps strength and functional capacity seen in this investigation. In contrast to the intensive rehabilitation undergone by the subjects in the present study, the patients studied by Sachs and associates[41] underwent a conservative program consisting of cast immobilization in 30° of flexion for 3 weeks followed by a range of motion brace with a 30° extension stop for 3 to 5 weeks, and touchdown weightbearing from Weeks 6 to 8.[41] Running exercises were initiated at 6 to 9 months, and terminal extension exercises were not performed during the 1st postoperative year. Although more aggressive rehabilitative regimens may hasten the return of quadriceps strength and functional capacity after ACL reconstruction, there remains a danger of overloading the reconstructed ligament and interfering with the remodeling process.

Traditionally, evaluation after ACL reconstruction has focused on physical characteristics and measures of knee stability such as strength, laxity, and range of motion. Recently, however, reliance on such criteria has been refuted based on the lack of a strong relationship between these measures and both the patient's perception of knee function[17] and return to sport.[30] Thus, tests with more specificity to functional capacity have been designed, including the hop test,[12] the figure-8 maneuver,[47] and the straight-cut maneuver.[48] The functional performance tests used in this study attempt to quantify performance in selected activities that mimic athletic maneuvers requiring functional strength and stability in the knee. These functional performance tests have been established as valid and reliable measures of the return to functional level and the patient's perception of knee function.[29] The present study found no difference in functional capacity between the patellar tendon autograft and allograft groups based on the functional performance tests and minimal difference between the involved leg and the uninvolved leg for either group based on the hop test. Although both groups in this study scored slightly lower mean scores on the functional performance tests than the mean score of a sample of intercollegiate male athletes (mean total functional performance test, 22.8 sec),[29] their scores were similar to a group of ACL-deficient athletes who had successfully returned to preinjury levels of athletic activity (mean total functional performance test, 30.8 sec).[30]

CONCLUSIONS

The results of this study indicate that harvesting the central third of the patellar tendon for autograft ACL reconstruction does not diminish quadriceps strength and functional capacity in highly active patients who undergo intensive rehabilitation. Furthermore, normal quadriceps strength and good functional capacity can be restored. Thus, patellar tendon allograft reconstruction does not hold an advantage over patellar tendon autograft reconstruction in terms of quadriceps strength and functional capacity in these patients.

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