ORTHOPEDIC CLINICS OF NORTH AMERICA

Orthop Clin N Am 34 (2003) 31–39

Anterior cruciate ligament reconstruction utilizing central quadriceps free tendon

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Surgical reconstruction of a torn anterior cruciate ligament (ACL) provides predictably good results. Most athletes are now able to return to their desired sport with a stable knee. ACL reconstructions have most commonly utilized the central third of the patellar tendon or double looped semitendinosis/gracilis "hamstring" as the autograft of choice. Both of these reconstruction techniques have a well-documented clinical record, but each has potential problems. In an attempt to refine further and develop alternative graft sources for ACL reconstruction, the senior author (JPF) has utilized central third quadriceps tendon almost exclusively for both primary and revision ACL reconstruction since 1994. Initially, this was with a bone plug taken from the proximal pole of the patella [1], but, currently, a central quadriceps free tendon (CQFT) graft is used [2]. This graft, which is entirely soft tissue, is sometimes augmented with EndoPearl™ (Linvatec, Largo, FL), a poly-lactic acid (PLLA) ball, or a bone disk taken from the tibia to optimize fixation with bioabsorbable soft tissue interference screws (Arthrex, Naples, FL) [3]. Endo-Button™ (Smith & Nephew, Mansfield, MA) fixation is another alternative that has worked well. These techniques provide stable, functional knees with minimal morbidity.

This article will present our short-term objective and subjective results of CQFT ACL reconstruction. Initially, a pilot study was performed on a relatively varied group of patients who had a CQFT ACL reconstruction [4]. Based on these generally good results, a second investigation was undertaken to evaluate postoperative knee stability more objectively in a group of patients having a CQFT ACL reconstruction that used an alternative technique [3]. The technique of CQFT ACL reconstruction, as well as the underlying rationale, will also be discussed here.

Materials and methods

Patients who underwent a CQFT ACL reconstruction performed by or under the direct supervision of one surgeon (JPF) with a minimum follow-up of 2 years (n = 29) were evaluated subjectively and objectively in a retrospective fashion. This includes patients with meniscal pathology (n = 13), Grade III to IV arthrosis (n = 5), revision cases (n = 2), and workmen's compensation cases (n = 1). Fixation methods were variable. On the femoral side, techniques included Endo-Button (n = 19), interference screw (n = 5), and Endo-Button/interference screw (n = 1). On the tibial side, techniques included sutures tied over a post (n = 12) or button (n = 7), interference screw (n = 2), and interference screw/button (n = 4). All patients followed a similar, supervised brace-free rehabilitation protocol.

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PII: S0030-5898(02)00068-8

The subjective evaluation used the 1999 International Knee Documentation Committee (IKDC) Subjective Knee Evaluation Form (n = 25). Symptoms of instability, activity level, and overall knee function in particular were scrutinized. The assessment of overall knee function used a visual analog score (VAS) from 0 to 10, including preinjury and postoperative comparison.

Objective evaluation consisted of a physical examination performed by one surgeon (PCT) independent of the operating surgeon (JPF). Lachman, pivot shift, and single leg hop test were performed, along with an assessment of ROM, graft site morbidity, and patellofemoral evaluation (n = 18). Knees were considered stable on exam if a firm end point on Lachman testing was noted with an absent pivot shift. This investigation was a pilot study and will be referred to as group 1.

Based on encouraging results of this study, a second investigation was performed on a more uniform population of patients with a CQFT ACL reconstruction. The purpose of this study was to evaluate the postoperative stability of the knee more objectively using KT-1000 (Med-Metric, San Diego, CA) arthrometric measurements. These patients will be referred to as group 2.

A total of 68 ACL reconstructions (29 male, 39 female) were completed between January 1999 and May 1, 2000 using CQFT, bioabsorbable soft-tissue interference screws, and a femoral-sided bone disk anchor. This technique has been described previously by Fulkerson [3]. The reconstructions were performed by the senior author (JPF). Patients were excluded if they lacked a normal contralateral knee for comparison, or if they had an associated posterior cruciate ligament (PCL) injury or chronic medial/lateral collateral ligament laxity. Seven patients were excluded from the study group and therefore not tested. Four of these patients were known to have had graft failure. Three patients were excluded as they lacked a normal contralateral knee for direct comparison. Sixteen patients could not be tested during the course of this study but were clinically functioning with a stable knee at the last follow up.

A total of 45 of 68 (68%) patients, with a mean age of 31 years (range, 15–46) underwent KT-1000 testing of bilateral knees at a minimum of 1 year following ACL reconstruction (mean, 20 months).

The KT-1000 arthrometer assessment was performed by two independent investigators. Side-to-side comparisons were based on 20 lbs (89N) and 30 lbs (134N) and/or manual maximum. Manual maximum was determined to be approximately 30 lbs, and, therefore, 30 lbs and manual maximum values were combined and are referred to as "maximum pull."

The acceptable range of side-to-side difference of a fully functional graft was defined as 0 to 3 mm. A value of more than 3 to 5 mm defined a partially functional graft. Values greater than 5 mm were defined as arthrometric failure.

Results (group 1)

Average subjective IKDC score was 86 (out of 100)

Eighty-four percent of patients could perform very strenuous or strenuous activities without any "giving way. Seventy-two percent of patients participated in strenuous or very strenuous activities on a regular basis. Examples of such activities include basketball, soccer, heavy physical work, skiing, or tennis. Ninety-one percent of patients could climb or descend stairs with minimal or no difficulty.

Overall knee function preinjury, graded with an average visual analog score, was 8.12. The average postoperative VAS was 8.16.

Ninety-four percent (17/18) of the knees were stable objectively; a firm end point on Lachman testing with an absent pivot shift.

Single leg hop averaged 92% of the contralateral side, whereas 65% of the patients tested at or above 100% on single leg hop testing.

No patient had restricted knee range of motion in comparison with the contralateral side.

No patient had pain on patellar compression or graft site tenderness.

Results (group 2)

KT-1000 assessment was performed on 45 patients (68%) at a mean of 20 months (range 12–29 months) following ACL reconstruction using CQFT. KT-1000 arthrometer difference in anterior tibial translation between the treated knee and the contralateral knee was assessed at 20 lbs (89N) and manual maximum or 30 lbs pull. KT-1000 arthrometer measurements are reported in Table 1.

A total of 38 of 45 (84%) patients exhibited a side-to-side difference of -2 to $+3$ mm on KT-1000 arthrometer testing based on manual maximum pull measurements. The remaining 7 of 45 (16%) patients exhibited a side-to-side difference of more than 3 mm but less than or equal to 5 mm based on maximum pull testing. There were no

Table 1
Postoperative knee stability

Involved knee			Uninvolved knee				
15 lb	20 lb	MAN/MA	15 lb	20 lb	MAN/MA	Si/Si-20	Si/Si-MM
5	7	9	5	7	9	0	0
2	4.5	8	2	2.5	5	2.5	3
3.5	5	7.5	3	4	7	1	.5
3	5	10	4	6	7.5	− 1	2.5
2.5	3.5	5	3.5	4.5	6	− 1	− 1
2.5	4	6	2	3	4	1	2
5	7.5	9	4	5	6	2.5	3
5.5	7.5	13	4	6	9	1.5	4
5	6	9	4	5	8	1	1
2	3	10	2	3	9	0	1
4.5	5.5	7	2	3	7	2.5	0
3.5	4.5	6	1.5	2.5	4	2	2
2	3	3.5	2.5	3.5	4	− 0.5	− 0.5
3	4	6	1.5	2	3	2	3
3.5	4.5	6	1.5	2	2.5	2.5	3.5
3.5	5.5	6	3.5	4.5	5.5	1	.5
8	9	10	6	7	9.5	2	.5
3	4	6	2	3	4.5	1	1.5
4	5	6	4	5	6	0	0
7	9	11.5	6	7	9	2	2.5
5	7	9	3	3.5	4	3.5	5
2.5	3.5	5	2.3	3	4	0.5	1
5	7	9	4	5	6	2	3
3.5	5.5	7	1.5	2.5	4	3	3
3	6	7	2	3	4	3	3
2	2.5	3.5	1.5	2	2.5	0.5	1
2	3.5	6	3	4	5	− 0.5	1
2	3	5	1	1.5	2	1.5	3
7	10	12	4	6	8	4	4
8	11	12	5	7	9	4	3
7	9	11	9	11	13	− 2	− 2
5	7	8	3	4	5	3	3
11	14	16	8	10	12	4	4
7	11	14	5	7	10	4	4
7	8	10	4	6	7	2	3
8	9	10	4	6	7	3	3
10	11	12	5	7	9	4	3
9	10	13	7	8	10	2	3
9	12	13.5	7	10	12	2	1.5
6	9	11	5	6	8	3	3
8.5	11	13	8	9	10	2	3
9	11	12	6	7	8	4	4
7	8	9	6	7	8	1	1
6	8	9	5	6	7	2	2
6	8	10	4	6	7	2	3

Abbreviations: MAN/MA, manual maximum; Si/Si-20, side-to-side difference at 20 lbs; Si/Si-MM- side-to-side difference at manual maximum.

patients with greater than a 5 mm side-to side difference based on 20 lbs or maximum pull evaluation (Fig. 1).

The mean side-to side differences were 1.8 mm at 20 lbs. and 2.1 mm on maximum pull (Fig. 1).

Arthrometric failure was defined as a side-to side difference of greater than 5 mm. There were no arthrometric failures in the group tested. There were four (5%) known clinical failures, however, in the total group of 68 patients. These patients were not

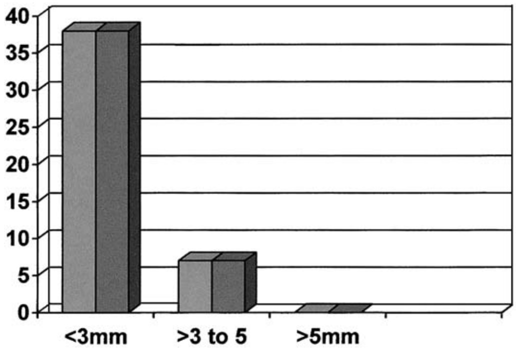

Fig. 1. KT-1000 side-to-side difference at 20 lbs and maximum pull. Mean side-to-side difference at 20 lbs (*light gray*)—1.8 mm. Mean side-to-side difference at maximum pull (*dark gray*)—2. mm.

tested. Of the remaining patients not evaluated, all are either known or believed to be clinically stable.

Technique

The patient is positioned supine on the operating room table, and after the induction of anesthesia, an examination is performed to confirm an ACL deficiency. A tourniquet is applied to the operative thigh, and the leg is placed into a leg holder. The limb is prepped and draped, exsanguinated, and the tourniquet is raised to 250 mm Hg.

Arthroscopic examination is initiated, first utilizing the central patellar tendon portal to facilitate visualization. An anteromedial, working portal is established. Meniscal and chondral pathology are treated as indicated. The residual ACL is debrided with a shaver. A limited nothchplasty is performed to allow adequate visualization of the posterior border of the intercondylar notch and to prevent notch impingement. A 3 cm longitudinal incision is made over the anteromedial surface of the proximal tibia, and the dissection is taken down to the periosteum. A periosteal elevator is used to expose cortical bone. A 9-mm cannulated coring reamer is used to harvest a cortico-cancellous "bone disk" from the tibia to be later incorporated into the central quadriceps graft. It is important to place the reamer perpendicular to the face of the tibia to prevent harvesting of an eccentric disk. This incision is used to place the guide for the tibial guide pin. Alternatively, a PLLA ball may be used for graft anchoring.

The tibial guide pin is placed in the appropriate position and overdrilled by 2 mm less than the diameter of the harvested central quadriceps autograft. Sequential dilatation of the tibial tunnel is then performed with tunnel dilators (Arthrex, Naples, FL) in .5 mm increments until the tibial tunnel diameter matches the graft size (usually 8–9 mm). The femoral guide pin is then placed through the tibial tunnel and drilled into the "10:30" (right knee) or "1:30" (left knee) position in the posterior aspect of the intercondylar notch with the knee at 90 degrees of flexion. The pin is drilled through the anterolateral cortex of the femur and out through the anterolateral soft tissue of the thigh. This guide pin is carefully placed to allow for a 2-mm back wall after the femoral tunnel is drilled to match the diameter of the graft. The femoral tunnel is drilled to a depth of 30–35 mm.

The CQFT graft can be harvested by a second surgeon while arthroscopy is proceeding. A 3- to 7-cm longitudinal incision is started over the superior pole of the patella and extended proximally. The subcutaneous tissue is divided to expose the insertion of the extensor mechanism, particularly the medial and lateral border at the insertion of the vastus medialis and lateralis. Parallel longitudinal incisions of 10 mm are then made in the central quadriceps tendon, extending proximally from the superior pole of the patella to the apex of the graft. The depth of these incisions is partial thickness. They should be into, but not through, the vastus intermedius. This is a depth of 6 to 7 mm and can be closely approximated by the depth of a #10 scalpel blade. A portion of the vastus intermedius is left in the bed of the graft harvest site overlying the suprapatellar pouch. If the suprapatellar pouch is violated, it can make arthroscopy difficult, but it can be sutured closed with little consequence. Some surgeons advocate a full-thickness graft, but we have found that this makes further arthroscopy more difficult because of lost distension. A hemostat is then used to define the undersurface of the graft by passing through the vastus intermedius approximately 2 cm from the superior pole of the patella from lateral to medial (Fig. 2). By careful spreading with a hemostat and sharp dissection, the distal portion of the graft is released from the superior pole of the patella. A grasping clamp is used to hold the distal portion of the graft while #5 braided, nonabsorbable whip stitches are placed in a locked fashion.

Once the distal portion of the graft is harvested, the 10-mm-wide strip of graft is freed proximally with a combination of sharp and blunt (finger) dissection, maintaining a portion of the vastus intermedius in the bed of the harvest site (Fig. 3). One is usually able to obtain 70 to 80 mm of graft proximally before the muscle of the vastus intermedius is encountered. The graft is transected sharply with a

Fig. 2. A hemostat defines the undersurface of the graft by passing through the vastus intermedius.

Mayo scissors under direct visualization, and a #5 suture is placed in the proximal end of the graft as done previously. The bifid nature of the graft is quite apparent at this point, and both the rectus femoris and vastus intermedius must be securely incorporated with the locking suture. The bone disk taken from the tibia or PLLA ball is then attached to the distal end of the graft by tying the heavy sutures in the end of the graft through a central hole in the disk or PLLA ball in a figure-of-eight fashion. The bone disk or PLLA ball serves as an ‘‘anchor’’ to augment interference screw fixation and must be securely attached and directly opposed to the graft tissue. The graft and anchor composite is then wrapped with a saline-soaked sponge and placed under tension on the back table to remove crimp from the ligament.

The graft is then placed into the knee. The side of the graft with the attached bone disk or PLLA ball is pulled through the tibial tunnel and firmly into the femoral tunnel using the femoral guide pin. Once the graft is seated, continued strong tension is placed on the graft by pulling on the sutures that have been retrieved out the anterolateral thigh. A 23-mm bioabsorbable, soft tissue interference screw that matches the femoral tunnel diameter is then inserted through the medial portal under direct visualization into the femoral tunnel. The screw should obtain rigid purchase, particularly upon the attached bone disk or PLLA ball. It is critical to avoid screw/tunnel divergence during insertion [5]. This can be avoided by creating a notch at the anterior lip of the femoral tunnel to guide the screw path initially. Also, it is necessary to hyperflex the knee during screw insertion to match the angle of the femoral tunnel that was drilled through the tibial tunnel. Secure graft fixation is confirmed, along with full range of motion and graft isometricity. Endo-Button fixation on the femoral side is also effective, placing two #5 sutures into the graft with whip stitches, and using these to attach the Endo-Button.

The knee is then held at 15 to 20 degrees of flexion with a moderate posterior drawer, and a 28-mm bioabsorbable, soft tissue interference screw is inserted over a guide pin up into the tibial tunnel so that the screw is anterior to the graft. The diameter of this screw should match the diameter of the tibial tunnel or, if the bone is soft, should be 1 mm larger in diameter. Strong tension is placed on the graft at all times during tibial screw insertion by pulling on the attached sutures hanging out the tibial tunnel. The screw is advanced until the most distal threads are visible arthroscopically at the intra-articular opening of the tibial tunnel. Tibial fixation is backed up by tying the sutures over a button (Arthrex, Naples, FL). This type of secure fixation provides ‘‘compression - anchor’’ fixation.

Full range of motion and knee stability should be confirmed prior to concluding the case. If the fascia over the CQFT has been maintained, this is closed. The tendon defect itself, however, is left without closure. The subcutaneous layer and skin are closed in layers. Sterile dressings, compressive wrap, a knee immobilizer, and a cooling pad are applied prior to release of the tourniquet.

The patient is encouraged to bear weight with crutches and to practice isometric quadriceps exercises and gentle range-of-motion exercises in the immediate postoperative period. Formal physical therapy, emphasizing attainment of early, full extension is initiated following the first postoperative visit.

Fig. 3. Distal detachment of the CQFT with partial preservation of the vastus intermedius.

Patients are allowed to return to full activity after demonstrating full range of motion, absence of effusion, a painless, stable knee, and strength in at least 80% of the contralateral limb. This is evaluated either by isokinetic or single leg hop testing. We encourage patients to delay return to full activity for 6 to 8 months following the procedure.

Discussion

Modern surgical management of the ACL-deficient knee predictably restores stability to the knee in the majority of patients. Current techniques use an intra-articular reconstruction of the ACL using either autograft or allograft tissue in an arthroscopically assisted fashion. The most commonly used autografts are the bone-patellar tendon-bone (BTB) and quadrupled semitendinosis/gracilis tendon (ST-G) grafts. These two graft options have a well-documented clinical record. Direct comparison of these two techniques has shown minor differences in restoration of knee stability, postoperative morbidity, and return to athletic activity [6–12].

The BTB has high initial ultimate tensile load and stiffness values, and it can provide rigid, bony fixation [13]. The use of the central third of the patellar tendon has been associated with donor site problems. Arthrofibrosis [14], patellar fracture [15], and patellar tendon rupture [16] can occur, but they are quite rare. Patellofemoral pain, however, is quite common [17–19], and it may be related to the development of patella baja [20]. Modern rehabilitation protocols emphasizing early motion and full extension seem to lessen central third patellar tendon ACL reconstruction donor site morbidity [14,21].

Caused in part by concern over potential donor site morbidity with central third patellar tendon, the hamstring autograft has become increasingly popular. This graft choice provides a relatively low incidence of graft site morbidity [22], and, when used in a quadrupled fashion, has very high initial ultimate tensile load and stiffness values [23,24]. The primary disadvantage of this graft choice is the concern of tendon healing in an osseous tunnel. Hamstring weakness following harvest of the semitendinosis and gracilis tendons has been documented [9,12] in the short term but may not be a problem either clinically or at later follow-up [25,26]. Tunnel widening has also been noted with hamstring grafts, but the clinical relevance remains unclear [27,28].

The use of quadriceps tendon as a graft source for ACL reconstruction has become increasingly popular [1,29–31]. In 1979, Marshall first described the use of a quadriceps tendon/prepatellar retinaculum/patellar tendon graft [32]. In 1984, Blauth described the use of the central third quadriceps tendon with a proximal patellar bone plug [33]. Fulkerson first described the use of the central third quadriceps tendon without a patellar bone plug for ACL reconstruction [2]. A distinct advantage of the central third of the quadriceps tendon as a graft source is the fact that it has a substantially greater (nearly double) cross-sectional area than the central third of the patellar tendon (Fig. 4) [1,2,34]. Extensive biomechanical studies have revealed favorable mechanical properties similar to that of the central third of the patellar tendon [34–36].

We advocate the use of the CQFT graft for ACL reconstruction for several reasons. It is a large, strong graft that is relatively easy to harvest, and it seems to cause very little morbidity. The results of the initial pilot study were striking in that no patient had signs or symptoms of patellofemoral pain at minimum 2-year follow-up evaluation [4]. This is an important advantage in comparison with central third patellar tendon reconstructions. The senior author (JPF) has not seen any case of quadriceps tendon rupture following harvest of the central quadriceps tendon. Additionally, patients who undergo CQFT ACL reconstruction have substantially less postoperative pain than patients who have ACL reconstruction with BTB or ST-G tendons.

The current technique of graft fixation has been refined and subjected to laboratory testing [37]. We

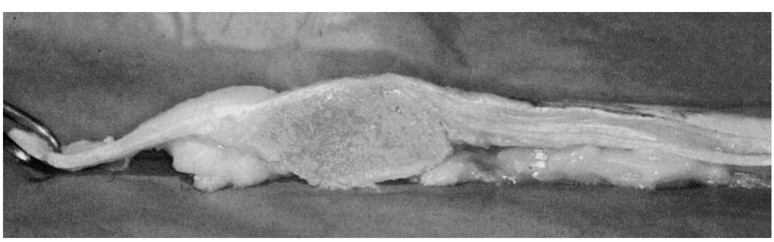

Fig. 4. Comparison of thickness of patellar tendon (*left*) and quadriceps tendon (*right*).

refer to the fixation construct as ‘‘compression-anchor’’ in nature (Fig. 5). Aperture fixation is obtained at the joint line with the interference screws. This has been shown to provide biomechanically superior fixation [38]. Interference screw fixation alone has been shown to have decreased pullout strength in comparison with other fixation methods [39], and, therefore, the use of the cortical bone disk on the femoral side in conjunction with an interference screw is a useful technique with proven biomechanical advantages [37]. A similar technique substitutes the cortical bone disk with the manufactured, bioabsorbable EndoPearl [40], and this also appears promising. Use of a bioabsorbable interference screw that is tightly matched to the tunnel diameter may stimulate direct-contact healing between the graft and the bony wall of the tunnel without graft degradation as the screw dissolves [41] and improves fixation strength [42]. It appears that bioabsorbable interference screws have pullout strengths

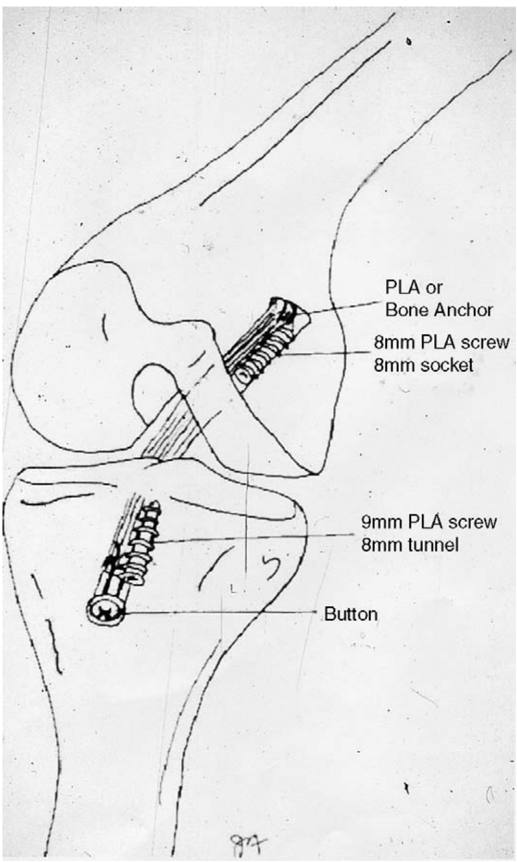

Fig. 5. Compression-anchor fixation is achieved at both the femoral and tibial sides.

similar to their metal counterparts when used with soft tissue grafts [43].

Instrumented arthrometric measurement of anterior tibial translation is an accepted method of documenting knee stability following ACL reconstruction [44,45]. KT 1000/2000 measurements have been widely reported in the literature following ACL reconstruction [6–11,46–49]. Most studies have used a side-to-side difference of less than or equal to 3 mm as indicative of a fully functional graft. A side-to-side difference of 3 to 5 mm represents a partially functional graft, whereas a greater than 5 mm side-to-side difference represents an arthrometric failure.

ACL reconstruction using CQFT reliably restores stability to the knee following ACL disruption. In the initial pilot study, 94% of patients had a stable knee on exam [4]. This finding was validated in the later study using KT 1000 measurements. Of the 45 patients tested at an average of 20 months post-surgery, 38 (84%) had a side-to-side difference of 3 mm or less. The remaining 7 all had a side-to-side difference of less than 5 mm. No patient had a greater than 5 mm side-to-side difference. The mean side-to-side difference at 20 lbs was 1.8 mm, whereas at maximum pull it was 2.1 mm. These results compare well with other published KT 1000 values following ACL reconstruction. Aune reported a mean manual maximum side-to-side difference at 2 years of 2.7 mm for both hamstring and central third patellar tendon reconstructions [12]. Marder reported mean KT 1000 scores at a minimum of 2 years of 1.6 mm for patellar tendon and 1.9 mm for hamstring reconstructions [9]. At a mean follow-up of 42 months, O’Neill reported 83% of hamstring reconstructions and 87% of patellar tendon reconstructions to have less than 3 mm of side-to-side difference at manual maximum force [8]. Howell reported that 88% of hamstring reconstructions at 2-year follow-up showed less than 3 mm of side-to-side difference at manual maximum force [47]. Noyes reported that 85% of chronic, and 92% of acute ACL reconstructions using central third patellar tendon, had less than 3 mm of side-to-side difference at 134 N [49]. At an average of 4 years following patellar tendon ACL reconstruction, Shelbourne reported a mean KT 1000 arthrometry score of 2.0 mm at manual maximum force [48]. Results of KT 1000 tests in follow-up of the CQFT reconstruction patients appear to be comparable to these reports.

The primary limitation of the arthrometric measurements presented in this study is that not all patients with CQFT ACL reconstructions were studied. There were four patients who were not tested because they were known to have failed their reconstruction. Three patients were excluded because they lacked a normal contralateral knee for direct comparison. Of the remaining 16 patients not tested, all were doing well at their latest evaluation. The average follow-up was 20 months, with a minimum of 12 months, which is less than many reports in the literature. Though it is possible that the results will deteriorate with time, Howell noted that there was no deterioration of knee stability between 4 months and 2 years postop with his hamstring reconstructions [47]. It is our impression as well that CQFT reconstructions do not deteriorate significantly with time.

Summary

CQFT ACL reconstruction yields a stable, highly functional knee with little associated morbidity. Patient satisfaction has been very high, and objective follow-up data collected thus far is very encouraging.

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