Quadriceps Insufficiency following Repair of the Anterior Cruciate Ligament*

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Following repair of the anterior cruciate ligament, it is fairly typical for a patient to return to activity at approximately 12 months postsurgery. The purpose of the study was to quantify quadriceps size and function at 1 year postsurgery. Bilateral isokinetic torque measurements, tomographic scans, muscle biopsies, and anthropometrics were performed on 13 patients (3 females, 10 males) at 13 months postsurgery. The operative leg was 3% smaller in circumference, 10% smaller in total muscle area, 12% smaller in quadriceps area (all p < 0.05) and had a 9% larger subcutaneous fat area (p = 0.06). No difference in hamstrings area was seen. Isokinetic torques for the quadriceps were reduced by 11–15% in the operative leg (p < .05) with no difference seen between the hamstrings torques. Types I and II fibers were clinically smaller in both legs with the type II fibers being significantly (p < 0.05) reduced in the operative leg. It was concluded that 1) leg circumference was a poor indicator of muscle size due to the selective fat deposition in the operative leg, 2) the cross-sectional area of muscle was proportional to isokinetic torque at 240/sec, and 3) there were clinically and statistically significant isokinetic torque differences between quadriceps 13 months post-surgery.

Immobilization of the leg following surgery of the lower extremity causes well known atrophy of skeletal muscle with disuse cited as the primary cause.19,23,24 This atrophy has been shown to have an initial component that occurs rapidly at the onset of casting, often within 7–15 days,5,26,27 followed by a slow component.26 Rehabilitation is designed to obtain adequate range of motion and regain skeletal muscle mass and function without compromising the surgical repair.15

For the patient who has had a surgical repair or reconstruction of the anterior cruciate ligament (ACL), a progressive rehabilitation process continues for approximately 12 months24 to a point where the patient with the reconstructed knee is considered ready to return to activity. In a recent survey, all the orthopaedic surgeons responding would allow full activity by 12 months postsurgery.6 This project examined the muscle's mechanical function and structure at the period when the patient is usually expected to return to full activity.

METHODS

Thirteen athletes (3 females, 10 males) ranging in age from 17 to 26 years were evaluated. Each had acutely ruptured the anterior cruciate ligament during various sporting activities. All were operated on by one of the three orthopaedic surgeons of the Cleveland Clinic Foundation, Section of Sports Medicine. A modified Jones patellar tendon graft11 was used as an intra-articular augmentation of the ligament repair. The interval between the original injury and the ligament repair was within 14 days. Each patient’s operative leg was fully immobilized for a 3–4 week period, followed by limited range of motion, beginning with 30–60° and progressing to full motion. Swimming and stationary cycling were initiated 3–4 months postoperatively, according to the discre-
of each surgeon. This was followed by a well outlined progressive resistance hamstring and, later, quadriceps exercise program. Jogging and sprinting were begun from the 6th through the 12th month based on the development of each patient. The rehabilitation program was a variation of that described by Paulos et al.24

Informed consent (or where appropriate, parental consent) was obtained from each subject before any examination or tests were performed. Each patient's history and mechanism of injury was reviewed and followed by an examination of each knee. Anthropometrics including skinfold measurements to determine body fat as outlined by Pollack et al.25 were performed. In addition, thigh circumferences and skinfold thicknesses were measured 15 cm above the superior pole of each patella.

Computerized axial tomograms were taken of each thigh at the same 15 cm mark which delineated the hamstrings and quadriceps.17,21 Cross-sectional areas (in sq cm) of each muscle grouping were determined by computerized digitization. The methodological error of duplicate determinations of the same tomogram was less than 2% (p > 0.05). Isokinetic peak torques of quadriceps and hamstrings of each leg were tested at angular velocities of 60, 120, 240°/sec using the Cybex II® Isokinetic Cynamometer (Cybex, Division of Lumex, Ronkonkoma, NY). Each evaluation was performed with the patient in a sitting position and the angle of the hip kept consistent by back support. The rotational axis was centered to that of the knee joint. Nonspecific, nongravity corrected peak torques were determined.

Finally, each athlete underwent bilateral vastus lateralis muscle biopsies using the suction modification12 of the percutaneous needle biopsy procedure as outlined by Bergstrom.3 The biopsy was taken 15 cm above the patella at a depth of about 5 cm. Biopsy specimens were immediately mounted and placed into isopentane (2-methyl butane) cooled by liquid nitrogen to a temperature of -150°C. Subsequently, 10 micron thick sections were cut and stained for myosin adenosine triphosphatase after alkaline preincubation as described by Dubowitz and Brooke.9 Type I and type II fibers were readily identified by their histochemical staining characteristics. Specimens were analyzed with the lesser fiber diameter method9 using the Texac Texture Analysis Computer with the Danza IP-5000 Image Processor (full system is available from the National Biomedical Research Foundation, Dr. Robert S. Ledley, Georgetown University, 3900 Reservoir Rd, Washington, DC). This system analyzed approximately 150–200 fibers of each type from each biopsy.

Standard descriptive statistics and repeated measure analysis of variance were performed when appropriate.8

RESULTS

The descriptive data is presented in Table 1. The males were older, taller, heavier, leaner, and carried more fat-free mass (p < 0.05). Circumference (circ) of each leg showed that the males and females operative leg was 3% (p < 0.05) smaller than the nonoperative leg. Skinfold (SF) measures indicated an 8% (males) and 12% (females) increase in skinfold thicknesses of the operative leg. The ratio of circ/SF was 10% smaller in the operative leg of the males and 14% in females (Table 2).

Isokinetic test results showed typical torque velocity curve for both sexes. Males generated more torque than females at each speed setting and muscle group (p < 0.05). Quadriceps torque (Q) in males was 12, 12, and 10% reduced at each test speed in the operative leg versus nonoperative leg. For females the differences were 25, 15, and 10% for each test speed. Mean results are presented in Figure 1. There were no detectable differences between legs in hamstring (H) torque at any test speed for either sex. The ratio of hamstrings to quadriceps (H/Q) torque at 60°/sec in the nonoperative leg was the expected 66%.7,16 However, for the operative leg, this ratio was about 75%. It has been suggested that males are able to generate their body weight in foot lb of torque at 60°/sec.7 In females, this ratio should be 0.8 or better.7 These patients were unable to accomplish their sex specific norm. Because of the lack of difference between the nonoperative leg and the operative leg in hamstring torque, the high H/Q ratio was due to a reduced quadriceps torque output.

Computerized tomography gave a cross sectional image of the leg that allowed for discrimination of various muscle groups. Wide variability between patients influenced the lack of sex differences as only the hamstring area was different between sexes. When all subjects were pooled, no differences in hamstring cross-sectional area was evident (Table 3). Average differences between the operative leg and nonoperative leg
TABLE 1

<table>
<thead>
<tr>
<th></th>
<th>Age (yr)</th>
<th>Height (cm)</th>
<th>Weight (kg)</th>
<th>Percent Fat</th>
<th>Fat (kg)</th>
<th>Fat Free Mass (kg)</th>
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</thead>
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<tr>
<td><strong>Males (N = 10)</strong></td>
<td></td>
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<tr>
<td>Mean</td>
<td>22.4</td>
<td>178.5</td>
<td>76.4</td>
<td>10.5</td>
<td>8.3</td>
<td>60.8</td>
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<tr>
<td>SD</td>
<td>(4.7)</td>
<td>(8.6)</td>
<td>(8.6)</td>
<td>(3.6)</td>
<td>(3.4)</td>
<td>(6.8)</td>
</tr>
<tr>
<td><strong>Females (N = 3)</strong></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Mean</td>
<td>18.3</td>
<td>163.8</td>
<td>60.3</td>
<td>18.5</td>
<td>11.2</td>
<td>48.5</td>
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<tr>
<td>SD</td>
<td>(1.5)</td>
<td>(1.8)</td>
<td>(5.2)</td>
<td>(2.4)</td>
<td>(1.5)</td>
<td>(5.1)</td>
</tr>
<tr>
<td><strong>Overall</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>21.2</td>
<td>176.1</td>
<td>72.6</td>
<td>12.5</td>
<td>9.0</td>
<td>64.5</td>
</tr>
<tr>
<td>SD</td>
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<td>(8.6)</td>
<td>(10.6)</td>
<td>(4.9)</td>
<td>(3.2)</td>
<td>(11.3)</td>
</tr>
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</table>

As a result, circumference correlated poorly ($r = 0.467, p = 0.15$), and $r = 0.499, p = 0.12$) with muscle area of leg for the operative leg and non-operative leg, respectively. However, a ratio of circ/SF showed correlation of $0.753 (p = 0.006)$ and $0.787 (p = 0.003)$ for muscle area of the operative and nonoperative legs, respectively.

Isokinetic test data was, overall, a poor indicator of muscle size. Torque correlated with the muscle area at 240°/sec ($r = 0.76, p < 0.05$).

Fiber types were not different between the two legs. Both fiber types were measurably smaller in both legs as determined by the clinical “atrophy factor” measurement. However, only the type II fibers were both statistically and clinically smaller ($p < 0.05$) in the operative leg (Fig. 2).

DISCUSSION

Baugher et al. defined clinical atrophy as a >1 cm difference in thigh circumference between legs. Subjects in this study met this criteria. The atrophy was further accentuated when considering that the skinfold thicknesses were greater in the operative leg. Thus, muscle atrophy was somewhat masked by the selective deposition of fat in the operative leg.
Computerized tomography gave a further look at the amount of atrophy. The area of the whole leg was just over 4% smaller in the operative leg, similar to the 3% reduction as measured by simple circumference. Looking further, the cross-sectional area of the total muscle and bone area was reduced by 9%. Of interest was the lack of difference in hamstrings area while the operative leg quadriceps was 13% smaller. Thus, the difference in leg area reflected a smaller quadriceps that was in turn partially masked by the increase in calculated area of subcutaneous fat. As a result, the use of circumference as a measure of quadriceps growth is probably too gross a measure. Based on the correlations in this study, a more desirable clinical figure to use would probably be a ratio of circ/SF (15 cm above the superior pole of the patella). Differences between legs would indicate different muscle area.

The current literature describing fiber areas in knee surgery patients suggest a selective type I atrophy, while these data show type II atrophy. The differences may be attributed to subject selection and timing of the biopsy. The delay from injury to surgery for the subjects in this study was very short (14 days). The authors biopsied the patients 13 months later. Eleven of the 12 subjects of Edstrom had chronic knee instability of 4-5 years duration and showed type I atrophy at the time of surgery. The other subject elected surgery soon after the injury. No differences in fiber areas of the type I and II fibers were seen. Hagmark and Eriksson’s subjects all had chronic knee instability of greater than 3 months duration. The biopsy was taken at surgery, then after 5 weeks of either a cylinder cast or moveable cast bracing. Hagmark et al. followed a similar protocol for the timing of their biopsies (at surgery and after 5 weeks of immobilization). Unfortunately, the follow-up nature of this study left the authors without a biopsy at surgery or after casting.

Gross performance measures on the isokinetic dynamometer are pictured in Figure 1. There was a parallel reduction in torque for the operative leg in both sexes with no differences in hamstrings torque production. This latter finding, coupled with the similarity in hamstring muscle area, is consistent with recently published data. Of course, this assumes an acceptable definition of “insufficient” or “within normal limits.” Goslin and Charteris have suggested that the “normative” relationship between the “nondominant” and “dominant” legs be less than a 14% deficit in males and 19% in females and that the normal ratio of hamstrings to quadriceps torque be from 0.3 to 0.8. According to these limits, the patients in this study would be considered normal. If a deficit of greater than 10% is considered to be abnormal or insufficient, then the subjects would be considered either as not being completely successful in their rehabilitation or not having had sufficient time for rehabilitation as previously suggested.

These data compare well with the 10–12% reduction in torque of the rehabilitated postmeniscectomy knee. The 5–10 year follow-up study by Arvidsson et al. grouped subjects according to clinical results (“excellent,” “good,” “fair,” “poor”). They reported operative leg deficits at a slow isokinetic speed (30°/sec) of 9, 10.25, 17, and 10% for each clinical group, respectively. These results at 1 year were quite similar to what has been reported at 5–10 years postsurgery. Combining this data set with reported data taken at less than 1 year postsurgery to that taken at extended, follow-up, it appears that differences between the surgical and nonsurgical legs lessen to a plateau at about 1 year and are maintained.

**SUMMARY**

In summary, it appeared, at a mean follow-up period of 13 months, that quadriceps function, as measured by isokinetic testing, was still depressed. This functional deficit reflected a reduced cross-sectional area of the quadriceps and general muscle fiber atrophy, particularly as type II atrophy. However, gross evidence of muscle atrophy was partially masked by selective fat deposition in the operative leg.
REFERENCES


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