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RESEARCH REPORT

Electromyographic Analysis of Quadriceps Fatigue After Anterior Cruciate Ligament Reconstruction

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Study Design: Prospective, observational study.
Objectives: To document changes in surface electromyographic activity during sustained maximum quadriceps contractions in patients before and 5 weeks after anterior cruciate ligament (ACL) reconstruction.
Background: Quadriceps weakness after injury and reconstruction of the ACL is well documented. The effect of weakness on muscle fatigue, however, is not well understood.
Methods and Measures: Electromyographic signals were recorded from the vastus lateralis, vastus medialis, and rectus femoris muscles during 30-second maximum isometric contractions at 30°, in 42 patients preoperatively and 5 weeks postoperatively. Signal amplitude was quantified by integrating the rectified signal (iEMG) for the initial and final 5 seconds and comparing the involved and uninvolved sides. Median frequency (MF) was computed from 4096 point fast Fourier Transforms performed at the beginning and end of the 30-second contractions.
Results: Patients had moderate preoperative quadriceps weakness (16% deficit) and gross postoperative weakness (41% deficit). Weakness was associated with deficits in both MF and iEMG ($r = 0.69$–0.67). During the preoperative fatigue test, torque declined similarly on the involved and uninvolved sides (significant fatigue effect). During the postoperative fatigue tests, however, torque increased on the involved side and declined on the uninvolved side (significant side by fatigue interaction). For the initial 5 seconds, MF was lower on the involved than the uninvolved side but subsequently showed a smaller decline over 30 seconds preoperatively and postoperatively (significant side by fatigue interactions). IEMG was lower on the involved side preoperatively and postoperatively. During the fatigue tests, iEMG increased similarly in the involved and uninvolved sides both preoperatively and postoperatively.
Conclusion: Quadriceps endurance exercises are not indicated after ACL reconstruction. Quadriceps weakness after ACL reconstruction was associated with fatigue resistance. Lower initial MF and smaller decline in MF during sustained contraction is consistent with fast-twitch fiber atrophy and explains fatigue resistance. *J Orthop Sports Phys Ther 2001;31:25–32.*

Key Words: *fiber type, isometric strength, median frequency*

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Quadriceps weakness after injury to and reconstruction of the anterior cruciate ligament (ACL) is well documented.[13,15,16,20] Before ACL reconstruction, patients typically have moderate quadriceps weakness.[15] More pronounced weakness is evident in the early postoperative period.[13,20] Despite aggressive rehabilitation, most patients have residual quadriceps weakness 6 months postoperatively.[16] The dramatic loss of quadriceps function in the immediate postoperative period is believed to be due to such factors as decreased weight-bearing, knee joint effusion, pain, and harvesting of the patellar tendon graft.[24] Immediate weight-bearing after ACL reconstruction improves voluntary activation of the quadriceps and results in a lower subsequent incidence of anterior knee pain.[24] Tyler et al[24] found that 2 weeks after ACL reconstruction the amplitude of vastus medialis electromyographic (EMG) activity was less than 50% of normal, indicating a profound loss of quadriceps function.[24] Activity from other quadriceps muscles was not recorded, however, and associated changes in the frequency content of the EMG signal were not examined.

The frequency content of the EMG signal during voluntary contractions in weakened quadriceps muscles has been studied in ACL deficient patients.[17,23] McNair and Wood[17] demonstrated lower vastus lateralis median frequency on the involved side in 17 unilateral ACL deficient patients. Lower median frequency was attributed to selective fast-twitch fiber atrophy. Effects on the amplitude of the EMG signal were not reported, however, and activity from other quadriceps muscles was not recorded. Tho et al[23] measured quadriceps EMG activity during sustained isometric knee extension contractions in 15 patients before ACL reconstruction. A greater decline in mean power frequency (MPF) was seen in the involved quadriceps, suggesting greater fatigue. The patients had 6 to 8 weeks of rehabilitation and did not have quadriceps weakness at the time of testing.

The effect of weakness on fatigue is not well understood. Snyder-Mackler et al[20] found that quadriceps weakness after ACL reconstruction was associated with reduced fatigue. The rate of torque decline during sustained electrically stimulated submaximal knee extension contractions was markedly less on the involved side 4 weeks after surgery.[20] This fatigue resistance was attributed to selective atrophy of fast-twitch fibers. However, these results have not been confirmed with voluntary contractions, and associated EMG indices of fatigue after ACL reconstruction have not been examined.

EMG signal changes associated with muscle fatigue have been studied extensively during voluntary contractions in normal muscle.[3,9] Fatigue is characterized by a shift in the frequency spectrum to lower frequencies. This has been referred to as spectral compression and primarily reflects a decrease in muscle fiber conduction velocity.[9,10,12] Mean power frequency (MPF) and median frequency (MF) are commonly used to quantify the fatigue-related frequency shifts.[7,11,12]

The purpose of our study was to analyze the frequency and amplitude changes in surface EMG activity during sustained voluntary quadriceps contractions in patients before and 5 weeks following ACL reconstruction.

METHODS

Quadriceps surface EMG signals were recorded during maximal sustained isometric contractions in 42 patients (29 men, 13 women; age 31 ± 1 year, height 173 ± 1 cm, weight 74 ± 2 kg) within 2 weeks before ACL reconstruction and again 5 weeks after reconstruction. Patient consent was secured in compliance with the institution's clinical research and investigations committee guidelines. Endoscopic reconstructions were performed by 1 of 2 surgeons (S.J.N., M.G.B.) at an average of 16 ± 6 months from the time of injury (2 weeks to 17 years). Bone-patellar-tendon-bone (BPTB) autografts were used in 41 patients and a BPTB allograft was used in 1 patient. Two patients were undergoing revision reconstruction (1 BPTB autograft from the contralateral knee, 1 BPTB allograft).

Postoperatively, patients ambulated using axillary crutches, with the knee in a drop-lock brace locked in extension. Crutch use was discontinued within 1 week, according to patient tolerance, and the brace was unlocked for ambulation at 2 weeks and discontinued 4 weeks postoperatively. Patients began daily rehabilitation exercises on postoperative day zero with physical therapy beginning at 1 week. All patients followed the same rehabilitation protocol.[13] No specific quadriceps endurance exercises were performed in the first 5 weeks of rehabilitation.

To measure isometric strength, patients were seated in an upright position with the hips at approximately 90° of flexion. The knee joint was aligned with the axis of rotation of the dynamometer (Biodex System 2, Shirley, NY) and the leg was secured to the dynamometer arm at the ankle. The knee joint was set at 30° of flexion and subjects were instructed to maximally contract the knee extensors; consistent verbal encouragement was provided to ensure maximal effort. Three 5-second contractions were performed with 10 seconds between efforts. After a 1-minute rest, patients were instructed to maintain a maximum knee extension contraction for 30 seconds. This protocol was performed with the involved and uninvolved limbs in an arbitrary order.

During isometric contractions EMG activity was recorded from surface electrodes placed over the rectus femoris (RF), vastus lateralis (VL) and vastus medialis (VM) muscles. The skin was shaved, cleaned, and abraded before application of 10mm diameter Ag/AgCl electrodes on a 34 by 22 mm adhesive gel surface. All electrodes were placed 3 centimeters apart (center to center). RF electrodes were placed midway along a line between the anterior superior iliac spine and the superior pole of the patella. VL electrodes were placed 4 finger breadths proximal to the superiolateral border of the patella along the assumed line of the fibers. VM electrodes were placed 2 finger breadths proximal to the superiomedial border of the patella along the assumed line of the fibers. A ground electrode was placed on the patella. These electrode placements could be reliably reproduced and they provided good separation to minimize crosstalk. It is possible, however, that the rectus femoris electrodes were not placed distal to the innervation zone and this may represent a confounding factor.

The telemetered EMG signal was band pass filtered from 12 to 500 Hz and sampled at 1000 Hz with a common-mode rejection ratio of 135dB (Telemyo, Noraxon, Scottsdale, Ariz). The raw signal was full-wave rectified and integrated (iEMG) for analysis.

Fast Fourier Transforms (FFT) of 4096 points (ie, 4.096 seconds) were applied to the raw signal from which MF was computed. All computations were performed using the manufacturer-supplied software (Noraxon, Scottsdale, Ariz).

Data Analysis

Mean torque, iEMG, and MF for the initial and final 5 seconds of the 30-second fatigue test were analyzed. MF measurements were actually calculated over 4.096 seconds since the number of points in the FFT must be a power of 2 and the sampling rate was 1000Hz. Repeated measures ANOVA was used to examine effects of side (involved, uninvolved), surgery (preoperative, 5 weeks postoperative), fatigue (initial, final), and muscle (RF, VL, VM) on isometric torque, MF, and iEMG. Planned pairwise comparisons, with Bonferroni corrections, were made between the involved and uninvolved sides and are reported as deficits (*P* values reported in the results section have been adjusted). Isometric knee extension strength deficit, MF deficit, and iEMG deficit were computed as (uninvolved-involved)/uninvolved, using the values from the initial 5 seconds of the 30-second fatigue test for each limb. MF and iEMG values for each muscle were summed for computation of deficits. Linear regression analysis (*r*) was used to test the bivariate associations between deficits in strength, MF, and iEMG. Stepwise multiple regression analysis (*R*) was used to determine if the explained variance could be improved by adding additional independent variables to bivariate analyses.

RESULTS

Isometric Torque During the Fatigue Test

Preoperative knee extension strength deficit was 16% (t_{41df} = 4.2, P = .001) (Figure 1), increasing to 41% by 5 weeks postoperatively (side by surgery $F_{1,41df}$ = 34.2; P = .001). Torque decline during the preoperative fatigue test was not different between the involved (2.1%) and uninvolved sides (5.2%) (side by fatigue $F_{1,41df}$ = 1.8; P = .187; fatigue effect $F_{1,41df}$ = 6.0; P = .019). However, during the postoperative fatigue tests, torque decline was greater on the uninvolved side (4.6% decline) compared with the involved side (4.1% increase) (side by fatigue $F_{1,41df}$ = 10.5; P = .002).

Median Frequency During the Fatigue Test

Preoperatively, a deficit in MF of the involved side was seen in VM (9.3%, t_{41df} = 3.7, P = .001) but not in VL (7.0%, t_{41df} = 2.5, P = .048) and RF (0.6%, t_{41df} = 0.4, P = .9)(Figure 2). Five weeks postoperatively, a deficit in MF was evident in all 3 muscles

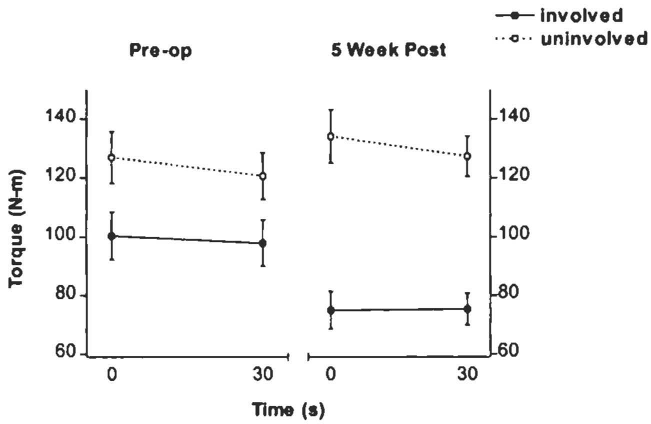

FIGURE 1. Isometric torque (mean±sem) during the initial and final 5 seconds of the 30-second maximum isometric contractions, before ACL reconstruction (Pre-op) and 5 weeks after surgery (5 Wk Post). Initial torque was lower on the involved side preoperatively (P < .01) and 5 weeks after surgery (P < .01). Change in torque over 30 seconds was significantly less in the involved side 5 weeks following surgery (side by fatigue P < .01).

(RF 12.1%, t_{41df} = 5.5; VL 15.9%, t_{41df} = 5.5; VM 16.4%, t_{41df} = 8.0; all P = .001). As expected MF declined during the fatigue tests on the uninvolved side in all 3 muscles, both preoperatively (RF 9%, VL 6.7%, VM 7.5%) and postoperatively (RF 14.1%, VL 7.1%, VM 7.9%). In contrast, on the involved side VL MF did not decline during the preoperative fatigue tests, and neither VL nor VM MF declined during the postoperative fatigue tests. Although there were significant declines in VM MF preoperatively (3.4%, t_{41df} = 4.8, P = .001) and RF MF postoperatively (7.7%, t_{41df} = 3.0, P = .015), these deficits were significantly less compared to the uninvolved side (side by fatigue VM $F_{1,41df}$ = 9.4, P = .005; RF $F_{1,41df}$ = 9.5, P = .004).

Integrated Electromyogram During the Fatigue Test

Preoperatively, deficits in iEMG were evident in VL (23%, t_{41df} = 3.6, P = .003) and VM (22%, t_{41df} = 4.3, P = .001) but not RF (4%, t_{41df} = 0.55, P = .9) (Figure 3). Postoperatively, these iEMG deficits were increased (VL 46%, t_{41df} = 7.3, P = .001; VM 39%, t_{41df} = 5.7, P = .001) and a deficit in RF (35%, t_{41df} = 5.1, P = .001) was also evident. For all fatigue tests, iEMG consistently increased by approximately 18% during the 30 seconds of sustained maximum contraction (fatigue effect $F_{1,41df}$ = 26.1, P = .001). This increase in iEMG was not different between involved and uninvolved sides (side by fatigue $F_{1,41df}$ = 0.35, P = .557), and the effect was similar in the 3 muscles tested (muscle by fatigue $F_{2,82df}$ = 0.7, P = .499). The data from postoperative fatigue tests for 2 subjects are provided in Figure 4.

Patients were categorized as acute (<2 months from injury to surgery), subacute (2–6 months from injury to surgery) or chronic (>6 months from injury to surgery). Sixteen patients (11 men, 5 women) had acute injuries, 8 (3 men, 5 women) had subacute injuries, and 15 (12 men, 3 women) had chronic injuries. Patients with acute injuries had greater preoperative strength deficits (32 ± 20%) than patients with subacute (9 ± 21%) and chronic injuries (5 ± 21%, $F_{2,39df}$ = 8.2, P = .001). Preoperative iEMG deficits were also greater in patients with acute injuries (34 ± 28%) than in patients with subacute (3 ± 33%) and chronic injuries (11 ± 23%, $F_{2,39df}$ = 4.7, P = .015).

Associations Between Deficits in Strength, Median Frequency and iEMG

Although deficits in both MF and iEMG were observed in the involved quadriceps, these electromyographic findings were not correlated, either preoperatively (r = 0.12, P = .443) or postoperatively (r = 0.11, P = .483). Preoperatively, knee extension strength deficit was related to the MF deficit (r = 0.34, y = 0.63x + 0.13, P = .026) and the iEMG deficit (r = 0.64, y = 0.52x + 0.07, P = .001). Together, MF and iEMG deficits explained 48% of the variance in knee extension strength deficit (R = 0.69, P = .001). Similarly, postoperative knee extension strength deficit was related to MF deficit (r = 0.46, y = 1.0x + 0.26, P = .002) and iEMG deficit (r = 0.53, y = 0.4x + 0.26, P = .001). Postoperative MF and iEMG deficits combined to explain 45% of the variance in knee extension strength deficit (R = 0.67, P = .001).

The marked increase in the strength deficit from preoperatively (16%) to 5 weeks after surgery (41%) was correlated with the corresponding increase in the iEMG deficit from 18 to 36% (r = 0.6, y = 0.37x + 0.18, P = .001). The change in the MF deficit (5% preoperative, 15% postoperative) was unrelated to the concurrent increase in the strength deficit.

Surprisingly, the preoperative and postoperative strength deficits were only weakly correlated (r = 0.36, y = 0.35x + 0.02, P = .018). In fact, the preoperative MF deficit was more strongly related to the postoperative strength deficit than the preoperative strength deficit (r = 0.4, y = 0.69x + 0.39, P = .008). While several factors appeared to contribute to postoperative weakness, 3 factors (postoperative iEMG deficit, postoperative MF deficit and preoperative MF deficit) combined to explain 47% of the variance in the postoperative strength deficit (R = 0.71, $y = 0.36x_1 + 0.71x_2 + 0.43x_3 + 0.16$, P = .001). In the regression equation x_1, x_2, x_3 refer to the postoperative iEMG deficit, postoperative MF deficit and preoperative MF deficit, respectively. The preoperative strength deficit did not further explain the variance in the postoperative strength deficit.

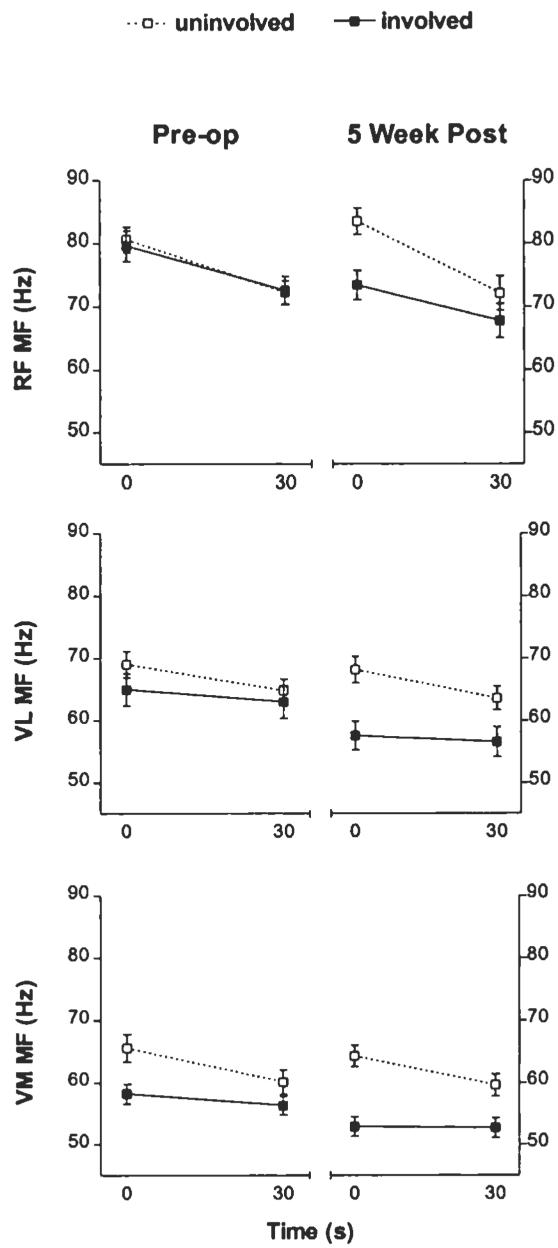

FIGURE 2. Median frequency (MF) in the rectus femoris (RF), vastus lateralis (VL), and vastus medialis (VM) muscles (mean±sem) during the initial and final 5 seconds of the 30-second maximum isometric contractions, before ACL reconstruction (Pre-op), and 5 weeks following surgery (5 Wk Post). Involved MF was initially lower and showed a smaller decline over 30 seconds preoperatively (side by fatigue P < .01) and 5 weeks following surgery (side by fatigue P < .01).

DISCUSSION

In the present study patients had moderate quadriceps weakness (16%) before ACL reconstruction and gross weakness 5 weeks postoperatively (41%). Preoperative and postoperative weakness were associated with deficits in MF and iEMG. Postoperative fatigue tests revealed marked differences between involved and uninvolved sides. As expected, both torque and MF declined on the uninvolved side during the fatigue test. In contrast, torque and MF were relatively unchanged on the involved side. These data provide

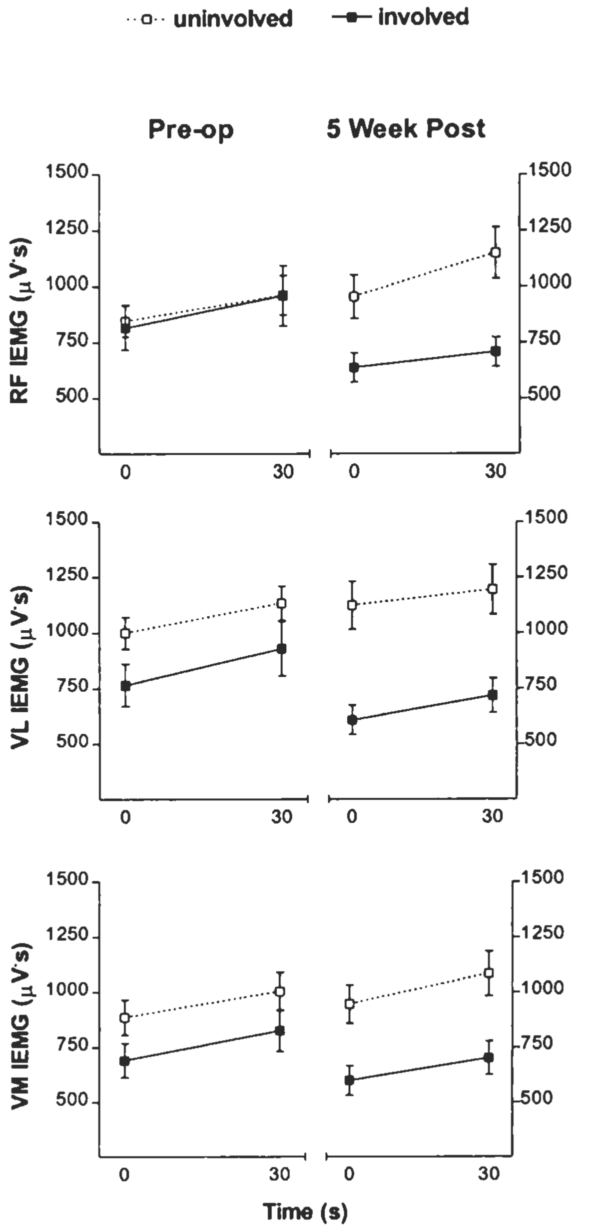

FIGURE 3. IEMG in the rectus femoris (RF), vastus lateralis (VL), and vastus medialis (VM) muscles (mean±sem) during the initial and final 5 seconds of the 30-second maximum isometric contractions, before ACL reconstruction (Pre-op) and 5 weeks after surgery (5 Wk Post). IEMG was significantly lower on the involved side preoperatively in the VL and VM ($P < .01$) and 5 weeks after surgery in all 3 muscles ($P < .01$). During the fatigue tests, iEMG increased ($P < .01$) similarly in the involved and uninvolved sides both preoperatively and 5 weeks after surgery.

electromyographic evidence of fatigue resistance in the weakened quadriceps muscles during voluntary contractions. Based on these and previous results,[20] quadriceps endurance exercises are not indicated after ACL reconstruction.

Isometric Strength and Fatigue

Despite marked postoperative weakness, patients exhibited less fatigue on the involved quadriceps side during maximum voluntary isometric contractions. This is consistent with a previous observation that used electrically stimulated contractions.[20] Snyder-Mackler et al[20] demonstrated approximately 20% less fatigue in the involved quadriceps in patients 4 weeks after ACL reconstruction. Isometric strength deficit (tested at 60°) was 40% in that study, compared with 41% at 30° in this study. The preoperative isometric knee extension strength deficit (16%) was slightly lower than previous preoperative results (20–25%) with slow speed isokinetic testing.[15,16]

Surprisingly, a 30-second sustained maximal contraction at 30° of knee flexion did not result in a marked decline in torque. This contrasts with previous data on nonimpaired subjects that showed a 25% torque decline during 30 seconds maximum quadriceps contraction at 90° of knee flexion.[8] The quadriceps, however, are much less fatigable at short versus long muscle lengths.[1] Arendt-Nielsen et al[1] demonstrated that a quadriceps contraction at 80% MVC could be maintained for 52 seconds at 45° but only for 24 seconds at 90°. In the present study 30° was chosen to minimize patellofemoral stress and reduce the potential for pain during maximal contractions in the postoperative condition. It is also likely that the patients in this study did not achieve a true maximum contraction. This possibility is supported by the increase in iEMG during the fatigue tests.

Median Frequency During the Fatigue Test

The principal finding in this study was a lower initial MF and smaller decline in MF on the involved side during maximum isometric contractions. Preoperatively, lower MF was seen primarily in the VM while all 3 muscles were affected equally postoperatively. MF declined minimally in the vastii muscles during the fatigue tests both preoperatively and 5 weeks after surgery. MF and MPF during maximal contractions have been related to muscle fiber type.[6,12] Gerdle et al[6] reported a strong negative relationship ($r = -0.93$) between MPF and percent type I fiber number in the vastus lateralis and isokinetic knee extension strength, in a group of 9 women. Additionally, MPF was higher in the RF compared with the vastii muscles. Similar effects were seen in the present data and may reflect a greater proportion of fast-twitch fibers in the rectus femoris muscle.[5] Kupa et al[12] also reported a relation ($r = -0.92$) between MF and percent slow oxidative fiber area in rats, using supramaximal stimulation. These associations between muscle fiber type and the frequency content of the electromyogram can be explained by lower muscle fiber conduction velocities in slow-twitch fibers.[12] Similarly, in the present study, lower MF in the involved quadriceps may reflect lower conduction velocity. MF and conduction velocity during maximum isometric contractions of the elbow flexors were lower in patients with hypokalemic periodic pa-

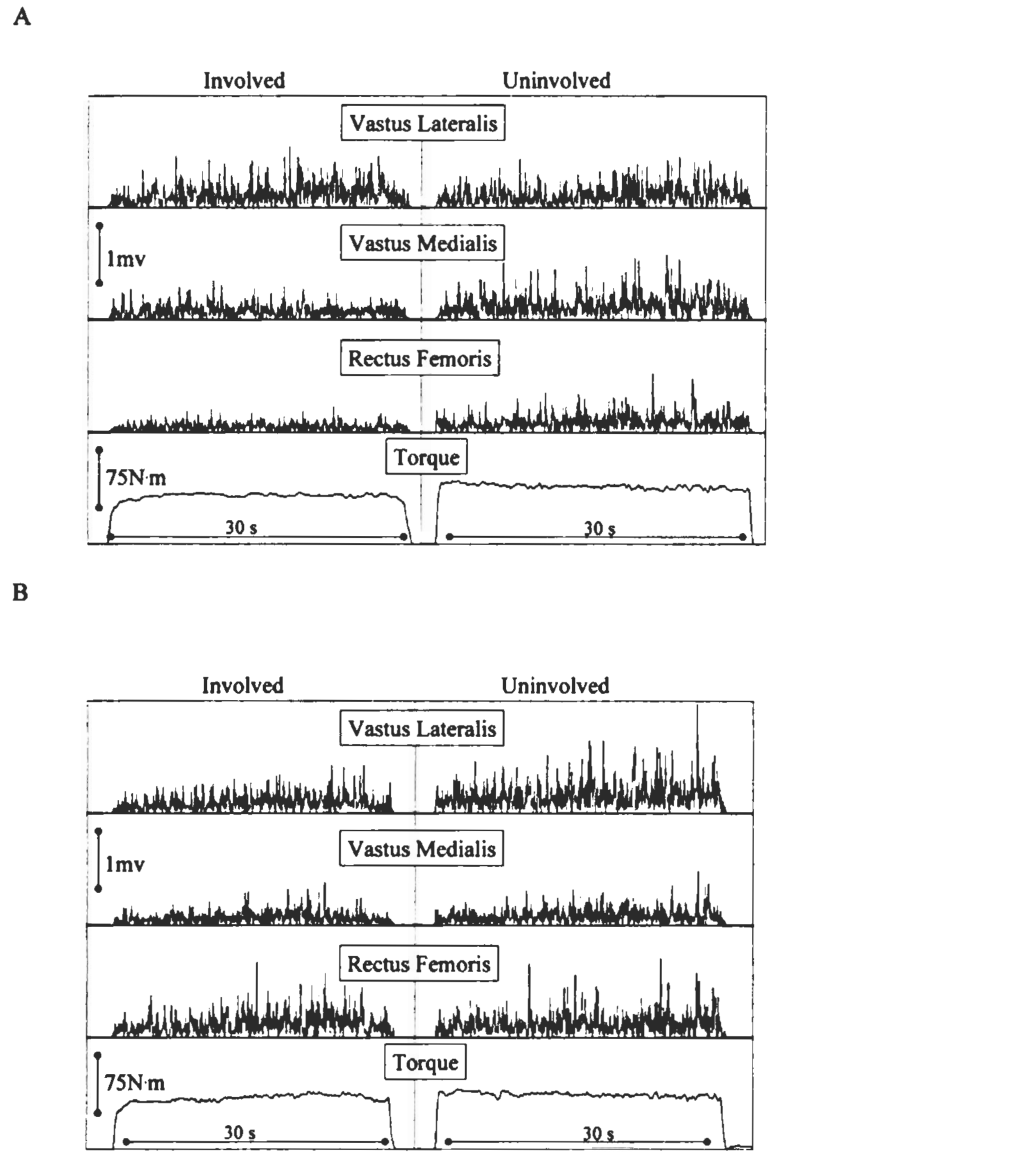

FIGURE 4. The rectified EMG activity and torque output from the involved and uninvolved quadriceps of 2 representative subjects (A and B) during the postoperative fatigue test. The EMG activity and torque are higher on the uninvolved side for both subjects. Additionally, the EMG appears to be lower in the initial 5 seconds than the final 5 seconds in most of the recordings. Initial torque is higher on the uninvolved side and declines over 30 seconds whereas torque is relatively unchanged over the 30 seconds on the involved side.

ralysis, a disease that results in preferential atrophy of fast-twitch fibers.[25] McNair and Wood[17] attributed lower VL MF in patients with ACL deficiency during maximal isokinetic contractions to selective atrophy of fast-twitch fibers. Although our data could be interpreted similarly, a decrease in conduction velocity could also reflect nonselective atrophy of all fibers. Lower longissimus MF in patients with chronic low back pain when compared with controls, was attributed to fiber atrophy.[18] Alternatively, a decrease in firing rate of all motor units may explain the lower MF.[10] However, MF is thought to be relatively insensitive to alterations in firing rate during high intensity contractions.[21] It is also possible that lower MF reflects an increase in fat tissue secondary to atrophy, with fat acting as a low-pass filter.[10]

The decline in MF and MPF during sustained or repeated contractions has also been related to muscle fiber type.[11,12] Komi and Tesch[11] showed that during 100 maximal knee extension contractions MPF declined by 12% in subjects with less than 50% fast-twitch fiber area, compared with a 25% decline in subjects with greater than 50% fast-twitch area.[11] Similarly, Kupa et al[12] demonstrated a strong relation ($r = 0.91$) between percent area of fast glytolytic fibers and the decline in MF during sustained supramaximal stimulated contractions in rats. These effects were attributed to metabolic differences between fiber types. Fast-twitch fibers have a greater potential for accumulation of lactic acid, K^+, H^+, and greater potential for decreased intramuscular pH, all of which slow conduction velocity.[12] Quadriceps fatigue has been studied in patients with 95–100% slow twitch fibers secondary to congenital myopathy.[14] Initial conduction velocity and decline in conduction velocity were less in 6 patients compared with 12 controls. Similar effects were seen with MF but did not reach statistical significance. Lower initial MF and smaller decline in MF on the involved quadriceps, as demonstrated in this study, are consistent with a predominantly slow-twitch muscle. Snyder-Mackler et al[20] attributed fatigue resistance after ACL reconstruction to selective fast-twitch fiber atrophy. Similarly, greater fast-twitch fiber atrophy has been demonstrated in the VL muscles of astronauts following short periods of spaceflight.[2]

Lower MF decline on the involved side during the fatigue tests is in contrast to the findings of Tho et al[23] who showed a greater decline in MPF in the involved quadriceps during sustained contractions in patients with ACL deficiency. The fact that their patients received preoperative physical therapy and had normal quadriceps strength may, in part, explain the disparity between our results and theirs. In our study, a larger sample was examined, patients had marked quadriceps weakness, and measurements were made both preoperatively and 5 weeks postoperatively, when quadriceps function was grossly impaired.

Integrated Electromyogram During the Fatigue Tests

IEMG was lower on the involved side both preoperatively (18%) and 5 weeks after surgery (36%). Reduced amplitude of the quadriceps electromyogram has been attributed to inhibition.[4,24] Tyler et al[24] found involved vastus medialis iEMG to be 60–70% of uninvolved values before ACL reconstruction with almost complete inhibition 1 day after surgery. Two weeks postoperatively vastus medialis iEMG had improved to 15–40% of the uninvolved, and by 6 months no difference was evident. The immediate loss of activity 1 day postoperatively was clearly due to inhibition. In general, iEMG changes have been attributed to neural, rather than trophic, effects. Increased iEMG early in strength training is attributed to neural facilitation while no change is seen in iEMG later in training when hypertrophic effects predominate.[19] It is likely that lower iEMG on the involved side in this study primarily reflected inhibition.

During sustained contraction, similar increases in iEMG were evident in the involved and uninvolved sides. The increase in iEMG over 30 seconds of maximum isometric contraction indicates that maximum motor unit recruitment was not initially achieved despite maximum voluntary effort. Similarly, Tesch et al[22] demonstrated progressively increasing iEMG during repeated maximum isokinetic contractions of the knee extensors in unimpaired subjects. They concluded that subjects did not initially achieve maximum recruitment. Alternatively, increased iEMG may, in part, reflect motor unit synchronization.

Associations Between Deficits in Strength, Median Frequency, and iEMG

Surprisingly, iEMG deficits were not correlated with MF deficits, suggesting that these effects were independent of each other. This independence is further supported by the relation of MF and iEMG deficits to quadriceps weakness in multiple regression analyses. Preoperatively, MF and iEMG deficits combined to explain 48% of the variance in the strength deficit. Postoperatively, these variables combined to account for 45% of the variance in the strength deficit. The independence of MF and iEMG deficits supports the conclusion that these effects reflect different processes. It is likely that the deficit in MF primarily reflected atrophy while the deficit in iEMG primarily reflected inhibition.

The weak relation between preoperative and postoperative strength deficits ($r = 0.35$) indicates that preoperative strength is not a strong predictor of weakness after ACL reconstruction. This finding agrees with previous work that showed preoperative strength to be a poor predictor of residual weakness 6 months after ACL reconstruction.[16] The dramatic loss of strength from preoperatively (16% deficit) to 5 weeks after surgery (41% deficit) was correlated ($r = 0.6$, $P < .01$) with the corresponding loss in iEMG (18 to 36% deficit). This supports the clinical impression that the immediate loss of quadriceps function after ACL reconstruction results from neural inhibition.

CONCLUSION

Quadriceps weakness after ACL reconstruction was associated with fatigue resistance. Weakness appeared to be caused by the combined effects of atrophy and inhibition. Lower initial MF and smaller decline in MF during sustained contractions are consistent with fast-twitch fiber atrophy. To optimize restoration of strength, an emphasis should be placed on short duration, high intensity contractions with ample recovery time.

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