Recovery of Contractile Properties of the Knee-Extensor Muscles After Arthroscopic Partial Meniscectomy

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Context: Contractile characteristics of the knee extensors after arthroscopic meniscectomy are poorly understood. Objective: To measure the recovery of knee-extensor-muscle contractility after arthroscopic partial meniscectomy. Design: Single-group repeated measures. Setting: Kinesiology and biomechanics laboratory. Subjects: Fourteen patients with arthroscopic partial medial meniscectomies. Main Outcome Measures: Maximal isometric voluntary contraction (MVC) force, rate of force development (MRFD$_{ES}$), and half-relaxation time (HRT$_{ES}$) of evoked tetanic contraction preoperatively and during 6 months postoperatively. Results: Two weeks postoperatively, a reduction in MVC force of 27.1% and in MRFD$_{ES}$ of 17.8% and a prolongation of HRT$_{ES}$ of 34.0% in the injured leg were found. A significant MVC-force deficit (17.5%) was observed 3 months postoperatively. Conclusions: The recovery of knee-extensor-muscle voluntary strength is more delayed than are evoked tetanic-contractile characteristics after partial meniscectomy. The rehabilitation protocol seems to be insufficient to attain effective recovery of knee-extensor-muscle voluntary strength. Key Words: meniscus injuries, knee extensors, electronically evoked tetanic contractions


There is a high rate of incidence of meniscus injuries resulting from different activities at work and in sport. Partial meniscectomy leads to impairment of the function of the menisci with regard to their load-transmission capability and stability. It has been observed that even isolated lesions of ligaments, joint surfaces, or menisci can lead to loss of muscle strength that might be associated with atrophy and the presence of abnormalities in the activation profiles of the knee-extensor muscles. Thigh-muscle atrophy and strength deficit are the major problems in rehabilitation after meniscectomy. The contractile properties and neural coordination of the knee-extensor muscles play an important role in the function and stability of the knee joint. Re-
habilitation of muscle function is therefore an important goal after knee injuries. Most studies on the changes in force-generating capacity of the knee-extensor muscles after arthroscopic meniscectomy have focused on maximum voluntary isometric or isokinetic strength deficit in the injured leg in relation to the uninjured leg. Less attention has been paid to the changes in electrically evoked contractile characteristics of the knee-extensor muscles after arthroscopic meniscectomy. Electrically elicited twitch or tetanic-contraction characteristics, however, can be used to measure force-generating capacity and time course of contraction and relaxation within the muscles, independent of volition, skill, and motivation of the subjects.

The purpose of this study was to measure the changes in contractile properties of the knee-extensor muscles in patients with arthroscopic partial medial meniscectomies during their 6-month postoperative recovery. We were especially interested in examining the isometric maximal voluntary contraction (MVC) force, as well as force-time and relaxation-time characteristics of the electrically evoked submaximal tetanic contraction, which corresponded to 25% of MVC force. All characteristics of the injured leg were compared with those of the uninjured leg.

**Methods**

**Subjects**

The subjects were 14 male patients age 21–33 years with arthroscopic partial medial meniscectomies who, after giving written informed consent, participated in this study. The mean (± SEM) age, height, and body mass of the patients were 26.4 ± 2.3 years, 179.6 ± 2.1 cm, and 77.4 ± 3.5 kg, respectively. Subjects had no previous knee injuries. Patients with concomitant injuries (eg, lesions of the lateral meniscus or cruciate ligaments, osteochondral injuries, or chondral damage in other components) were excluded. The period of duration of knee pain before the operation was 3.7 ± 1.2 months. One surgeon at Tartu University Hospital performed the arthroscopic operation for all patients. The subjects were moderately physically active—no competing athletes were included. They had no orthopedic or neurological limitations or contraindications for exercise testing or training. Immediately after the surgery and throughout the 3rd postoperative week, multiple-angle isometric and cocontraction exercises plus straight-leg raises (in supine position, 20° to 70° knee flexion, approximately 10 seconds up and 10 seconds down for 5 minutes, with a rest period of 1 hour, 10–12 times per day) were used to limit thigh-muscle atrophy. Four to 8 weeks postoperatively, ergometry on stationary bicycle was recommended. After 9 weeks the therapeutic exercises were progressed gradually from submaximal to maximal to ensure normal range of motion of the tibiofemoral and patellofemoral joints, and closed kinetic chain exercises (leg presses, semisquats) were introduced.
Isometric MVC force and electrically evoked tetanic-contraction characteristics of the knee-extensor muscles in the injured and uninjured leg for all patients were recorded preoperatively and 2 weeks and 3 and 6 months postoperatively. Postoperatively, during every test session pain and swelling were registered. The subjects were asked to report their complaints of pain in general and during the strength test. In both cases pain was scored on a 5-point scale: 0 = no pain, 1 = occasional moderate pain, 2 = continuous moderate pain, 3 = occasional severe pain, and 4 = continuous severe pain. Knee swelling was scored before strength testing took place. A 4-point scale was used to rate swelling: − = no clinical signs of intra-articular effusion, ± = clinical signs of intra-articular effusion, + = patellar tap sign after compression of the suprapatellar pouch, and ++ = patellar tap sign without compression of the suprapatellar pouch. The study carried the approval of the university’s ethics committee.

Measurement

We gave the subjects instructions and demonstrated the strength-testing and electrical-stimulation procedures 24–48 hours before collecting the first data. This was followed by a practical session to familiarize the subjects with the procedures. Before testing, each subject underwent a 10-minute warm-up (submaximal leg ergometry during 6 minutes at low intensity, followed by stretch exercises).

During measurement, the subjects were seated in a specially designed dynamometric chair with knee and hip angles at 90° and 110°, respectively. Three Velcro™ belts placed over the chest, hip, and thigh secured the body position. Knee-extension force was recorded by a standard strain-gauge transducer mounted inside a metal frame, which was fastened around the distal part of the ankle above the malleoli using a Velcro belt. The electrical signals from the strain-gauge transducer were digitized on-line (sampling frequency 1 kHz) via a personal computer. The digitized signals were stored on hard disk for further analysis.

Each subject was asked to perform a knee extension against the belt of the strain-gauge system while the isometric MVC force was recorded. The MVC was held for approximately 3 seconds. The force-time curves were analyzed on a personal computer, and the best result from 3 attempts was taken as the MVC force. Before each isometric contraction, subjects were instructed to “push as hard as possible.” Visual on-line feedback was also used to help motivate the subjects. A rest period of 1 minute was allowed between attempts.

The position of the subjects during the recording of force-time and relaxation-time characteristics of the electrically evoked tetanic contraction of the knee-extensor muscles was the same as during MVC-force measurements. Two large (23-× 7-cm) carbon-rubber electrodes (Nemectron, Germany) were used. The skin over the quadriceps muscle was washed with liquid soap and water to reduce electrical impedance. The anode was placed approximately 10 cm proximally from the patella and the cathode 10 cm
proximally from the anode (Figure 1). Transcutaneous electrical stimulation from a standard electrostimulator (Medicor, Hungary) with a frequency of 50 Hz, impulse duration of 1 millisecond, and train duration of 1 second was performed. The electrical impulses were monophasic rectangular waves. The stimulation voltage was adjusted to provide the initial force of about 25% of the isometric MVC force of the knee-extensor muscles. The interval between the final MVC trial and the start of the electrical-stimulation trials was 5 minutes in order to minimize the effects of muscle fatigue. Before stimulation, subjects were instructed to relax their muscles. The force-time curves of the electrically elicited tetanic contraction were analyzed on a personal computer. The following characteristics of the submaximal tetanic contraction were recorded: maximal rate of isometric force development ($\text{MRFD}_{\text{ES}}$), which is the first derivate of force development ($dF/dt$), and half-relaxation time ($\text{HRT}_{\text{ES}}$), which is the amount of time to half of the decline in tetanic force.

**Statistical Analysis**

Data are presented as means and standard errors (± SEM). One-way analysis of variance (ANOVA) for repeated measures, followed by Tukey post
hoc comparisons, was used to evaluate differences between the injured and uninjured legs and between testing periods. The level of $P < .05$ was selected to indicate statistical significance.

**Results**

The MVC force of the knee-extensor muscles was 14.2% less in the injured leg than in the uninjured leg preoperatively, 27.1% less 2 weeks postoperatively, and 17.5% less 3 months postoperatively ($P < .05$; Figure 2[a]). No significant differences ($P > .05$) in MVC force between the injured and uninjured legs were observed 6 months postoperatively. The MRFD$_{ES}$ of the knee-extensor muscles was 17.1% lower in the injured leg than in the uninjured leg preoperatively and 17.8% lower 2 weeks postoperatively ($P < .05$; Figure 2[b]). No significant differences ($P > .05$) in MRFD$_{ES}$ of the knee-extensor muscles were observed between the injured and uninjured legs 3 or 6 months postoperatively. The HRT$_{ES}$ of the knee-extensor muscles in the injured leg was 14.1% longer than in the uninjured leg preoperatively and 34.0% longer 2 weeks postoperatively ($P < .05$; Figure 2[c]). No significant differences ($P > .05$) in HRT$_{ES}$ were found between the injured and uninjured legs 3 or 6 months postoperatively.

Postoperatively, no patients scored 2, 3, or 4 when asked to rate their pain. Complaints of occasional moderate pain (a score of 1) are distributed in Table 1. Two weeks after surgery, 1 patient experienced occasional moderate pain in general, and 6 patients during strength testing. Three months after surgery, only 1 patient complained of moderate pain during strength testing. Six months postoperatively, none of the patients experienced pain.

Two weeks postoperatively, all patients had moderate to severe symptoms of intra-articular effusion (Table 1). During the period of rehabilitation there was a tendency to a gradual reduction of swelling in the injured knee. There were clinically detectable signs of intra-articular fluid in only 1 patient 3 months after surgery. Six months postoperatively no swelling was found.

**Comments**

Several authors have reported recovery of the isometric MVC force of the knee-extensor muscles in patients with partial meniscectomies within a period of 2 months.1-7 The present study indicated significantly lower isometric MVC force of the knee-extensor muscles in the injured leg than in the uninjured leg 3 months after knee-arthroscopic surgery. The rehabilitation program used after partial meniscectomy seems to be insufficient for effective recovery of knee-extensor-muscle voluntary strength. The reduction of maximal voluntary force-generating capacity of the knee-extensor muscles might be caused by several factors. Knee-extensor muscles are closely related to the anatomy of the knee joint (the patella and the patellar tendon
form a part of the knee joint), and instability in the knee can directly affect the quadriceps femoris muscle. The results of this study indicate that all patients had moderate to severe swelling of the knee during the early phase of rehabilitation (2 weeks) after surgery. This is in agreement with previous reports. These symptoms can inhibit the voluntary expression of muscle strength.

It is known that persistent symptoms of knee injuries lead to thigh-muscle-strength deficits in the affected leg. Immobilization is the main cause of muscle atrophy in patients after knee injury and surgery. Surgery and immobilization are associated with immediate atrophy of slow-twitch muscle fibers, and after long-term disuse of the knee, the fast-twitch muscle fibers begin to atrophy. Only part of the deficit in voluntary muscle strength of the injured leg can be attributed to structural atrophy. Muscle-

**Figure 2** Preoperative and postoperative changes in isometric maximal voluntary contraction (MVC) force: (a) maximal rate of isometric force development (MRFD\textsubscript{ES}) and (b) half-relaxation time (HRT\textsubscript{ES}) of (c) electrically evoked tetanic contraction of the knee-extensor muscles after arthroscopic partial medial meniscectomy. Data are means ± SEMs.

*P < .05; **P < .01; ***P < .001.
force production is determined significantly by the central excitatory drive. Full development of potential muscle tension requires maximal recruitment of the motoneurons of agonists and synergists and effective inhibition of the motoneurons of antagonists. Reduced muscle strength can occur if a patient avoids normal use of the extremity because of pain. In this study, approximately 40% of measured patients experienced occasional moderate pain during strength testing 2 weeks after surgery. Thus, postoperative deficit in maximal voluntary force-generating capacity of the knee-extensor muscles in the injured leg is partly a result of an impaired central excitatory drive.

Electrical stimulation has been shown to be effective in aiding knee-extensor-muscle force production after anterior cruciate ligament reconstruction. The changes in electrically evoked contractile characteristics of the knee-extensor muscles after arthroscopic partial meniscectomy, however, have been given less attention. This study showed a significant reduction in electrically evoked force-generating capacity of the knee-extensor muscles in the injured leg, as estimated by maximal rate of isometric force development of tetanic contraction, preoperatively and 2 weeks after knee-arthroscopic surgery. It is well documented that the rate of muscle-force development is closely related to the speed of Ca\(^{2+}\) release by the sarcoplasmic reticulum and the Ca\(^{2+}\) sensitivity of contractile proteins, as well as myosin-ATPase activity and rate of formation of cross-bridges between actin and myosin. The preoperative period and earlier recovery period after knee surgery

<table>
<thead>
<tr>
<th>Table 1</th>
<th>Incidence of Complaints of Occasional Moderate Pain and Each of the Scores on a 4-Point Swelling Scale After Partial Meniscectomy (N = 14)*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time Postoperative</td>
<td>2 weeks</td>
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<tr>
<td>Pain in general</td>
<td>1</td>
</tr>
<tr>
<td>Pain during testing</td>
<td>6</td>
</tr>
<tr>
<td>Intra-articular effusion</td>
<td></td>
</tr>
<tr>
<td>−</td>
<td>0</td>
</tr>
<tr>
<td>±</td>
<td>8</td>
</tr>
<tr>
<td>+</td>
<td>6</td>
</tr>
<tr>
<td>++</td>
<td>0</td>
</tr>
</tbody>
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*− indicates no clinical signs of intra-articular effusion; ±, clinical signs of intra-articular effusion; +, patellar tap sign after compression of the suprapatellar pouch; and ++, patellar tap sign without compression of the suprapatellar pouch.
are characterized by reduced muscle loading and immobilization, and thus the associated muscles experience atrophy of the muscle fibers.\textsuperscript{18,19} It is well known that immobilization is linked with decreased muscle force-generating capacity. Thus, the reduction in electrically evoked force-generating capacity of the knee-extensor muscles in the injured leg might be caused largely by leg immobilization and muscle atrophy.

In the present study, a markedly longer half-relaxation time of electrically evoked tetanic contraction, as an indication of the time course of muscle relaxation, was observed in the knee-extensor muscles of the injured leg than in the uninjured extremity preoperatively and 2 weeks after knee-arthroscopic surgery. Two main factors have been described as being responsible for the duration and rate of muscle relaxation: sarcoplasmic reticulum \( \text{Ca}^{2+} \) uptake and the rate of cross-bridge kinetics.\textsuperscript{26} The prolonged half-relaxation time could result from decreased efficiency in the function of the sarcoplasmic reticulum.

In conclusion, this study indicates that in patients who have had arthroscopic partial medial meniscectomies, the recovery of maximal voluntary force-generating capacity of the knee-extensor muscles of the injured leg to the level of that of the uninjured leg is more delayed than is recovery of electrically evoked force-generating capacity and the time course of muscle relaxation. Swelling of the knee joint seems to be an important cause of inhibition of MVC force of the knee extensors during the early phase of recovery from knee-arthroscopic surgery. The rehabilitation protocol that was used in this study was probably insufficient for effective recovery of knee-extensor-muscle voluntary strength. The results of the study support the use of submaximal tetanic electrical stimulation to evaluate the recovery of knee-extensor-muscle contractility during rehabilitation after arthroscopic partial meniscectomy.

References


