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Effect of arthroscopic partial meniscectomy on the function of quadriceps femoris

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Abstract The purpose of this study was to investigate the functional characteristics of the quadriceps femoris (QF) muscle group after the effect of presurgery disuse, surgery, and postsurgery disuse using surface electromyography and muscle functional magnetic resonance imaging (mfMRI). A total of 20 individuals (11 men and nine women) who underwent arthroscopic knee surgery participated in this study. Maximum voluntary contraction (MVC) of the QF muscle group was measured in the legs that received surgery and those that did not. To acquire the functional properties of the QF muscle group, electromyographic (EMG) activity during repetitive dynamic knee extension exercises (five sets of ten repetitions; load 30% MVC) and mfMRI before and after the exercises were obtained. EMG activity was evaluated in three phases depending on the knee joint angle: concentric and eccentric phases (Con/Ecc), concentric (Con) phase only, and eccentric (Ecc) phase only. The mean MVC of the legs that received surgery was significantly lower (22%) than that of the legs that did not. Regarding the EMG activity during the Con/Ecc and Con phases, there were significant leg and set effects but no significant leg-by-set interactions; however, during the Ecc phase, there was a significant set effect. Regarding changes in the mfMRI signal, leg and exercise had significant effects, but there was no significant leg-by-exercise interaction. These results suggest that presurgery disuse, partial meniscectomy, and postsurgery disuse induce dysfunction of the QF muscle group that is dependent on a decrease in MVC. Thus, these patients need maximal muscle-force improvement for effective rehabilitation after surgery.

Keywords Quadriceps femoris · Meniscal lesion · Maximal voluntary contraction · MRI · Dysfunction

Introduction

It is well known that muscle dysfunction is induced by knee injury, such as before and after arthroscopic meniscectomy for treatment of meniscal lesions. Moffet et al. [18] reported that the type of meniscal lesion affected preoperative knee function in 35 patients. They showed that work during isokinetic knee extension at 30 s^{-1} and 180 s^{-1} was decreased by <36% following treatment of meniscal lesions compared with the uninjured leg. Similarly, Gapeyeva et al. [12] showed that isokinetic torque deficit of the knee extensor muscle group following arthroscopic partial meniscectomy was approximately 30% after 1 month, 18% after 3 months, and 13% after 6 months.

Surface electromyography is generally used to assess the neuromuscular function of the atrophied quadriceps femoris (QF) muscle group. Surprisingly, only two studies, as far as we know, have reported studying meniscal lesion-induced dysfunction of the QF muscle group using surface electromyography (EMG) [17, 18]. Moffet et al. [17, 18] showed that EMG activity of the vastus medialis (VM) and

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vastus lateralis (VL) muscles in an injured leg was −1% to 40% lower than that for the uninjured leg during isokinetic knee extension at 30 s^{-1} and 180 s^{-1}. Their study focused on the maximal effort of knee extension. No study, as far as we know, has focused on neuromuscular activity during submaximal knee extension exercises in patients following arthroscopic meniscectomy. We emphasize that evaluation of neuromuscular activity during submaximal exercise is important because almost all activities in our daily life are not maximal effort activities but submaximal effort, such as standing, walking, and stair climbing.

Neuromuscular activity during exercise has been studied using conventional techniques such as surface EMG. Whereas muscle functional magnetic resonance imaging (mfMRI) has been used to acquire anatomical information, the use of human skeletal muscle has also been assessed with exercise-induced contrast shift in spin–spin relaxation times of MRI. Change in mfMRI signal has been shown to be correlated with integrated EMG activity [2, 15], related to isometric torque induced by electromyostimulation [3], increases with exercise intensity [11, 14], and related to the metabolic state of skeletal muscle [27, 28]. For example, Adams et al. [2] showed that there were significant high correlation coefficients between change in mfMRI signal after concentric and eccentric forearm curl exercises at various intensities and integrated EMG activity during exercises in the biceps brachii muscle. Therefore, this technique seems to be ideal for assessing the neuromuscular system of exercising human skeletal muscles. Our previous study and other studies reported the feasibility of using this technique to assess the functional properties of disuse- or age-related atrophied muscle during exercise [4, 6, 21, 22].

It is known that eccentric contractions can be associated with different central nervous system (CNS) control mechanisms from those of concentric contractions [13, 19, 20]. A commonly reported observation supporting this notion is that maximal- and submaximal-performed voluntary eccentric contractions are associated with smaller activation levels than are maximal and submaximal voluntary concentric contractions. The lower activation levels are generally attributed to the inability of the CNS to fully activate the motoneuron pool [8, 23, 29]. This inability of humans to fully activate eccentrically contracting muscle may partially explain the resistance of eccentric contractions to fatigue compared with concentric contractions. As far as we know, fatigue during eccentric contraction has not been studied in patients following arthroscopic meniscectomy. Examination of characteristics of EMG activity during concentric and eccentric muscle contractions between the leg that received surgery and the leg that did not would provide important information on the mechanisms responsible for quadriceps muscle movements in patients who underwent arthroscopic partial meniscectomy.

The aim of our study was to clarify the effect of presurgery disuse, arthroscopic partial meniscectomy, and postsurgery disuse on the neuromuscular function of the QF muscle group using a conventional EMG technique combined with new technology, i.e., mfMRI. Our hypothesis was that the QF muscle group would show dysfunction, e.g., decrease of muscle strength and neuromuscular activity, in the leg that received surgery relative to the leg that did not in patients who underwent arthroscopic partial meniscectomy.

Materials and methods

Subjects

Twenty patients (11 men and nine women) in whom a meniscal lesion was diagnosed participated in this study after giving written informed consent. The subjects performed muscle testing (knee extension force and dynamic knee extension exercises for mfMRI and EMG activity) in the leg that received surgery and in the leg did not an average of 6.8 ± 3.0 months (range 1–14 months) after surgery. The study was approved by the Ethical Committee of the Research Center of Health, Physical Fitness and Sports, Nagoya University. The physical characteristics of the subjects and their history of injury are shown in Table 1.

Procedure

Subjects started with the resting mfMRI study, at the end of which subjects stretched their lower legs. The subjects were then evaluated for their maximal voluntary contraction (MVC) force during isometric knee extension. Following a 2- to 3-min rest period, subjects were then instructed to perform submaximal unilateral knee extension exercise that consisted of five sets of ten repetitions concomitant with the measurement of EMG activity. After completing the exercise, subjects quickly moved into the MRI for the mfMRI study.

Table 1 Physical characteristics of subjects

	Mean ± standard deviation	Range
Age (years)	45.0 ± 15.1	23–70
Height (cm)	162.7 ± 7.8	148–175
Weight (kg)	62.3 ± 10.5	50–97
Duration from injury to surgery (months)	8.0 ± 21.5	1–96
Duration from surgery to measurement (months)	6.8 ± 3.0	1–14

Knee-extension force

MVC force for the legs with and without surgery during unilateral isometric knee extension was measured using a custom-made dynamometer (Takei Scientific Instrument, Tokyo, Japan), as reported in our previous study [4]. Tests were conducted with the subject seated on a padded bench with a backrest tilted 15° beyond vertical. Custom-made handgrips on both sides of the subject allowed additional upper-body stabilization. The hip was fixed to the dynamometer by a strap, and the knee-joint angle was flexed at 90° (0° = fully extended). A lever arm consisted of a vertical aluminum bar and a horizontal padded aluminum bar to which the ankle joint was fixed by straps during MVC testing. The length of the vertical aluminum bar was adjustable for the length of each subject. The horizontal padded aluminum bar was linked with a load cell (TKK1269f, Takei Scientific Instrument, Tokyo, Japan). Before testing, the load cell was calibrated. After stretching, the subjects performed several submaximal force exertions and then maximal force exertion. The MVC test consisted of three or four MVC trials for each leg with and without surgery. If maximal force was found at the third trial, the subjects performed one more trial. If maximal force was found at the first or second trial, there was no fourth trial. We ensured that the leg with surgery was not uncomfortable; however, no claim was given by the subjects. MVC test involved a force-rising phase (approximately 1 s), sustained phase (>2 s), and relaxation phase (approximately 1 s). When the force was plateaued during the sustained phase, the experimental supervisor offered the subject vigorous encouragement. Approximately 2 min of rest was allowed between trials to avoid fatigue. The calibrated force signal from the load cell was stored on a computer (iBook G3, Apple Computer, Cupertino, CA, USA) at a sampling rate of 1 kHz using an AC/DC converter (PowerLab 8SP, ADInstruments, Sydney, NSW, Australia), synchronized with EMG data. The highest average for a 500-ms window was considered the maximal force for a given contraction. Reproducibility of the MVC testing was performed in nine healthy subjects twice at least 2 weeks between the tests. MVC at the first test was 452.4 ± 144.4 N and at the second test 474.8 ± 179.9 N. There was no significant difference in MVC between the two tests. We found that the intraclass correlation coefficient was 0.978.

Exercise-test protocol for electromyography and muscle functional magnetic resonance imaging

The exercise bout for measurement of EMG activity and mfMRI was performed using a custom-made dynamometer near the MRI facility. This custom-made dynamometer was designed to perform MVC measurement as well as isotonic knee extension exercises.

Following oral instruction and several warm-up contractions, each subject performed an exercise bout that consisted of five sets of ten unilateral knee extension actions at loads of 30% of MVC for each leg with or without surgery. The subjects were allowed to use handgrips on both sides of the dynamometer for additional upper body stabilization. Before the exercise, each subject's QF muscle was relaxed, and the legs were at right angles. The exercise began with the knee joint in a right-angle position. The exercise required the QF muscle group to contract concentrically (i.e., knee extension) to raise the weights in 2 s to the maximal possible position and then to lower the weights eccentrically (i.e., knee flexion) so that the knee joint resumed its initial position in 2 s. The average range of motion (ROM) of the exercise bout was 64.7 ± 7.7° for the leg that received surgery and 63.4 ± 7.5° for the leg that did not. Thus, the average end-point angle of the knee joint was 25.5 ± 7.7° for the leg that received surgery and 26.7 ± 7.5° for the leg that did not (0° = fully extended). There were no significant differences in ROM and the end point of the knee-joint angle between the legs. The exercise bout was performed with the electronic metronome. There were no rest periods between the knee extension and knee flexion phases or between repetitions of the movement; however, subjects were allowed a 1-min rest between sets. After the end of five sets of ten unilateral knee extension exercises, all sensors for measuring EMG activity and knee-joint angle were quickly removed from the subjects, and the subjects entered the MRI as promptly as possible. It took approximately 1.5 min from the end of the exercise to the beginning of the MRI scanning.

Electromyography measurement

EMG activity was recorded from the midbellies of the rectus femoris (RF), VL, and VM muscles using two sets of EMG devices (Bagnoli 2, Delsys Inc., Boston, MA, USA), with preamplifer surface electrodes from the QF muscle group, as done in our previous study [4]. Prior to electrode placement, the skin area was shaved, cleaned with isopropyl alcohol, and abraded with a skin preparation gel to reduce skin impedance and ensure good electrode adhesion. Electrode specifications in this study were as follows: amplification, differential; interelectrode distance, 1 cm; contact sensor composition, 0.1 × 1 cm of two silver bars; preamplifier gain, ten times; and common mode rejection ratio, 92 dB. The main amplifier unit feature was a gain of 1,000 times and frequency response of 20 ± 5 –450 ± 50 Hz (sensor, DE-2.1; Delsys Inc, Boston, MA, USA). Signals from the EMG system were sampled at

1 kHz using an AC/DC converter (PowerLab 8SP, ADInstruments) with the knee-joint angle by an electrogoniometer (SG150, Biometrics, Ltd., Gwent, UK) and stored on a personal computer (iBook G3, Apple Computer) for later analysis. The electrode for VL was placed at the midpoint between the head of the greater trochanter and the inferior edge of the patella. For the RF and VM muscles, electrodes were placed at the midpoint of the line joining the anterior superior iliac spine and the superior patella pole and slightly proximal and medial to the patella, respectively. These electrodes were placed parallel to the estimated muscle fibers. The reference electrode was attached to the patella. Care was taken not to place the electrodes over the periphery of the muscles to minimize EMG cross-talk between the muscles.

EMG analysis is summarized in Fig. 1. Peak knee-joint angle during repetitive knee-extension exercises was expressed as “T” (Fig. 1). We calculated the values of 0.2 and 0.8 T. Then, we determined the knee-joint angles that corresponded to the points of 0.2 and 0.8 T from the baseline. These two points were referred to as “A” and “B” during the concentric (Con) phase and “C” and “D” during the eccentric (Ecc) phase, respectively. In addition, from “A” to “D” was referred as the total phase, i.e. Con/Ecc phase. The root mean square (RMS) was calculated during the Con/Ecc, Con, and Ecc phases for 50 repetitions of knee extension after EMG signals were full-wave rectified. EMG signals recorded from three superficial muscles (RF, VL, and VM) were normalized by EMG activity during the MVC task, then the normalized EMG activities of the three muscles were averaged. This average was considered as the EMG activity of the QF muscle group.

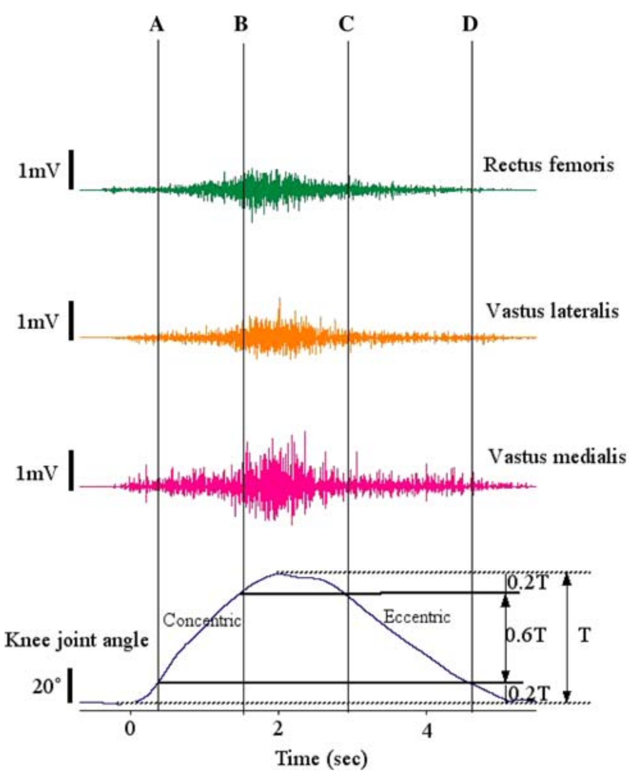

Fig. 1 Sample electromyographic (EMG) activity of the rectus femoris, vastus lateralis, and vastus medialis muscles and knee-joint-angle change during dynamic knee extension exercises, along with an explanation of EMG activity analysis. **a** Point of knee-joint angle at 0.2 T from the bottom during the concentric phase; **b** point of knee joint angle at 0.8 T from the bottom during the concentric phase; **c** point of knee-joint angle at 0.8 T from the bottom during the eccentric phase; **d** point of knee-joint angle at 0.2 T from the bottom during the eccentric phase. EMG activity was analyzed in three phases: concentric (*Con*) phase (from **a** to **b**), eccentric (*Ecc*) phase (from **c** to **d**), and the total concentric and eccentric (*Con/Ecc*) phase (from **a** to **d**). *T* peak knee-joint angle

Muscle functional magnetic resonance imaging

The mfMRI data of the thigh for legs with and without surgery were collected as performed previously [4, 6]. The mfMRI of the exercised thigh was taken at rest and immediately after completion of the knee-extension exercise. All images were taken after approximately 15 min rest to avoid fluid shifts that might induce interstitial and/or intracellular volume changes. Eleven axial images were obtained for each subject with a 0.2 T (Signa Profile OpenSpirit, General Electric, NJ, USA) MRI magnet using an extremity coil. The fifth image from the most proximal of the 11 images corresponded to the mid thigh. T2-weighted spin echo, axial-plane imaging was performed with the following variables: repetition time (TR), 1,600 ms; echo time (TE), 30 and 60 ms; matrix, 256×128; field of view, 320 mm; number of excitations, 1; slice thickness, 10 mm. Subjects were imaged in a prone position with the knee at 0° and ankle kept at $\sim$60°, with 0° being the full extension of each joint. An ink mark on the skin of the thigh was aligned with the center of the extremity coil. In addition, both legs were fixed with straps to avoid movement during scanning. Mid-thigh images were used for calculating the mfMRI signal changes, i.e., transverse relaxation times (T2).

Regions of the working muscle, i.e., the QF muscle group, were traced on an MRI console, after which the mean T2 of the QF muscle group was calculated on a pixel-by-pixel basis from the formula $T2 = (ta–tb)/\ln(ia/ib)$, where ta and tb were spin-echo collection times, i.e., TE, and ia and ib were signal intensities. We excluded visible aponeurosis, vessels, fat, and nerves from the regions of interest. Reproducibility of T2 measurements using this procedure have been reported elsewhere [6]. We found the intraclass correlation coefficient of this technique was 0.998 ($n = 5$).

Outline of the variables of interest

We summarized the variables of interest used in this study. All tests were performed for the leg that received surgery and the leg that did not.

MVC: To investigate the force-generating capacity of the QF muscle group, maximal contraction force during unilateral isometric knee-extension was measured.

EMG activity: Surface EMG activity of the QF muscle group was recorded during the Con/Ecc, Con, and Ecc phases of the repetitive knee extension task (five sets of ten repetitions with 30%MVC load).

mfMRI: Before and immediately after the repetitive knee extension task, mfMRI signal change of the QF muscle group was calculated to acquire neuromuscular properties.

Statistical analysis

All data are presented as means and standard deviation (SD). MVC data between legs with and without surgery were analyzed with a paired *t* test. A two-way analysis of variance (ANOVA) with repeated measures was used to compare the dependent variables for the EMG activity and mfMRI. To determine the relationship between variables, Pearson correlation coefficients were calculated. All analysis was performed using the SPSS statistical package (Version 15.0 J for Windows) or StatView software (Version 5.0 for Macintosh). The level of significance was set at $P < 0.05$.

Results

MVC values during knee extension for legs with and without surgery are shown in Fig. 2. MVC for the leg that received surgery (527.8 ± 214.8 N) was significantly lower than that for the leg that did not (416.0 ± 201.8 N). Thus, the leg that received surgery had a significant decline, 77.6 ± 14.6%, relative to the leg that did not receive surgery.

Figure 3 shows EMG activity during submaximal knee-extension exercise. Regarding EMG activity during the Con/Ecc phase, significant effects were found for the leg ($P = 0.031$) and the set ($P = 0.000$); however, no leg-by-set interaction was found ($P = 0.252$). Regarding EMG activity during the Con phase, significant effects for the leg ($P = 0.015$) and the set ($P = 0.000$) were found; however, no leg-by-set interaction was found ($P = 0.051$). Regarding EMG activity during the Ecc phase, there was a significant effect for the set ($P = 0.000$); however, no effect for the leg ($P = 0.143$) or leg-by-set interaction ($P = 0.235$) was found.

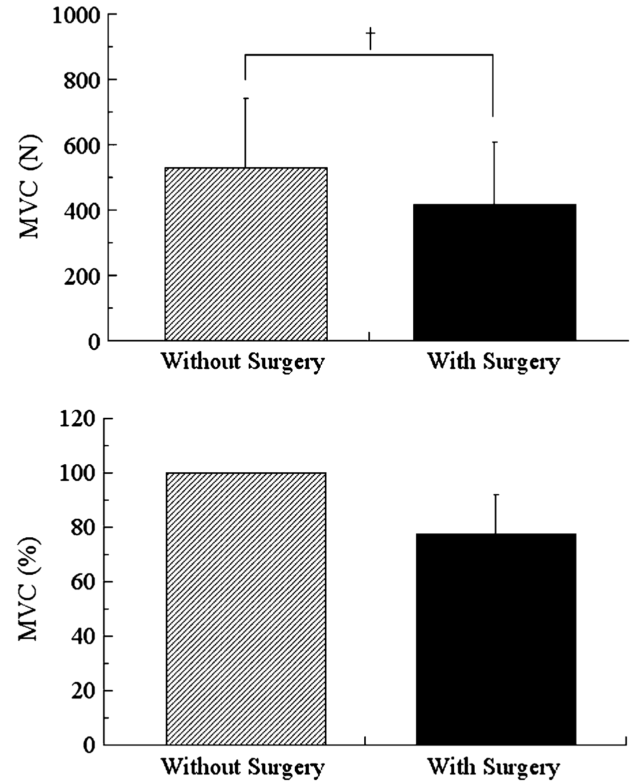

Fig. 2 Maximum voluntary contraction (*MVC*) during unilateral isometric contraction in legs with and without surgery. † $P < 0.001$

Figure 4 shows the mfMRI signal of the QF muscle group in legs with and without surgery during repetitive knee-extension exercise. There were significant effects of exercise ($P = 0.000$) and leg ($P = 0.011$), but no leg-by-exercise interaction was found ($P = 0.058$).

Figure 5 shows the relationship between ΔmfMRI and ΔEMG activity in legs with and without surgery. There were significant correlation coefficients between ΔmfMRI and ΔEMG activity for the leg that received surgery ($r = 0.731$, $P < 0.001$) and the leg that did not ($r = 0.656$, $P < 0.01$).

Discussion

The purpose of this study was to investigate the neuromuscular activity of the QF muscle group in 20 patients as a result of presurgery disuse, arthroscopic partial meniscectomy, and postsurgery disuse. As far as we know, this is the first study to show the neuromuscular activity using surface EMG and mfMRI techniques in patients who underwent arthroscopic partial meniscectomy. In this investigation, the QF muscle group showed a decrease in MVC during knee extension and EMG activity declined during repetitive knee-extension exercise.

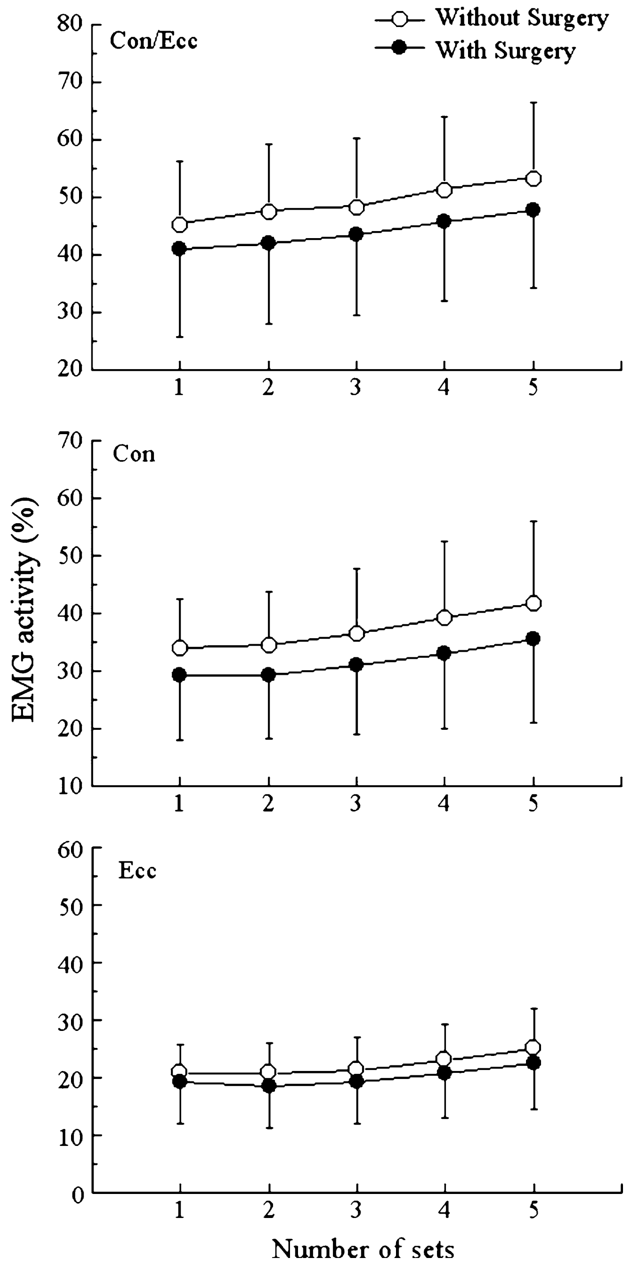

Fig. 3 Electromyographic (*EMG*) activity of the quadriceps femoris during repetitive dynamic knee-extension exercises in the concentric (Con), eccentric (Ecc), and total Con/Ecc phases in legs with and without surgery

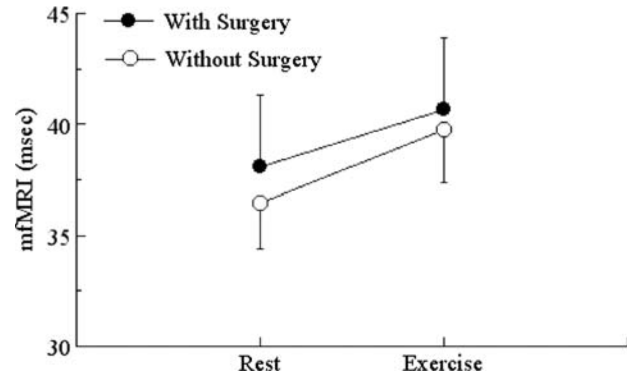

Fig. 4 Muscle functional magnetic resonance imaging (*mfMRI*) of the quadriceps femoris during repetitive dynamic knee-extension exercises in legs with and without surgery

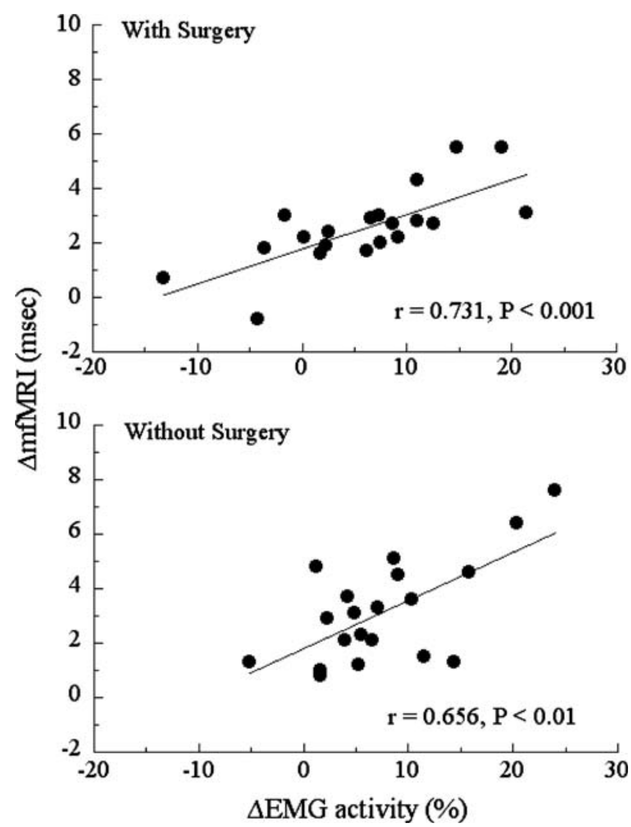

Fig. 5 Relationship between the change in signal during muscle functional magnetic resonance imaging (*ΔmfMRI*) and the change in electromyographic activity (*ΔEMG*) in legs with and without surgery

MVC during knee extension in the leg that received surgery was 22%, significantly lower than that of the leg that did not, which supports the study by Gapeyeva et al. [12]. They showed 18% of significant peak torque deficit during isokinetic knee extension at 180 s^{-1} 6 months after arthroscopic partial meniscectomy [12]. Ericsson et al. [10] reported that isokinetic strength loss induced by partial meniscectomy lasts at least 4 years after surgery. In this study, subjects performed the MVC test after 6.8 months; therefore, a 22% reduction in MVC for the leg that received surgery over the one that did not is reasonable compared with these previous studies. It is generally accepted that strength loss is larger than atrophy as a result of disuse [1]. In our previous study, we demonstrated that the QF muscle group of a leg that underwent arthroscopic partial meniscectomy was 13% smaller than that of a leg that did not. Therefore, this result is consistent with the previous study.

We found unique neuromuscular activation in the QF muscle group during repetitive knee-extension exercise, in particular during the Con/Ecc and Con phases. We investigated three different phases during dynamic submaximal knee-extension exercise. During the Con/Ecc and Con phases, there were significant effects of leg and set, suggesting that the EMG activity of the QF muscle group in the leg that received surgery was significantly higher than that in the leg that did not. Furthermore, there was no significant interlimb difference in the pattern of EMG activity change with increasing sets. These results imply that the neuromuscular activity of the QF muscle group in the leg that received surgery was consistently lower than in the leg that did not received surgery, even though they were performing with nearly the same exercise intensity normalized by MVC. The results also imply that the pattern of fatigue was not different with an increasing number of sets. As shown in Fig. 3, a significant difference in EMG activity during the Con/Ecc phase between legs with and without surgery seems to be mainly due to the Con phase. This is because EMG activity during the Con phase of the leg that did not received surgery was significantly higher than that of the leg that received surgery.

We found that EMG activity of the QF muscle group in the leg that received surgery was significant lower than that in the leg that did not when performing dynamic knee-extension exercise with nearly the same exercise intensity normalized by MVC. We believe two factors that may contribute to this discrepancy. First, a force-generating capacity, such as central activation failure, may account for the lower EMG activity in the leg that received surgery compared with the leg that did not. Williams et al. [30] showed that the central activation estimated by the superimposed stimulation technique during the QF-muscle-group strength test was not significantly different between the anterior cruciate ligament (ACL)-deficient limb and the contralateral normal limb. The pattern of atrophy and strength loss of the QF muscle group in patients in this study was similar to that in the Williams et al. study [30]. Thus, we speculate that similar central activation potential could exist in our subjects. If a similar mechanism related to the central activation potential existed in our subjects, the difference in the EMG activity pattern found in the Con/Ecc and Con phases between the leg that underwent surgery and the one that did not would not be explained by an interlimb difference in central activation, because no central activation difference would be expected between the legs. Second, the loss of feedback from mechanoreceptors in the menisci may be associated with decreased EMG activity in the leg that received surgery compared with the leg that did not. It is known that there are many mechanoreceptors, such as the Ruffini endings, Pacinian corpuscles, and Golgi receptors, in the menisci [25]. These mechanoreceptors are fully capable of monitoring various types of stimuli, such as pressure, bending, joint position, rate of motion, elongation, and applied forces. Konishi et al. [16] showed that the loss of feedback from mechanoreceptors in the ACL is the underlying mechanism of weakness of the QF muscle group in patients with ACL lesions and that this feedback loss induced chronic suppression of recruitment of high-threshold motor units during voluntary contraction. If a similar mechanism existed for patients who underwent partial meniscectomy in this study, interlimb EMG activity difference may be partly explained.

In contrast, the pattern of EMG activity in the Ecc phase during knee-extension exercise was different in the Con/Ecc and Con phases between the leg with and without surgery; there was no significant leg effect. It is well known that eccentric contraction requires lower levels of voluntary activation by the nervous system [8, 9]. In this study, EMG activity during the Ecc phase was significantly lower than in the Con phase during dynamic knee extension, as has been demonstrated in previous studies [9, 26]. Unfortunately, we were unable to find potential mechanisms to explain the lack of significant difference in EMG activity during the Ecc phase in interlimb comparison.

The mfMRI is a relatively new technology that is used to investigate muscle recruitment during exercise. There is evidence that mfMRI signal is closely related to the integrated EMG activity of working muscles [2, 15] and increases with exercise intensity [11], the number of repetitions [5, 31] and the metabolic state of the muscle [7, 27, 28]. For example, Yue et al. [31] reported that there was a linear relationship between mfMRI signal change of the elbow flexors and the number of repetitions after five sets of an elbow-flexion exercise ($r = 0.98$–0.99). Adams et al. [2] showed that both integrated EMG activity and mfMRI signal change of the long and short head of the biceps brachii increased as a linear function of load when concentric or eccentric actions of forearm curls were performed (concentric actions, $r = 0.99$; eccentric actions, $r = 0.99$). Furthermore, Akima et al. [6] showed that there was a significant increase in mfMRI signal change of the calf muscles (medial and lateral gastrocnemius and soleus muscles) after a repetitive calf-raising exercise following 20 days of bed rest deconditioning, indicating disuse induced more muscle use than before bed-rest deconditioning. Thus, this technique is ideal to test both healthy and unused muscles [4, 6, 21, 24, 32].

In this study, we found significant effects of exercise and leg but no significant effect of leg-by-exercise interaction in mfMRI. This result suggests that mfMRI signal change as a result of exercise, which reflects the neuromuscular system of exercising muscles, was not impaired by the effect of presurgery disuse, knee surgery, and postsurgery disuse when legs were performing the same intensity of exercise normalized by MVC. Furthermore, there was higher mfMRI signal in the leg that received surgery compared with the leg that did not according to ANOVA. This higher mfMRI signal would be simply associated with a higher resting mfMRI signal (see Fig. 4). In the previous studies, resting mfMRI signal in older individuals with atrophied muscles was significantly higher than in younger individuals [22]. Those researchers suggested that the higher resting mfMRI was due to an increased amount of intramuscular fat, which shows higher signal than skeletal muscles on MRI. In our subjects as well, increased intramuscular fat may account for the higher resting mfMRI signal. In our previous study, we demonstrated that the relative change of mfMRI signal during dynamic knee extension exercises for the QF muscle group was not different between before and after 20 days of bed-rest deconditioning, even though the exercise load was normalized to MVC (exercise load equaled 30% of MVC for pre- and post-MVC testing) [4]. Taken together, presurgery disuse, arthroscopic knee surgery, and postsurgery disuse induced muscle-function changes that seem to be dependent on MVC decline.

We found a significant correlation coefficient between ΔmfMRI and ΔEMG activity in legs with and without surgery (Fig. 5). As stated above, mfMRI signal change is closely related to EMG activity [2, 15]; thus, ΔmfMRI change is one index, as demonstrated by previous studies [2, 15], for legs that do not received surgery as well as those that do. Adams et al. [2] reported that mfMRI signal change, i.e. T2 relaxation time, is closely related with integrated EMG activity of the working muscle during low to high intensity of concentric or eccentric elbow-flexion exercises. In this, we clearly showed that there was a significant correlation coefficient between ΔmfMRI and ΔEMG activity for legs with and without surgery, suggesting that the capability of neuromuscular activity in the leg that received surgery was not impaired by presurgery disuse, knee surgery, and postsurgery disuse. Furthermore, mfMRI is a useful technique for measuring the recruitment pattern in unused and atrophied muscle during exercises.

A limitation of this study should be mentioned. EMG activity of the hamstrings was not measured during MVC and submaximal dynamic knee-extension exercise. In our previous study, we showed that there was no significant difference in the muscle size of hamstrings between the leg that received surgery and the one that did not [4]. Thus, we speculated that the contribution of the hamstrings to MVC and submaximal dynamic exercise would be similar between both legs. Further studies are needed to confirm the results.

In conclusion, we tested the neuromuscular activity of the QF muscle group in patients who underwent arthroscopic partial meniscectomy using surface EMG and mfMRI techniques to measure the effects of presurgery disuse, knee surgery, and postsurgery disuse. We found that MVC during knee extension for the leg that received surgery was significantly lower, by 22%, than that for the leg that did not receive surgery. EMG activity during submaximal dynamic knee extension was not significantly different between legs with and without surgery; however, during the Con/Ecc and Con phases, the QF muscle group of the leg that received surgery had significantly lower activation than that of the leg that did not receive surgery. These results suggest that the effect of presurgery disuse, partial meniscectomy, and postsurgery disuse induces dysfunction of the QF muscle group that is dependent on MVC reduction. Thus, these patients need maximal muscle force improvement for effective rehabilitation after surgery.

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