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Atrophy of thigh muscles after meniscal lesions and arthroscopic partial menisectomy

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Abstract The purpose of this study was to investigate the atrophic pattern of the muscle groups and their individual muscles in the thigh after meniscal lesions and arthroscopic partial menisectomy. A total of 32 individuals (17 men and 15 women) who underwent arthroscopic knee surgery participated in this study. Their operated and non-operated thighs were scanned by magnetic resonance imaging to determine the volume of the quadriceps (QF), hamstring (HM), and adductors (AD). Compared with the non-operated limb, the volume of the QF was significantly lower in the operated limb; however, no significant difference was observed in the HM and AD. The volume of individual muscles of the QF, i.e. the rectus femoris (RF), vastus lateralis (VL), vastus intermedius (VI), and vastus medialis (VM), in the operated limb was significantly lower than the volume of those in the non-operated limb ($P < 0.01$, all). Although the relative change in the VM was significantly higher than that of the RF ($P < 0.05$), specific atrophy was not found among four individual muscles in the QF. We concluded that meniscal lesions and partial menisectomy induce atrophy in the QF only in the thigh, and that no specific atrophy, e.g. VM, seemed to occur within the individual muscles in the QF.

Keywords Muscle volume · Skeletal muscle · Quadriceps femoris · Rehabilitation

Introduction

It is well known that atrophy is induced in the thigh muscles, especially the quadriceps, by presurgical disuse, knee surgery (e.g. menisectomy and anterior cruciate ligament reconstruction), and postsurgical disuse. However, limited data have shown a change of thigh musculature as a result of knee surgery [5, 7, 8, 14, 18]. Unfortunately, little is known about the atrophic pattern of each muscle group in the thigh, i.e. the quadriceps (QF), hamstring (HM), and adductor (AD), and their individual muscles by presurgical disuse, surgery, and postsurgical disuse. This information would be of great help for rehabilitation of patients after surgery.

It has been suggested that the vastus medialis (VM) is affected the most among the individual muscles in the QF [6]. As far as we know, there is no evidence showing that the atrophy of the VM is greater than the other individual muscles in the QF, i.e. rectus femoris (RF), vastus lateralis (VL), and vastus intermedius (VI), so far. Furthermore, conflicting evidences with regard to atrophy due to disuse and aging in human skeletal muscles show that there is no significant difference in relative change in the cross-sectional area (CSA) and/or volume among individual muscles in the QF [3, 4, 19]. It is questioned whether this is also the case in knee injury- and surgery-induced atrophy, the notion believed in orthopedics research,

i.e. the VM is the most atrophic muscle in the QF after knee surgery.

To clarify these questions, we used magnetic resonance (MR) imaging, which is a powerful non-invasive imaging technique, to provide anatomical characteristics of tissues such as skeletal muscle, ligament, tendon, and brain etc. Recent studies have suggested that the volume measurement would be the most accurate method to estimate muscle size rather than the CSA measurement as done in the previous studies [10, 16]. We demonstrated that region-specific atrophy along the length of the thigh occurred after a short duration of disuse, which indicated that calculation of the CSA from a single image would lead to a misunderstanding of the change muscle size [3, 4]. Furthermore, Fukunaga et al. [9] demonstrated that the correlation coefficients were higher for muscle volume and joint torque ($r=0.92$ to 0.94, $P<0.001$) than CSA and joint torque ($r=0.71$ to 0.89, $P<0.05$ to 0.01) during isometric elbow flexion and extension in 26 healthy men. Therefore, we calculated the volume as an index of the muscle size of each thigh muscle for the operated and non-operated limb.

The aim of the present study was to investigate the effect of presurgical disuse, arthroscopic partial menisectomy, and postsurgical disuse on the volume of three muscle groups and their individual muscles in the thigh. Our hypothesis was that the QF muscle group may atrophy after knee surgery, and that there is no selective atrophy within the individual muscles of the QF.

Materials and methods

Subjects

Thirty-two patients (17 men and 15 women) diagnosed with a meniscus lesion participated in this study, after giving written informed consent. Longitudinal data for ten patients, who tested two or three measurements at least 2 months apart, are included as a different subject. There was no use of a tourniquet for these patients. The rehabilitation protocol consisted of progressive weight bearing, continuous passive motion (CPM) devices started from 1-week postsurgery, and neuromuscular electrical stimulation (10–to 30 Hz) for 15 min a day approximately once a week. The study was approved by the Ethics Committee of the Research Center of Health, Physical Fitness& Sports, Nagoya University. The physical characteristics of the subjects and their history of injury are shown in Table 1.

Table 1 Physical characteristics of patients

		Range
Age (years)	45.5 ± 13.0	23–70
Height (cm)	162.0 ± 7.4	148–175
Weight (kg)	62.3 ± 11.5	50–97
Duration from injury to surgery (M)	9.4 ± 22.9	1–96
Duration from surgery to Measurement (M)	5.7 ± 3.5	1–14

Values are means and SD

Magnetic resonance imaging

MR images of the operated and non-operated thigh for all subjects were collected. MR imaging was performed with a 0.2 T (Signa Profile OpenSpirit, General Electric, USA). T2-weighted spin echo, axial-plane imaging was performed with the following variables, TR: 1,600 ms, TE 30 ms, matrix: 256×128, field of view 320 mm, number of excitations: 1, slice thickness: 10 mm, interslice gap: 10 mm. Images of the subjects were taken in a prone position with the knee and ankle kept at 180° and ~120° respectively, with 180° being full extension of each joint. The number of axial images obtained for each subject was 11. The fifth image from the proximal corresponds to the middle of the thigh. The muscles investigated were as follows: the QF: m. rectus femoris (RF), m. vastus lateralis (VL), m. vastus intermedius (VI), and m. vastus medialis (VM); the HM: m. biceps femoris, short head (BFs), m. biceps femoris, long head (BFl), m. semitendinosus (ST), m. semimembranosus (SM); the AD: m. gracilis (Gr), and m. sartorius (Sar), m. adductor longus, m. adductor magnus and m. adductor brevis (AB). From the series axial images, outlines of each muscle were traced, and the traced images were transferred to a personal computer (Power Mac G4, Apple Computer, Inc.) for calculation of the CSAs using a public domain NIH image software package (written by Wayne Rasband at the NIH and available from the Internet by anonymous ftp://rsbweb.nih.gov/pub/nih-image/nih-image162_fat.hqx). The muscle volume was determined by summing the CSA of each image times the thickness (10 mm) and interslice gap (10 mm) of each section as done in the previous studies [3, 4, 10].

Statistics

All data were presented as means and standard error (SE). The muscle volume between operated and non-operated limb was analyzed with a paired t-test. Relative change in muscle volume in each individual muscle was analyzed with a one-way analysis of variance (ANOVA). Tukey's post hoc test was used to determine specific differences in relative change in muscle volume among individual muscles of the QF. To determine the relationship between variables, Pearson correlation coefficients were calculated. All analyses were performed using the SPSS statistical

package (Version 11.5J for Windows). The level of significance was set at $P < 0.05$.

Results

Figure 1 shows the representative MR images of the mid thigh of a (36 year-old female patient) of the operated (Fig. 1 b: left thigh) and non-operated (Fig. 1a: right thigh). Decrease in the CSA of the QF in the operated limb is clearly shown compared to the non-operated limb.

Table 2 shows the volume of the four muscle groups of the thigh for the operated and non-operated limb. The muscle volume of the VM, VL, VI, and RF of the operated limb was significantly smaller that of the non-operated limb (all muscles: $P < 0.0001$). Similarly, muscle volume of the QF of the operated limb was significantly smaller than that of the non-operated limb ($P < 0.0001$). There was no significant difference in the volume of the HM, AD, and their individual muscles between the operated and non-operated limbs.

Figure 2 shows the relative difference in muscle volume of the RF, VL, VI, and VM of the operated limb compared to the non-operated limb. One-way ANOVA indicated that there were significant differences in the relative change in muscle volume of individual muscles of the QF ($P < 0.05$). No significant difference in the relative change in muscle volume was observed, except for the RF and VM ($P < 0.05$), among four individual muscles in the QF with Tukey's post hoc test.

The relationship between the relative change in the volume among individual muscles of the QF is shown in Fig. 3. Relative change in the volume of the individual muscle of the QF highly correlated with one another ($r = 0.372$ to 0.625, $P < 0.05$ to 0.001).

Fig. 1 Representative axial magnetic resonance images of the non-operated (**a**) and operated (**b**) limb at the middle region along the length of the thigh for a female patient. **c** *RF* rectus femoris, *VL* vastus lateralis, *VI* vastus intermedius, *VM* vastus medialis, *BFl* biceps femoris, long head, *ST* semitendinosus, *SM* semimembranosus, *Gr* gracilis, *Sar* sartorius, *AM* adductor magnus, *F* femur. The biceps femoris, short head and adductor brevis can not be visible at this level

Discussion

Important findings in this study were that presurgery disuse, surgery, and postsurgery disuse induces atrophy in the QF only in the thigh, not in the HM and AD, and that atrophy appeared to be uniform within the individual muscles in the QF. Thus, muscle-specific atrophy within the QF did not occur in the partial meniscectomy patients, which is a conflicting result as has been suggested in orthopedics research.

There are a limited number of studies that have shown the profile of atrophy in the thigh muscle groups and/or their individual muscles as a result of knee surgery [7, 14, 18]. Takarada et al. [18] showed that the CSA of the knee extensors and flexors in eight anterior cruciate ligament (ACL) reconstructed patients significantly decreased by 21% and 11%, respectively, 14 days after the operation. On the contrary, Elmqvist et al. [7] demonstrated that the CSA of the QF significantly decreased in the operated limb compared to the non-operated limb; however, no significant difference was observed in the CSA of the HM in 41 patients with chronic symptomatic instability of the ACL. Similarly, Lorentzon et al. [14] reported that no significant difference was observed in the CSA of the HM in the operated limb compared to the non-operated limb in 18 patients who had untreated chronic ACL rupture. These results support the present study, i.e. the volume of the QF decreased after disuse and partial menisectomy, but the HM was less affected. There is a problem in these studies: the word expressing the "hamstring or knee flexors" [7, 14, 18] would include both the HM (BFs, BFl, ST, and SM) and AD (AL and AM). Therefore, it is unclear whether the change in the muscle size was due to the HM and/or AD. Furthermore, there is no information about individual muscles of the HM and AD following injury and surgery, in these studies [7, 14, 18]. In this study, we clearly showed that the volume of the HM and AD and their individual muscles in the operated limb was maintained completely even when in disuse and after knee surgery (see Table 2).

It has been demonstrated that the hamstring muscle group undergoes less atrophy and/or strength loss than

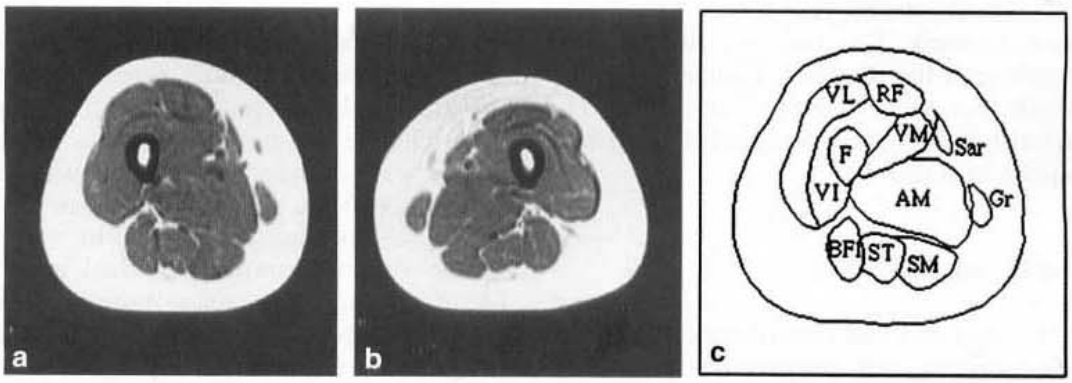

Table 2 Volume of individual muscles and muscle groups of the thigh of operated and non-operated limb ($n = 32$)

	Operated	Non-operated
Quadriceps femoris	816.3 ± 235.2*	943.3 ± 254.5
Vastus medialis	253.8 ± 70.9*	275.4 ± 73.6
Vastus lateralis	242.6 ± 67.2*	299.2 ± 77.0
Vastus intermedius	233.5 ± 79.1*	274.9 ± 84.3
Rectus femoris	86.4 ± 30.4*	93.9 ± 31.2
Hamstrings	445.5 ± 111.5	446.5 ± 106.2
Adductors	462.5 ± 141.6	461.2 ± 147.8

Values are means and SD. Unit in cubic centimeter. *$P < 0.001$

the QF following knee surgery for a variety of pathologies. Vegso et al. [20] showed that there were no strength deficits in the HM in thirty postsurgery patients who underwent an arthrotomy and medial menisectomy. From the result of the present study, we speculate that the function of the hamstring seems to be unchanged postsurgery. The volume of the AD muscle group showed no significant difference between the operated and non-operated limb. Although the real function of the AD muscle during movement, including that in daily life, is not well known, recent studies have revealed that this muscle group is involved in basic human movements such as running and cycling [2, 13, 15, 17]. We showed that this muscle group did not decrease in volume, thus the effect of the AD on these movements would be less after the surgery.

In orthopedics and rehabilitation research it has been recognized that injury- and/or surgery-related atrophy in the thigh is predominantly found in the VM within the human QF [6, 11]. However, there is little evidence with regard to selective atrophy of the VM within the QF after knee injury and/or postoperative observation [11].

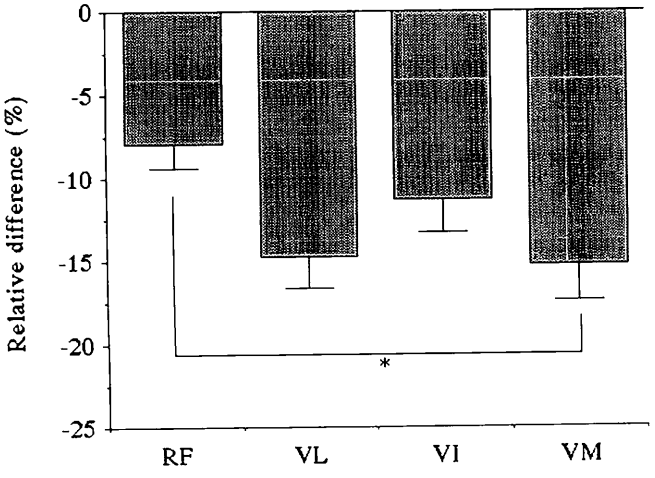

Fig. 2 Relative difference in the volume of the quadriceps between the operated and non-operated limb. *$P < 0.05$. *RF* rectus femoris, *VL* vastus lateralis, *VI* vastus intermedius, *VM* vastus medialis

We found that there is no significant difference in the relative change (operated limb vs non-operated limb) in the volume of each individual muscles in the QF, except between the VM and RF, in this study. We have demonstrated that there is no difference in the change in the volume of the individual muscles of the QF after a short period of disuse [3, 4]. Furthermore, Trappe et al. [19] illustrates that the percentage of the QF volume of each muscle was not significantly different between young and old individuals, implying that each of the individual muscles of the QF atrophied to a similar degree with aging. These results imply that the volume of the VM did not predominantly decrease compared with the other individual muscles in the quadriceps as results of disuse, aging, and injury. On the contrary, Gerber et al. [11] reported that the relative decrease in the CSA of the VM was significantly larger than that of the QF in 41 ACL patients with chronic symptomatic instability. They concluded that atrophy predominantly affected the quadriceps, and within the QF, predominantly the VM in these patients. The difference in the result between this study and Gerber et al. [11] may be due to methodological error of CSA calculation in their study. With regard to the CSA calculation as an index of muscle size, some researchers suggest that the CSA would not be appropriate for obtaining an index of the muscle size [10, 16]. Fukunaga et al. [10] demonstrated that it is difficult to estimate of muscle size in given muscles with a single CSA measurement. Roman et al. [16] also showed that calculating the muscle volume is a more accurate method for determining changes in muscle size after resistance training, because they found a large difference in relative change between muscle volume (14%) and CSA (23%). Furthermore, it has been demonstrated that joint torque during isometric elbow flexion and extension was more related to muscle volume than to CSA in humans [9]. These reports suggested that the CSA method for determining muscle size would lead to a misunderstanding of accurate muscle size and estimation of potential force.

There is no consistent understanding whether atrophy in a certain muscle depends on the fiber type, or not [5, 8]. There seems to be no distinct difference in fiber types among the individual muscles in the QF [12]. Therefore, it is easy to understand the atrophy fiber type point of view. Recently, Adams et al. [1] reviewed atrophy of skeletal muscle as a result of disuse in humans, e.g. spaceflight, bed rest, and immobilization. They concluded that the impact of disuse (e.g. bed rest and unloading model) on muscle fiber size appears to be similar in both slow-twitch (ST) and fast-twitch (FT) fibers. Indirectly, we also have data to support the notion that there is no significant difference in the change in the volume of the gastrocnemius (contained both ST and FT fibers equally) and soleus (rich in ST fibers) muscles after 20 days of disuse in humans [3, 4].

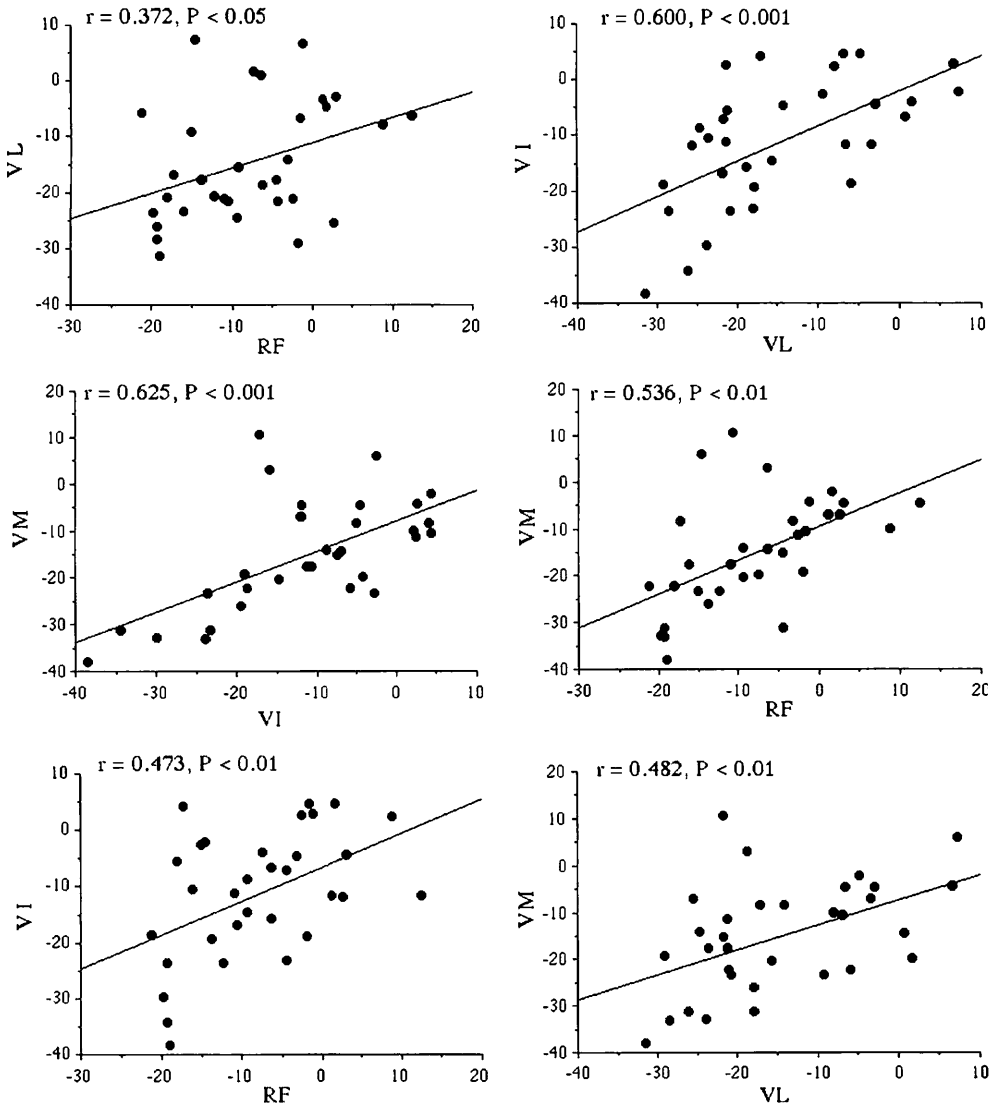

Fig. 3 Relationship between relative change in volume of operated limb compared with non-operated limb among individual muscles in the quadriceps. *RF* rectus femoris, *VL* vastus lateralis, *VI* vastus intermedius, *VM* vastus medialis

We demonstrated that atrophic patterns of four individual muscles in the QF were closely related to each other (Fig. 3). This result suggests that atrophy of individual muscles in the QF would be dependent on the invasion of the synergy. In addition, this result further supports that selective muscle atrophy, i.e. the VM, did not occur in all patients who underwent partial meniscectomy. Overall, relative changes in muscle volume among the vasti muscles seemed to be higher correlation coefficients (e.g. VM versus VI, $r=0.625$ and VI versus VL, $r=0.600$) than those among the RF and vasti muscles (e,g. VL versus RF, $r=0.372$ and VI versus RF, $r=0.473$). This may be due to the anatomical factor, i.e. mono-articular vs. bi-articular muscles, and functional factor, i.e. extension of the knee joint versus extension of the knee joint and flexion of the hip joint, between the vasti muscles and RF.

In conclusion, we measured the volume of the QF, HM, and AD and their individual muscles in 32 patients who underwent partial meniscectomy before 5.7 months of the experiment. The volume of the QF in the operated limb was significantly smaller than that of the control limb; however, no significant difference was observed in the HM and AD. Among individual muscles of the QF, there was no significant difference in decrease of the volume of the operated limb compared with the control, except for the VM and the RF. These results suggested that presurgical disuse, surgery, and postsurgical disuse induced atrophy is predominant in the QF in the thigh; however, the atrophy was similar among four individual muscles in the QF.

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