Electromyographic analysis of training to selectively strengthen the lumbar multifidus muscle: effects of different lifting directions and weight loading of the extremities during quadruped upper and lower extremity lifts.

Mitsuhiro Masaki[1], Hiroshige Tateuchi[1], Rui Tsukagoshi[2], Satoko Ibuki[1], and Noriaki Ichihashi[1]

[1]Department of Physical Therapy, Human Health Sciences, Graduate School of Medicine, Kyoto University, Kyoto
53 Kawahara-cho, Shogoin, Sakyo-ku, Kyoto 606-8507, Japan.
[2]Department of Physical Therapy, Faculty of Rehabilitation, Hyogo University of Health Sciences, Hyogo
1-3-6 Minatojima, Chuo-ku, Kobe 650-8530, Japan.

Corressponding author
Mitsuhiro Masaki, R.P.T., M.Sc.
Department of Physical Therapy, Human Health Sciences,
Graduate School of Medicine, Kyoto University,
53 Kawahara-cho, Shogoin, Sakyo-ku, Kyoto 606-8507, Japan.
E-mail: masaki.mitsuhiro.27w@st.kyoto-u.ac.jp
Office phone: +81-75-751-3935
Office fax: +81-75-751-3909

ABSTRACT

Objectives: Objectives: The lumbar multifidus muscle (LMF) is a lower back muscle that contributes to spinal stability. Several electromyographic analyses have evaluated LMF activity during various types of training. The present study examined the activity of the back muscles during quadruped upper and lower extremity lifts (QULEL) with different lifting direction and weight loading of extremities.

Methods: Seventeen healthy men were included as subjects. The exercise conditions comprised raising the upper extremity of one side and the lower extremity of the opposite side in a quadruped position with different lifting direction and weight loading. The various combinations of lifts were modifications of conventional QULEL, in which the upper extremity is raised to 180° shoulder flexion and the lower extremity to 0° hip extension. The effects of different lifting directions and weight loading on LMF and lumbar erector spinae muscle (LES) activities were measured using surface electromyography.

Results: The LMF activity and the LMF/LES activity ratio on the side of lower extremity lifting were higher during QULEL with the upper and lower extremities in abduction than during conventional QULEL. The LMF/LES activity ratio was lower during QULEL with weight loading on the upper and lower extremities than during conventional QULEL.

Conclusions: QULEL with abduction of the upper and lower extremities is effective for selectively strengthening LMF.

INTRODUCTION

The lumbar multifidus muscle (LMF) is a lower back muscle that contributes to spinal stability.[1–3] Several electromyographic analyses have evaluated LMF activity during various types of training.[4–10]

LMF atrophy in acute[11,12] and chronic LBP patients has been observed in studies using computed tomography (CT) and magnetic resonance imaging (MRI) images.[13–16] In patients with LBP, the selective atrophy of LMF compared with that of lumbar erector spinae muscle (LES) has been demonstrated,[17] and the proportion of fatty tissue in LMF increases in them.[18,19] Therefore, the importance of effective strengthening of LMF is attracting attention in the rehabilitation of patients with LBP.

Furthermore, previous studies[20–22] revealed that the activity of LMF, which is a member of the deep muscles of the back, decreases, whereas the activity of LES, which is a member of the superficial muscles of the back, increases in individuals with LBP or those with LBP history (LBPH). Decreased LMF activity causes lumbar spine instability, which may contribute to LBP recurrence.[23] A previous study has also examined the effect of training on the strengthening of lower back muscles in patients with LBP,[24] revealing that selective training of LMF immediately increases LMF activity and decreases LES activity during spinal movement in a standing position compared with training of all lower back muscles (including both LMF and LES). Therefore, training to selectively strengthen LMF is considered to be effective in increasing LMF activity in individuals with LBP or LBPH.

There are various different types for training of the low back muscles including LMF and LES. Quadruped upper and lower extremity lift (QULEL), in which the subject raises the upper extremity on a side and the lower extremity on the other side to a horizontal position in the quadruped position, is known to activate LMS. Ekstrom et al. compared the muscle activities during various exercises in healthy subjects and found that QULEL resulted in relatively high activity of the LMF muscle on the side where the lower extremity was lifted (lower extremity side) and that the % maximum voluntary contraction (%MVC) of LMF was higher than that of LES. On the other hand, LMF activity on the side where the upper extremity was lifted (upper extremity side) was lower than LES activity.[10] Therefore, it is considered that QULEL is an adequate exercise to selectively activate the LMF muscle on the lower extremity side. However, because the muscle activity was expressed as %MVC in their study, the selectivity of the muscle activity among exercises cannot be compared. Therefore, in this study, to obtain a method to train the LMF muscle more selectively and strongly, we examined the effect of modifying this exercise by adding rotation moment of the spine by changing the direction of lifting upper and lower extremities and weight loading of the extremities. In addition, to estimate the selectivity, we examined the activity ratio of LMF and LES (LMF/LES activity ratio). The muscle activity ratio has been calculated in some studies examining the activity of the shoulder girdle[25,26] or the scapular[27] muscles. However, to our knowledge, this is the first study to examine the activities of LMF and LES in terms of the activity ratio.

METHODS

Participants

The sample size required for the present study was calculated utilizing G*Power software version 3.1.9.2 (Franz Faul, University of Kiel, Kiel, Germany). Results indicated that 10 subjects would provide a statistical power of 0.80 and an effect size of 0.40 for analysis of variance.

The subjects comprised 17 healthy young men (age 22.4 ± 1.3 years, height 173.1 ± 5.7cm, weight 65.5 ± 11.7 kg). Individuals with musculoskeletal conditions or those with neurological or cardiovascular disorders that would limit their ability to perform the exercises were excluded. All subjects provided informed consent, and the protocol was approved by the Ethics Committee of the Kyoto University Graduate School and Faculty of Medicine.

Experimental procedure

The experiment was broadly divided into two parts: lifting extremities in (a) different directions and with (b) different weight loading. Conventional QULEL is performed by lifting the right upper and the left lower extremities to a horizontal position. In the present study, variants of conventional QULEL were performed in which the extremities were lifted in different directions as follows (Figure

1): (1) right upper extremity lifted to 180° shoulder flexion and left lower extremity lifted to 0° hip extension (F–E), (2) right upper extremity lifted to 90° shoulder abduction and left lower extremity lifted to 0° hip extension (A–E), (3) right upper extremity lifted to 180° shoulder flexion and left lower extremity lifted to maximum hip abduction (F–A), and (4) right upper extremity lifted to 90° shoulder abduction and left lower extremity lifted to maximum hip abduction (A–A). The exercise conditions with different weight loading of the lifted extremities were further divided as follows (Figure 1): (1) F–E (2) F–E with a weight belt weighing 2.5% of the body weight attached to the right wrist (BW; F2.5–E), (3) F–E with a weight belt weighing 5.0% of BW (F–E5) attached to the left ankle, and (4) F–E with a weight belt weighing 2.5% of BW attached to the right wrist, and weight belt weighing 5.0% of BW attached to the left ankle (F2.5–E5).

Exercises were assigned in a random order to each subject. Each exercise was performed thrice, with adequate rest periods between the different exercises.

Electromyography (EMG) recording and data analysis

EMG data were collected by sampling at 1500 Hz, using the Telemyo 2400T (Noraxon USA; Scottsdale, AZ, USA). After the electrode sites were cleaned with a scrubbing gel and washed with alcohol, bipolar surface electrodes (Ambu; Baltorpbakken, Denmark) with a 2-cm center-to-center inter-electrode distance were applied to the four muscles: LMF (at the level of the L5 spinous process on a line extending from the posterior superior iliac spine to the interspace between L1 and L2)[28] bilaterally and LES (4-cm lateral to the L1 spinous process)[10] bilaterally. The ground electrode was affixed to the skin over the iliac crest. In each exercise, the EMG signals were measured for 3 s after the subjects raised their extremities and were able to maintain a stable position. The original raw EMG signals were bandpass filtered at 10–500 Hz and the root-mean-square amplitude of the signals was computed using 50-ms windows. EMG values of each muscle were then expressed as percentages of the EMG values during MVCs. The EMG signals during the stable 3-s period were recorded as MVCs for each muscle. Furthermore, the LMF/LES activity ratio, which shows the selective strengthening of LMF compared with that of LES, was calculated.

Statistical analysis

Statistical analyses were performed using SPSS version 20.0 (IBM Japan; Tokyo, Japan). LMF activity, LES activity, and the LMF/LES activity ratio in both the upper extremity and lower extremity sides were measured and compared in the exercise conditions with different directions (F–E, A–E, F–A, A–A) and different weight loading (F–E, F2.5–E, F–E5, F2.5–E5). After EMG variables were examined using Shapiro–Wilk tests, differences in the variables were evaluated using repeated measure analysis of variance or Friedman tests. If a significant primary effect was found, the differences were determined by posthoc Bonferroni or Bonferroni correction test for multiple comparisons. P values of <0.05 were considered statistically significant.

RESULTS

Effects of lifting direction (Table 1)

There was a significant primary effect on LMF and LES muscle activities and the LMF/LES activity ratio in both the upper and lower extremity sides.

On the upper extremity side, LMF activity during the F–A and A–A conditions was significantly lower than that during the F–E condition. LES activity during the A–A condition was significantly lower than that during the F–E condition.

On the lower extremity side, LMF activity during the F–A and A–A conditions was significantly higher than that during the F–E condition. There was no significant difference in LES activity between the F–E and A–A conditions. The LMF/LES activity ratio during the A–A condition was significantly higher than that during the F–E condition.

Effects of weight loading (Table 2)

There was a significant primary effect in LMF and LES activities in both the upper and lower extremity sides. A significant effect was also observed in the LMF/LES activity ratio on the lower extremity side only.

On the upper and lower extremity sides, LMF and LES activities during the F2.5–E, F–E5, and F2.5–E5 conditions were significantly higher than that during the F–E condition. However, the LMF/LES activity ratio during the F2.5–E5 condition was significantly lower than that during the F–E condition on the lower extremity side.

DISCUSSION

The present study examined the effects of different lifting directions and weight loading of the extremities during QULEL to clarify effective methods that can selectively strengthen LMF.

Analyses with different lifting directions revealed that LMF activity in both the upper and lower extremity sides were influenced by hip abduction, as observed in the F–A and A–A conditions. Compared with the F–E condition, LMF activity on the lower extremity side was higher, whereas that on the upper extremity side were lower, in these conditions. However, shoulder abduction did not influence LMF activity on either side, and there was no significant difference in LMF activity between the F–E and A–E conditions. A previous study showed that during QULEL in the F–E condition, LMF activity on the lower extremity side was higher than LES activity.[10] This is because the weight of the lifted upper and lower extremities contributes to the rotation moment of the spine, relative to the pelvis, toward the lower extremity side, i.e., the ipsilateral rotation moment to the lower extremity side increases. Therefore, LMF activity contributing to the contralateral rotation of the spine increases on the lower extremity side. Hip abduction during QULEL affects both the flexion and rotation moments of the spine. It is assumed that the flexion moment of the spine caused by the weight of the lifted lower extremity decreases because the flexion moment arm of the spine, caused by the weight of the lifted lower extremity, decreases with hip abduction. Therefore, LMF activity that results in spinal extension is considered to decrease with a decrease in the flexion moment of the spine on the lower extremity side. On the other hand, the rotation moment arm and the rotation moment of the spine toward the lower extremity side, i.e., ipsilateral rotation moment of the lower extremity side, increases with hip abduction, and therefore, would lead to increased LMF activity.

LES activity has been shown to be higher than LMF activity on the upper extremity side during

QULEL in the F–E condition.[10] This is probably because the rotation moment of the spine toward the lower extremity side, caused by the weight of the lifted upper and lower extremities (contralateral rotation moment to the upper extremity side), increases when the upper and lower extremities are lifted. The increase in rotation moment contributes to an increase in LES activity, resulting in the ipsilateral rotation of the spine to the upper extremity side. In the present study, LES activity on the upper extremity side was significantly lower during the A–A condition than during the F–E condition, whereas there was no such difference on the lower extremity side. Hip and shoulder abduction would decrease LES activity, resulting in spinal extension on the upper extremity side. This is because the flexion moment of the spine resulting from the weight of the lifted upper and lower extremities decreases with shoulder and hip abduction. An MRI study has documented that LES acts on the long extension moment arm of the spine,[29] and it is assumed that it greatly contributes to the generation of spinal extension torque.

The fact that the LMF/LES activity ratio on the lower extremity side increased to a greater degree during the A–A condition than during the F–E condition is also noteworthy. However, there was no significant difference in the LMF/LES activity ratio on the upper extremity side between the F–E and A–A conditions. It is assumed that the increased LMF/LES activity ratio on the lower extremity side is related to increased LMF activity and unchanged LES activity. Therefore, the A–A condition is effective in selectively strengthening LMF.

Furthermore, LMF activity on both sides increased with weight loading compared with that during the F–E condition. The increase in LES activity was similar to that in LMF activity. It is assumed that the flexion moment of the spine increased because of the weight belts added to the original weight of the lifted upper and lower extremities, and LMF and LES activities that result in the extension of the spine increased to maintain the position.

The LMF/LES activity ratio on the lower extremity side decreased when weight was loaded onto the lifted upper and lower extremities compared with that during the F–E condition. However, no change in the LMF/LES ratio was observed on the upper extremity side between weight loading conditions and the F–E condition. This was probably because the increase in LES activity was greater than that in LMF activity on the lower extremity side, although LMF and LES activities increased in both sides. Therefore, our results suggest that weight loading of the lifted upper and lower extremities during QULEL is disadvantageous for selective LMF training, although it may be effective in cases where it is desirable to globally increase LMF and LES activities.

In future, intervention studies are required to investigate immediate and long-term changes in the activity pattern of back muscles during movement in the standing position in patients with LBP and LBPH using the training methods that were examined in the present study. Such an investigation will contribute to the establishment of effective training techniques for patients with LBP and individuals with LBPH.

LIMITATIONS

The present study has several limitations. First, the present study was performed in healthy subjects. It is unclear whether the muscle activity pattern of patients with LBP and individuals with LBPH, who may have altered back muscle activity, will show patterns similar to that observed in the present study. Second, it is unclear how the intervertebral joints and disks are loaded during these exercises in patients with unilateral LBP and individuals with unilateral LBPH who have intervertebral joint and disk degeneration. Previous studies have demonstrated that the changes in lower back and abdominal muscle activities induced a change in anteroposterior joint shear force at the lumbar intervertebral joint and intervertebral compression force during movement.[7,30] These findings suggest that loads at the intervertebral joints and disks during training may be altered by the change in back muscle activity. In the present study, LMF and LES activities changed because of the difference in the lifting direction of the extremities and loading weight onto the extremities. However, the shear force of the intervertebral joint and the compression force on the intervertebral disk were not measured. Thus, we propose that consideration of these factors is necessary when these subjects perform the training exercises in the present study.

CONCLUSION

The results of the present study suggest that QULEL with shoulder and hip abduction is more effective to selectively strengthen LMF on the side where the lower extremity is lifted. Loading weight onto both the lifted upper and lower extremities during QULEL is disadvantageous as a selective LMF training method because the LMF/LES activity ratio is low.

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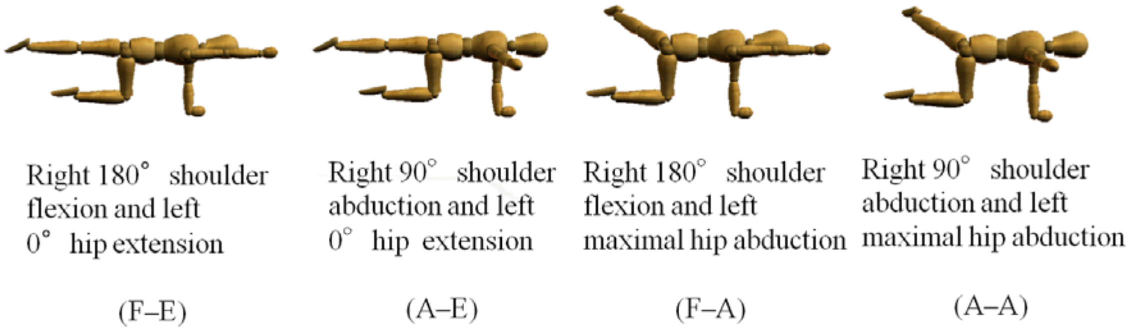
(a) Exercise conditions where the extremities were lifted in different directions



(b) Exercise conditions where weight was loaded onto the lifted extremities

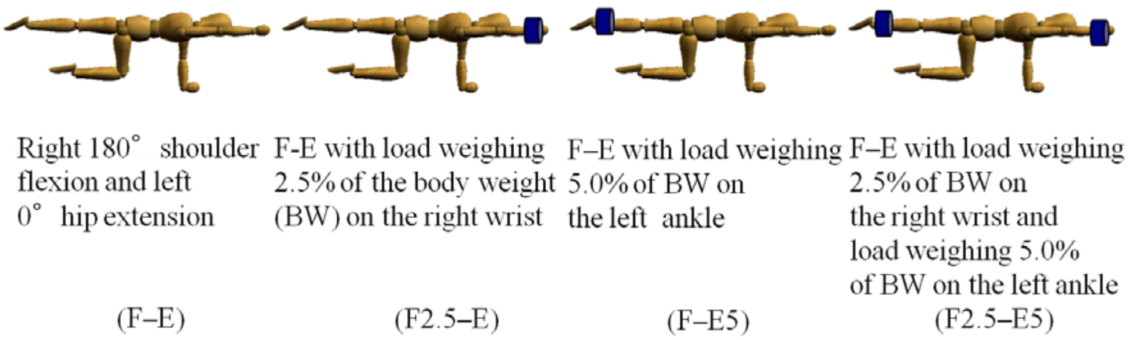


Fig 1. Variants of conventional quadruped upper and lower extremity lifts with the extremities lifted (a) in different directions and (b) with different weight loading.

Table 1. Lumbar multifidus and lumbar erector spinae muscle activities (% maximal voluntary contraction) and the Lumbar multifidus muscle/the lumbar erector spinae muscle activity ratio in exercise conditions where the extremities were lifted in different directions.

	F–E	A–E	F–A	A–A
The upper extremity side				
LMF	19.3 ± 5.8	16.7 ± 4.9	12.6 ± 4.7[*†]	11.3 ± 3.8[*†]
LES	22.5 ± 6.6	19.4 ± 6.3[*]	19.4 ± 5.7[*]	15.4 ± 4.7[*†‡]
LMF/LES activity ratio	0.89 ± 0.29	0.88 ± 0.22	0.66 ± 0.21[*†]	0.75 ± 0.24[†]
The lower extremity side				
LMF	28.5 ± 10.0	28.2 ± 9.3	34.1 ± 8.4[*†]	33.1 ± 8.0[*†]
LES	15.1 ± 7.4	12.5 ± 5.2	16.2 ± 7.7[†]	14.5 ± 6.2
LMF/LES activity ratio	2.21 ± 1.09	2.56 ± 1.12	2.64 ± 1.43	2.75 ± 1.37[*]

[*] significantly different from F–E ($p < 0.05$), [†] significantly different from A–E ($p < 0.05$)

[‡] significantly different from F–A ($p < 0.05$)

LMF: lumbar multifidus muscle, LES: lumbar erector spinae muscle

F–E: Right 180° shoulder flexion and left 0° hip extension, A–E: Right 90° shoulder abduction and left 0° hip extension, F–A: Right 180° shoulder flexion and left maximal hip abduction, A–A: Right 90° shoulder abduction and left maximal hip abduction

Table 2. Lumbar multifidus and lumbar erector spinae muscle activities (% maximal voluntary contraction) and the Lumbar multifidus muscle/the lumbar erector spinae muscle activity ratio in exercise conditions where weight was loaded onto the lifted extremities.

	F–E	F2.5–E	F–E5	F2.5–E5
The upper extremity side				
LMF	19.3 ± 5.8	25.5 ± 6.8[*]	23.8 ± 8.5[*]	27.2 ± 8.6[*]
LES	22.5 ± 6.6	28.6 ± 8.7[*]	26.8 ± 8.5[*]	31.5 ± 9.7[*‡]
LMF/LES activity ratio	0.89 ± 0.29	0.92 ± 0.17	0.89 ± 0.24	0.88 ± 0.21
The lower extremity side				
LMF	28.5 ± 10.0	32.9 ± 10.2[*]	33.8 ± 13.1[*]	38.6 ± 14.5[*†‡]
LES	15.1 ± 7.4	19.0 ± 7.0[*]	21.6 ± 10.5[*]	24.7 ± 9.8[*†]
LMF/LES activity ratio	2.21 ± 1.09	1.81 ± 0.50	1.79 ± 0.74	1.68 ± 0.55[*]

[*] significantly different from F–E ($p < 0.05$), [†] significantly different from F2.5–E ($p < 0.05$)

[‡] significantly different from F–E5 ($p < 0.05$)

LMF: lumbar multifidus muscle, LES: lumbar erector spinae muscle

F–E: Right 180° shoulder flexion and left 0° hip extension, F2.5–E: F–E with load weighing 2.5% of body weight (BW) on the right wrist, F–E5: F–E with load weighing 5.0% of BW on the left ankle, F2.5–E5: F–E with load weighing 2.5% of BW on the right wrist and load weighing 5.0% of BW on the left ankle