The Relationship between Muscle Activity and Muscle Grade of the Trunk Flexors Using Manual Muscle Testing with Electromyography

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Abstract. [Purpose] To quantitatively investigate whether the muscle grades of the Curl-up (CU) and Double-leg-lowering (DLL) test show any electromyographic changes in the upper and lower rectus abdominis (RA) as trunk flexors. [Methods] The muscle activities of both the upper and lower RA in thirty healthy young males were recorded during each muscle grade task of two tests. The percentages of maximum voluntary contractions (%MVC) of the upper and lower RA were compared between each muscle grade and test. The %MVC ratios of the upper and lower RA were calculated to investigate the contribution of each muscle site in two tests. [Results] Although there were significant electromyographic differences among muscle grades in the CU test, there was no significant difference in the DLL test. The %MVC from both sites in the CU test were significantly larger in all muscle grades than in the DLL test. However, the %MVC ratio was consistently ~1.0 in both tests and the contribution of each muscle site did not differ. [Conclusion] These findings suggest that the three grading tasks used in this manual muscle testing procedure may be insufficient to objectively detect muscle weakness in the trunk flexors. The grading criterion for trunk flexors may need remediation.

Key words: Manual muscle testing, Abdominal muscles, Electromyogram

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INTRODUCTION

Trunk muscle performance is considered important for spinal stability, posture and movement. Inadequate trunk muscle strength and endurance increase the risks of lower back pain, falls and dependence in daily living activities. Muscle strength tests provide very important information to help guide therapeutic interventions for patients with neurological and orthopedic disorders in the clinical setting^{1–8)}.

Two tests are commonly used to clinically assess

and monitor trunk flexor strength. One is the traditional manual muscle testing (MMT) that has been widely used by clinicians since its introduction by Vaughn in the later 1960s⁹⁾, and in which Lovett instructed subjects to curl-up until the angulus inferior scapulae were raised up off the bed¹⁰⁾. The grading criteria for limbs in MMT are based on the ability to move voluntarily against gravity or the manual resistance added by an examiner. During the curl-up test (CU test), however, the resistance for assessing the trunk flexors is adjusted according to the shape of the upper limbs, using a 5-point

grade scale. Several studies have investigated the grading criteria for limbs using hand-held dynamometers^{11,12)} or surface electromyography (EMG)^{13–15)}. However, the adequacy of the grading criteria for trunk muscles has not yet been reported.

Kenndal et al. proposed the double-leg-lowering test (or DLL test hereafter) for the trunk flexors and added that the CU test assesses the upper trunk flexors and the DLL test assesses the lower trunk flexors¹⁶⁾. This can be explained by the metameric nerve supply of the rectus abdominis muscle (RA) and the anterior primary rami of the lower six or seven nerves (T6/7 to T12)¹⁷⁾. Also, the segmentation of RA by its tendinous inscriptions may imply the ability to selectively isolate different portions of this muscle¹⁷⁾. Clinically, the CU and DLL tests are used not only for testing but also for training, and some studies have assessed the adequacy of these tests using the intraclass correlation coefficient or EMG^{8,18)}. However, whether the strength of the upper and lower RA muscles can actually be evaluated separately using these methods has not been investigated.

The purpose of this study was to demonstrate the relationship between the muscular activities of RA in the grading criteria of the CU and DLL tests using surface EMG. In addition, this study also examined whether, by using a different motor task, the two methods could change EMG patterns between the upper and lower RA.

SUBJECTS AND METHODS

Subjects

This study recruited 30 healthy young males (mean age, 22 ± 2 [S.D.] years; mean height, 171 ± 6 cm; mean weight, 61 ± 7 kg; mean body mass index, 21 ± 2 kg/m²). All subjects had moderate activity levels and had been free of any chronic lower back pain for at least one year prior to the study. Exclusion criteria included any previous history of fractures or surgeries involving the lumbar spine, diseases that could affect motion (e.g., rheumatoid arthritis, spondylolisthesis, etc), or current symptoms of lower back pain. To ensure natural movements, participants were also excluded if they had a body mass index of greater than 28 kg/m²¹⁹⁾. All subjects provided their informed consent to the procedures which were approved by the ethics committee of Hokkaido University School of Medicine.

Methods

Surface electromyogram (EMG) activities were recorded of the upper and lower RA on the right side of the trunk flexors. After first cleaning the skin with alcohol, bipolar surface disk electrodes (Ag/AgCl, Blue sensor P-00-S, diameter = 3.3 mm, Ambu, Denmark) were fixed with adhesive tape to each muscle at an inter-electrode distance of approximately 30 mm. Referring to Vera-Garcia²⁰⁾, the EMG electrodes were placed above the upper and lower rectus abdominis. For the upper rectus abdominis muscle, the pair of electrodes was placed approximately 3 cm lateral and 5 cm superior to the umbilicus, and for the lower rectus abdominis muscle, the pair of electrodes was placed approximately 3 cm lateral and 5 cm inferior to the umbilicus. The placement of the electrodes varied slightly according to the shapes of the subjects' bodies. The reference electrode was attached to the iliac crest.

All EMG data were collected using a Noraxon MyoSystem 1200 (Noraxon USA Inc., Scottsdale, AZ, USA). Unit specifications include a differential input impedance of greater than 10 M Ω , a gain of 1000, and a common-mode rejection ratio of greater than 100 dB at 60 Hz. The EMG signals were band-pass filtered from 10 to 500 Hz using first-order high-pass and fourth-order low-pass Butterworth filters. The Myosystem 1200 interfaced with a Windows PC using an USB A/D converter with a 16 bit A/D board. All data were sampled at a frequency of 1 kHz.

All EMG data were processed using MyoResearch EM-123 Ver.2.11 software (Noraxon USA Inc., Scottsdale, AZ, USA). During data collection, the raw recordings were monitored. The average amplitude of each muscle activity in the stable state was recorded for 3 seconds after subjects adopted the instructed posture, and then calculated using the average-rectified-value method. Raw EMG data were full-wave rectified and processed using a root-mean-square algorithm (window: 10 ms) to quantitatively-calculate the amplitude of the EMG signals. The amplitudes were then normalized to the amplitudes obtained during maximum voluntary contraction (MVC) and the value was expressed as a percentage of MVC (%MVC). Also, the %MVC ratio of upper to lower RA (i.e., the ratio = the upper RA %MVC / the lower RA %MVC) was calculated in each muscle grade to examine the contributions of the upper and lower RA during the two tests.

In this study, subjects performed both the CU and DLL tests. The CU test was practiced according to the procedure of Hislop¹⁰⁾, and the DLL test was practiced according to procedure of Kendall¹⁶⁾. Briefly, during the CU test, subjects were asked to lie in a supine position with their knees extended. Subjects were then instructed to elevate their trunks to the point where the scapula was raised up off the mat and then to maintain the posture for over 3 seconds. Subjects were asked to repeat this procedure three times using a different upper limb posture each time. The three postures were: "Normal" with hands clasped behind the head during the task, "Good" with forearms folded across the chest, and "Fair" with arms extended forward, respectively. We didn't examine the "Poor", "Trace" and "Zero" tests in the CU test because these muscle grade tasks are not performed with resistance. In the DLL test on the other hand, subjects assumed a supine posture with forearms folded across their chests. Subjects were instructed to hold their lower backs flat on the table with their legs at a 75° angle (Fair), 30° angle (Good), and 10° angle (modified Normal) and to maintain each posture for over 3 seconds while avoiding anterior pelvic tilt as much as possible. In all tasks, the examiner measured and monitored all trunk and leg angles both before and after the EMG recording. We didn't examine the "Poor", "Trace" and "Zero" tests in the DLL test because Kendall¹⁶⁾ did not describe how to measure these muscle grades. Before performing these tests, MVC was measured while the subjects were in the supine position pushing against manual resistance applied to their shoulders by an examiner. All tasks were performed randomly. The interval time between each task was of a sufficient duration to prevent muscle fatigue.

To estimate the reliability of the CU and DLL tests used in this study, an intraclass correlation coefficient (ICC) with one-way factorial analysis of variance (ANOVA) was determined for three females and three males. Further, test-retest reliability of these tests was determined by the Pearson-moment method using linear regression analysis. All analyses were performed using SPSS 11.5J (SPSS Inc., Chicago, IL). The ICC values for the muscle activities of the upper and lower RA during the CU and DLL tests were 0.84–0.96 and 0.93–0.98 for Normal, Good and Fair, respectively. Therefore, the reliability of these tests ranged from

good to excellent for these exertion levels. Also, the mean correlation coefficients for the test-retest reliability of the CU and DLL tests were 0.76 and 0.73, respectively. The reliability of our measurements was similar to that reported by Shields and Heiss²¹⁾.

Mean values and standard deviations (SD) are given in the description of the subjects and data. Three-way factorial ANOVA's were used for the comparison of the EMG data. The three ANOVA levels were tests, muscle sites and muscle grades ($2 \times 2 \times 3$). If interaction effects were not significant between factors, then the relevant data were collapsed and two-way or one-way factorial ANOVA was then performed. Then, Fisher's PLSD was used to test the significance level of those values that showed a significant difference in ANOVA. Statview 5.0 software (SAS institutes Inc, Berkley, CA) was used for statistical analyses. P values less than 0.05 were considered significant.

RESULTS

The %MVC of the upper and lower RA during the three muscle grade tasks of the two tests is summarized in Table 1. ANOVA analyses indicated that all factors showed significant differences (tests: $F_{(1,348)}=37.6$, $p<0.01$, muscle sites: $F_{(1,348)}=6.0$, $p<0.05$, and muscle grades: $F_{(2,348)}=5.7$, $p<0.01$). Interaction effects were not significant between the factors.

For the CU test, there was a significant difference between muscle grades ($F_{(2,174)}=7.0$, $p<0.01$), and a follow-up Fisher's PLSD test showed that there were significant differences between Fair and Normal ($p<0.01$) and/or Good ($p<0.05$). There was no significant difference between muscle sites. On the other hand, for the DLL test, there were no significant differences among muscle grades and between muscle sites.

The percentage differences of muscle activities between the CU and DLL tests in the upper RA were $15.0 \pm 19.4\%$ (Normal), $8.2 \pm 21.2\%$ (Good) and $9.3 \pm 18.8\%$ (Fair) and those in the lower RA were $16.9 \pm 18.5\%$ (Normal), $9.5 \pm 19.7\%$ (Good) and $6.7 \pm 22.5\%$ (Fair). Using ANOVA analysis, both the %MVC of upper and lower RA in the CU test increased significantly compared with the DLL test ($p<0.01$). However, there was no significant difference for the ratio of %MVC of upper and lower RA between the CU (0.9–1.0) and DLL (0.9–1.1) tests.

Table 1. Muscle activity level (the percentage of maximum voluntary contractions) in each muscle grade of the CU and DLL tests

	Upper rectus abdominal			Lower rectus abdominal		
	Normal	Good	Fair	Normal	Good	Fair
CU	49.0 ± 14.4	43.8 ± 14.1	38.7 ± 13.6*†	52.4 ± 16.4	50.3 ± 17.5	41.8 ± 16.2*†
DLL	34.0 ± 17.9	35.6 ± 19.0	29.4 ± 15.3	35.5 ± 19.5	40.8 ± 19.7	35.1 ± 18.5

(%)

Mean ± Standard deviation. * indicates a significant difference between “Normal” and “Fair”. † indicates a significant difference between “Good” and “Fair”. *, †: $p < 0.05$.

DISCUSSION

The manual muscle testing procedures investigated in this study are used to assess muscle weakness and rehabilitation effects of patients with various disorders. Thus, it is necessary to objectively clarify whether the resistance loads used in each test produce significant changes between each muscle grade during trunk muscle activities. This study used electromyograms to investigate the muscle activities of RA during different CU and DLL test grades. We could show that there was a significant difference in RA activities in the CU test but there was no significant difference in RA activities among muscle grades in the DLL test. In addition, although the muscle activities of the upper and lower RA were greater during the CU test than during the DLL test, the contribution of each RA site for the trunk flexors strength did not change between tests.

Although several previous studies exist for comparison with the present results, the results of these studies do not always agree^{17,21–23}). This disagreement may result from differences in the maneuvering and displacement of the recording electrodes used in each study. The %MVC of the upper and lower RA obtained during Normal in the CU test corresponded with results from previous studies that examined this task as a rehabilitation training^{24,25}). Although we could not fully compare the DLL test, our data during Normal were similar to the data of Lehman and McGill²⁴). Their measurements of the same task were performed when both legs were kept raised 25 cm off the bench. Resistance during the CU test was supplied by the weight of the head, neck, upper limbs, and upper torso segments. By calculating the mass ratio for body weight according to Dempster²⁶), the

average weight load during the CU test in this study was expected to be about 41 kg. During the DLL test on the other hand, the resistance was supplied by the weight of the lower limbs and the average weight load was expected to be about 20 kg²⁶). Thus, the total weight load was clearly larger during the CU test. This difference in total weight may have contributed to our result that maximal RA %MVC was higher in the CU test than in the DLL test in young males (about 50% vs. 35%).

The external torque caused by moving both upper limbs away from the movement axis around T10 increases resistance in the CU test²⁷). During the Fair task of this test, both upper limbs are extended straight over RA and cross over the movement axis in the sagittal plane. On the other hand, during both the Normal and Good tasks, the upper limbs do not cross over the movement axis in the sagittal plane at all. In addition, the percent weight of both upper limbs was only about 10 %²⁶) Smidt reported that there was no significant difference between subjects' trunk flexor torques at each muscle grade²⁸). Our results also showed that RA activity during Good in the CU test was similar to that during Normal. Dvir suggested that muscle grade 4 (i.e. Good) was an inadequate criterion of limb muscle strength²⁹). In the CU test, the weight of the upper limbs may be lighter for young males and the distances involved in the positional change of the upper limbs between Normal and Good may be insufficient to change RA activities.

The DLL test assesses the ability of trunk flexors to stabilize the pelvis in the posterior-tilted position against an external load imparted by the lower limbs as they are lowered from a vertical starting position¹⁷). However, previous studies have reported that the pelvis tilted anteriorly before completely lowering to 0° even in asymptomatic

young men and women^{8,30,31)}. Smidt et al.²⁸⁾ suggested that this clinical test was a poor discriminator as indicated by their trunk flexor torque data. Data from a previous study suggests that there are two differential coordination movements between the lumbar spine and the pelvis³²⁾, a phenomenon that may occur in healthy subjects regardless of any trunk flexor weakness.

This study showed that there was no significant difference in RA activities between each muscle grade in the DLL test although the weight of both lower limbs (about 30 % of the body weight)²⁶⁾ was larger than that of both upper limbs. For the DLL test, both strong eccentric abdominal contraction as well as hip flexor contraction is required⁸⁾. Using the DLL task as an exercise, Norris reported that it could compound hip muscle imbalance³³⁾. Also, Gillerad and Brown¹⁸⁾ observed that as the challenge level increased (both lower limbs were lowered by degrees) there was a decrease in RA activity while the activity of the oblique abdominal muscles continued to rise. The RA activity in this study also showed a decrease in the Normal grade although there was no significant difference in the DLL test. Therefore, it is necessary for clinicians to comprehensively judge by adding the muscle strength of the hip flexors to the oblique abdominal muscles when evaluating the muscle strength of trunk flexors using the DLL test.

The CU and DLL tests are performed to assess the muscle strength of the upper or lower trunk flexors, separately. However, recent studies^{17,20,23–25)} examining the muscle activity of the upper and lower rectus abdominal muscles during these motor tasks have reported that there is no difference between the muscle activity of the upper and lower RA and our results support these findings. Clark¹⁷⁾ suggested that the anatomical discovery that some RA fibers extend beyond the tendinous inscription might explain why there was no difference between upper and lower RA activity in the CU and DLL exercise tasks. From previous studies and our results, it is difficult to imagine that a single muscle has different activities in each region within its muscle. Further study on this point is needed from both anatomical and physiological perspectives.

The current study had several limitations. First, the subjects were comprised of healthy young males only. Second, this study did not collect any data on the muscle activities of other trunk flexors (e.g., assistant movers, oblique abdominis, psoas

muscles) or hip flexors because the prime mover of trunk flexion is the rectus abdominis. Third, we collected data on muscle activity during the stable phase of the motor task. These three points made it impossible to fully compare our data with previous studies. Further study is required to collect and analyze the data from a more diverse range of subjects and/or muscles sites.

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