A vertical load applied towards the trunk unilaterally increases the bilateral abdominal muscle activities

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Abstract. [Purpose] It is considered that evaluation of the vertical trunk function is important, because humans stand and move with two legs. To evaluate this, a novel method named Trunk Righting Test has been reported. The purpose of this study was to examine the trunk muscle activity during a TRT using electromyogram analysis. [Participants and Methods] This study included 7 healthy volunteer males. The TRT evaluated the supportability of the posture after moving 10 cm laterally from the sitting position using a hand-held dynamometer. The TRT measurements were analyzed separately at the measurement side (ipsilateral side) and at the non-measurement side (contralateral side). The measurements were obtained bilaterally, and the evaluated muscles included the rectus abdominis, internal oblique, external oblique, multifidus, and transversus abdominis. The measured value was expressed as a percentage after comparing with the value at the maximum voluntary contraction (% MVC) for standardization. The changes in the muscle activities in the sitting position and TRT were evaluated. [Results] All the muscle activities significantly increased during the TRT in contrast to that in the sitting posture. [Conclusion] The load support of the trunk on one side during the TRT was significant in all the muscles on both the sides, which increased the muscle activity, in contrast to that in the sitting position.

Key words: Trunk function, EMG, Trunk muscles

INTRODUCTION

Improvement in the trunk functions, including muscle, sensory, and nerve functions has been reported to have positive effects, such as reduction of lower limb disorder\textsuperscript{1,2,3} and improvement of the performance\textsuperscript{1}. According to Hodges et al.\textsuperscript{2}, the abdominal transverse muscles work prior to other muscles during exercise. The abdominal transverse muscle starts to contract 0.03 second earlier during upper limb movement; and 0.11 second earlier during lower limb movement. These functions make it possible for humans to move the limbs freely by increasing the stability of the lumbar spine. Abdominal transverse muscle dysfunction causes low back pain and spinal instability\textsuperscript{3}. Thus, the trunk is considered to be the source of motion.

There are a number of methods to evaluate the trunk function, and the methods are selected according to the situation and circumstances. Majority of the methods to evaluate the trunk function are performed in a supine position\textsuperscript{4}. However, it is considered that evaluation of the vertical trunk function is important, because humans stand and move with two legs.
Recently, a novel method named Trunk Righting Test (TRT) to evaluate the vertical trunk function has been reported. In this method, the evaluation is performed in a sitting position; and the vertical trunk supportability can be checked by loading the vertical direction. It has been reported that the trunk function evaluated by a TRT is correlated with TRT measuring side’s (ipsilateral side) knee extension strength, ipsilateral side dynamic balance test, and timed up and go test (TUG) in patients with knee osteoarthritis. However, a detailed evaluation of the trunk muscle activities during the TRT is unknown at present. The results show that TRT outcomes are correlated with the ipsilateral side dynamic balance test and TUG indicate that the TRT may be useful to enhance not only the TRT non-measurement side (contralateral side), but also the ipsilateral side lumbar muscle activity. Understanding muscle activity during the TRT is useful to comprehend the trunk function, and thus, helps acquire better trunk function that leads to better movement.

The hypothesis of this study is that a TRT may be useful to enhance not only the contralateral side, but also the ipsilateral side lumbar muscle activity. Hence, the purpose of this study was to examine the trunk muscle activity during a TRT using an electromyogram (EMG) analysis.

**PARTICIPANTS AND METHODS**

This study included 7 healthy volunteer males (age: 27 ± 2 years, height: 171.7 ± 4.5 cm, weight: 67.6 ± 4.9 kg). All the participants understood the purpose of this study and provided informed consent prior to participation according to the ethical standards of the Declaration of Helsinki; and this research was conducted with the approval of Osaka Sangyo University Ethics Committee (2015-Human Lib-03). In this study, the TRT was performed in a sitting position and the muscle activity was measured by using an EMG. The sitting position was guided to be in a natural state and was kept as neutral as possible. The position was confirmed by a surface EMG, which did not show remarkable crosswise difference. The TRT was performed as explained previously. Briefly, the TRT evaluated the supportability of the posture after moving 10 cm laterally from the sitting position using a hand-held dynamometer. The TRT measurements were analyzed separately at the ipsilateral side and at the contralateral side. The measurements were obtained bilaterally and the evaluated muscles were as follows; the rectus abdominis (RA), the internal oblique (IO), the external oblique (EO), the Multifidus (MF), and the transversus abdominis (TrA). The RA, IO, EO, and MF were evaluated with a surface electrode, and the TrA was evaluated with a wire electrode. The muscle action potential on the surface electrode was measured using a Myo system 1200 (Noraxon, AZ, USA). Analyses of the surface EMGs were performed using a waveform analysis software (Myo Research XP, Noraxon). The signal of the wire electrode was recorded in the computer via an Input box (LabChart, AD instrument, Co., USA). Analyses of the wire EMGs were also performed using the waveform analysis software (LabChart, AD instrument, Co., USA). The surface and the wire EMGs were set to a sampling frequency of 1,000 Hz. The electrode used for the wire EMG was made with a 22-G cathelin needle and a stainless-steel wire (A-M Systems), and was used after peeling off the coating from the tip up to 2 mm. Twenty-two stainless-steel wires were passed through a 22-G cathelin needle, and the tip was bent. Two wires were fixed by a Vetbond (3M), so that the distance between the electrodes was 0.5 cm. The wire electrode was made up of 0.75 mm Teflon coated stainless-steel wire (A-M Systems), and was used after peeling off the coating from the tip up to 2 mm. Twenty-two stainless-steel wires were passed through a 22-G cathelin needle, and the tip was bent. Two wires were fixed by a Vetbond (3M), so that the distance between the electrodes was 0.5 cm.

**Fig. 1.** Wire needle.
The wire electrode was made up of 0.75 mm Teflon coated stainless-steel wire (A-M Systems), and was used after peeling off the coating from the tip up to 2 mm. Twenty-two stainless-steel wires were passed through a 22-G cathelin needle, and the tip was bent. Two wires were fixed by a Vetbond (3M), so that the distance between the electrodes was 0.5 cm.

**Fig. 2.** Ultrasound image during the installation of the wire electrode.
An ultrasound was performed to confirm that the wire needle was fixed in the abdominal transverse muscle.

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about 2–3 cm from the midline)\(^ {13} \). The sampling frequency was 1,000 Hz. The amplitude of the EMG signal was obtained by deriving the root-mean-square of the signal over a 50-millisecond moving window, resulting in a full-wave rectification and smoothing of the raw signal. For statistical comparisons, the normalized and stable waveforms of 200 ms were selected, and the averaged amplitudes were calculated. The measured value was expressed as percentage after comparing with the value at the maximum voluntary contraction (%MVC) for standardization. An MVC was recorded for each muscle. The amplitudes of the MVC for the RA, IO, and EO were same after manual muscle testing\(^ {14} \). For the MF, the activity during the maximum eccentric contraction was measured in a prone trunk-extension position. RA, IO, EO and MF were measured with maximum voluntary contraction. For the TrA, the activity was measured in a sitting position and abdominal hollowing task position\(^ {15} \).

Simultaneously, the MVCs of each muscle were also measured. The changes in the muscle activities in the sitting position and TRT were evaluated. Statistical analysis was performed by using an SPSS, Version 20. The Friedman’s test of two-way analysis of variance was used for the analysis. The level of significance was set at 5%. The value measured for the sitting position was considered as the average value of the activity of each muscle measured on both the sides.

### RESULTS

The results are shown in Table 1. All the muscle activities significantly increased during the TRT in contrast to that in the sitting posture. The activities of the TrA, RA, IO, and MF muscles on the contralateral side significantly increased during the TRT in contrast to those on the ipsilateral side.

### DISCUSSION

This study aimed to examine the activity of the lumbar muscles during the TRT using surface and wire EMGs. The result showed that the activity of the bilateral lumbar muscles significantly increased during the TRT in contrast to those measured in the sitting posture. Watanabe et al.\(^ {16} \) reported that the activity of the ipsilateral side lumbar muscles is maintained, whereas, the activity of the contralateral lumbar muscles increases when a lateral load transfer is performed in the sitting position. The results of this study reveal that the ipsilateral side lumbar muscle activities also increase when the vertical load is applied in addition to the lateral load transfer in the sitting position. The results suggest that a TRT is important for the evaluation of not only the contralateral, but also the ipsilateral side lumbar muscle activity.

The lumbar stability involves a large number of the circumferential lumbar muscles. These muscles can be classified as the local muscle and global muscle, depending on the anatomical difference\(^ {17} \). The IO attached to the thoracolumbar fascia, MF, and TrA are classified as the local muscles, and are responsible for the segmental lumbar stability. These muscles are activated as weight supporting muscles in the closed kinetic chain\(^ {18} \). The RA and EO are classified as the global muscles, and it has been reported that these muscles control the direction of the movement\(^ {18} \). Consequently, the local muscles work co-operatively with each other to increase the lumbar stability when the trunk functions are working at the time of load; and simultaneously, the global muscles become active to control the movement and its direction.

A TRT is performed with the support of a vertical load applied on the unilateral side. The posture during the TRT enhances the vertical load already applied during the test in contrast to that with gravity alone. Therefore, the lumbar region further requires postural stability and exercise control. Thus, the TRT enhances the bilateral lumbar muscle activity. It is suggested that bilateral IO, MF, and TrA muscles stabilize the thorax and pelvis, and are also involved in trunk stability. It is presumed that the EO and RA resist against the load applied in the vertical direction to prevent the trunk from bending or rotating.

The RA, IO, MF and TrA muscle activities significantly increased on the contralateral side in contrast to that on the ipsilateral side. This result is similar to that of the past reports\(^ {16} \). As the lateral load transfer during the TRT resulted in the trunk bending towards the contralateral side, which requires lift-up of the contralateral pelvis, it was inferred that the lumbar

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### Table 1. The variance analysis of the muscle activities measured in the sitting position and TRT

| Measurement item | Sitting (Mean) | TRT (Mean) | Interaction | Main effect |
|------------------|---------------|------------|-------------|-------------|
|                  | Contralateral |            |             |             |
|                  | Ipsilateral   | Contralateral |             |             |
| RA               | 2.5           | 5.5        | 7.56**      | 48.19**     |
|                  | 1.3           | 2.5        | 5.25*       | 22.87**     |
| IO               | 4.1           | 14.4       | 34.53**     | 106.60**    |
|                  | 2.3           | 8.6        | 0.57        | 60.50**     |
| EO               | 3.4           | 30.8       |             |             |
|                  | 2.2           | 19.6       |             |             |
| MF               | 9.8           | 19.6       |             |             |
|                  | 6.8           | 8.1        |             |             |
| TrA              | 16.4          | 31.3       |             |             |
|                  | 13.1          | 24.7       |             |             |

Upper row: mean. Lower row: standard deviation. 
*p<0.05; **p<0.01 (Interaction and the main effect are expressed as p-values.)
Unit: %MVC.
muscle activity increased on the contralateral side in contrast to that on the ipsilateral side.

Bipedal animals require a load applied to the trunk in the vertical direction for movement. Therefore, it is meaningful to measure the vertical force supporting the trunk. It is suggested that the TRT can directly evaluate the use of the trunk during bipedal movement. It is suggested that actions like a TRT are required in situations such as walking or in situations of applying further load in the clinical setting. A previous study which reported a TRT for osteoarthritis found that a TRT is positively correlated with the knee extensor strength, which is important for walking and dynamic balance[19]. Our results also indicate that when the ipsilateral side legs have higher supportability, the TRT is better.

This study found that the bilateral lumbar muscles are important for a TRT. Snijders et al. have reported that an increment in the load towards the lower limb also increases the IO muscle activity. The IO muscle activities stabilize the pelvis via vertical compressing force against the shear stress of the sacroiliac joint due to the load[19]. In addition, Callaghan et al. have reported that the IO muscular activity on the stance side increases when the heel touches the ground, and the bilateral RA and EO muscular activities are continuously active during walking.[20] These facts also indicate that the bilateral lumbar muscle activities are needed to increase the motion of one leg. TRT is a simple and useful test to evaluate which supportability is a problem between the lower limbs and trunk when evaluating one-leg support motion. It is strongly suggested that the evaluation of the vertical trunk supportability is important and should be generally performed to assess the muscle activity. It is also suggested that a TRT can be a useful procedure, because it can be easily performed clinically.

The limitations of this study include a small sample-size, and no comparison between actual situations such as walking and TRT. Therefore, it is unknown whether the limb movement and TRT are related electromyographically.

The load support of the trunk on one side during the TRT was significant in all the muscles on both the sides, which increased the muscle activity in contrast to that in the sitting posture. Thus, during the TRT, the activity of the TrA, RA, IO, and MF muscles significantly increased on the contralateral side in contrast to that on the ipsilateral side.

Conflict of interest

None.

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