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ORIGINAL RESEARCH REPORT

Contributions of Muscle Elasticity and Lateral Slide of the Transversus Abdominis to Lumbar Stability

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Context: Lumbar instability can cause lumbar spondylolisthesis and chronic low-back pain in sports situation. Abdominal hollowing is commonly used in clinical practice to preferentially target the transversus abdominis (TrA) to stabilize the lumbar vertebrae; however, the contribution of muscle elasticity and lateral slide of the TrA to lumbar stability has not yet been clarified. ***Objective:*** To clarify the contribution of elasticity and lateral slide of the TrA to lumbar stability and to identify an effective exercise to stabilize the lumbar vertebrae. ***Design:*** Experimental study. ***Setting:*** Laboratory. ***Patients:*** A total of 29 healthy males participated in this study. ***Interventions:*** The participants performed hollowing during measurement of muscle elasticity of TrA and both knees extension from crook lying position for pelvic stability measurement. ***Main Outcome Measures:*** Lumbar stability, muscle elasticity change ratio, and lateral slide amount of TrA. ***Results:*** There was a significant correlation between elasticity of the TrA and lumbar stability; however, no relationship was observed between lateral slide and lumbar stability or elasticity of the TrA. ***Conclusion:*** Elasticity of the TrA and lumbar stability was significantly correlated; therefore, improving the tonicity of the TrA may stabilize the lumbar vertebrae in healthy individuals. Moreover, hollowing with maximum effort may be effective as training aimed to stabilize the lumbar vertebrae for physical dysfunction due to lumbar instability.

Keywords: elastography, exercise, low back pain, lumbar instability, abdominal hollowing

Lumbar instability can cause lumbar spondylolisthesis and chronic low-back pain.[1] Contraction of the transversus abdominis (TrA) and the diaphragm increases the intraabdominal pressure,[2] thereby playing a role in stabilizing the lumbar vertebrae. To train the TrA, the abdominal hollowing technique (hollowing) is recommended.[3] Abdominal hollowing is performed in a supine position with the hips flexed until the knees exhibit 90° of flexion and with the feet flat on the bed (crook lying position). Hollowing is applied in various clinical situations. For example, hollowing was effective to improve the following: pain and dysfunction in patients with low-back pain,[4] stability of standing,[5] stair climbing,[6] activity of local trunk muscle,[7] hip extension angle during walking,[8] and pulmonary function in patients with spinal cord injury.[9] In addition, hollowing resulted in an earlier onset of TrA (as measured by electromyography) during rapid arm flexion and extension,[10] an increased cross-sectional area of the TrA.[11] Moreover, Rostami et al[12] reported that off-road cyclists with low-back pain tend to have atrophy of the TrA, and atrophy of the TrA is recognized in older adults who need assistance in activities of daily living.[13]These previous studies indicated that TrA dysfunction may be associated with low-back pain. However, to the best of the authors' knowledge, there was no research that investigated a potential relationship between the TrA elasticity and lumbar stability.

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In addition, both muscle activity and the morphological aspect of the TrA have been investigated to evaluate the function of the TrA. A systematic review investigating the morphological changes and clinical outcomes of the TrA in patients with low-back pain[14] revealed that the most important factor related to low-back pain and motor dysfunction was the lateral slide of the TrA and not muscle thickness or onset of the TrA contraction. Thus far, it is unknown whether the lateral slide of the TrA is related to lumbar instability.

Therefore, the objective of this study is to determine the contribution of elasticity and lateral slide of the TrA to lumbar stability. A secondary objective of this study is to identify an effective exercise intervention to increase lumbar stabilization. The authors reported that the muscle elasticity of the TrA increased with the increase in the intensity of the hollowing.[15] On the other hand, Hides et al[16] reported that elite cricketers with low-back pain decreased amount of lateral slide of TrA. Therefore, the hypothesis was that participants who can improve the elasticity of the TrA can slide the TrA wider and, as a result, can stabilize the lumbar vertebrae.

Materials and Methods

Design

This was an experimental study in the laboratory.

Participants

A total of 29 healthy male medical workers working in a clinic volunteered to participate in this study (25.9 [7.5] y old, 173.8 [5.4] cm, 64.5 [7.0] kg). The participants were excluded if they had low-back pain at the time of evaluation; history of orthopedic, neurological, respiratory, or circulatory disorders; previous spinal surgery; or history of low-back pain lasting 3 months or more. None of the participants were excluded by exclusion criteria or data loss. All the participants provided written informed consent, and the protocol was approved by the ethics committee of the Nittazuka Medical Welfare Center (Shinrin 29-26). The sample size required for the Pearson correlation coefficient (effect size = 0.5, α error = .05, power = 0.8) was calculated using G*Power software (version 3.1; Heinrich Heine University, Dusseldorf, Germany). The results showed that 26 participants were required; therefore, 29 participants were recruited considering potential withdrawals.

Procedures

All measurements were performed by the same experienced physical therapist. Each participant laid in a supine position with the hips flexed until the knees exhibited 90° of flexion with the feet flat on the treatment table (crook lying position).[10,17,18] With the guidance of the examiner, the participants practiced the hollowing movements, avoiding movements of the pelvis and thorax. The participants were then instructed to hold their breath for 5 seconds at the end of normal relaxed exhalation in the crook lying position and hollow the abdomen maximally. Concurrently, the examiner measured the lumbar stability, the muscle elasticity, and the lateral slide of the TrA. All the tasks were carried out after practicing several times while showing the value of the pressure biofeedback unit to the participants.

Measurement of the Lumbar Stability

The lumbar stability was measured 3 times per participant referring to the method of Azevedo et al.[19] A pressure biofeedback unit was placed under the lumbar vertebrae in the crook lying position with the pelvis in neutral, and the pressure of the biofeedback unit was set at 40 mm Hg. Participants fully extended the knee joints, keeping the original angle of the hip joints in the crook lying position, and the examiner measured the changes of the value of the pressure biofeedback unit, which was set to change positively according to the intensity of the pelvic posterior tilt (Figure 1).

Measurement of the Muscle Elasticity and Lateral Slide of the TrA

The muscle elasticity of the TrA was measured at rest and during hollowing with maximum effort through ultrasonography (HI VISION Avius; HITACHI Aloka Medical, Tokyo, Japan) with the SL-18-5 linear ultrasound transducer in real-time tissue elastography mode. The probe was set to the target region parallel to the muscle fibers of the left TrA. The target region was determined by moving the probe transversely to the longitudinal axis of the body and medially from the anterior superior iliac spine until the image of the muscle belly of the TrA could be confirmed (Figure 2).

The lateral slide movement of the TrA was measured via B-mode ultrasonography, and the target region was the same as that used to measure the muscle elasticity. The amount of movement required for hollowing the abdomen with maximum effort from rest was measured using the method of Hides et al[20] by measuring the movement of the V-shaped inner edge of the TrA (Figure 3).

Data Processing

Lumbar Stability. The index of the lumbar stability was calculated based on the absolute value of the difference between rest (40 mm Hg) and during full extension of both knees as measured by the pressure biofeedback unit. Therefore, lower values of lumbar stability indicated higher lumbar spinal stability.

Muscle Elasticity of the TrA. The real-time tissue elastography mode measures muscle elasticity or the hardness quantifying tissue

Figure 1 — Measurement of the lumbar stability from the crook lying position to full extension of the knee.

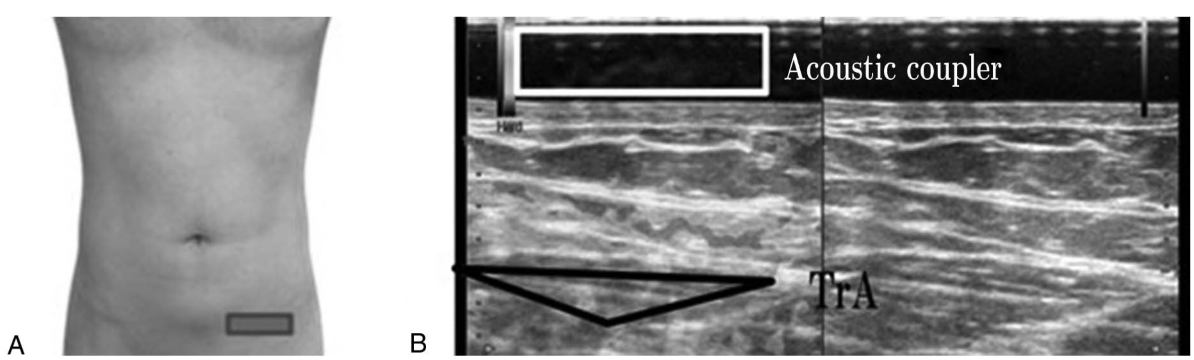

Figure 2 — Measurement of elasticity of the TrA. (A) TrA measurement point. (B) Example of TrA imaging using the real-time tissue elastography mode. The muscle elasticity is presented on a color-coded scale. TrA indicates transversus abdominis.

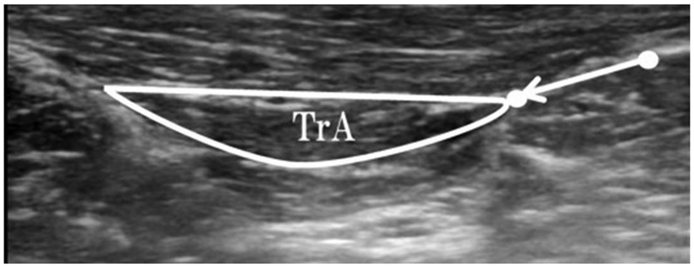

Figure 3 — Measurement of lateral slide of the TrA at the level of the anterior superior iliac spine. The amount of movement required for hollowing the abdomen with maximum effort from rest was measured of the V-shape at the inner edge of the TrA. TrA indicates transversus abdominis.

distortion during external force application. Muscle elasticity of the TrA was corrected by the elasticity of the acoustic coupler, and the strain ratio was calculated as the muscle elasticity of the TrA using the following equation:

$$\text{Muscle elasticity (strain ratio)} = (\text{muscle elasticity of the TrA}) / (\text{elasticity of the acoustic coupler}).$$

Lower values of muscle elasticity indicate less distortion against external force and greater hardness of the tissue. Furthermore, the muscle elasticity change ratio was calculated from rest to abdominal hollowing using the following formula:

$$\text{Muscle elasticity change ratio} = (\text{muscle elasticity at rest} - \text{muscle elasticity at abdominal hollowing}) / \text{muscle elasticity hardness at rest}.$$

The muscle elasticity change ratio indicates that the larger the value, the more the TrA can be "hardened" or have its tone increased by abdominal hollowing.

Statistical Analysis

Statistical analysis was performed using R (version 2.8.1; R Development Core Team, Vienna, Austria). To examine, the intraexaminer reliability of the measurement, the intraclass correlation coefficient (1, 3) of the 3 measurements of lumbar stability, muscle elasticity change ratio, and lateral slide of the TrA were calculated. Furthermore, Pearson correlation coefficient test was performed for lumbar stability, muscle elasticity change ratio, and lateral slide of the TrA. The significance level was set to $P < .05$.

Results

The reliability of the measurement of lumbar stability, muscle elasticity change ratio, and lateral slide is presented in Table 1. The intraclass correlation coefficient (1, 3) was lumbar stability (.847), muscle elasticity change ratio (.961), and lateral slide (.999).

There was a significant negative correlation between lumbar stability and muscle elasticity change ratio of the TrA (Figure 4; $r = -.490$, $P = .007$), but there was no significant correlation between lumbar stability and lateral slide (Figure 5; $r = .067$,

Table 1 $ICC_{1,3}$ of Lumbar Stability, Muscle Elasticity Change Ratio, and Lateral Slide of the TrA

Measurement	$ICC_{1,3}$	95% CI
Lumbar stability	.847	0.715–0.924
Muscle elasticity change ratio	.961	0.921–0.983
Lateral slide	.999	0.997–0.999

Abbreviation: CI, confidence interval; ICC, intraclass correlation coefficient ; TrA, transversus abdominis.

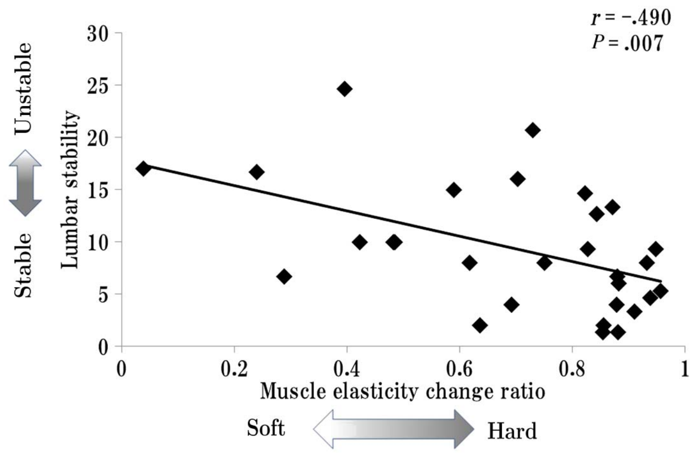

Figure 4 — Changes in the relationship between lumbar stability and muscle elasticity. Lumbar stability indicates a lower numerical value, as the lumbar spinal stability is higher. The muscle elasticity change ratio means that the larger the value, the more the TrA can be hardened by abdominal hollowing. Two variables showed a significant negative correlation between lumbar stability and muscle elasticity of TrA, and this result indicated that the participants who can harden the TrA can stabilize the lumbar vertebrae. TrA indicates transversus abdominis.

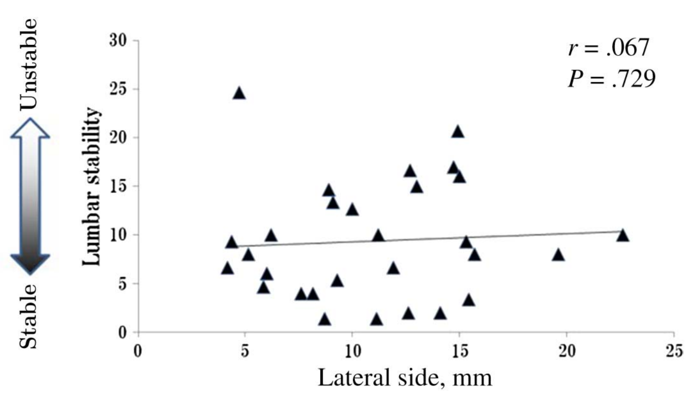

Figure 5 — Relationship between lumbar stability and lateral slide. Lumbar stability indicates a lower numerical value as the lumbar spinal stability is higher. There was no significant correlation between the lumbar stability and lateral slide.

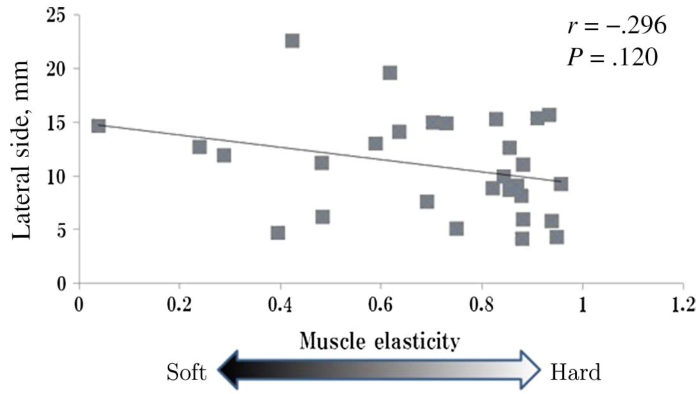

Figure 6 — Change in the relationship between lumbar stability and muscle elasticity. The muscle elasticity change ratio means that the larger the value, the more the TrA tonus can be increased by abdominal hollowing. There was no significant association between the muscle elasticity change ratio and lateral slide. TrA indicates transversus abdominis.

$P = .729$). Moreover, there was also no significant association between muscle elasticity change ratio and lateral slide (Figure 6; $r = -.296$, $P = .120$).

Discussion

Azevedo et al[19] suggested the possibility of evaluating the lumbar stability due to lumbar/pelvic disturbance during lower limb movement. The relationship between lumbar stability and elasticity of the TrA suggest that participants who could harden or increase the tonus of the TrA during hollowing can stabilize the lumber vertebrae, which is consistent with the authors' hypothesis. Recent studies using fine-wire electromyography clarified that hollowing involved increased activity of the TrA[3] and increased the stiffness of the abdomen.[21] In the authors' current study, the participants activated the TrA, increased the stiffness of the abdomen, and prevented pelvic disturbance against rotational force by raising both legs. In clinical practice, it has been suggested that abdominal hollowing with maximum effort may be effective in training the TrA for patients with low-back pain and reduced lumbar stability.

Lateral slide of the TrA does not correlate with the lumbar stability and elasticity of the TrA, which is not consistent with the authors' hypothesis that the larger the lateral slide of the TrA, the higher the lumbar stability. Hides et al[22] reported that the amount of lateral slide of the TrA significantly increased with a load of 25% to 45% of the body weight. The functional contraction of the TrA was clarified to be 5% to 10% of the maximum contraction (5% to 10% maximum voluntary contraction),[18] and the activity of the TrA during stand-and-sit was about 10% maximum voluntary contraction.[23] Therefore, contraction of the TrA due to a load of 25% to 45% of the body weight is considered to be <5% of the maximum contraction of the TrA. Hodges et al[24] investigated that the thickness and activity of the abdominal muscle were linearly related up to 20% maximum voluntary contraction, but no association was observed above that; thus, they revealed a ceiling effect in TrA muscle thickness. Muscle elasticity and lumbar stability did not respond sensitively to lateral slide during hollowing with maximum effort (the technique adopted in this study) owing to the ceiling effect, which may be recognized at low intensities of TrA contraction.

Based on the results of this study, it can be suggested that performing abdominal hollowing with maximum effort as trunk stabilization training is effective in enhancing TrA in clinical and sports settings. Moreover, enhancing the elasticity of TrA may improve the stability of the trunk, improve posture control, and prevent low-back pain in athletes.

There are several limitations to this study. First, participants were limited to young male medical workers; therefore, the results to this study are difficult to apply to other populations. Second, lumbar stability was only evaluated in the sagittal plane. Allison et al[25] reported that the TrA activated unilaterally as a brake against the external force in the rotational direction; however, the authors' current study did not sufficiently evaluate the stability on the frontal and horizontal planes.

Conclusion

This study examined the contribution of the elasticity and lateral slide of the TrA to lumbar stability. A significant correlation between elasticity of the TrA and lumbar stability was observed. This result indicated that participants who can harden the TrA can consequently stabilize the lumbar vertebrae. Therefore, abdominal hollowing with maximum effort may be effective when administered as a training method aimed at stabilizing the lumbar vertebrae improving posture control and preventing low-back pain in athletes. An intervention study is needed to clarify the effect of abdominal hollowing with maximum effort for physical dysfunction due to lumbar instability.

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