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Original Research

Trunk Muscle Thickness During Supine and Crawling Exercises

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ABSTRACT

International Journal of Exercise Science 16(4): 1103-1112, 2023. The purpose of this study was to measure and validate trunk muscle thickness while performing the Heel Off (HO-ex) and Bird Dog exercises (BD-ex), which are hip extension exercises in the supine position. Thirty-one healthy young males who provided informed consent were included in the study. The thicknesses of the right trunk muscles (lumbar multifidus (LM), erector spinae (ES), external oblique (EO), internal oblique (IO), and transverse abdominis (TrA) were measured using an ultrasound machine. Measurements were taken under four random conditions: supine, HO-ex, crawling on all fours, and BD-ex. One-way analysis of variance and Friedman tests were performed to determine the differences between the conditions for each muscle thickness. LM was significantly thicker in the HO-ex. ES was significantly thicker in HO-ex than in supine, and in BD-ex than in supine, HO-ex, or crawling on all fours. EO was significantly thicker in the supine position than in HO-ex, crawling on all fours. IO was significantly thicker in the HO-ex than in the supine position. TrA was significantly thicker in HO-ex, crawling on all fours, and BD-ex than in the supine position, with no significant difference between HO-ex, crawling on all fours, and BD-ex. The results of this study suggest that HO-ex is more advantageous than BD-ex in stimulating contraction of the multifidus and IO muscles, and that HO-ex can stimulate contraction of the TrA to the same degree as BD-ex.

KEY WORDS: Ultrasound imaging system, heel off exercise, bird dog exercise

INTRODUCTION

Trunk muscle weakness is among the most important clinical issues in rehabilitation medicine. Trunk muscles play an important role in stabilizing and maintaining posture and in controlling spinal and pelvic movement. Therefore, trunk muscle atrophy is thought to increase the falls risk and impair activities of daily living in the elderly (1, 24). It has also been reported that atrophy is more pronounced in antigravity muscles such as the back and transversus abdominis muscles when the patient is chronically bedridden (10). Therefore, it is very important to strengthen the trunk muscles in elderly individuals who are losing muscle strength or who have been lying in bed for an extended period of time.

Exercises that increase muscle activity in the trunk include some involve moving the extremities on sitting, standing, prone, supine, and crawling on all fours. (4, 17, 18, 25). Previous studies have shown the clinical utility of the Bird Dog exercise (BD-ex) (3, 19, 25), which involves raising two limbs whilst on all fours, and the Superman exercise (3, 18, 27), which involves raising one-four limbs from the prone position. Some of the aforementioned previous studies (3, 17, 27) used ultrasound imaging devices. However, training in these postures may not be possible if the patient does not have the muscle strength or range of motion to assume the posture itself, as in cases of paralysis or limb disease, or if the patient is using an intravenous drip. Therefore, it is necessary to consider effective methods for improving the trunk muscle in the supine position. Therefore, we created the Heel Off-ex (HO-ex) to efficiently train the trunk muscles in the supine position. HO-ex involves hip extension from a supine position to the point at which the pelvis does not float and is very easy to perform.

To validate this exercise method, it is necessary to examine multiple trunk muscles. Trunk muscles can be divided into global and local groups. Global muscles include the rectus abdominis and external oblique muscles, which are mainly involved in trunk movement. Local muscles include the lumbar multifidus, erector spinae, internal oblique, transverse abdominis, and multifidus muscles and are involved in body stabilization (7). Although these muscles have different roles, they are connected via the thoracolumbar fascia and contract synergistically to increase abdominal pressure and spinal stability (8). Therefore, in this study, we decided to measure and validate trunk muscle thickness in young healthy male subjects in the supine, HO-ex, crawling on all fours, and BD-ex positions as a preliminary step to using HO-ex in clinical practice.

Since the BD-ex is trained in a very unstable posture, we expect that the transversus abdominis, internal oblique, and multifidus muscles (8), which play a strong role in ensuring spinal stability and improving abdominal pressure, as well as the erector spinae and external oblique muscles (8), which have reported advantages in exerting force, will work to ensure stability. Thus, BD-ex was predicted to thicken all trunk muscles more than in any other condition. In addition, HO-ex is an exercise in which the patient is asked to perform hip extension to the extent that the pelvis does not float in the supine position, which reduces the need to ensure stability compared with BD-ex. Thus, HO-ex was predicted to have thinner erector spinae and external obliques and thicker or similar transverse abdominis, internal oblique, and multifidus muscles than did BD-ex. Since the base support surface is narrower and the center of gravity is higher than in the back-lying position, we expect that crawling on all fours also requires more muscular strength in the trunk. Therefore, we predicted that crawling on all fours would thicken all the trunk muscles compared to the supine position.

METHODS

Participants

To determine minimum adequate sample size, an a priori power analysis was conducted (G*power V 3.1.9.7). The significance level α =0.05, power 80%, and effect size d = 0.25. The test results showed that the required sample size was calculated to be at least 24 cases in each group. Assuming that there would be a few who would not cooperate with the study until the end, the number of subjects for this study was set at around Thirty to begin the study.

Thirty-one healthy young males who provided informed consent were included in the study. Participants were aged 20.4 ± 1.1 years, with height: 172.4 ± 6.3 cm, weight: 62.1 ± 9.0 kg, body mass index (BMI): 20.9 ± 2.6 kg/m² (mean ± SD). The exclusion criteria were history of orthopedic or neurological disease and complaints of low back pain. This research was carried out fully in accordance to the ethical standards of the International Journal of Exercise Science (16), and in accordance with the Declaration of Helsinki. The subjects were fully informed orally and in writing, and their consent was obtained. This study was approved by the Ethics Review Committee of International University of Health and Welfare (Approval No.: 20-Io-54).

Protocol
The thicknesses of the right trunk muscles: lumber multifidus (LM), erector spinae (ES), external oblique abdominis (EO), internal oblique abdominis (IO), and transverse abdominis (TrA) were measured using an ultrasound machine (FUMBO, Seikosha Corporation, Japan). The ultrasound images obtained during the measurement of each trunk muscle are shown in Figure 1. Based on previous studies, LM was measured 2 cm lateral to the spinous process of the fifth lumbar vertebra and the distance from the subcutaneous tissue to the intervertebral joint (5, 6, 11, 15). ES was measured 5 cm lateral to the spinous process of the third lumbar vertebra and the distance from the subcutaneous tissue to the subcostal margin, based on previous studies (5, 26). TrA, IO, and EO were measured at the midpoint of a segment of the anterior axillary line that passes between the costal margin and iliac crest and the distance between the fascia of each muscle, based on previous studies. (5, 12, 14). The ultrasound probe was placed perpendicular to the spinal column for all measurements. Studies examining the validity of capturing muscle thickness measured with ultrasound imaging devices as muscle activity have been conducted with electromyography (EMG) and have demonstrated a certain validity. Kiesel et al. focused on the lumbar multifidus (LM) muscle (11), while McMeeken et al. (13) focused on the transversus abdominis muscle. Both studies involved healthy subjects and showed that ultrasound-induced changes in muscle thickness are highly correlated with EMG activity in the respective muscles. A systematic review (22) investigates whether muscle thickness changes measurable by ultrasound imaging devices can be interpreted as muscle activity depending on task, position, or contraction type. The results showed significant correlations between muscle thickness and electromyographic readings measured with ultrasound imaging equipment in the lumbar multifidus and erector spinae muscles at most contraction levels and postures. In addition, significant correlations were found in the transversus abdominis and medial oblique muscles with low-impact abdominal tightening exercises and bracing. These previous studies provide important evidence that increased muscle activity can be confirmed by ultrasound.

Measurements were taken in four conditions: supine, HO-ex, crawling on all fours, and BD-ex. The conditions were done in randomized orders. Each of the 31 participants take part in all four conditions. Each posture is shown in Figure 2. In all postures, postural correction was performed verbally and manually as appropriate. Measurements in the supine and HO-ex positions were taken by connecting two beds of the same height with a 20 cm gap between them. This allowed the ultrasound probe to be placed in the specified position when measuring the LM and ES. Physiological kyphosis of the lumbar spine was checked, and the subject was positioned such that the part of the spine elevated above the bed in the normal supine position was placed over the gap. In the HO-ex posture, a balance disk (Diner Senso Mini, 16 cm, Togu Co., Ltd. JAPAN), and the scale was placed under the right heel. From this position, a force of 10% of the body weight was applied to promote right hip extension. The measurer verbally instructed the subject, "Please push your heels into the bed to the extent that your hips do not float. To ensure that the participants could push in with a force of 10% of their body weight, a different researcher from the measurer watched the scale and instructed the participants to increase or decrease the force. The load was set at 10% to control the amount of load applied to each participant. Before starting the study, the load was set at 10% of body weight after multiple HOex trials. Some subjects would float on their hips if more than 10% of their body weight was applied. We used this load for clinical versatility as many patients can only apply enough load to keep their bodies from floating. Crawling on all fours was performed with 90° shoulder joint and hip flexion. The BD-ex was performed with the participant positioned from all fours with the right lower extremity and left upper extremity elevated. In doing so, the right lower limb and left upper limb were maintained at the level of the floor. In all postures, verbal instructions and manual correction were provided to prevent excessive anterior-posterior pelvic tilt.

Measurements were performed twice during the resting expiration period. One person was used for the measurements. Measurements were obtained after 3 months of instruction from a physiotherapist with 12 years of clinical and research experience. All measurements were taken on the same day. The skin was marked with a skin pen to maintain consistency during measurement. Since too much pressure on the probe would change the shape of the muscle itself, the probe was coated with enough echo jelly and the minimum pressure necessary was used. Muscle thickness was calculated using ImageJ image analysis software. ImageJ was operated by a researcher different from the person who measured the ultrasound imaging system. The average of the two muscle thickness measurements was used as a representative value.

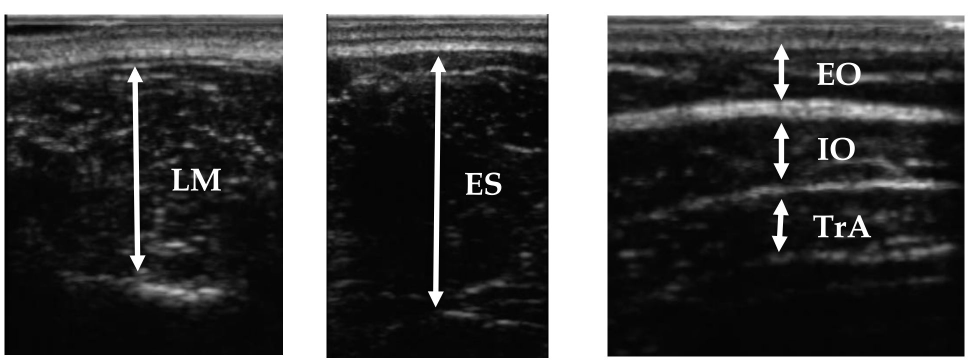

Figure 1. Ultrasonography images of each muscle. Abbreviations: LM, lumbar multifidus; ES, erector spinae; TrA, transversus abdominis; IO, internal oblique; EO, external oblique.

Supine

Heel Off exercise（HO-ex）

Crawling on all fours

Bird Dog exercise (BD-ex).

Figure 2. Postures in which measurements were taken.

Statistical Analysis

The intraclass correlation coefficient (ICC (1, 2)) was determined from the first and second measured values for each trunk muscle, and reproducibility was examined. ICC values ≤0.60 were considered rework, 0.60–0.70 were considered possible, ≥0.70 were considered good, ≥0.80 were considered good, and ≥0.90 were considered very good (23). The Shapiro-Wilk test was performed on all representative values obtained to confirm the normality of the data. The following statistical analyses were performed to determine the differences between conditions. For the trunk muscles for which normality was observed, repeated measures one-way analysis of variance (repeated measures one-way ANOVA) and Bonferroni's multiple comparison test, a parametric test, were performed. For trunk muscles for which normality was not found, nonparametric tests, the Friedman test, and Bonferroni's correction were performed. Cohen's d was adopted to objectively evaluate the difference in mean values between groups. Cohen's d is an index that standardizes the difference between groups, with larger differences resulting in larger values of Cohen's d. SPSS Statistics 28 was used for statistical analysis. The significance level was set at 5%.

RESULTS

For all postures and all muscle thicknesses, ICC (1, 2) was greater than 0.7 (possible – very good). The results are presented in Table 1. The values for all trunk muscle thicknesses in all postures are presented in Table 2 and Figure 3. Details of the statistical results are provided in Table 3. LM and ES thicknesses showed normality in all measured conditions, while those of EO, IO, and TrA did not show normality in some of the measured conditions. Therefore, the following statistical analyses were performed to determine the differences between each condition. For LM and ES, repeated measures one-way ANOVA and Bonferroni's multiple comparison tests were performed. For EO, IO, and TrA, Friedman test and Bonferroni correction were performed. The results showed a main effect in all the cases, LM ($p<0.001$), ES ($p<0.001$), EO ($p=0.018$), IO ($p=0.009$), TrA ($p<0.001$). The results of the subtests are presented below. Significant differences in LM were found between all conditions and were the thickest in the HO-ex position($p < 0.05$).

ES was significantly thicker in the HO-ex than in the supine position(p=0.009), and in the BD-ex than in the supine (p<0.001), HO-ex(p=0.023), or crawling on all fours positions (p<0.001). EO was significantly thicker in the supine position than in the HO-ex(p=0.022), and crawling on all fours positions(p=0.025). IO was significantly thicker in the HO-ex position than in the supine position(p=0.005). TrA was significantly thicker in the HO-ex(p=0.002), crawling on all fours (p<0.001), and BD-ex positions(p=0.001) than in the supine, with no significant difference between the HO-ex, crawling on all fours, and BD-ex positions.

Table 1. Intraclass correlation coefficients (1, 2) for trunk muscles in each condition.

	Supine	HO-ex	Crawling on all fours	BD-ex
Lumber Multifidus	0.92	0.94	0.82	0.73
Erector Spinae	0.84	0.88	0.91	0.89
External Oblique abdominis	0.93	0.95	0.81	0.75
Internal Oblique abdominis	0.94	0.94	0.89	0.92
Transverse Abdominis	0.90	0.92	0.74	0.90

Abbreviations: HO-ex, Heel Off exercise; BD-ex, Bird Dog exercise.

Table 2. Trunk muscle thickness in each condition.

	Supine (mm)	HO-ex (mm)	Crawling on nall fours (mm)	BD-ex (mm)
Lumbar Multifidus	34.6 ± 3.9	38.1 ± 4.1	27.7 ± 4.4	32.8 ± 4.1
Erector Spinae	34.8 ± 5.6	35.9 ± 5.9	34.3 ± 5.8	39.1 ± 5.6
External Oblique abdominis	9.2 ± 1.9	8.7 ± 2.1	8.4 ± 1.4	9.3 ± 2.4
Internal Oblique abdominis	11.0 ± 2.6	12.0 ± 2.9	11.5 ± 3.0	11.1 ± 3.4
Transversus Abdominis	3.3 ± 0.9	4.3 ± 1.8	4.9 ± 1.4	4.6 ± 1.8

n=31. mean ± standard deviation. Abbreviations: HO-ex, Heel Off exercise; BD-ex, Bird Dog exercise.

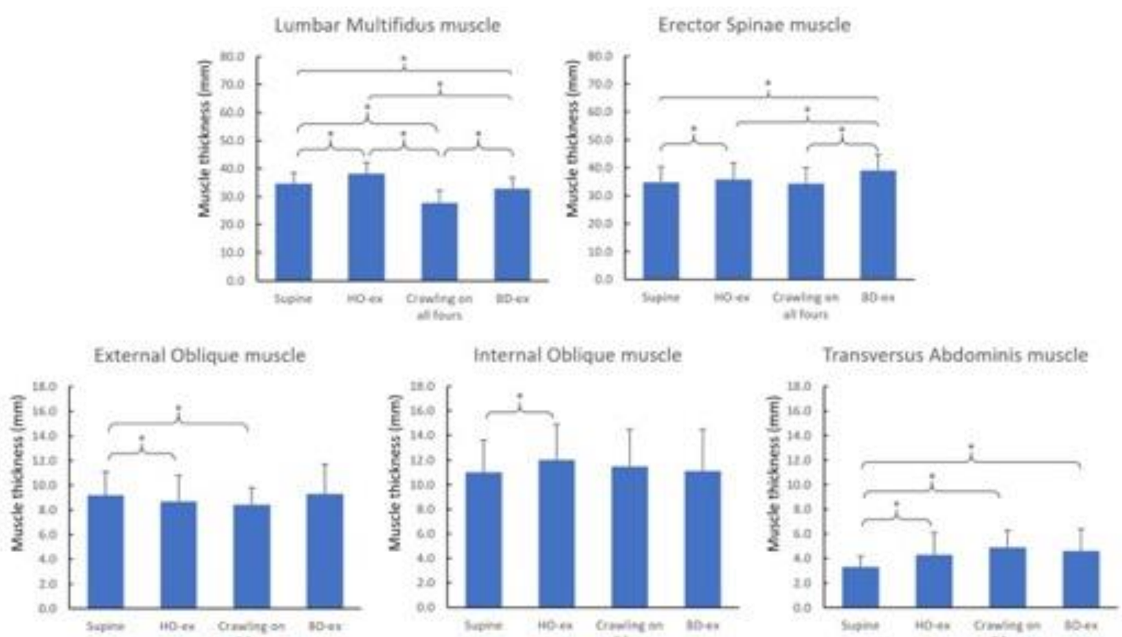

Figure 2. The results of the subtest (*p<0.05). Abbreviations: HO-ex, Heel Off exercise; BD-ex, Bird Dog exercise.

Table 3. Details of the statistical results.

		Condition 1	Condition 2	p value		Cohen's d
Lumbar Multifidus	Repeated measures one-way ANOVA p value: <0.001	Supine	HO-ex	<0.001	*	-0.87
		Supine	Crawling on all fours	<0.001	*	1.66
		Supine	BD-ex	0.040	*	0.45
		HO-ex	Crawling on all fours	<0.001	*	2.45
		HO-ex	BD-ex	<0.001	*	1.29
		Crawling on all fours	BD-ex	<0.001	*	-1.20
Erector Spinae	Repeated measures one-way ANOVA p value: <0.001	Supine	HO-ex	0.009	*	-0.19
		Supine	Crawling on all fours	1.000		0.09
		Supine	BD-ex	<0.001	*	-0.77
		HO-ex	Crawling on all fours	0.667		0.27
		HO-ex	BD-ex	0.023	*	-0.56
		Crawling on all fours	BD-ex	<0.001	*	-0.84
External Oblique abdominis	Friedman test p value: 0.018	Supine	HO-ex	0.022	*	0.25
		Supine	Crawling on all fours	0.025	*	0.48
		Supine	BD-ex	1.000		-0.05
		HO-ex	Crawling on all fours	1.000		0.17
		HO-ex	BD-ex	0.715		-0.27
		Crawling on all fours	BD-ex	0.058		-0.46
Internal Oblique abdominis	Friedman test p value: 0.009	Supine	HO-ex	0.005	*	-0.36
		Supine	Crawling on all fours	1.000		-0.18
		Supine	BD-ex	1.000		-0.03
		HO-ex	Crawling on all fours	1.000		0.17
		HO-ex	BD-ex	0.101		0.28
		Crawling on all fours	BD-ex	0.648		0.12
Transversus Abdominis	Friedman test p value: <0.001	Supine	HO-ex	0.002	*	-0.70
		Supine	Crawling on all fours	<0.001	*	-1.36
		Supine	BD-ex	0.001	*	-0.91
		HO-ex	Crawling on all fours	0.187		-0.37
		HO-ex	BD-ex	1.000		-0.17
		Crawling on all fours	BD-ex	1.000		0.19

For LM and ES, repeated measures one-way ANOVA and Bonferroni's multiple comparison tests were performed. For EO, IO, and TrA, Friedman test and Bonferroni correction were performed. *p<0.05, Abbreviations: HO-ex, Heel Off exercise; BD-ex, Bird Dog exercise.

DISCUSSION

LM was significantly thicker in the HO-ex position, indicating that this exercise is more likely to produce activity in the multifidus muscles than is BD-ex. This result differed from the prediction that BD-ex, more than any other condition, would result in the thickest multifidus muscle. This is because BD-ex has a strong training load. If the load is too strong, the erector spinae muscles, which have a favorable structure for force generation, are engaged and the activity of the multifidus muscles is inhibited. Therefore, the level of contraction required for training the multifidus muscle is very small compared with that required for strength training or cardiovascular exercises (20).

IO was significantly thicker in the HO-ex than in the supine position. The TrA was significantly thicker in HO-ex and BD-ex than in the supine position, and there was no significant difference between HO-ex and BD-ex. In other words, the HO-ex led to similar TrA activity and greater IO activity than did the BD-ex. This differed from the prediction that the activity of the transversus abdominis and internal oblique muscles would be the highest in the BD-ex. We believe that this mechanism is related to our finding that multifidus muscle activity is more likely to occur in the HO-ex. The multifidus and ES comprise one compartment within the thoracolumbar fascia, via which this compartment connects to the TrA and IO muscles (21). This structure facilitates trunk muscle cooperation. Thus, while the multifidus muscles was the thickest in the HO-ex, we believe that the TrA and IO muscles also became thicker in conjunction.

EO was significantly thicker in the supine position than in the HO-ex and crawling on all four positions. This differs from the prediction that EO muscles would thicken during exercise. We believe that because the EO muscles are closest to the skin and the outermost parts of the trunk muscles, they were affected by the skin stretching in the HO-ex and BD-ex postures. The HO-ex position was in the form of hip extension from the supine position, which caused some anterior pelvic tilt that may have pulled the abdominal skin in a caudal direction. In HO-ex, gravity pulls fat downward on the body surface. In addition, posterior thoracic tilt and anterior pelvic tilt occurred when the upper and lower limbs were raised from this position. Thus, the abdominal skin was pulled downward and caudally. It is thought that the muscle was stretched along with the skin.

It was suggested that the thickness of the multifidus and IO muscles is highest in HO-ex, and the thickness of the transversus abdominis muscle is similar to that in BD-ex. Previous studies (2) have reported that it is important to inhibit global muscles and activate local muscles in patients with low back pain due to global muscle hyperactivity. Therefore, we believe that HO-ex is clinically useful in patients with low back pain. In addition, because HO-ex can be performed in the supine position, it can efficiently improve trunk muscle strength, even in cases where the patient does not have physical functions such as muscle strength and range of motion to assume a posture such as BD-ex, or when the patient is paralyzed, has a limb disease, or uses an intravenous drip. Therefore, we believe that HO-ex is useful in clinical practice.

Our study had limitation which need to be addressed in future research. First, this study was conducted on healthy young adults. For future clinical application, it is necessary to validate this method in patients with trunk muscle dysfunction. Second, the trunk muscle thickness does not necessarily indicate muscle activity. Many factors (such as resting muscle length, extensibility, structure, contraction type, and level of measurement) are influenced measured muscle thickness (9). Therefore, it is necessary to devise methods to reduce these effects. Third, this study did not track changes over time, which should be examined for future clinical application. Fourth, the study was limited to male participants as the ultrasound imaging device measurements were taken from males. This was deemed important to maintain the privacy and comfort of the participants. Therefore, it is unclear whether these results can be generalized to women. In the future, a broader group of subjects, including women, should be included in the study.

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REFERENCES

1. Bogduk N, Macintosh JE, Pearcy MJ. A universal model of the lumbar back muscles in the upright position. Spine 17(8):897-913, 1992.

2. Cholewicki J, McGill SM. Lumbar posterior ligament involvement during extremely heavy lifts estimated from fluoroscopic measurements. J Biomech 25(1):17-28, 1992.

3. Dafkou K, Kellis E, Ellinoudis A, Sahinis C. Lumbar multifidus muscle thickness during graded quadruped and prone exercises. Int J Exerc Sci 14(7):101-112, 2021.

4. Danneels LA, Vanderstraeten GG, Cambier DC, Witvrouw EE, Bourgois J, Dankaerts W, De Cuyper HJ. Effects of three different training modalities on the cross sectional area of the lumbar multifidus muscle in patients with chronic low back pain. Br J Sports Med 35(3):186-191, 2001.

5. Endo Y, Ito A, Hotta S, Yakabi A, Onoda K, Tani H, Kubo A. Intraclass correlation coefficient of trunk muscle thicknesses in different positions measured using ultrasonography. J Phys Ther Sci 33(3):283-287, 2021.

6. Hides JA, Richardson CA, Jull GA. Magnetic resonance imaging and ultrasonography of the lumbar multifidus muscle. Comparison of two different modalities. Spine 20(1):54-58, 1995.

7. Hodges P. Chapter 2 - lumbopelvic stability: A functional model of the biomechanics and motor control. In: C Richardson, P W Hodges and J Hides editors. Therapeutic exercise for lumbopelvic stabilization (second edition). Edinburgh: Churchill Livingstone; 2004, pp. 13-28.

8. Hodges P. Chapter 3 - abdominal mechanism and support of the lumbar spine and pelvis. In: C Richardson, P W Hodges and J Hides editors. Therapeutic exercise for lumbopelvic stabilization (second edition). Edinburgh: Churchill Livingstone; 2004, pp. 31-57.

9. Hodges PW. Ultrasound imaging in rehabilitation: Just a fad? J Orthop Sports Phys Ther 35(6):333-337, 2005.

10. Ikezoe T, Mori N, Nakamura M, Ichihashi N. Effects of age and inactivity due to prolonged bed rest on atrophy of trunk muscles. Eur J Appl Physiol 112(1):43-48, 2012.

11. Kiesel KB, Uhl TL, Underwood FB, Rodd DW, Nitz AJ. Measurement of lumbar multifidus muscle contraction with rehabilitative ultrasound imaging. Man Ther 12(2):161-166, 2007.

12. Lyu L, Fan J, Chai X, Qi H, Zhang X, Huo M, Murakami S, Onoda K, Maruyama H. Measurement reliability and cooperative movement of the pelvic floor and transverse abdominal muscles. J Phys Ther Sci 33(10):767-771, 2021.

13. McMeeken JM, Beith ID, Newham DJ, Milligan P, Critchley DJ. The relationship between emg and change in thickness of transversus abdominis. Clin Biomech 19(4):337-342, 2004.

14. Misuri G, Colagrande S, Gorini M, Iandelli I, Mancini M, Duranti R, Scano G. In vivo ultrasound assessment of respiratory function of abdominal muscles in normal subjects. Eur Respir J 10(12):2861-2867, 1997.

15. Nabavi N, Mosallanezhad Z, Haghighatkhah HR, Mohseni Bandpeid MA. Reliability of rehabilitative ultrasonography to measure transverse abdominis and multifidus muscle dimensions. Iran J Radiol 11(3):e21008, 2014.

16. Navalta JW, Stone WJ, Lyons TS. Ethical issues relating to scientific discovery in exercise science. Int J Exerc Sci 12(1):1-8, 2019.

17. Okubo Y, Kaneoka K, Imai A, Shiina I, Tatsumura M, Izumi S, Miyakawa S. Electromyographic analysis of transversus abdominis and lumbar multifidus using wire electrodes during lumbar stabilization exercises. J Orthop Sports Phys Ther 40(11):743-750, 2010.

18. Oliver GD, Stone AJ, Plummer H. Electromyographic examination of selected muscle activation during isometric core exercises. Clin J Sport Med 20(6):452-457, 2010.

19. Pirouzi S, Emami F, Taghizadeh S, Ghanbari A. Is abdominal muscle activity different from lumbar muscle activity during four-point kneeling? Iran J Med Sci 38(4):327-333, 2013.

20. Richardson C, Jull G, Hides J, Hodges P. Therapeutic exercise for spinal segmental stabilization in low back pain. Churchill Livingstone London; 1999.

21. Schuenke MD, Vleeming A, Van Hoof T, Willard FH. A description of the lumbar interfascial triangle and its relation with the lateral raphe: Anatomical constituents of load transfer through the lateral margin of the thoracolumbar fascia. J Anat 221(6):568-576, 2012.

22. ShahAli S, Shanbehzadeh S, ShahAli S, Ebrahimi Takamjani I. Application of ultrasonography in the assessment of abdominal and lumbar trunk muscle activity in participants with and without low back pain: A systematic review. J Manipulative Physiol Ther 42(7):541-550, 2019.

23. Shrout PE, Fleiss JL. Intraclass correlations: Uses in assessing rater reliability. Psychol Bull 86(2):420-428, 1979.

24. Teyhen DS, Gill NW, Whittaker JL, Henry SM, Hides JA, Hodges P. Rehabilitative ultrasound imaging of the abdominal muscles. J Orthop Sports Phys Ther 37(8):450-466, 2007.

25. Vera-Garcia FJ, Irles-Vidal B, Prat-Luri A, García-Vaquero MP, Barbado D, Juan-Recio C. Progressions of core stabilization exercises based on postural control challenge assessment. Eur J Appl Physiol 120(3):567-577, 2020.

26. Watanabe K, Miyamoto K, Masuda T, Shimizu K. Use of ultrasonography to evaluate thickness of the erector spinae muscle in maximum flexion and extension of the lumbar spine. Spine 29(13):1472-1477, 2004.

27. Xu Y, Wang J, Wu J. A preliminary study on the equivalence between standing back-extension and superman training in lumbar multifidus exercise. Comput Math Methods Med 2022:3677831, 2022.