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Comparison of Thickness of Abdominal Muscle Along Flexion Angle of Hip Joint and Type of Surface During Plank Exercise

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Abstract:

The purpose of this research is to propose a more efficient exercise method by comparing the change of the hip angle during plank exercise in relation to muscle hyper trophy of the trunk. The participants consisted of 29 normal adults, including 15 male and 14 female. In order to compare the motion of the hip joints in different angles, the elbow was supported on the floor in the prone position, and the hip joint was composed of 0° flexion, 20° flexion and 40° flexion. All exercises were carried out on a rigid support surface and an smooth support surface, and the exercise sequence was randomized. A Repeated one-way ANOVA was used to determine a statistical significance for the thickness variation of the superficial and deep abdominal muscles. The thickness of the abdominal external oblique muscle during a plank exercise was significantly different according to the angle, both on rigid and smooth support surfaces ($p < 0.05$) and revealed a significant difference according to the surface types in cases with a 40° hip joint flexion ($p < 0.05$). The thickness of the abdominal internal oblique muscle was significantly different relying on the angle, both on rigid and smooth support surfaces ($p < 0.05$) and revealed a significant difference according to the surface types when hip joint flexion was 0° ($p < 0.05$). The thickness of the abdominal transverse muscle was significantly different according to the angle, both on rigid and smooth support surfaces ($p < 0.05$) and showed a significant difference according to the surface types in all cases of hip joint flexion of 0°, 20°, and 40° ($p < 0.05$).

Conclusionally, the results of this research regarding the thickness changes of abdominal muscles during a plank exercise according to the hip joint flexion angle and surfaces will contribute to finding more efficient postures for posture-correcting exercises.

Keywords: Abdominal muscle, Core exercise, Plank exercise, Thickness, Type of surface

1. Introduction

The core part refers to the part of the body from the diaphragm, between the abdominal and thoracic cavities, to the pelvic floor muscles. In general, core muscles are known to be primarily activated when the body moves and aid in maintaining body stability. They also stabilize the body during daily activities and control the balance of weight against body sway[1].

Core stabilization should be activated correctly to maintain the spine and enable movements of the arms and legs in accordance with the load conditions and postural changes[2]. It not only improves functional movements of the body but also improves mobility and power from a dynamic aspect[3]. Exercises for core stabilization improve nerve root control, muscle strength, and muscle endurance, ultimately maintaining the dynamic stability of the spine and trunk[4]. In particular, the core muscles are frequently trained and used in sports and rehabilitation with the aim of maximizing muscle

strength, enhancing endurance, and preventing injury[5]. Several previous studies have demonstrated that the strengthening of core muscles improves body stability, postural alignment, exercise ability, and balance as well as preventing injury[6,7]. Furthermore, core exercise has been shown to have a positive impact on reinforcing and stabilizing muscle strength in the core following deep breathing and repeated movements with strong muscle contractions[8].

Core muscles consist of abdominal muscles that bend the body forward, extensor muscles that bend it backward, and lateral flexors that bend it to the sides. All these muscles have an important role in trunk stabilization. Core stability is obtained according to the direction of surface muscles and deep muscles and is activated by the co-contraction of these muscles. The transverse abdominal and internal abdominal oblique muscles, which are deep muscles, are directly attacted to the spinal vertebra and help to supply stability among the spinal segments and fine control of the spine. They are also critical for postural stability, spine stabilization, and helping to maintain a correct posture[9]. Many researches regarding core stabilization using posture control have applied diverse exercise schemes. The plank exercise has been proposed as one of the representative trunk-stabilizing exercises that increases the activity of trunk muscles[10,11]. This exercise can be carried out either on a rigid support surface or on an smooth support surface using tools, such as a Swiss ball[12]. Because the origins of the external abdominal oblique muscles, the serratus muscles, and latissimus dorsi muscles are interconnected, the plank exercise has been used as a method of inducing the activity of the external abdominal oblique muscles[13]. The plank posture refers to being in the prone bridge position where the body is supported by the arms and feet on both sides[14]. Recently, research on schemes of using tools for smooth support surfaces has aimed at maximizing the effect of the plank and is actively progressing[15]. Most of these studies have used electromyograms to analyze the effects of the plank. Recently, however, ultrasonic equipment has been broadly used, which can non-invasively and safely assess the characteristics of skeletal muscles.

Although there are some researches that have investigated the core muscle-strengthening effect of the plank, few studies have examined how the type of supporting ground during a plank exercise affects the muscle thickness. This research analyzed the changes in thickness of the abdominal transverse muscles, internal oblique muscles, and external oblique muscles during plank exercises on diverse surfaces to propose a more effective method of performing the plank exercise. Although the plank is generally performed in a standard posture (hip joint at 0°), it is important to investigate the appropriate angle of the hip joint for the activation of trunk muscles as the length-tension relationship among the muscles can change. For the purpose of proposing an efficient plank exercise, which is a typical exercise that improves the activity of the trunk muscles, this research compared the thickness of trunk muscles during the exercise according to the changes in hip joint angles and surface types.

2. Materials and Methods

2.1. *Participants*

This research was carried out with 29 healthy adults, consisting of 15 male and 14 female students enrolled at University K in Busan, South Korea. In the participant selection process, those who had been diagnosed with a fracture, muscle/ligament injury, a lesion in the central/peripheral nervous system over the past six months, or those who had a relevant surgical history were excluded from the research.

2.2. *Measurement method*

2.2.1. Goniometer

As shown in Figure 1, to minimize the error of measuring hip joint angles, models in various angles were first manufactured using a goniometer (PhysioSupplies.de, Germany) and then used in this research.

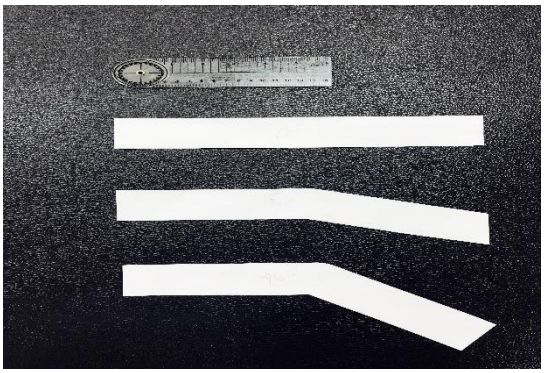

Figure 1. Manufactured goniometer

2.2.2. Ultrasonic device

A diagnostic ultrasonic measuring device (MyLab One World, Esaote, Italy) was used to measure the thickness of the transverse abdominal muscle, external abdominal oblique muscles, and internal abdominal oblique muscles of the participants before and after exercise. A straight line-type probe specialized for measuring muscles and surface layers was used.

2.2.3. Togu

For smooth support surfaces, the TOGU (DYN AIR, Ballkissen, Germany) was used.

2.3. *Exercise methods*

In this research, plank exercises were performed in three different postures and on two types of surfaces, including a rigid and smooth support surface. For the experiment, the participants performed a plank on a firm mat on a rigid support surface. For the smooth support surface, the participants performed the exercise by placing the TOGU on the tips of their toes. To compare the exercise with different hip joint angles, the participants performed a plank in the prone position with their elbows on the ground while keeping the angle of hip joint flexion at 0°, 20°, and 40°. The beginning position of the plank exercise was the prone posture with the arms lowered in front of the chest[18]. All experiments were conducted on rigid and smooth support surfaces and the order of exercises was randomly determined. Each exercise was performed for nine seconds with a one-minute rest period after each exercise to prevent fatigue.

2.4. *Measurement methods*

To measure the ultrasonic image of deep muscles, including the external abdominal obliques, internal abdominal obliques, and transverse abdominal muscle, the participants maintained a hip joint flexion angle of 0°, 20°, and 40° for 9 seconds. To maintain objectivity, images were shot at a fixed frequency of 5 MHz in B (brightness) mode and the depth was controlled such that the fascia line of the abdominal muscles could maintain a straight line on the screen as much as possible. For measuring the muscle thickness using ultrasound, a vertical line was drawn on the point that was 2.5 cm from the muscle fascia junction where the transverse abdominal muscle and the thoracolumbar fascia meet. The thickness of each muscle was then measured from that vertical line[16].

2.5. *Data analysis*

For statistical analyses of the data, descriptive statistics (mean ± standard deviation [SD]) were computed using a statistics program (SPSS/PC Version 24.0 for Windows). Repeated-measures analysis of variance and independent *t*-tests were used to compare the differences according to the angles and surfaces, respectively. Scheffe's post-hoc tests were performed in cases where statistical significance was observed. Statistical significance was set at $\alpha = 0.05$ for all measurements.

3. Results and Discussion

The participants consisted of 29 normal adults, including 15 male and 14 female students enrolled at University K in Busan, South Korea. Those who had no orthomechanical problems of the spine or limbs over the past six months were able to participate in the experiment. The experimental methods and precautions were sufficiently explained to all participants. The participants had a average age of 21.3 years, a average height of 167.9 cm, and a average weight of 61.8 kg. The average body mass index (Korean Dietetic Association, 2008) was 21.8 kg/m^2.

As shown in Table 1, the thickness of the external abdominal oblique muscle during a plank exercise was significantly different according to the angle, both on rigid and smooth support surfaces ($p < 0.05$). In Scheffe's post-hoc test results, a statistical difference was observed between 0° and 20° of hip joint flexion and between 0° and 40° of hip joint flexion, both on rigid and smooth support surfaces ($p < 0.05$). The thickness of the abdominal external oblique muscle revealed a statistical difference according to the support surface types in cases with a 40° hip joint flexion ($p < 0.05$).

The thickness of the abdominal internal oblique muscle was statistically different relying on the angle, both on rigid and smooth support surfaces ($p < 0.05$). Post-hoc analyses found a statistical difference between 0° and 40° of hip joint flexion and 20° and 40° of hip joint flexion, both on rigid and smooth support surfaces ($p < 0.05$). The thickness revealed a statistical difference according to the support surface types when hip joint flexion was 0° ($p < 0.05$).

The thickness of the abdominal transverse muscle was statistically different according to the angle, both on rigid and smooth support surfaces ($p < 0.05$). In post-hoc tests, statistical differences were observed in all cases of hip joint flexion between 0° and 20°, between 0° and 40°, and between 20° and 40°, both on rigid and smooth support surfaces ($p < 0.05$). The thicknesses showed a statistical difference according to the support surface types in all cases of hip joint flexion of 0°, 20°, and 40° ($p < 0.05$).

Table 1 : Comparison of thickness of abdominal muscle along hip flexion angle and type of surface (unit : mm)

		0°	20°	40°	F	p
External Oblique	Rigid	5.72±1.37	6.17±1.32	6.10±1.48	14.024	.000*
	Smooth	6.08±1.70	6.53±1.59	6.69±1.70	11.475	.000*
	t	-1.781	-1.869	-2.823		
	p	.076	.063	.005		
Internal Oblique	Rigid	7.38±1.65	7.38±1.71	8.05±2.6	4.884	.009*
	Smooth	7.83±1.71	7.84±1.85	8.28±1.94	10.084	.000*

	t	-2.007	-1.955	-0.770		
	p	.046	.052	.442		
Transverse Abdominis	Rigid	3.52±0.71	3.75±0.53	4.26±1.23	28.209	.000*
	Smooth	4.14±0.86	4.42±1.32	4.67±1.17	20.474	.000*
	t	-5.947	-5.044	-2.560		
	p	.000	.000	.011		

* p<.05

The plank exercise is a typical trunk-stabilizing exercise that improves the activity of trunk muscles[10]. A diagnostic ultrasonic measuring device was used in the current research to investigate how the thickness of the abdominal muscles change relying on the hip joint angles and surface types. This device has an advantage in that the response of the abdominal muscles can be observed and quantified in a non-invasive way[17,18].

Performing core exercises on smooth ground, rather than rigid ground, has been shown to enhance the activity of core muscles[19]. A previous research has shown that the plank exercise using a Swiss ball maximized the muscle activity of the abdominal internal oblique and transverse muscle[20]. This may be because the co-activation of muscles and nerves was improved to continuously maintain the posture on the smooth support surface[21].

The principle is to perform a plank in a standard posture (hip joint = 0°). However, the length-tension relationship among the muscles can change and the change of flexion angle of the hip joint directly affects the movements of the pelvis, lower back, and trunk because the abdominal muscles have myofibers that run in various directions. Hence, this research examined the thicknesses of the abdominal muscles during the plank exercise, and their changes in thickness, which were dependent on the hip joint flexion angles and support surface types.

All abdominal external oblique muscles, internal oblique muscles, and transverse muscles showed statistical differences according to the angle and support surface ($p < 0.05$). This suggests that the activity of the abdominal external and internal oblique muscle, which run vertically, increases statistically as the hip joint angle increases due to the length-tension relationship among the muscles. The transverse abdominal muscle, which is responsible for the fine control of the spine and maintains the stability of spinal segments, is directly connected to the spine and its thickness statistically increases as the spine instability increases due to the length-tension relationship.

A previous research has demonstrated that performing the plank exercise on smooth support surfaces, such as a Swiss ball, increases the activity of core muscles more than when performing it on rigid support surfaces. This result implies that plank exercises on smooth support surfaces, such as an inflated TOGU, requires stronger contractions of the abdominal muscles. In the current research, the thickness of the abdominal internal oblique muscle, external oblique muscle, and transverse muscle during the plank exercise with different hip joint angles was higher when the exercise was performed on smooth support surfaces using the TOGU than on rigid support surfaces, which is consistent with previous researches.

4. Conclusion

To propose the most efficient application of plank exercises, this research examined the thickness changes in the abdominal internal oblique muscle, external oblique muscle, and transverse muscle during plank exercises according to the support surface type and hip joint angle using ultrasonic images. The research produced the following outcomes.

1. The thicknesses of the abdominal internal oblique muscle, external oblique muscle, and transverse muscle during the plank exercise were statistically different according to the hip joint flexion angle.
2. The thickness changes in muscles were larger when the participants performed the plank exercise on smooth support surfaces, using the TOGU, than on rigid support surfaces.

In conclusion, the results of this research regarding the thickness changes of abdominal muscles during a plank exercise according to the hip joint flexion angle and support surfaces will contribute to finding more efficient postures for posture-correcting exercises. These findings should prove beneficial in both research and clinical settings.

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