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PREVENTION & REHABILITATION — MUSCLE PHYSIOLOGY

MUSCLE PHYSIOLOGY

Abdominal hollowing and lateral abdominal wall muscles' activity in both healthy men & women: An ultrasonic assessment in supine and standing positions

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Summary The objective of this study was to investigate the effects of Abdominal Hollowing (AH) maneuver on External Oblique (EO), Internal Oblique (IO) and Transversus Abdominis (TrA) muscles in both healthy men and women during the two postures of supine and upright standing. The study was conducted on 43 asymptomatic volunteers (22 males and 21 females) aged 19-44 (27.8 ± 6.4) years. Rehabilitative Ultrasonic Imaging (RUSI) was simultaneously performed to measure muscle thickness in both rest and during AH maneuvers while activation of the TrA during AH was controlled by Pressure Biofeedback (PBF) device. Mixed-model ANOVA with repeated measures design, and Pearson correlation tests were used to analyze the data. Muscle thickness of all muscles was significantly higher for male subjects ($F > 6.2$, $p < 0.017$). The interaction effect of gender and muscle status was significant only for IO ($F = 7.458$, $p = 0.009$) indicating that AH maneuver increased the thickness of IO in men. Interaction

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effect of posture and muscle status on muscular thickness indicated that changing position only affects the resting thickness of TrA ($F = 5.617$, $p = 0.023$). Standing posture significantly affected the TrA contraction ratio ($t = 3.122$, $p = 0.003$) and TrA preferential activation ratio ($t = 2.76$, $p = 0.008$). There was no relationship between age and muscle thickness ($r = 0.262$, $p = 0.09$). The PBF has been introduced as a clinical and available device for monitoring TrA activity, while RUSI showed that both TrA and IO muscles had activated after AH maneuver. We recommend performing further investigations using electromyography and RUSI simultaneously at more functional postures such as upright standing.
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Introduction

The Transversus Abdominis Muscle (TrA) forms the deepest abdominal musculature, producing little force for trunk flexion, extension and lateral flexion. Despite its involvement in rotation of the trunk, it has only a small lever arm to produce rotational moment (Urquhart and Hodges, 2005; Urquhart et al., 2005). The TrA contributes to lumbo-sacral stability by its role in intra-abdominal pressure, creating tension of thoraco-lumbar fascia, and compression of sacroiliac joints (Richardson et al., 2004; Arjmand et al., 2001; Snijders et al., 1995). As Richardson's clinical model explains, the TrA is a local stabilizer of lumbo-sacral region alongside multifidus, pelvic floor and lumbar spine musculature and also diaphragm (Richardson et al., 2004).

Abdominal hollowing (AH) maneuver has been presented as an activity which exercises the TrA muscle in an isolated fashion. In order to control the contraction of TrA during this maneuver, palpation of its tendon medial to anterior superior iliac spine, and also Pressure Biofeedback (PBF) have been used. The latter is a tool developed by physiotherapists to aid the retraining of stabilizing muscles using specific exercises, and detects movement of the lumbar spine in relation to an air-filled reservoir. In prone position 4—10 mmHg reduction from the basic pressure, of 70 mmHg, and in supine position no change in primary 40 mmHg pressure may depict the person's ability to activate the TrA muscle independently from other abdominal wall muscles (Richardson et al., 2004).

Hodges et al. (1996) used electromyography to investigate the relationship between the ability of reducing the pressure in the PBD device during AH maneuver and the time of onset of TrA activity during limb movement. Their findings indicated that the quality of motor control of TrA, directly measured by fine- wire electrodes, can be estimated indirectly by PBF, as well. Cairns et al. (2000) used PBF for comparing the activity of antero-lateral abdominal musculature in prone position in people with and without low back pain. It was indicated that PBF is a useful device for recognition and investigation of antero-lateral abdominal musculature. Stroheim et al. (2002) used PBF in order to assess TrA activity in prone position and concluded that although PBF provides appropriate feedback for contraction of TrA, its application for scientific and research purposes requires further investigations. Rehabilitative Ultrasonic Imaging (RUSI) approved by the World Federation of Ultrasound in Medicine and Biology (WFUMB) since 2006, is a non- invasive method used by physiotherapists to assess the morphology and function of deep tissues and muscles, including TrA (Whittaker et al., 2007). Numerous studies have depicted the reliability of this method in comparison to MRI and electromyography for assessing the activity of abdominal musculature (Richardson et al., 2004; Mc Meeken et al., 2004). Its validity for evaluation of abdominal muscle thickness in various contracting positions has been confirmed in several studies (Bunce et al., 2004; Norasteh et al., 2007). However, other researchers have emphasized the necessity of more extensive investigations before utilization of this method in clinical evaluation of activity of muscles of the lateral abdominal wall in different functional positions and during interventions in both genders (Teyhen et al., 2007; Mannion et al., 2008).

The two objectives of this study were 1) the ultrasonic evaluation of the effect of abdominal hollowing maneuver on the activity of the muscles of the lateral abdominal wall in standing and supine postures in both genders 2) and to assess the efficiency of PBF device in depicting the isolated contraction of TrA in standing position.

Methods

Study design

We analyzed the muscle thicknesses with a mixed-model ANOVA with a repeated-measures design to determine the effects of gender, posture (supine and upright standing) and muscle status (rest and AH). Dependent variables were muscle thickness for the EO, IO, and TrA, and the contraction ratios computed based on literature (Mannion et al., 2008) and the independent variables were gender, posture and muscle status.

Subjects

Forty-three healthy volunteers, 21 females and 22 males, in the age range of 19—44 (27.8 ± 6.4) years, with no previous history of sporting activity, low back pain and urinary incontinence were included in this study (Table 1). The participants completed their consent form that had approved by the Ethics Committee of the Iran Medical University.

Table 1 The demographic characteristics data (mean ± SD) of both female and male participants.

	Age (year)	Height (m)	Weight (kg)	BMI (kg/m^2)
Female	26.2 ± 6.2	1.61 ± 6.1	57.6 ± 10.2	22.1 ± 3.4
Male	29.3 ± 6.3	1.74 ± 6.6	74.1 ± 13.4	24.4 ± 4.1

Data collection protocols

The tools utilized in the study included a data form to record demographic data, PBF device manufactured by Chattanooga Ltd., USA, and a brightness B-mode ultrasound instrument manufactured by BK Medical, Denmark with 7.5 MHz linear probe, frequency range of 5—12 MHz and central frequency of 7.5 MHz.

Procedures

The participants were instructed to activate their TrA muscle in standing position using the AH maneuver with biofeedback received from the ultrasonography device; this activation was controlled simultaneously with palpation of muscle insertion (Richardson et al., 2004; Mannion et al., 2008). For imaging, the individuals were lying with extended lower limbs. For EO, IO and TrA muscles, the mid-axillary line was determined, and then a mark was put 2.5 cm anterior to the line in the region between iliac crest and the last rib (Richardson et al., 2004; Whittaker et al., 2007). The abdominal wall muscles underwent imaging at this point in both standing and lying positions. The ultrasonography equipment was prepared for muscular imaging, gel was poured on the probe, and the probe was put on the skin without applying any pressure (Bunce et al., 2004; Aniscough-Potts et al., 2006). Initially, imaging was performed while subjects were in supine position with muscle at rest. Then, the person was required to perform the AH maneuver, and imaging continued while the contraction of TrA was controlled by PBF. In standing position, an inflexible piece of board, measuring 35×50 cm and weighing 400 g was fastened with two straps of elastic band to the individual's back, like a backpack, in order to hold the PBF device between itself and the person's back. Similarly, with simultaneous control of muscle contraction with PBF, imaging was performed at rest and with AH maneuvers. All images were taken on the left side of the abdomen and at the end of expiration. Finally, the absolute values of thickness of muscles were recorded. Furthermore, some proposed indices were calculated using the following equations (Teyhen et al., 2007; Mannion et al., 2008).

- TrA contraction ratio = (TrA thickness contracted)/(TrA thickness at rest).
- EO contraction ratio = (EO thickness contracted)/(EO thickness at rest).
- EO + IO contraction ratio = (EO + IO thickness contracted)/(EO + IO thickness at rest).
- TrA preferential activation ratio = (TrA contracted/(TrA + EO + IO contracted)) − (TrA at rest/(TrA + EO + IO at rest)).

The Kolmogorov—Smirnov (K—S) goodness-of-fit test was used to evaluate normality of the distribution. Mixed-model ANOVAs with repeated measures design were used to test the effects of posture, gender and muscle status on muscle thicknesses. To further analyze bonferroni post hoc tests followed on marginal means of the model. The paired t-test was used to compare the computed contraction ratios between standing and supine postures. In addition, a two-way ANOVA was performed to assess interactions between the gender and BMI on the three muscle thicknesses. Where there was a significant main effect for groups, post hoc comparisons were made using Tukey test. Also a Pearson correlation test was used to investigate the relationship between age and muscle thickness. The significance level was set at α of 0.05.

Results

The p values were higher than 0.05 for all K—S tests, indicating that the variables under study have normal distribution. The descriptive statistics (mean ± SD) of the thicknesses of IO, OE and TrA under different experimental conditions are shown in Table 2. The summary results of the analyses of ANOVA are shown in Table 3. Muscle thickness of all muscles was significantly higher for male subjects ($F > 6.2$, $p < 0.017$). The interaction effect of gender and muscle status was significant only for IO ($F = 7.458$, $p = 0.009$) indicating that AH maneuver increased the thickness of IO in men. Interaction effect of posture and muscle status on muscular thickness indicated that changing position only affects the resting thickness of TrA ($F = 5.617$, $p = 0.023$). Main effects of posture and muscle status were significant for only IO and TrA muscle thicknesses (Table 3). The OE's thickness was not significantly affected by posture or muscle activation.

The descriptive statistics of computed contraction ratios are presented for both supine and standing postures in Table 4. Gender has no significant effect on these ratios which allowed us to use the paired t-tests which indicated that TrA contraction ratio ($t = 3.122$, $p = 0.003$) and EO contraction ratio ($t = 2.76$, $p = 0.008$) were significantly affected by posture (Table 4).

Table 2 The mean (±SD) values of Lateral Abdominal wall muscles' thickness in rest and during AH, in supine and standing positions for each gender (mm).

Subject's Position	Supine				Standing			
Muscle Status	Rest		During AH		Rest		During AH	
Gender	F*	M**	F	M	F	M	F	M
Muscles								
EO	3.1 ± 0.8	4.5 ± 1.7	3.3 ± 0.9	4.9 ± 1.8	3.4 ± 1.1	3.7 ± 1.3	3.4 ± 1.3	4.9 ± 1.8
IO	4.1 ± 0.9	6.7 ± 2.09	4.5 ± 1.03	7.5 ± 2.5	4.7 ± 1.01	6.6 ± 2.2	5.1 ± 1.5	8.2 ± 2.5
TrA	2.3 ± 0.6	3.06 ± 0.7	3.5 ± 1.2	4.6 ± 1.7	3.1 ± 0.8	3.7 ± 1.2	4.09 ± 1.4	4.5 ± 1.4

*F: Female, ** M: Male.

Table 3 The summary statistics (*F* and *P* values) of ANOVA testing the effects of Gender (G), Status (S), and Posture (POS) on abdominal muscle thicknesses.

Muscle	Main Effects						Interaction Effects							
	Gender		Posture		Status		G*POS		G*S		POS*S		G*POS*S	
	F	p	F	p	F	P	F	p	F	p	F	p	F	p
EO	13.744	0.001*	0.916	0.344	2.791	0.102	0.043	0.838	0.779	0.383	2.415	0.128	0.03	0.864
IO	28.960	0.0001*	5.189	0.028*	43.251	0.0001*	1.139	0.292	7.458	0.009*	3.481	0.069	3.070	0.087
TrA	6.203	0.017*	18.488	0.001*	82.082	0.001*	2.832	0.100	0.228	0.636	5.617	0.023*	1.405	0.243

*Significant level.

The cross tabulation of muscle thickness about BMI and gender is provided in Table 5. No significant interaction effect of gender and BMI was seen on muscle thickness ($F = 0.865$, $p = 0.46$) using two-way ANOVA. Pearson test did not show relationship between age and muscle thickness ($r = 0.262$, $p = 0.09$).

Discussion

Measuring the thickness of lateral abdominal wall muscles sonographically indicated that a significant increase in thickness of TrA was observed in both standing and supine positions, demonstrating the activation of this muscle during AH maneuver (Teyhen et al., 2007; Mannion et al., 2008). As for the IO muscle, several studies (Mc Meeken et al., 2004; Misuri et al., 1997) that have investigated the sub-maximal activity of muscle electromyographically, have reported a good correlation between the activity of TrA and IO muscles. In a recent research, 26 healthy individuals performing classic Pilates exercises were assessed ultrasonically to conclude that TrA and IO muscles do not work independently (Critchley, 2008). Our study also observed this coordination and synergy; that is, performing the AH maneuver causes activation and therefore an increase in thickness of IO muscle compared to resting state. We also found that during AH maneuver, males activate IO muscle more than females, demonstrating gender dependency of abdominal muscle activation strategies (Kulas et al., 2006).

Previous studies have indicated that a person's ability to contract TrA muscle in an isolated fashion depends on three factors; namely: deep sensation, respiratory pattern, and capacity of motor learning (Teyhen et al., 2007). Furthermore, a study conducted by Stevens et al. (2007) indicated that muscular training programs based on neuro-muscular control in healthy individuals alter the patterns of muscular activity. The fact that isolated contraction of TrA muscle was not observed ultrasonically in our study may be accounted for by lack of homogeneity among the above factors in people participating in the study.

The findings of this study indicate that the change in thickness of TrA muscle during AH maneuver compared to resting state was the same in lying and standing positions. Also, the resting thickness of the muscle was significantly greater in standing position; in other words, changing position activates the TrA muscle with a feed forward mechanism and increases the thickness significantly (Richardson et al., 2004; Hodges et al., 1997). This conclusion was confirmed by comparing the TrA indices in standing and supine positions. Therefore, it is affirmed that changing from a stable position to a less stable one can affect the resting thickness of TrA muscle (Teyhen et al., 2007). Bunce et al. (2004) reported a significant difference in the resting thickness of TrA in standing and supine positions. However, Norasteh et al. (2007) did not observe a significant difference in the resting thickness of TrA between standing and supine positions, concluding that the standing position cannot cause sufficient instability and load, whereas they had actually selected standing position to apply greater load and instability.

Moreover, change in thickness of IO was observed in standing position compared to supine position (Tables 2 and 4). The study conducted by Aniscough-Potts et al. (2006) on 22 healthy individuals for measurement of muscular thickness in different positions, both TrA and IO muscles equally responded to postural changes. Sparkes's electromyographical study on 20 young and healthy individuals demonstrated that with development of stabilizing exercises from a position with 3 fulcra to one with 2 fulcra (i.e. decreasing level of stability), activity of IO muscle develops alongside TrA. This study highlights the pivotal role of IO in spine stabilization (Sparkes et al., 2006). In a study conducted by Arjmand et al. (2008) the

Table 4 The means (±SD) for abdominal muscle Computed Contraction Ratios in the present study and Mannion et al. (2008).

Computed contraction ratios	Mannion et al. ($n = 14$) supine position	Present study ($n = 43$)			
		Supine	Standing	t	p Value
TrA contraction ratio	1.45 ± 0.21	1.53 ± 0.37	1.29 ± 0.32	3.122	0.003
EO + IO contraction ratio	1.05 ± 0.05	1.09 ± 0.15	1.11 ± 0.18	−0.524	0.6
TrA preferential activation ratio	0.06 ± 0.03	0.06 ± 0.04	0.02 ± 0.06	2.76	0.008
EO contraction ratio	1 ± 0.1	1.1 ± 0.2	1.03 ± 0.2	1.750	0.08

Table 5 The mean (±SD) values of Lateral Abdominal wall muscles' rest thickness based on BMI in both genders (mm).

BMI	Underweight		Normal		Overweight		Obese	
Gender	F	M	F	M	F	M	F	M
Muscles	($n = 4$)	($n = 2$)	($n = 13$)	($n = 12$)	($n = 3$)	($n = 5$)	($n = 1$)	($n = 3$)
EO	2.96 ± 1.11	3.90 ± 1.54	3.28 ± 0.81	4.09 ± 1.58	2.99 ± 0.53	5.41 ± 2.07	2.59 ± 0	5.32 ± 1.71
IO	3.87 ± 0.86	6.62 ± 2.23	4.351.08	6.443 ± 2.21	3.56 ± 0.23	7.07 ± 1.30	4.56 ± 0	9.29 ± 1.86
TrA	1.96 ± 0.39	2.91 ± 0.41	2.36 ± 0.68	2.81 ± 0.79	2.17 ± 0.27	3.22 ± 0.39	3.11 ± 0	3.93 ± 0.77

IO muscle is attributed a greater role in maintaining upright stability compared to external oblique and TrA. In summary, the above findings corroborate Richardson's theory that with lowering stability, the activity of IO and TrA increases (Richardson et al., 2004).

Clinically in rehabilitative programs for low back pain patients, it has been suggested to lower the stability of underlying surface in order to augment the activity of muscles responsible for stability of the region, including IO and TrA (Richardson et al., 2004; Teyhen et al., 2008). A study conducted by Vera-Garcia et al. (2000) indicated that compared to fixed surfaces, performing exercise on oscillating surfaces increases the activity of abdominal muscles (TrA and EO) and facilitates their synchronized activity in maintaining vertebral and corporal stability. To what extent the activities of EO and IO could have been isolated in that study is unclear. In our study, we found much more coordination between IO and TrA than between EO and TrA. More detailed biomechanical studies of the kind performed by Arjmand et al. (2001, 2008) is needed to increase our understanding of this issue.

In our study, the absolute value of muscle thickness in lateral abdominal wall was greater in men compared to women; a finding in keeping with previous studies (Norasteh et al., 2007; Teyhen et al., 2007). In this regard, Teyhen et al. (2007) stated that this difference between genders may bear a clinical significance in terms of exercise recommended; however, no study has been conducted so far to indicate whether rate of success for neuromuscular rehabilitation programs is affected by gender (Teyhen et al., 2007). A lack of relationship between muscular thickness and age in this study corroborates the findings of previous studies (Norasteh et al., 2007; Teyhen et al., 2007). Age was not considered as independent variable in our study, and the small range of participants' age may limited the ability to detect any possible correlation. Our study measured muscular thickness only at one point; however, recent explorations have indicated morphological variations in IO and TrA muscles and suggested that each part of these muscles may involve a specific function (Urquhart and Hodges, 2005; Urquhart et al., 2005). Furthermore, the probability has been proposed that neuro-muscular control of different muscular segments in the abdomen may be independent of each other and dependent on the activity levels (Moreside et al., 2008). Therefore, investigating the change in muscle thickness at different anatomical points and with different degrees of activity in both genders may enhance our knowledge of the function of abdominal muscles. Moreover, since the results of imaging method is partly dependent on operator (Hodges et al., 1996), we recommend conducting studies in order to investigate the repeatability among operators.

Conclusion

Regarding the effects of AH maneuver and changing position on TrA thickness, it appears that performing AH maneuver in standing position can be effective on TrA training. Although, the PBF has been introduced as a clinical and available device for monitoring TrA activity, RUSI showed that both TrA and IO muscles had activated during AH maneuver. We recommend performing further investigations using electromyography and RUSI at the same time.

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