Journal of Bodywork & Movement Therapies 38 (2024) 175–179

Contents lists available at ScienceDirect

Journal of Bodywork & Movement Therapies

journal homepage: www.elsevier.com/jbmt

Variations in abdominal muscle activities of obese females during abdominal bracing exercise in different body positions

Chidiebele Petronilla Ojukwu [a], Amarachi Blessing Eze [a], Ibifubara Ayoola Aiyegbusi [b], Stephen Sunday Ede [a,c,*], Ifeoma Blessing Nwosu [d]

[a] Department of Medical Rehabilitation, Faculty of Health Sciences and Technology, College of Medicine, University of Nigeria, Enugu, Nigeria
[b] Department of Physiotherapy, College of Medicine, University of Lagos, Nigeria
[c] School of Sport and Health Sciences, Faculty of Allied Health & Well-being, University of Central Lancashire, Preston, UK
[d] Department of Medical Rehabilitation, Faculty of Health Sciences and Technology, College of Medicine, Nnamdi Azikiwe University, Awka, Nigeria

A R T I C L E I N F O

Handling Editor: Dr Jerrilyn Cambron

Keywords:
Abdominal bracing exercises
Abdominal muscles
Body positions
Electromyography

A B S T R A C T

Aims: This study evaluated the activities of the Rectus Abdominis (RA) and Transversus Abdominis (TrA) muscles during abdominal bracing exercises (ABE) in different body positions.
Methodology: Electrical activities of both components of the RA and TrA muscles were assessed respectively in 25 obese females via surface electromyography during ABE in four (4) different body positions (crook lying, side lying, standing, and sitting). Each trial lasted for five (5) seconds with an hour rest period between trials.
Results: Electrical activities of each of the right RA ($p = 0.008$) and TrA ($p = 0.001$) muscles significantly varied across the four trials. For the left components of the RA ($p = 0.243$) and TrA ($p = 0.332$) muscles, no significant differences were observed across trials. The highest muscular activities were recorded during the standing trial while the crook lying position resulted in the least muscular activities.
Conclusion: For the best results, abdominal bracing exercises should be performed in a standing position. The efficacy of adopting these body positions for long-term rehabilitation purposes should be investigated in future studies.

1. Introduction

The abdominal muscles are extremely important for the support and containment of viscera, as well as for assisting the processes of expiration, defecation, urination, vomiting, and parturition (Kera and Maruyama 2005). They are also key components of the core muscles, popularly described as a 'muscular box' with the abdominals in the front paraspinal and gluteals in the back, the diaphragm at the top, and the pelvic floor on the bottom (Akuthota and Nadler, 2004). These muscles work collectively as a corset to support the spine and pelvis, thus maintaining postural stability (Sharon and Denise, 2008). Several conditions including pregnancy (Gilleard, 1996), chronic low back pain, abdominal strains (Suleiman 2001), and abdominal obesity (de Carvalho, 2019) have been reported to alter the structure and function of the abdominal muscles.

Abdominal obesity, referring to abdominal fat mass with a waist circumference >102 cm for men and >88 cm for women is common in women and has been associated with declines in abdominal muscle strength (Buro, 2019; de Carvalho et al., 2019). The increased loading of the abdominal muscles by increasing abdominal fat usually translates to a reduction of core strength and endurance, postural stability, and other musculoskeletal disorders (Andrews and Turin, 2019). In addition, there could be alterations in the vascularity of these muscles, resulting in decreased blood supply, nutrient supply for the sustenance of muscle metabolic activities, diminished recovery efficiency, and rapid fatigability (Cavuoto and Baum, 2014). Through other mechanisms, abdominal obesity affects muscular function by increasing the levels of insulin resistance (Gurudut et al., 2017). Obese and postpartum women with abdominal obesity are typically keen to get back to shape (Gunderson, 2009), especially with the use of therapeutic exercises and lifestyle modifications (Kesztyüs et al., 2018). Such exercises are targeted at losing abdominal fat (Vispute et al., 2011), achieving core stability, strength, and endurance as well as reducing injury rates (Knapik et al., 2004; Kiani et al., 2010; Sadoghi et al., 2012). A wide range of abdominal exercises is utilized for different purposes and at different stages of rehabilitation programs (Huxel and Anderson, 2013).

* Corresponding author. School of Sport and Health Sciences, Faculty of Allied Health & Well-being, University of Central Lancashire, Preston, UK.
E-mail addresses: chidiebele.ojukwu@unn.edu.ng (C.P. Ojukwu), SSEde@uclan.ac.uk (S.S. Ede).

https://doi.org/10.1016/j.jbmt.2024.01.008
Received 20 October 2021; Received in revised form 8 July 2023; Accepted 13 January 2024
Available online 17 January 2024

Nevertheless, Abdominal Bracing Exercises (ABE) are integral components of abdominal muscle training and core rehabilitation principles (Akuthota et al., 2008). It includes maximal voluntary co-contraction of the abdominal muscles and has been reported to be the most effective technique for achieving core stability (Monfort-Pañego et al., 2009a; Maeo et al., 2013) as well as a safer exercise option for most conditions, particularly in women at risk of developing diastasis recti abdominis (Werner and Dayan, 2019). Performance of ABE is achieved through the exertion of maximum sustained isometric contraction of the abdominal muscles as hard as possible. More recently, performing an abdominal bracing exercise, which includes activation of the transverse abdominis, has been recommended for both the general population (Liaw et al., 2011) and women during pregnancy and after childbirth (Richardson et al., 2004; Mannion et al., 2008).

Abdominal bracing is prescribed for performance in different starting positions, including supine and side-lying, standing, sitting, or quadruped as deemed accessible and comfortable for the client. In practice, the emphasis had been on exercises in prone and supine lying to strengthen different groups of spinal muscles (Kisner and Colby, 2007). In some other cases, clients are asked to perform trunk exercises in any position of choice, including supine and prone lying, as well as standing, sitting, and four-point kneeling. This flexibility in its performance has increased compliance with such exercises as it is possible for clients to perform them at any time and place (McGill, 2006). Most clinical protocols also combine different positions, and different exercise programs for more efficacy (Hayden et al., 2005).

However, there is limited evidence on how muscle activities may differ while performing abdominal bracing in different body positions. Snijders et al. (1995a, b) reported more activities of the abdominal muscles when abdominal exercises were performed in standing than sitting positions in postpartum women. Other previous studies (Beith et al., 2001; Chanthapetch et al., 2009) have also revealed some variations in abdominal muscle recruitment during abdominal hollowing in different starting positions. More studies are needed to evaluate the role of starting positions on the recruitment of abdominal muscles during ABE. Many of these studies were conducted among postpartum women. It is also important to ascertain possible variations in abdominal muscle contractions, relative to starting positions in obese women. Therefore, this study evaluated the activities of selected abdominal muscles (transversus and rectus abdominis muscles) during ABE in different starting positions. These two muscles are considered important in ABE among other abdominal muscles given their role in diastasis recti (Acharry and Kutty, 2015; Hall and Sanjaghsaz, 2022), which justifies why this study is focused on only them. The findings from this study will therefore inform physiotherapists and other women's health clinicians about choosing the appropriate ABE exercise parameters for this group of women.

2. Materials and methods

2.1. Participants

Twenty-five healthy sedentary obese females (age: 22.72 ± 2.68 years, body mass index: 31.55 ± 7.24 kg/m2; waist-hip ratio: 0.84 ± 0.08) voluntarily participated in this study. A preliminary power analysis showed that a sample size of 25 participants were needed for the analysis of variance at degree of freedom (df_b) = 1, to achieve 96% (0.96) power with a moderate to a large effect size of 0.60 at an alpha level of 0.05 (Cohen, 1988). All participants gave written informed consent to the procedures as approved by the University of Nigeria Health Research Ethics Committee prior to the examination. The inclusion criteria were non-pregnant, having no history of recti abdominis. The exclusion criteria were recent abdominal and/or thoracic surgeries, and neuromusculoskeletal conditions of the lower extremities, pelvis, or spine.

2.2. Experimental procedure

2.2.1. Preparatory phase

On enrollment, participants were familiarized with the experimental procedures through verbal explanations and pictorial demonstrations of ABE in the four starting positions until they were satisfactorily orientated.

Participants completed two sets of 5-sec maximum voluntary contraction (MVC) tests for muscles in the four different positions, with a 2-min rest period between trials. Biofeedback on the activities of these muscles was examined and adequate prompting was given to properly educate the participants.

2.2.2. Experiment protocol

Participants performed the ABE by isometrically contracting their abdominal muscles through the action of pulling the umbilicus towards the spine. Verbal prompts were used to motivate them to sustain contraction for 5 s without cessation of breathing.

Each participant adopted four starting positions during the exercise: A) left side-lying, B) crook lying C) sitting, and D) standing. To avoid fatigue and order effects, the sequence of performing trials varied per participant, as determined on a Latin square; an imaginary design used for randomizing treatment (Cryan et al., 2006). Exercise in each position was performed three consecutive times with a 10-s interval between each attempt and the mean values of the EMG reading were recorded.

In the left side-lying position, participants turned onto their left side with a pillow placed under the head. The back was kept straight with both knees flexed to 90° and arms relaxed. For the crook position, they lay on their backs with a pillow placed under the head and shoulder. Ensuring contact between the lumbar region of the spine and the plinth, the knees were flexed to 90° with both feet resting flat on the surface. To achieve the sitting position, participants sat on a comfortable chair, back resting on the back support and both feet placed at 90° on a footstool. The standing position was carried out with participants standing erect, ears, shoulders, and hips aligned in an imaginary straight line. Both feet were pointed forward, hip-distance apart.

2.2.3. Evaluation of muscle activity

Surface electromyography (EMG) was utilized to measure the two components of the lower Rectus Abdominis (RA) and Transversus Abdominis (TrA), respectively.

Before electrode placement, the skin surface was prepared by thoroughly cleaning with an alcohol swab to minimize skin impedance. Pairs of disposable Ag/AgCl surface electrodes (Verity Medicals, UK) with dimensions of 10 × 1 mm and an inter-electrode distance of 1 cm were used. The electrodes were placed at the center of the muscle belly in line with the muscle fibers according to previous studies. Specifically, the electrodes for the RA muscle were positioned 8° from vertically in an inferomedial direction and centered on the muscle belly near the midpoint between the umbilicus and pubic symphysis and 3 cm lateral from the midline (Escamilla et al., 2010; Imai et al., 2010). The electrodes for the TrA muscle were placed approximately midway between the rib cage and the iliac crest, 20 mm medial to the anterior superior iliac spine (Imai et al., 2010; McCook et al., 2009; Chon et al., 2012). The reference electrode was placed over the sternum.

EMG input signal activities were recorded using a data collection system (Neuro Trac Myoplus 2, Verity Medicals, UK). The signals were amplified and sampled at 1000 Hz. Using the Neurotrac software.

2.3. Data analysis

Data were virtually expressed with the root-mean-square of each muscle normalized and expressed as a percentage of the peak root-mean-square during each trial (%MVC).

Descriptive statistics of mean and standard deviation were used to summarize data. The %MVC values of each muscle were analyzed with

 Journal of Bodywork & Movement Therapies 38 (2024) 175–179

repeated-measures one-way Analysis of variance (ANOVA) design to identify differences across the four exercise trials. All statistical tests were performed at the 0.05 level of probability ($p < 0.05$), using the Statistical Package for Social Sciences software (SPSS, version 23.0, SPSS Inc., Chicago, IL, USA).

3. Results

Table 1 summarizes the participants' general characteristics with their mean age, BMI, and waist-hip ratio as 22.72 ± 2.68 years, 31.55 ± 7.24 kg/m2, and 0.84 ± 0.08 respectively. Comparisons of percentage maximum voluntary contraction (%MVC) values of the abdominal muscles revealed significant differences in the right TrA ($p < 0.008$) and RA ($p < 0.001$) muscles across the four trials of ABE. However, the left components of RA ($p < 0.243$) and TrA ($p < 0.332$) muscles did not significantly vary in their activities across trials (Table 2). In ascending order, the starting positions of ABE elicited muscular activities in the TrA and RA in the following order: crook lying, side lying, sitting, and standing positions.

The Post-Hoc analysis (Table 3) compares right RA and TrA muscle activities across trials. It shows that in the right RA, the EMG activity during supine lying was significantly different from the activity during standing ($p = 0.038$) and sitting ($p = 0.027$). Also, in the right TrA muscles activities, there are significant differences between the standing positions and the side-lying ($p =< 0.001$), and between the standing position and the supine lying ($p = 0.024$), as well as between the sitting position and the side-lying ($p = 0.002$).

4. Discussion

The study findings revealed that all four starting positions could facilitate TrA and RA contraction at varying intensities during ABE. This is clinically valuable as physical activity has been shown in the literature to help in maintaining optimal muscle mass and strength, which are important predictors of core stability (Hsu et al., 2018), safe and effective mobility (Aartolahti et al., 2020) and reduces muscle fat infiltration (Goodpaster et al., 2008).

Standing, sitting, crook and side-lying positions have been proposed as useful positions to activate the deep abdominal muscles during ABE. The activities of the TrA and RA muscles during ABE in all four positions suggest that these positions are appropriate for performing ABE. These positions have been adopted for core strengthening exercises in clinical settings (Richardson and Jull, 1995; O'Sullivan, 2000). One caveat to this conclusion is that the baseline values of the muscle activities were not documented at rest to enable more reliable comparisons with the % MVC values of each specific position.

From the results, TrA and RA EMG activities varied across starting positions and were highest in the standing position. Previous studies have reported different findings regarding variations in muscle activities relative to changing starting positions. Our findings corroborated Mew (2009) which recorded increased thickness of TrA muscle while performing abdominal hollowing in standing, as compared to the crook lying position. On the contrary, abdominal muscle activities also varied among crook lying, prone lying four-point kneeling, and wall support standing positions with crook and prone lying positions facilitating TrA and internal oblique activities better than the four-point kneeling and wall support standing positions (Chanthapetch et al., 2009). This consistently supports Beith et al. (2001) which reported higher activities in the TrA and internal oblique muscles during prone lying, as compared to four-point kneeling positions (although the differences were not statistically significant). Urquhart et al. (2005a, b) also reported more isolated TrA activities in crook lying better than in the prone lying position.

Considering the above, it is obvious that starting position influences abdominal muscle activation during core strengthening exercises. However, the mechanisms of variations in muscular activities vary among these studies, including ours. Our findings revealed that performing ABE in erect positions (standing and sitting) elicited more muscular activities, as compared to reclined positions (side and crook lying). While this finding supports Mew (2009), it disagrees with other studies (Chanthapetch et al., 2009; Beith et al., 2001). Chanthapetch et al. (2009) posit that variations in abdominal muscle activities among crook lying, prone lying four-point kneeling, and wall support standing starting positions might be explained by the differences in the amount of support provided in each position. In their opinion, higher muscular activities in lying positions may be attributed to the fact that the trunk is supported, eliminating co-contraction of back and leg muscles with increased concentration on the abdominal muscles, unlike in the kneeling and standing positions. However, we share different views on this explanation. In erect positions, the contralateral trunk muscles at the back are consistently active to maintain the erect position of the spine. Recruiting the abdominal muscles during ABE in such erect positions will most likely require more muscle fibre recruitment to counter the antagonistic effect of the back muscles. Thus, there is an increased co-contraction mechanism of the trunk muscles while performing ABE in erect positions, as compared to the reclined positions that are characterized by increased trunk support. In addition, greater effort is required for effective abdominal muscle contraction in erect positions, resulting from the direction of gravitational force pressure on the structures of the abdomen (Madill and McLean, 2008). These mechanisms may likely

Table 1
General characteristics of the participants (n = 25).

Variables	Mean ± std	Minimum	Maximum
Age (years)	22.72 ± 2.68	18.00	28.00
Heights (m)	164.96 ± 4.31	154.00	172.00
Weight (kg)	88.70 ± 7.47	77.00	106.00
BMI(kg/m^2)	32.64 ± 2.33	30.00	38.50
Waist Circumference (cm)	95.12 ± 9.04	71.00	112.00
Hip Circumference (cm)	114.42 ± 12.94	100.00	164.00
Waist Hip Ratio	0.84 ± 0.08	0.59	1.08

BMI = body mass index, Std = standard deviation.

Table 2
Comparisons of normalized abdominal muscle activities across the four experimental trials.

Muscles	Side-lying	Crook lying	Standing	Sitting	f-value	p-value
Right RA	33.04 ± 18.21	30.25 ± 19.02	39.26 ± 19.05	30.28 ± 14.38	5.010	0.008*
Left RA	29.75 ± 19.88	23.84 ± 14.79	31.18 ± 16.38	30.93 ± 21.37	1.496	0.243
Right TrA	24.23 ± 13.83	32.88 ± 18.28	46.24 ± 18.51	36.96 ± 14.47	11.214	0.001*
Left TrA	30.77 ± 16.84	28.44 ± 19.23	35.40 ± 20.24	35.68 ± 18.36	1.203	0.332

RA = rectus abdominis TrA = transversus abdominis; * indicates significance at p < 0.05.

Table 3
Bonferroni Post-hoc results showing pairwise comparisons of right rectus abdominis and transverses abdominis muscles across trials.

Test conditions	Side lying	Supine lying	Standing	Sitting
Right Rectus Abdominis muscle				
Side lying	–	1	1	1
Supine lying			0.038[a]	1
Standing				0.027[a]
Right Transversus abdominis muscle				
Side lying		0.301	<0.001	0.002
Supine lying			0.024	1
Standing				0.200

[a] The mean difference is significant at the 0.05 level.

elicit greater feedback from the abdominal muscle stretch receptors, raising the excitability of their motor-neuron pools with increased muscle fiber recruitment (Beith et al., 2001).

The above depicts that in lying positions, there may be reduced requirements for spinal stabilization as such positions is regarded as relaxing positions (Jesenský et al., 2016). Also, lying positions, particularly in crook positions that involve knee and hip flexion, usually results in a more neutralized lumbar lordosis and may be considered more relaxing, as compared to erect positions (Monfort-Pañego et al., 2009a, b). Another important factor may be the end range of muscle relaxation and its subsequent concentric contraction in varying body positions. According to Véle (1995), abdominal muscles do not achieve maximum relaxation in lying positions and as such may not achieve effective shortening in return. This may explain the reduced electrical activity of these muscles recorded in the two lying positions.

These variations in %MVC values across the four starting positions suggest that for better clinical outcomes, ABE should be prescribed and performed in erect positions. O'Sullivan (2000) previously suggested that reclined (prone and supine lying) and four-point kneeling positions should only be used for related exercises if an isolated contraction cannot be achieved in weight-bearing positions such as sitting or standing.

Despite the marginal changes observed in all the studied muscles, EMG activities of the left TrA and RA muscles did not vary significantly among the four starting positions. While the right TrA and RA muscles showed significant variations in their activities across starting positions, the left components did not. The explanation for this variation in statistical outcomes is not immediately obvious from the results. We also observed that for most trials, activities in the right components of each muscle were higher than in the left components. This finding may be attributable to limb dominance which is a contributing factor to muscular activities and strength. Several studies (Maly et al., 2016; Park, 2013; Maeo et al., 2013) have proposed that all things being equal, muscles on an individual's dominant side exhibit more strength than their contralateral counterparts. Kim et al. (2011) suggested a leg-dominance effect on trunk muscle activity when they observed that all their participants who were right-leg dominant demonstrated stronger muscle contractions in the right muscle groups, as compared to the left while during a unilateral single-legged hold exercise. In our study, all the participants were right-handed, thus the explanation for the predominant strength in the right muscle groups, as compared to the left side.

However, the application of these findings should be considered considering the limitations in the use of surface EMG electrodes to record EMG activity from the TrA muscle. Despite the adoption of recommended electrode placement guidelines for the TrA muscle, needle electrodes would have yielded more valid findings than surface electrodes because of the reduced interaction of the related muscles in that region. Secondly, certain factors that could have influenced the ABE such as the postural analysis of the prospective subjects were only grossly measured for all participants with apparently healthy postural conditions, and a mix of primiparous and multiparous were considered equally in the analysis. Despite these limitations, the strength of this study's findings is in its novel findings regarding how muscle activities may differ while performing abdominal bracing in different body positions among Nigerian postpartum women where data were previously unavailable. To further improve the clinical applications of these findings, future studies could focus on obese females with existing musculoskeletal dysfunctions of the trunk region as this will better elucidate the mechanisms of muscular activity changes in such conditions. The presence of pain may alter the ability of participants to contract their abdominal muscles and an additional change in the starting positions may further cause differences in the activation of the muscles (Key 2013).

5. Conclusions

This study has implications for the utilization of ABE in the core rehabilitation of obese females in clinical practice. The results suggest that all four positions can facilitate EMG activity in TrA and RA muscles. Specifically, more effective outcomes of ABE will be achieved in erect positions, including standing and sitting positions, as compared to reclined or lying positions. Therefore, abdominal muscle rehabilitation should be facilitated in positions of greater function, such as standing and sitting.

Clinical relevance

- Abdominal bracing exercises are adopted for core stabilization in the management of obesity.
- This study finding showed that abdominal bracing exercise is most effective in the standing position.
- However, a combined body posture is recommended for better outcomes and safety.
- The body positions for long-term rehabilitation purposes should be assessed and prescribed according to individual presentation.

Ethical considerations

All experimental protocols were approved by the University of Nigeria Health Research Ethics Committee (NHREC/05/01/200BB-FWA00002458-1RB00002323) and conducted according to the Declaration of Helsinki.

Consent to participate

All participants provided written informed consents prior to participation in this study.

Funding

No external funding was obtained for this study.

CRediT authorship contribution statement

Chidiebele Petronilla Ojukwu: Conceptualization, Data curation, Formal analysis, Writing – review & editing. **Amarachi Blessing Eze:** Data curation, Methodology, Writing – review & editing. **Ibifubara Ayoola Aiyegbusi:** Data curation, Methodology, Writing – original draft, Writing – review & editing. **Stephen Sunday Ede:** Conceptualization, Data curation, Methodology, Writing – original draft, Writing – review & editing. **Ifeoma Blessing Nwosu:** Writing – review & editing, Data curation.

Declaration of competing interest

None.

Acknowledgement

Not applicable.

References

Aartolahti, E., Lönnroos, E., Hartikainen, S., Häkkinen, A., 2020. Long-term strength and balance training in prevention of decline in muscle strength and mobility in older adults. Aging Clin. Exp. Res. 32 (1), 59–66.

Acharry, N., Kutty, R.K., 2015. Abdominal exercise with bracing, a therapeutic efficacy in reducing diastasis-recti among postpartal females. Int. J. Physiother Res. 3 (2), 999, 5.

Akuthota, V., Nadler, S.F., 2004. Core strengthening. Arch. Phys. Med. Rehabil. 85 (3), 642–646. Suppl. 1):S8692. 14(6).

Akuthota, V., Ferreiro, A., Moore, T., Fredericson, M., 2008. Core stability exercise principles. Curr. Sports Med. Rep. 7 (1), 39–44.

Andrews, J.M., Turin, A.M., 2019. Correlation between body mass index and core muscular strength among schoolchildren between 11 and 14 years of age: a cross sectional Study. Indian J. Physiother Occup. Ther. 13 (3).

Beith, I.D., Synnott, R.E., Newman, S.A., 2001. Abdominal muscle activity during the abdominal hallowing manoeuvre in the four point kneeling and prone positions. Man. Ther. 6 (2), 82–87.

Buro, A., 2019. Nutrition in the prevention and treatment of abdominal obesity. J. Nutr. Educ. Behav. 51 (9), 1130–1131.

Cavuoto, L.A., Nussbaum, M.A., 2014. The influences of obesity and age on functional performance during intermittent upper extremity tasks. J. Occup. Environ. Hyg. 11 (9), 583–590.

Chanthapetch, P., Kanlayanaphotporn, R., Gaogasigam, C., Chiradejnant, A., 2009. Abdominal muscle activity during abdominal hollowing in four starting positions. Man. Ther. 14 (6), 642–646.

Chon, S.C., You, J.H., Saliba, S.A., 2012. Cocontraction of ankle dorsiflexors and transversus abdominis function in patients with low back pain. J. Athl. Train. 47 (4), 379–389.

Cohen, J., 1988. Statistical Power Analysis for the Behavioural Sciences, second ed. Lawerence, & Eribaurn Associates, p. 101.

Cryan, M., Dyer, M., Goldberg, L.A., Jerrum, M., Martin, R., 2006. Rapidly mixing Markov chains for sampling contingency tables with a constant number of rows. SIAM J. Comput. 36 (1), 247–278.

de Carvalho, D.H.T., Scholes, S., Santos, J.L.F., de Oliveira, C., Alexandre, T.D.S., 2019. Does abdominal obesity accelerate muscle strength decline in older adults? Evidence from the English Longitudinal Study of ageing. Journals of Gerontology. Series A, Biological Sciences and Medical Sciences 74 (7), 1105–1111.

Escamilla, R.F., Lewis, C., Bell, D., Bramblet, G., Daffron, J., Lambert, S., Andrews, J.R., 2010. Core muscle activation during swiss ball and traditional abdominal exercises. J. Orthop. Sports Phys. Ther. 40 (5), 265–276.

Gilleard, W.L., Brown, J.M., 1996. Structure and function of the abdominal muscles in primigravid subjects during pregnancy and the immediate postbirth period. Phys. Ther. 76 (7), 750–762.

Goodpaster, B.H., Chomentowski, P., Ward, B.K., Rossi, A., Glynn, N.W., Delmonico, M. J., Newman, A.B., 2008. Effects of physical activity on strength and skeletal muscle fat infiltration in older adults: a randomized controlled trial. J. Appl. Physiol. 105 (5), 1498–1503.

Gunderson, E.P., 2009. Childbearing and obesity in women: weight before, during, and after pregnancy. Obstet. Gynecol. Clin. N. Am. 36 (2), 317–332.

Gurudut, P., Rayani, M., Tar, N., 2017. A clinical trial to study the effect of 5 Week core strengthening protocol on shoulder strength in young obese individuals. J Med Sci Clin Res 5, 19144–19153.

Hall, H., Sanjaghsaz, H., 2022. Diastasis recti rehabilitation. In: StatPearls. StatPearls Publishing.

Hayden, J.A., Van Tulder, Malmivaara, A.V., Koes, B.W., 2005. Meta-analysis: exercise therapy for nonspecific low back pain. Ann. Intern. Med. 142 (9), 765–775.

Hsu, S.L., Oda, H., Shirahata, S., Watanabe, M., Sasaki, M., 2018. Effects of core strength training on core stability. J. Phys. Ther. Sci. 30 (8), 1014–1018.

Huxel Bliven, K.C., Anderson, B.E., 2013. Core stability training for injury prevention. Sport Health 5 (6), 514–522.

Imai, A., Kaneoka, K., Okubo, Y., Shiina, I., Tatsumura, M., Izumi, S., Shiraki, H., 2010. Trunk muscle activity during lumbar stabilization exercises on both a stable and unstable surface. J. Orthop. Sports Phys. Ther. 40 (6), 369–375.

Jesenský, M., Mihaľ, J., Malý, T., Kokinda, M., Marenčáková, J., Kandráč, R., 2016. Differences between the selected trunk muscles activity during breathing in different body positions. J. Phys. Educ. Sport. 16 (2), 1064–1068.

Kera, T., Maruyama, H., 2005. The effect of posture on respiratory activity of the abdominal muscles. J. Physiol. Anthropol. Appl. Hum. Sci. 24 (4), 259–265.

Kesztyüs, D., Erhardt, J., Schönsteiner, D., Kesztyüs, T., 2018. Therapeutic treatment for abdominal obesity in adults. Deutsches Ärzteblatt International 115 (29–30), 487–493.

Key, J., 2013. 'The core': understanding it, and retraining its dysfunction. J. Bodyw. Mov. Ther. 17 (4), 541–559.

Kiani, A., Hellquist, E., Ahlqvist, K., Gedeborg, R., Michaëlsson, K., Byberg, L., 2010. Prevention of soccer-related knee injuries in teenaged girls. Arch. Intern. Med. 170 (1), 43–49.

Kim, S.J., Kwon, O.Y., Yi, C.H., Jeon, H.S., Oh, J.S., Cynn, H.S., Weon, J.H., 2011. Comparison of abdominal muscle activity during a single-legged hold in the hook-lying position on the floor and on a round foam roll. J. Athl. Train. 46 (4), 403–408.

Kisner, C, Colby, LA, 2007. Therapeutic Exercise Foundation and Techniques, 5th ed. F. A. Davis, Philadelphia (PA).

Knapik, J.J., Bullock, S.H., Canada, S., Toney, E., Wells, J.D., Hoedebecke, E., Jones, B. H., 2004. Influence of an injury reduction program on injury and fitness outcomes among soldiers. Inj. Prev. 10 (1), 37–42.

Liaw, L.J., Hsu, M.J., Liao, C.F., Liu, M.F., Hsu, A.T., 2011. The relationships between inter-recti distance measured by ultrasound imaging and abdominal muscle function in postpartum women: a 6-month follow-up study. J. Orthop. Sports Phys. Ther. 41 (6), 435–443.

Madill, S.J., McLean, L., 2008. Quantification of abdominal and pelvic floor muscle synergies in response to voluntary pelvic floor muscle contractions. J. Electromyogr. Kinesiol. 18 (6), 955–964.

Maeo, S., Takahashi, T., Takai, Y., Kanehisa, H., 2013. Trunk muscle activities during abdominal bracing: comparison among muscles and exercises. J. Sports Sci. Med. 12 (3), 467–474.

Maly, T., Zahalka, F., Mala, L., 2016. Unilateral and ipsilateral strength asymmetries in elite youth soccer players with respect to muscle group and limb dominance. Int. J. Morphol. 34 (4).

Mannion, A.F., Pulkovski, N., Toma, V., Sprott, H., 2008. Abdominal muscle size and symmetry at rest and during abdominal hollow-ing exercises in healthy control subjects. JAnat. J. Anat. 213 (2), 173–182.

McCook, D.T., Vicenzino, B., Hodges, P.W., 2009. Activity of deep abdominal muscles increases during submaximal flexion and extension efforts but antagonist co-contraction remains unchanged. J. Electromyogr. Kinesiol. 19 (5), 754–762.

McGill, S., 2006. Ultimate Back Fitness and Performance. Backfitpro Incorporated, Ontario, p. 325.

Mew, R., 2009. Comparison of changes in abdominal muscle thickness between standing and crook lying during active abdominal hollowing using ultrasound imaging. Man. Ther. 14 (6), 690–695.

Monfort-Pañego, M., Sanchez-Zuriaga, D., Vera-García, F.J., Sarti-Martínez, M.Á., 2009a. Electromyographic studies in abdominal exercises: a literature synthesis. J. Manipulative Physiol. Therapeut. 32 (3), 232–244.

Monfort-Pañego, M., Vera-García, F.J., Sánchez-Zuriaga, D., Sarti-Martínez, M.A., 2009b. Electromyographic studies in abdominal exercises: a literature synthesis. J. Manipulative Physiol. Therapeut. 32 (3), 232–244.

Park, S., 2013. Comparison of muscle activation during dominant hand wrist flexion when writing. J. Phys. Ther. Sci. 25 (12), 1529–1531.

Richardson, C., Hodges, P., Hides, J., 2004. Therapeutic Exercise for Lumbopelvic Stabilization: A Motor Control Approach for the Treatment and Preven-Tion of Low Back Pain, second ed. Churchill Livingstone, Edinburgh.

Richardson, C.A., Jull, G.A., 1995. Muscle control–pain control. What exercises would you prescribe? Man. Ther. 1 (1), 2–10.

Sadoghi, P., von Keudell, A., Vavken, P., 2012. Effectiveness of anterior cruciate ligament injury prevention training programs. J. Bone Jt. Surg. Am. Vol. 94 (9), 769–776.

Sharon, A., Denise, L., 2008. Exercise Physiology for Health, Fitness and Performance, second ed. Lippincott Williams & Wilkins company, Philadelphia, pp. 522–527.

Snijders, C.J., Bakker, M.P., Vleeming, A., Stoeckart, R., Stam, H.J., 1995a. Oblique abdominal muscle activity in standing and in sitting on hard and soft seats. Clin. BioMech. https://doi.org/10.1016/0268-0033(95)92042-k. Retrieved from. http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.914.2075&rep=rep1&type=pdf.10(2).

Snijders, C.J., Slagter, A.H., Van Strik, R., Vleeming, A., Stoeckart, R., Stam, H.J., 1995b. Why leg crossing? The influence of common postures on abdominal muscle activity. Spine 20 (18), 1989–1993.

Suleiman, S., Johnston, D.E., 2001. The abdominal wall: an overlooked source of pain. Am. Fam. Physician 64 (3), 431–438.

Urquhart, D.M., Hodges, P.W., Story, I.H., 2005a. Postural activity of the abdominal muscles varies between regions of these muscles and between body positions. Gait Posture 22 (4), 295–301.

Urquhart, D.M., Hodges, P.W., Allen, T.J., Story, I.H., 2005b. Abdominal muscle recruitment during a range of voluntary exercises. Man. Ther. 10 (2), 144–153.

Véle, F., 1995. Kinesiology of Postural System (Kineziologie Posturálního Systému). FTVS, Praha: UK.

Vispute, S.S., Smith, J.D., LeCheminant, J.D., Hurley, K.S., 2011. The effect of abdominal exercise on abdominal fat. J. Strength Condit Res. 25 (9), 2559–2564.

Werner, L.A., Dayan, M., 2019. Diastasis recti abdominis-diagnosis, risk factors, effect on musculoskeletal function, framework for treatment and implications for the pelvic floor. Curr. Women's Health Rev. 15 (2), 86–101.