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Changes in morphology of the lateral abdominal wall muscles during sagittal tilting in young healthy subjects

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Abstract

Introduction. The lateral abdominal wall muscles and their recruitment are the subjects of common interest for researchers due to their clinical importance and practical application in athletes and non-athletes. So far, no repeatable method aimed at activating specific muscles by passive tilting has been discovered. In this paper, changes in the morphology of muscles of the lateral abdominal wall during passive body inclinations in the sagittal plane in a standing position were assessed. The objective was to determine whether a device with the mentioned function would be able to induce reflex activation of the trunk stabilisers and can be used in an initial stage of postural rehabilitation and re-education.
Methods. A total of 179 healthy subjects aged 18–30 (96 women and 83 men) participated in the study. They were divided into groups according to the body mass index and the value of the pelvic tilt in the sagittal plane. The subject's body (in a standing, habitual position in a specially developed device) was tilted in steps, every 1 angular degree, each time taking ultrasound measurements of the muscle thickness on the right side, starting from the vertical to a maximum value of 7 degrees. The cross-section of the external oblique, internal oblique, and transverse abdominal muscles was measured.
Results. Each of the three muscles changed its thickness in a statistically significant way accidentally at different degrees of inclination, thus not showing a homogeneous contraction pattern.
Conclusions. There are no indications for clinical application of the forward sagittal inclination in accordance with the implemented procedure in therapeutic practice..
Key words: passive inclination, muscle thickness, transverse abdominal, external oblique, internal oblique

Introduction

The muscles of the lateral abdominal wall include the external oblique (EO), internal oblique (IO) and transverse abdominal (TRA). Together with the pelvic floor muscles and the multifidus, they form a muscular cylinder whose task is to control the neutral zone both when static and in movement [1, 2]. The aforementioned neutral zone constitutes a key concept in the context of improving the stability of spine segments. Maintaining its proper range reduces overloads and limits the risk of back pain [3, 4]. Tilting the pelvis or movements within the trunk or limbs increase the activity of stabilisers in anticipation of reactive forces [1, 2, 5, 6]. Striving to maintain a stable and firm torso, regardless of its position and postural perturbations, initiates a reflex of the lateral abdominal muscles activation [7, 8], which is fundamental for the human body kinematics.

The lateral abdominal wall muscles and their recruitment are a subject of common interest for researchers due to their clinical importance and practical application in athletes and non-athletes [9, 10]. Numerous studies focus on this problem. It seems to be crucial for successful spinal pain or instability treatment, as well as for decreasing the likelihood of posture disorders in children. It can be achieved by using commonly available tools, such as exercises. There are no doubts that intentional actions, movements and contractions are the most adequate and generate the best muscular response. Nonetheless, they cannot be applied in every clinical case or stage of rehabilitation. There is a certain niche. Non-standard patients with special needs are less common in medical practice but still occur and their problems are of the same importance as any other. Except for electrical stimulation of the muscles, which has limitations and is difficult to generate deep muscle contraction, no passive activator of the muscle tone has been discovered and presented in the literature so far.

The multitude of publications does not exhaust the subject of muscle activation comprehensively. They provide much knowledge about the general morphology of muscles and individual differences in cross-section related to sex or body type [11–13], highlight changes in muscle thickness and their ability to activate depending on age [14] and evidence numerous methods of activating muscles and modifications of basic exercises that increase the recruitment of trunk stabilisers [15–20]. Mew [21] reported that the greatest activation of the lateral abdominal wall muscles can be obtained in a standing position. This very position is the most natural one for every human being. The majority of actions undertaken in life are performed in an upright stance. The simultaneously most complex and basic form of human activity – gait – takes place in this position. To ensure the correct, ergonomic kinematics of gait mechanism, as well as proper postural stability, it is necessary that the muscles, in particular those stabilising the trunk and pelvis, work properly and

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control the neutral zone in each of the biomechanical planes [1, 2, 22]. However, the influence of whole-body inclination when subjects remain passive is yet to be investigated to better understand their reflexive response [21, 23]. This would fill a gap in the literature and knowledge, and meet the needs of some niche patients.

In this study, changes in the morphology of muscles of the lateral abdominal wall during passive body inclinations in the sagittal plane in a standing position were assessed. An additional objective was to determine whether an original device with the above-mentioned function can be used in an initial stage of postural rehabilitation and re-education aimed at inducing reflex activation of the trunk stabilisers. Questions related to the effect of passive inclination of the body on the change in the muscle tissue of trunk stabilisers, in terms of sex and body type, were posed. Obtaining answers to these questions could constitute the basis for further work engaging construction of the device that might be able to reflexively stimulate activity of the mentioned muscle groups.

Subjects and methods

This experiment was designed to determine whether passive whole-body tilt can induce a change in the muscle thickness. Would this change, if it appears, be useful for therapeutic practice and cause a desirable effect of activation of the abdominal wall muscles? Does the pattern of activation during body tilt in the sagittal plane differ in terms of sex, BMI and pelvic inclination? For all the participants, the trial was performed once. The data was collected from 2018 to 2021 in the Silesia region (Poland), with a pause in 2020 caused by the Covid-19 pandemic.

Participants

A total of 179 healthy subjects aged 18–30 (96 women and 83 men) participated in the study. Their weight, height, BMI and pelvic inclination ranged between 45–107.4 kg, 153–194 cm, 16.46–40.42 and 7.8–29 degrees. The subjects, including students and graduates of two universities, were randomly invited to participate in the study and assigned to the experimental group. The inclusion criteria were: (1) no musculoskeletal dysfunction and pain that could affect the test results, (2) general well-being, and (3) consumption of a meal at least two hours before the study commencement. The exclusion criteria were: (1) any injuries during the 3 months directly preceding the study, and (2) any surgeries that could affect the muscle tone and early termination of the study. Subjects were divided into subgroups according to the body type determined by their BMI (underweight, normal weight, overweight and obese), the value of the pelvic tilt in the sagittal plane (anterior pelvic tilt, neutral pelvis, posterior pelvic tilt) [24], and sex. Among the subjects, 85 had a BMI ratio within the normal range, 54 were underweight and 40 were overweight or obese [25]. In terms of pelvic inclination, 96 participants were classified into the group with the neutral pelvis, 50 into the group with the anterior pelvic tilt, and 53 people into the group with the posterior pelvic tilt.

The detailed procedure was explained to the participants and informed consent was obtained from all individuals included in this study. The research complied with all the relevant national regulations, institutional policies and was in accordance with the tenets of the Declaration of Helsinki, and was approved by the authors' institutional review board or equivalent committee.

Instrumentation and procedures

All procedures in the study were performed according to the literature to fulfil the requirements of evidence-based medicine. Division into subgroups was done based on other authors' findings. The instrumentation used for the measurements has all the necessary certificates. Prior to study commencement, anthropometric parameters were estimated as follows: body height using a Martin anthropometer (accuracy up to 0.1 cm), hip width measurement using a large calliper (accuracy up to 0.1 cm), body weight measurement using a FDM-S Zebris platform (accuracy up to 0.1 kg), pelvic inclination measurement in the sagittal plane using a 'Duometr' device (accuracy up to 0.1 degree) [24]. The BMI index was calculated on the basis of body height and weight [25, 26]. The thickness of the muscles of the lateral abdominal wall was measured using a SonoScape E2 ultrasound device, linear transducer, frequency 4.0–16.0 MHz, 128 elements, transducer face width (FOV) 46 mm. The muscle thickness was estimated at rest, at the end of the exhalation phase. The ultrasound transducer was placed on the right side of the body, perpendicularly to the muscle fibres, 2 cm below the umbilicus (in the horizontal plane) and in the axillary line above the iliac crest. Based on the image, the cross-section of the external oblique, internal oblique, and transverse abdominal muscles was measured. Each angle setting of inclination was measured three times and the average values were calculated [27–29].

Figure 1. Ultrasound image of the lateral abdominal wall muscles. Determination of the cross-section: 1 – external oblique, 2 – internal oblique, 3 – transverse abdominal (own material)

Body tilt and measurement

The tilting of the body in the sagittal plane was performed in a standing, habitual position in a specially developed device of original origin. It consisted of a test stand with dimensions of 51 × 51 cm, a vertical beam of 200 cm height and an inclinometer attached to the platform next to the beam on the right side. A specially constructed electrical mechanism implemented under the platform with a control pad displaying three buttons – '+' and '–' and a power button – were developed to enable body tilt by steps of 1 degree. Each subject was asked to assume a habitual standing position with the

Figure 2. Test stand and stages of tilting the body in the sagittal plane (own material)

feet set in parallel, hip-width apart, with the heels to the tangent line to the front edge of the beam, indicating correct positioning. The subject was advised to maintain a free breathing rhythm and lean his or her back against the vertical beam, to which he or she was stabilised with two belts. The flexible one stabilised the subject's head at the level of the forehead, while the other ran around the anterior superior iliac spine. In the device's starting position (0 degree), the initial measurement of the muscles' thickness was estimated. Subsequently, the subject's body was tilted in steps, every 1 angular degree, each time taking ultrasound measurements of the muscle thickness on the right side, starting from the vertical to a maximum value of 7 degrees. The end of the study and the final degree of inclination could also be determined by the patient's reporting their further inability to control their posture or by the appearance of disturbing symptoms (pain, malaise).

Statistical analysis

In the course of the study, all data collected were subjected to statistical analysis. STATISTICA version 12 and the RStudio environment were used for the statistical analysis. The means, standard deviations, maximum and minimum values, medians and upper and lower quartiles were calculated. For further analysis, data screening was performed in order to verify the normality assumption. At first for the entire study group, and then separately for the male and female subjects, as well as for all study subgroups (determined by parameters such as pelvic tilt, BMI type) using the Shapiro–Wilk test. The analysis showed that some of the examined variables and research subgroups do not fulfil the normal distribution condition $p < 0.05$. In the next step, the variables subjected to analysis (muscle thickness and degree of inclination) were classified as related (dependent variables). They fulfil the equinumerous group condition. For those reasons, Friedmann's ANOVA was used for further analysis to estimate changes in muscles thickness in all groups and subgroups and their dependence on the inclination degree. All statistical tests were performed at a significance level of alpha = 0.05.

Results

As shown in Figure 3, the test showed that the thickness of the external oblique muscle (EO), determined by the medians, between 0 and 1 degrees in the female subjects increased by 0.12 mm (2.25%) $p < 0.05$. As shown in Figure 4, in the male group, both the thickness of the external oblique (EO) and internal (IO) abdominal muscles changed $p < 0.05$. For the external oblique (EO) muscle, this was between 2–3 and 6–7 degrees (0.4 mm – 5.68%, 0.01 mm – 0.13%), and for the internal oblique (IO) between 0–1 degrees (0.54 mm – 4.82%).

As shown in Figure 5, the test showed that the thickness of the external oblique (EO) and the internal oblique (IO) increased between 2–3 degrees and 0–1 degrees (0.33 mm – 6% and 0.08 mm – 0.83%) $p < 0.05$ in the underweight male subjects.

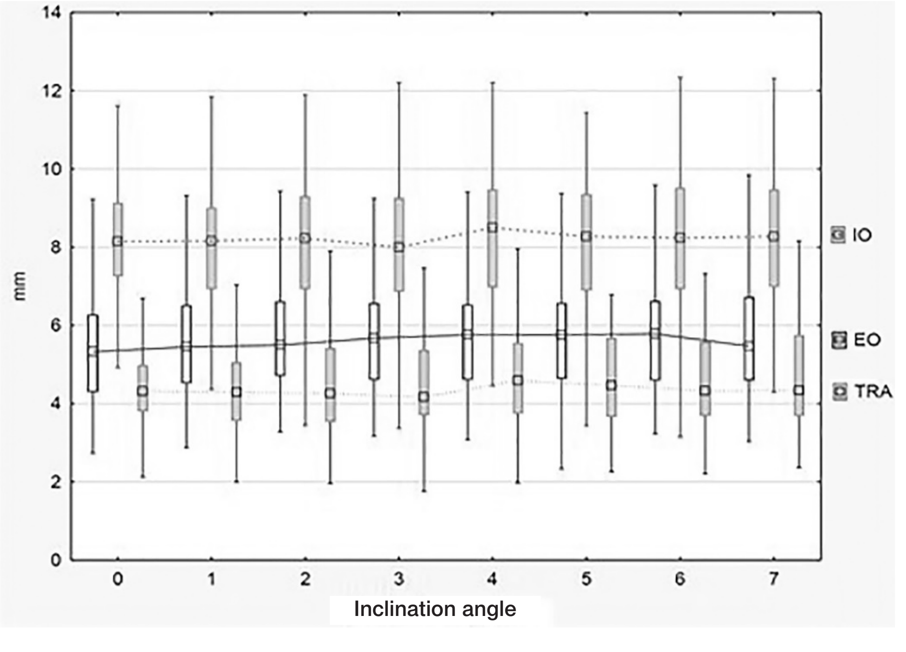

Figure 3. Thickness of the external oblique (EO), internal oblique (IO) and transverse abdominal (TRA) muscles for 0–7 degrees of angular inclination in the female group

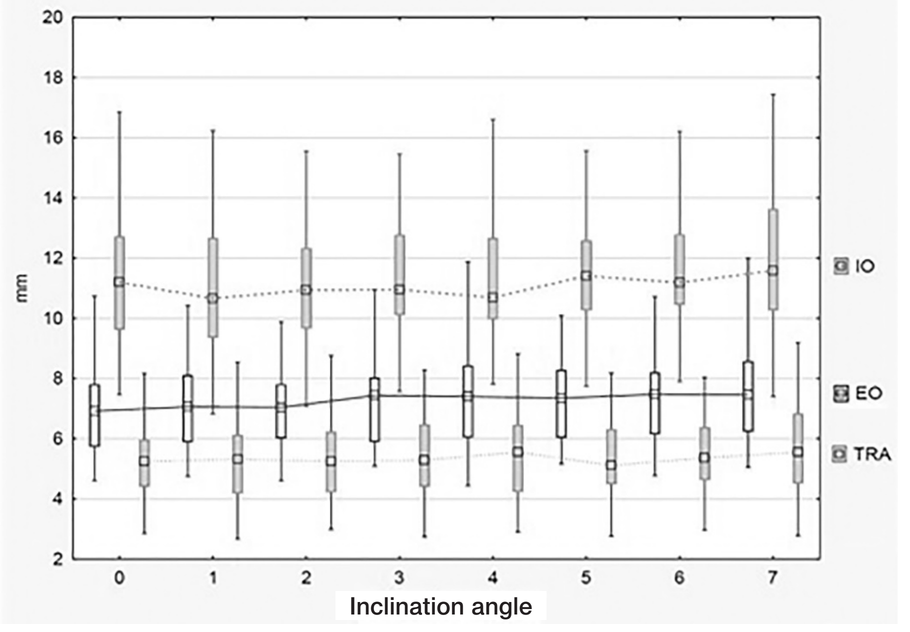

Figure 4. Thickness of the external oblique (EO), internal oblique (IO) and transverse abdominal (TRA) muscles for 0–7 degrees of angular inclination in the male group

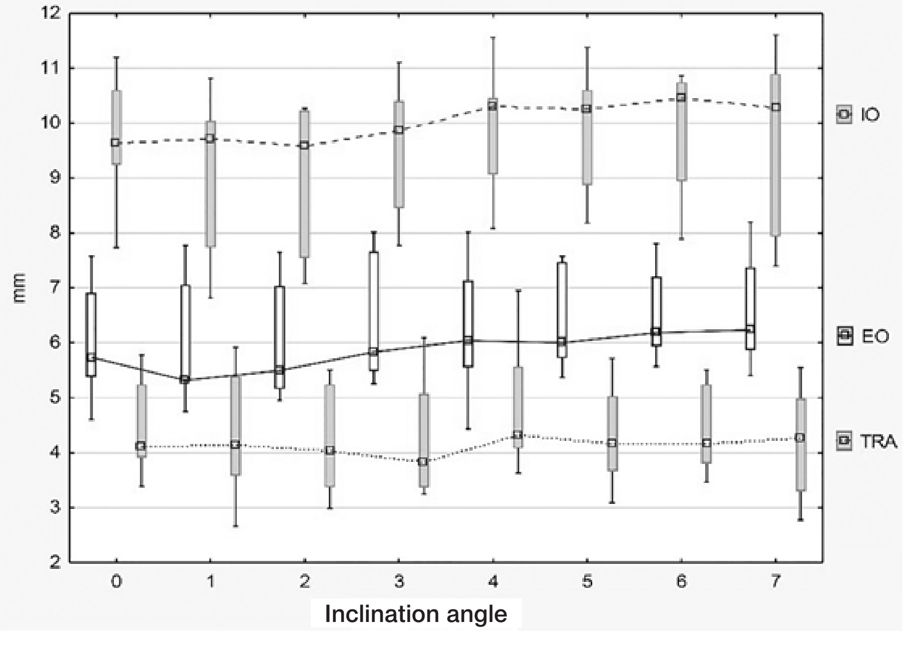

Figure 5. Thickness of the external oblique (EO), internal oblique (IO) and transverse abdominal (TRA) muscles for 0–7 degrees of angular inclination in the male underweight group

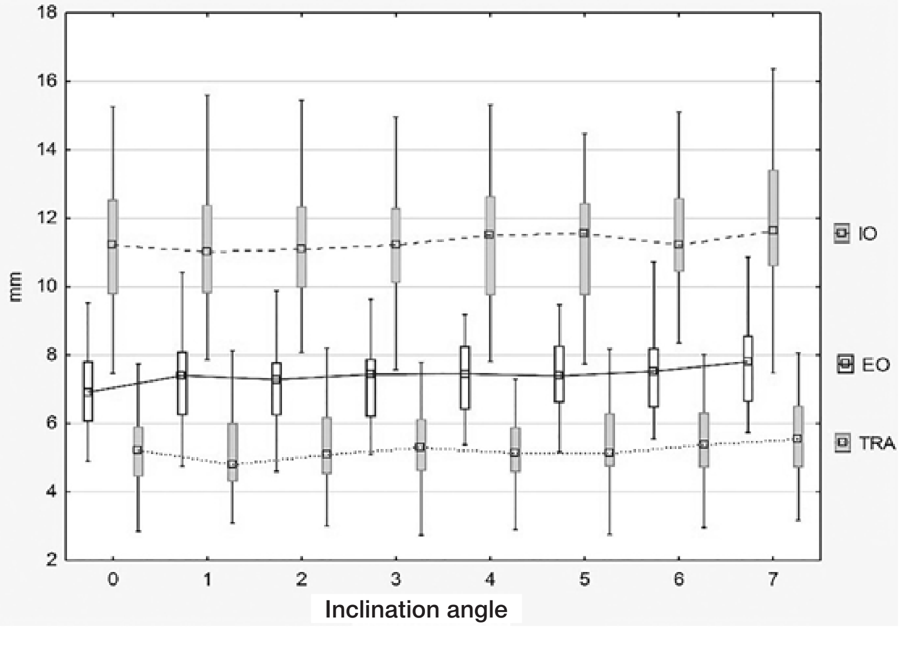

Figure 6. Thickness of the external oblique (EO), internal oblique (IO) and transverse abdominal (TRA) muscles for 0–7 degrees of angular inclination in the male group with normal BMI

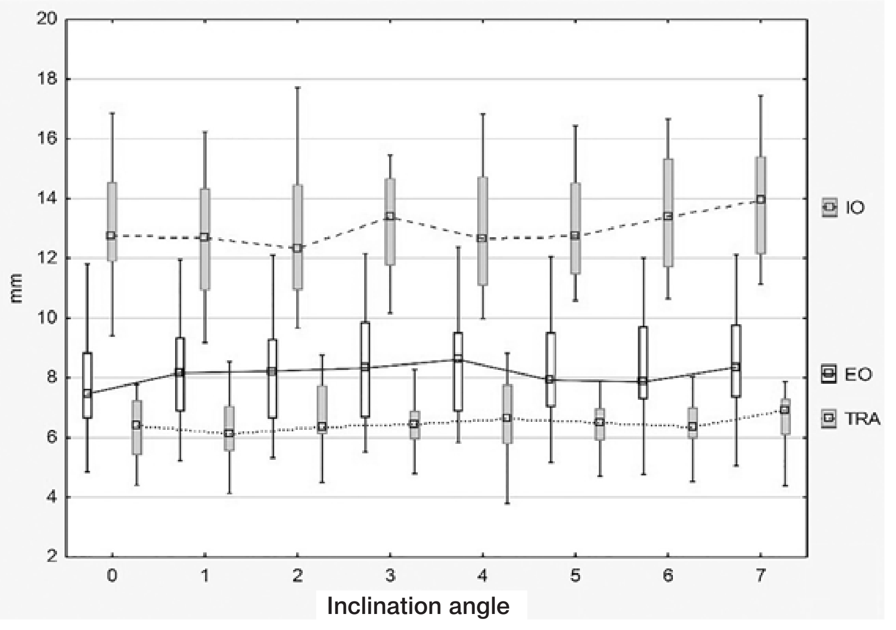

Figure 7. Thickness of the external oblique (EO), internal oblique (IO) and transverse abdominal (TRA) muscles for 0–7 degrees of angular inclination in the male overweight and obese group

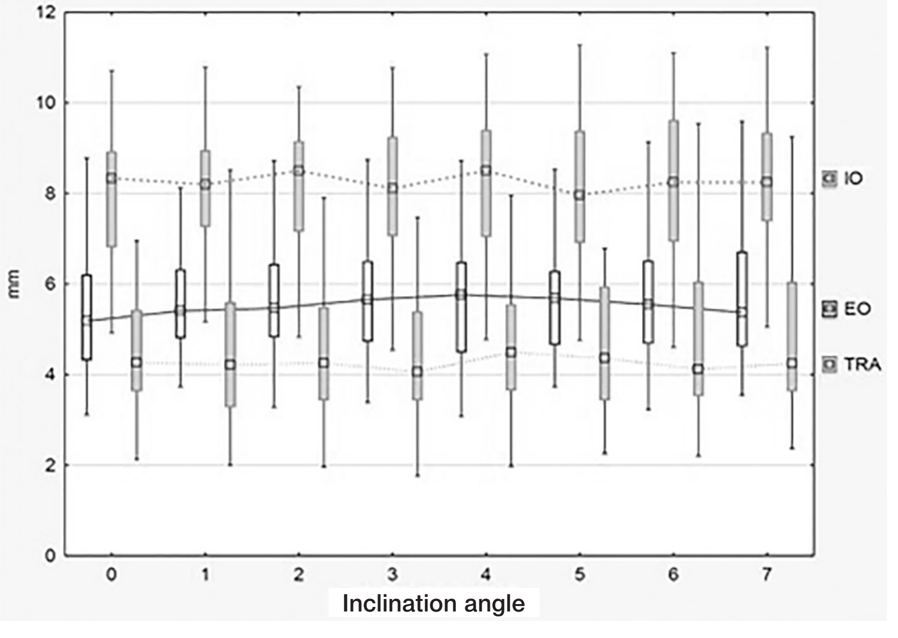

Figure 8. Thickness of the external oblique (EO), internal oblique (IO) and transverse abdominal (TRA) muscles for 0–7 degrees of angular inclination in the female subjects with neutral pelvis

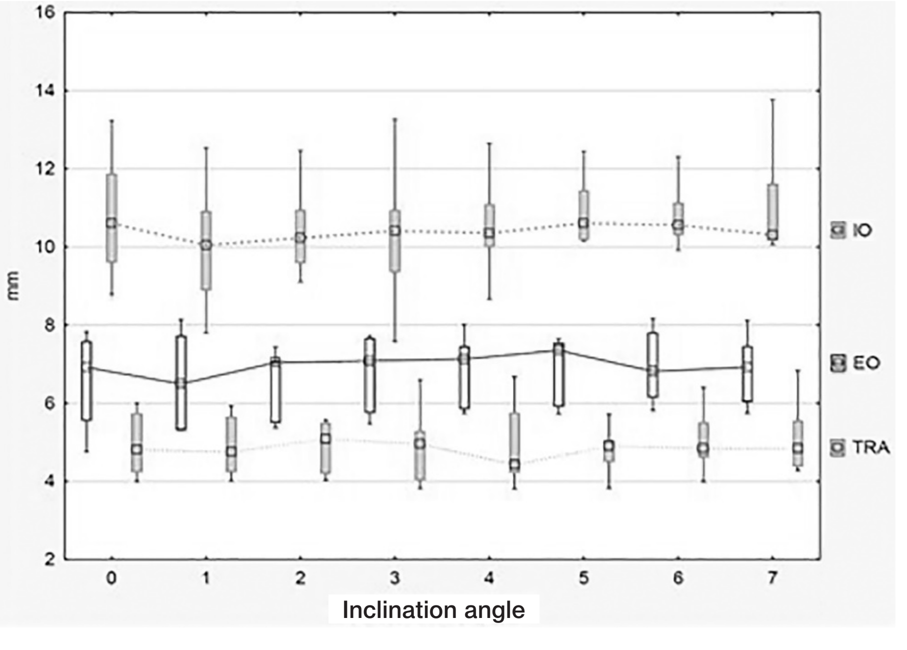

Figure 9. Thickness of the external oblique (EO), internal oblique (IO) and transverse abdominal (TRA) muscles for 0–7 degrees of angular inclination in the male subjects with pelvis tilted anteriorly

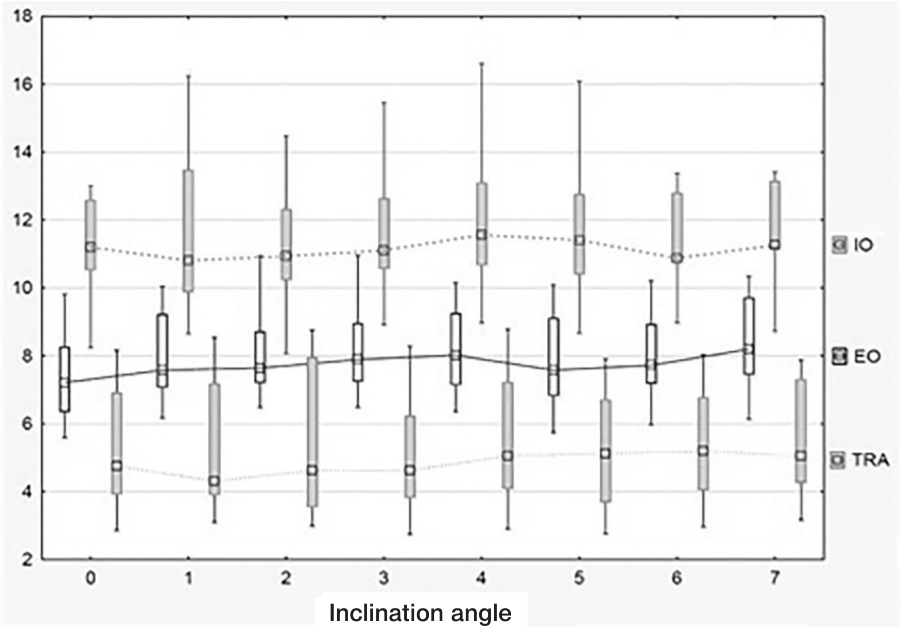

Figure 10. Thickness of the external oblique (EO), internal oblique (IO) and transverse abdominal (TRA) muscles for 0–7 degrees of angular inclination in the male subjects with pelvis tilted posteriorly

As shown in Figure 6, the test showed that the thickness of the internal oblique (IO) increased between 6–7 degrees (0.43 mm – 3.84%) $p < 0.05$ in the male subjects with a normal BMI.

As shown in Figure 7, the test showed that the thickness of the transverse abdominal muscle (TRA) increased between 6–7 degrees (0.52 mm – 8.15%) $p < 0.05$ in the male overweight and obese subjects.

As shown in Figure 8, the thickness of the external oblique muscle (EO) increased between 0–1 degrees in the female subjects with a neutral pelvis (0.23 mm – 4.44%) $p < 0.05$.

As shown in Figure 9, the thickness of the internal oblique muscle (IO) decreased between 0 and 1 degrees (0.56 mm – 5.28%) in the male group with the pelvis tilted anteriorly $p < 0.05$, while Figure 10 shows that the thickness of the external oblique muscle (EO) increased between 0–1 degrees (0.37 mm – 5.13%) in the group with the pelvis tilted posteriorly $p < 0.05$.

Discussion

The lateral abdominal wall muscles play a very important role in the stabilising system of the spine and the posture of the human body [1, 30–32]. They also support many vital functions and safety reflexes [33]. So far, their ability to automatically activate has been demonstrated, especially in perturbation conditions, and when the support plane is being reduced to maintain equilibrium through body posture and increased stability is required [30, 34]. The contraction of the transverse muscle accompanying movements of limbs precedes the movement, which makes it possible to create a firm base within the body centre for the mobility of peripheral elements [1]. Stabilising the torso and stiffening the lumbopelvic region, the transverse muscle protects them against overloads during physical activity [23]. That is why finding the best way to activate the muscles of the lateral abdominal wall is so important. Both in athletes and non-athletes, as well as actively and passively when needed.

In the presented study, despite initial morphological differences between groups characterised by different body types, the analysis of muscle morphology during inclination did not show any characteristic activity patterns. Each of three muscles – the external oblique, internal oblique and transverse abdominal – changed its thickness in a statistically significant way at different degrees of inclination, thus not showing a homogeneous contraction pattern. In the literature, congruent studies analysing the morphology of the lateral abdominal wall muscles in similar groups during low-degree body tilts in the sagittal plane were not found. It has been confirmed so far that changing the body position and its relation to the gravitational force induces muscular response [34–37], which is enabled by the information flow between effectors and numerous receptor organs, such as the vestibular system, eyes and also receptors within the soles [38–40]. The available reports mainly concern changes in the muscles during body movements and tilts at large degrees. The analysis is often limited to the measurement of the electrical potential of the superficial muscles [35, 37]. Shin et al. [34] reported that a backward inclination in the range of 10–40 degrees increases the activation of the rectus abdominis muscle and oblique muscles. Forbes et al. [38] reported that balance disturbances and head roll initiates a balance response of the vestibular system and stabilising reflexes. Reeve et al. [36] reported that muscle activity differs for each pelvic position and posture type. A correct and neutral lumbopelvic posture is characterised by the greatest muscles activity compared to poor postures, such as slouched sitting and sway-back standing. Whereas the results reported by Takaki et al. [6] clearly demonstrate that an active posterior pelvic tilt activates the transverse abdominal muscle.

No analysis has been made so far on passive tilting of the whole body, assuming as a hypothesis that it will cause changes in the thickness of the muscles of the lateral abdominal wall. This could serve as a proposal for a kind of reflex muscle stimulator. In the literature, there are confirmations for the effectiveness of active techniques and exercises that constitute powerful tools for strengthening lateral abdominal wall muscles [8, 17, 20, 36]. Undoubtedly, they are of great clinical value. However, there are circumstances when performing a given exercise combined with an act of movement or a significant body tilt is not possible or it may carry some risk. In this case, the initial reflex activation of the stabilising muscles could be a proper and safe introduction to the therapeutic process.

Limitations

This study has potential limitations. The results obtained in this analysis cannot be compared with other analyses conducted so far due to unique methodological assumptions.

The methodology assumed only forward body tilt. This, however, does not rule out the very sense of inclination itself. Perhaps modifying components of the experiment or carrying out a similar procedure of tilting backwards, as previously mentioned [38] would yield different results. In this concept (in contrast to other authors' methodologies), two belts were used to stabilise the body. It is possible that the exclusion of passive stabilisation of the head and the need to maintain the control over it while tilting could increase the activity of the muscles of the lateral abdominal wall through a synergistic mechanism. These studies provide a lot of valuable information about the activity of the muscles of the lateral abdominal wall. However, the topic can still be considered not fully exhausted. And the body's stabilisation mechanisms may be the subject of further, more detailed analyses.

Conclusions

In this study, a characteristic pattern of contraction of the external oblique, internal oblique, and transverse abdominal muscles during passive forward movements of small angular values was not observed. Statistically significant changes were accidental. Therefore, there are no indications for clinical application of the above-mentioned method of inclination in therapeutic practice. It is worth further investigation with the aim of finding a method that will achieve above presented goals.

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Ethical approval

The research related to human use has complied with all the relevant national regulations and institutional policies, has followed the tenets of the Declaration of Helsinki, and has been approved by the University's Bioethical Committee for Scientific Research attached to the Jerzy Kukuczka Academy of Physical Education in Katowice (approval No.: 3/2019).

Informed consent

Informed consent has been obtained from all individuals included in this study.

Disclosure statement

No author has any financial interest or received any financial benefit from this research.

Conflict of interest

The authors state no conflict of interest.

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