



Paweł Linek

Could changes in the ultrasound image of the muscles of the lateral abdominal wall be seen as a sign of muscle activity? A narrative review

Department of Kinesitherapy and Special Methods in Physiotherapy, The Jerzy Kukuczka Academy of Physical Education, Katowice, Poland

ABSTRACT

Aim. Currently, ultrasonography (USG) is used to study changes occurring in the lateral abdominal wall muscles (LAM). Here, the question that naturally arises is whether a change in the thickness of the ultrasound image can be identified with a change in muscle activity. Therefore, the purpose of the present work is to: 1) undertake an analysis of available publications exploring the relationship between electromyography (EMG) and USG; 2) define the USG measurement of each LAM; 3) identify gaps in the literature.

Material and methods. The databases MEDLINE, POL-index and Google Scholar were used to search the literature. We used a combination of terms (in Polish and English) containing the abbreviated and full names of the following expressions: ultrasound, electromyography and external oblique muscle, internal oblique muscle, or transverse abdominal muscle.

Results. Nine publications fulfilled the conditions for inclusion in the analysis. These used different methodologies and test conditions, making it difficult to interpret the results of individual works. The majority demonstrated poor or no correlation between EMG and USG measurements.

Conclusion. Changes in the thickness of the LAM using USG should not be equated with a change in muscle activity. To avoid misinterpretation, one should avoid the term “muscle activity” in evaluating changes in the thickness of the LAM. It is recommended that the terms “thickness change” or “morphological change” be used in the assessment of this phenomenon, which is closely related to real changes in USG imaging, expressing a more complex phenomenon than a mere change in bioelectrical potential.

Keywords. ultrasonography, electromyography, lateral abdominal wall, muscle activity, muscle morphology

Corresponding author: Linek Pawel, Department of Kinesitherapy and Special Methods in Physiotherapy, The Jerzy Kukuczka Academy of Physical Education, 40-065, Mikołowska 72B, POLAND, phone: +48 661 768 601, e-mail: linek.fizjoterapia@vp.pl

Participation of co-authors: A – Author of the concept and objectives of paper; B – collection of data; C – implementation of research; D – elaborate, analysis and interpretation of data; E – statistical analysis; F – preparation of a manuscript; G – working out the literature; H – obtaining funds

Received: 21.12.2016 | Accepted: 16.02.2017
Publication date: June 2017

Linek P. *Could changes in the ultrasound image of the muscles of the lateral abdominal wall be seen as a sign of muscle activity? A narrative review.* Eur J Clin Exp Med. 2017;15(1):59–65. doi: 10.15584/ejcem.2017.1.9

Introduction

The lateral abdominal wall muscles (LAM) have been the subject of numerous research papers in different academic facilities. This is probably due to the release of studies that assign an important role to these muscles in the stabilization of the lumbar spine and pelvis,^{1,2} as well as LAM testing techniques becoming more common. In the study of this area of the body, each LAM – the oblique external (OE) abdominal, the oblique internal (OI) abdominal and the transverse (TrA) abdominal – should be analysed separately, because each of these is assigned a somewhat different role in lumbar-pelvic stabilization.^{3,4} Therefore, there are additional equipment requirements to allow for separate analysis of the characteristics of each LAM.

The most common and best known tool for measuring muscle activity is electromyography (EMG), which expresses muscle activity using the change in electric potential. The resulting EMG signal is the result of the stimulation of muscle fibres by the potentials of the nervous system.⁵ In this way, the EMG signal allows the time of activation of a muscle, the duration of muscle activity and the level of intensity of this activity to be determined.⁶ Scientific research uses two types of EMG electrodes, superficial (sEMG) or deep (dEMG), which provide different research capabilities. The main feature differentiating the two techniques of research is the method of collecting EMG signals from the muscles. The sEMG electrodes receive potentials from above the surface of the muscle using outer electrodes placed on the skin, while dEMG analyses individual motor units using deep intramuscular electrodes. In the case of the LAM, the requirement for separate testing of individual muscles, as well as the need for detailed analysis of the TrA muscle (the most deeply situated muscle, considered the most important in the stabilization of the lumbar and pelvic region) makes dEMG the only appropriate technique; in this case, sEMG is useless as a test method. While the dEMG method offers selective assessment of individual LAM, it is an invasive method of study, which carries some risk of infection. It is also time consuming and hence is difficult to use in clinical studies concerning a larger population.

The tools that appear to combine features of sEMG and dEMG are magnetic resonance imaging (MRI) and ultrasound imaging (USG), which are non-invasive, safe, permit the collection of information through the skin (as is the case of sEMG), as well as allowing independent assessment of individual muscles (as is the case with dEMG). Although the LAM results acquired through MRI and the USG are highly correlated with each other,⁷ MRI has a number of restrictions (time consuming, high cost, special conditions), as a result of which USG seems to be the preferable research tool since it does not suffer from such restrictions.

In 2006, the term “rehabilitative ultrasound imaging” (RUSI) was introduced and the procedures for the

morphological assessment of muscles (including LAM) were defined.⁸ In addition, work on determining (in consultation with the World Federation for Ultrasound in Medicine and Biology) the educational framework for physical therapists regarding the use of USG in rehabilitation has commenced. This led to the further expansion of the use of this measurement tool in scientific research and physical therapy.^{9–11}

However, in the case of EMG evaluation, we consider the electric potential, expressed in millivolts, while USG (as well as MRI) provides information on the LAM characteristics in millimetres (mm) or centimetres (cm), which sometimes gives rise to a degree of controversy and raises questions about the way we should define the phenomenon investigated. The available literature usually refers to an individual measurement of LAM using USG in terms of thickness,^{12–19} size^{15,20} or cross-section,²¹ while the analysis of the two measurements in different situations (e.g. one measurement at rest and the other during some physical activity, e.g. the movement of the limb) is usually defined as the activity,^{22–24} a thickness change,^{12,13,25,26} or the rate of contraction^{15,27} in OE, OI and/or TrA muscles during a motor task.

The high correlation between the results of MRI and USG⁷ means that USG can be considered an appropriate tool for defining the shape of the LAM. The shape is an important structural element and in this case the term “morphology” can be used; in relation to living organisms, this refers to the “construction”, or “shape”. Therefore, it is reasonable to use terms such as the “thickness” or “morphology” to identify the results of TrA, OI and OE analysis. Moreover, these terms have been established in the scientific literature for a long time. However, there is less consistency in the analysis of the two measurements evaluating changes in the thickness of the muscle in USG images. Researchers have acknowledged that the change in thickness during a specific motor activity (to resting) is probably a more clinically useful and diagnostically helpful analysis rather than the resting thickness alone.^{25,28} The question that arises here is whether a change in the thickness of the USG image can be identified definitively with a change in muscle activity.

Aim of the study

This narrative review attempts to find an answer to this question. Therefore, the purpose of the present study is to: 1) analyse available works exploring the relationship between EMG and USG; 2) define USG measurement for each LAM; 3) identify gaps in the literature currently available.

Method

Works concerning the study of the relationship between USG and EMG of the OE, OI and TrA muscles were considered for evaluation. Of these works, only articles in which both tools were tested at the same time were finally

included in the analysis. Two electronic databases (MEDLINE and POL-index), as well as the Google Scholar search engine, were used to find the articles. We used a combination of terms containing the abbreviated and full terms of the following expressions: USG, EMG, OE, OI, TrA and/or lateral abdominal wall muscles, taking into account their respective wording in Polish and English. All works were accepted, regardless of the age, gender, origin or health of the subjects. The search was restricted to only articles available in Polish and/or English.

An analysis was undertaken of the scope of the titles and the content of the abstracts. Articles clearly indicating a lack of connection with the issue were immediately rejected. The complete texts of the remaining articles were analysed in detail. Lists of references of these papers were also examined to check for the possible omission of relevant articles.

Results

Nine research papers met the conditions for inclusion in this analysis.^{29–37} All of these analysed the relationship between EMG (sEMG or dEMG) and the thickness of the OE, OI and/or TrA in the USG images during different types of contraction and/or motor activity. The detailed characteristics of the individual works are presented in Table 1.

Hodges et al.'s³⁷ paper demonstrated curvilinear growth between the EMG signal and the thickness of the OE ($r = 0.23$; $p = 0.43$), OI ($r = 0.84$; $p < 0.01$) and TrA ($r = 0.90$; $p < 0.01$) during isometric tension. However, it was found that the measurement of the thickness of OI and TrA was linear for changes in EMG only in the range of 12–23% of the maximum volitional contraction. In another work, which also assessed the isometric contraction of LAM, but somewhat differently, Ferreira et al.³³ demonstrated a strong correlation between EMG and USG for TrA ($r = 0.85$; $p < 0.01$) and OI ($r = 0.74$; $p < 0.01$) and a weak correlation for OE ($r = 0.28$; $p = 0.22$).

Other works have examined the correlation between the results of EMG and USG while drawing in the lower abdomen (the abdominal drawing-in manoeuvre – ADiM). In the first, McMeeken et al.³⁶ obtained a linear and strong relationship between the EMG signal and the change in thickness of TrA ($r^2 = 0.87$; $p < 0.001$) at all levels of EMG activity at any contraction. On the other hand, Brown and McGill³⁴, studying OI and OE, did not find any relationship with EMG during either the isometric contraction or ADiM. Moreover, Tahan et al.³² did not observe any dependence of OI or TrA in the EMG or USG signals. Detailed analysis of individual cases in the research conducted by Whitaker et al.³¹ showed that the relationship between EMG and USG is inconsistent and the coefficient of determination is low during ADiM ($r^2 = 0.00–0.13$) and the active straight leg raise (ASLR) ($r^2 = 0.00–0.18$).

In the paper by John and Beith³⁵, a relationship between EMG and the change in the thickness of OE in

the USG image was demonstrated only for isometric trunk rotation, although this relationship differed among individual patients ($r^2 = 0.28–0.92$). For ADiM, the relationship was not significant and differed among the subjects ($r^2 = 0.02–0.74$). In a recently published study, Rabello et al.³⁰ demonstrated radically different relationships between the change in thickness of the OE and the EMG signal (for example: $r = -0.90–0.92$ for flexion of the trunk; $r = -0.83–0.93$ for the trunk rotation to the left) during isometric contractions in three directions (anterior flexion of the trunk, lateral flexion of the trunk, rotation of the trunk to the left) and in the range 0–50% for maximum shrinkage. The final publication considered, by Blanchard et al.²⁹ also revealed a lack of relationship between EMG and the thickness of TrA and OI in the USG image ($R^2 < 0.13$) during deadlift and the Valsalva manoeuvre.

Discussion

The review of the literature clearly shows that the relationship between bioelectric activity and the change in the thickness of the USG image for LAM depends on the type of examination. Taking into consideration the work by McMeeken et al.³⁶, it can be concluded that a change in the thickness of TrA in the USG measurement during ADiM reflects the activity of the muscle. Unfortunately, another study contradicts this type of dependency³¹. A similar inconsistency affects the other research works listed, with significant between-subject discrepancies in the degree of correlation of USG and EMG, even within a single research paper. Thus, it is the responsibility of researchers to select the studies considered credible to confirm their assumptions. As can be seen, researchers wishing to consider the evaluation of changes in the thickness of LAM as an expression of their activity will find works that confirm this phenomenon.^{36,37} However, opponents of the argument for such a relationship can find arguments in other scientific works.

This narrative review is the result of emerging problems with the proper identification and qualification of changes occurring during USG examination of the LAM. An intuitive assumption is that size of the muscles changes during contraction as individual muscle fibres are shortened. The type of contraction (isometric, concentric, eccentric) should not matter, because every change in muscle length entails a change in its size. In the case of the LAM, this change will relate to the thickness. However, the lateral abdominal wall is a specific site, where the activity of the individual muscles of which it is composed may induce or inhibit changes in the thickness of the other muscles. A good example here is the OE muscle, which can be squeezed by the muscles that are located deeper during various motor tasks, making it impossible to obtain a thickness that reflects a real change in activity in the USG image. Thus, the force generated in a single muscle affects the adjacent muscles, especially if they are inclined relative to each other.³⁴ This may

Table 1. The relationship between electromyography and ultrasonography of the lateral abdominal muscles

Study	Participants	Subject position	Muscle state or task	US examination	EMG examination	Results
Hodges et al. 2003 (OE, OI, TrA)	healthy males 27 – 45 lat/years	Sitting on a reclining chair with the hips flexed to 30°	Isometric contraction	B – mode (normalization to rest thickness)	dEMG	Nonlinear increases in TrA, OI, OE thickness up to 22% MVC
McMeeken et al. 2004 (TrA)	healthy subjects 29 – 52 years	supine	Abdominal drawing-in maneuver	M-mode (per cent thickness change to rest position)	dEMG	linear increases in TrA thickness up to 80% MVC
John and Beith, 2007 (OE)	healthy subjects 24,5 mean age	Crook lying position	trunk rotation and abdominal drawing-in maneuver	M-mode (per cent thickness change to rest position)	sEMG	linear increases during only trunk rotation in 21 participants
Brown and McGill, 2010 (OE, OI)	healthy males 25,2 mean age	sitting on a kneeling chair	Abdominal drawing-in maneuver and abdominal brace	B-mode (per cent thickness change to rest position)	sEMG	lack of significant dependence
Ferreira et al. 2011 (OE, OI, TrA)	10 healthy and 10 LBP Mean age – 30 years	Supine, hip flexed 50° and knee flexed 90°	Isometric contraction at low-load knee flexion and extension	?-mode (normalization to rest thickness)	dEMG	Significant dependence only for TrA and OI
Tahan et al 2013 (TrA, OI)	healthy subjects 18 – 42 years	Crook lying position	Abdominal drawing-in maneuver with and without pelvic floor muscle	B-mode (normalization to rest thickness)	sEMG	lack of significant dependence
Whittaker et al 2013 (OE, OI, TrA)	participants Mean age – 30 years		Abdominal drawing-in maneuver with and active straight leg rise	B-mode (per cent thickness change to rest position)	dEMG	lack or very low significant dependence of TrA and OI
Rabello et al 2015 (OE)	18 male Mean age – 25 years	sitting	forward flexion, right side flexion, left side rotation of the trunk	M-mode (per cent thickness change to rest position)	sEMG	non-consistent dependence
Blanchard et al 2016 (TrA, OI)	11 participants Mean age – 20 years	standing	Deadlift and Valsalva maneuver with or without belt	M-mode (change in thickness)	sEMG	lack dependence of TrA and OI

also explain the improbable findings that are sometimes recorded (e.g. in ³⁰), showing a reduction in the thickness of OE in the USG image, together with an increase in the EMG activity of the muscle.

The systematic review published by Koppenhaver et al.³⁸ in 2009 indicated that the relationship between EMG and USG depends on the intensity and strategy of the contraction. This review, which only takes into account works on LAM, updated with research produced recently, also indicates that the degree of connection of measurements of the thickness of the LAM in USG images depends on the intensity and the type of contraction, as well as the measurement tools used. Recognizing EMG as the gold standard for examining muscle activity, it should be emphasized that the LAM constitute a challenge for this research tool.

Hence, analysis of the literature must take into account the possible inaccurate estimation of the EMG signal, which could also be a reason for low dependence with USG in the individual studies. Namely, in the case of dEMG, the electrodes injected analyse a small number of motor units, rather than providing a more global assessment using superficial electrodes (sEMG). In the case of the LAM, we may suspect a regional variation of activation (activity) within a single muscle. The research conducted by Urquhart et al.³⁹ provided evidence of morphological differences between the regions in the OE, OI and TrA muscles, which indicates their variable function. In previously published studies, the dEMG measurement was obtained from an area that differed from that in USG imaging; based on the suggestions made by Urquhart et al., this helps explain the lack of or weak relationships between these research tools.

On the other hand, the use of sEMG to assess LAM significantly impedes the ability to separate the signal into those derived exclusively from OI and TrA. Studies comparing sEMG and dEMG for TrA measurement clearly indicate a weak correlation, which is probably caused by interference (the collection of additional signals) coming from the adjacent muscles during sEMG.⁴⁰ Thus, the results of the works examined in this review in which the EMG assessment of the OI and TrA muscles was obtained using superficial electrodes provide little cognitive value in terms of changes in the thickness of the muscles in USG images. In general, researchers acknowledge that EMG analysis of individual LAM using superficial electrodes is rather susceptible to interference from the surrounding muscles.^{41,42} In addition, changing the activity of the LAM involves changing their shape in all dimensions and often causes a displacement of these muscles (especially of the TrA muscle). In USG examinations, the head in a sense follows the contracting muscle belly, while the electrode placed during sEMG examination does not do so. It should also be noted that the location of the LAM is not the same in all people as elderly patients and subjects with abdominal obesity often have a more lateral location of the LAM (Linek et al., 2016, unpublished observations). This will

cause significant measurement errors if the electrodes in the sEMG examination are placed in locations where the LAM should be “by the book”, rather than where they are actually located, both at rest and during any physical activity. Thus, the bioelectric potentials can be collected from structures other than those the researchers plan to examine.

A lack of or a weak relationship between EMG and USG in the analysis of the LAM does not necessarily prove that the changes in USG images do not relate to the activity of these muscles. Logically, the change in the geometry (thickness) of the muscle is an expression of its activity (changing its shape), but this change cannot be unambiguously identified with activity understood from the point of view of EMG as the electric potential difference. This is evidenced by the research analysed, albeit this should be treated with caution as in the case of EMG examination of the OI and TrA muscles, the use of deep electrodes does not provide activation (activity) information for the whole muscle and the use of superficial electrodes provides imprecise information about the actual state of these muscles. However, the evidence seems sufficient to conclude that USG is not the right tool to assess the activity of OE as there might be insufficient conditioning of this muscle to increase its thickness through the actions of the deeper muscles.

With the current state of knowledge, one must therefore move away from the understanding of changes in the morphology (thickness) of the LAM, as examined using USG, as the only source of information concerning the activity of these muscles. Changes in the thickness of the muscle illustrate the combined effect of many biomechanical factors, as well as neuromuscular control.³¹ Indeed, muscle activity is reflected by only one of all these factors.⁴³ There are also suggestions that the changes in the geometry of muscles measured by means of USG correspond to real changes in their function compared to other research tools.⁴⁴ Therefore, it seems reasonable for changes in the thickness of the LAM in USG imaging not to be described as muscle activity. However, where such a term is used, it should clearly be explained that this activity is understood as a change in thickness. To avoid possible misinterpretation, however, it would be better to use a term that really captures the phenomenon investigated for changes in the morphology (thickness) of the LAM in USG imaging, namely “thickness change” or “morphological change”. Researchers will be able to express this change in thickness/morphology in various ways (e.g. as a percentage) and this value will describe a much more complex phenomenon than bioelectric activity, including the impact of intra-abdominal pressure and tension and contraction or stretching of the surrounding tissue.^{45,46}

The current literature evaluating the relationship between EMG and USG of the LAM is very meagre and considers rather limited research material. This review has shown that over the last few years, this type of research

has seen participation from less than 130 subjects. Among these, the vast majority were healthy individuals in a quite narrow age range. In addition, in the majority of studies, the authors used different research methodologies in terms of the measurement tools applied, as well as the motor tasks performed, further hindering the ability to draw any common conclusions. It should also be noted that in some of the studies, the methodology used does not allow reliable inference in terms of the results obtained and thus it seems unreasonable to use surface electrodes to evaluate the EMG of the TrA muscle. On the other hand, recognizing the variability of different functional fibres of the LAM, deep electrodes should be located as close as possible to the location of the USG head as dEMG is the optimal tool for the assessment of deeply-located small muscles. Therefore these aspects should be taken into account when designing further research in this area of scientific exploration.

Conclusion

Changes in the thickness of the individual lateral wall muscles using ultrasound imaging should not be equated with a change in their activity. According to current knowledge and to avoid misinterpretation, one should avoid the term “muscle activity” during the evaluation of changes in the thickness of the lateral abdominal wall muscles. It is recommended that the terms “thickness change” or “morphological change” be used in the assessment of this phenomenon; these are more closely related to real changes in the ultrasound image and thus express a more complex phenomenon than a mere change in bioelectrical potential.

Acknowledgement

The author would like to acknowledge and thank Prof. dr hab. Edward Saulicz for the inspiration to conduct research using ultrasound imaging, as well as numerous discussions that contributed to the creation of this publication.

Compliance with ethical standards

Conflict of interest: The authors declare that they have no conflicts of interest.

Funding: None

References

- Gardner-Morse MG, Stokes IA. The effects of abdominal muscle coactivation on lumbar spine stability. *Spine (Phila Pa 1976)*. 1998;23(1):86-92.
- Richardson CA, Snijders CJ, Hides JA, Damen L, Pas MS, Storm J. The relation between the transversus abdominis muscles, sacroiliac joint mechanics, and low back pain. *Spine (Phila Pa 1976)*. 2002;27(4):399-405.
- Bergmark A. Stability of the lumbar spine. A study in mechanical engineering. *Acta Orthop Scand Suppl*. 1989;230:1-54.
- Cresswell AG, Grundström H, Thorstensson A. Observations on intra-abdominal pressure and patterns of abdominal intra-muscular activity in man. *Acta Physiol Scand*. 1992;144(4):409-18.
- Błaszczuk J. *Biomechanika Kliniczna*. Warszawa:PZWL; 2004.
- Pullman SL, Goodin DS, Marquinez AI, Tabbal S, Rubin M. Clinical utility of surface EMG: report of the therapeutics and technology assessment subcommittee of the American Academy of Neurology. *Neurology*. 2000;55(2):171-7.
- Hides J, Wilson S, Stanton W, et al. An MRI investigation into the function of the transversus abdominis muscle during “drawing-in” of the abdominal wall. *Spine (Phila Pa 1976)*. 2006;31(6):175-8.
- Teyhen D. Rehabilitative Ultrasound Imaging Symposium San Antonio, TX, May 8-10, 2006. *J Orthop Sports Phys Ther*. 2006;36(8):A1-3.
- Wolny T, Linek P. Rehabilitative Ultrasound Imaging - anatomia sonograficzna i sonofeedback w ocenie i kinezyterapii zespołu boczno przyparcia rzepki. *Rehabil w Prakt*. 2016;4:28-32.
- Wolny T, Linek P, Wróbel Ł. Rehabilitative Ultrasound Imaging - podstawy fizyczne oraz zastosowanie w codziennej pracy fizjoterapeuty. *Rehabil w Prakt*. 2016;3:30-4.
- Wolny T, Linek P, Wróbel Ł. Rehabilitative Ultrasound Imaging - anatomia sonograficzna i sonofeedback w ocenie i kinezyterapii zespołu ciasnoty podbarkowej. *Rehabil w Prakt*. 2016;5:28-35.
- Linek P. Assessment of the deep abdominal muscles at rest and during the abdominal drawing-in maneuver in adolescents practicing volleyball: A case control study. *Isokinet Exerc Sci*. 2015;23(4):215-20.
- Linek P, Saulicz E, Kuszewski M, Wolny T. Ultrasound Assessment of the Abdominal Muscles at Rest and During the ASLR Test Among Adolescents with Scoliosis. *Clin spine Surg*. 2016;30(4):181-6.
- Linek P, Saulicz E, Wolny T, Myśliwiec A, Gogola A. Ultrasound evaluation of the symmetry of abdominal muscles in mild adolescent idiopathic scoliosis. *J Phys Ther Sci*. 2015;27(2):465-8.
- Linek P, Saulicz E, Wolny T, Myśliwiec A, Kokosz M. Lateral abdominal muscle size at rest and during abdominal drawing-in manoeuvre in healthy adolescents. *Man Ther*. 2015;20(1):117-23.
- Linek P, Saulicz E, Wolny T, Myśliwiec A. Assessment of the abdominal muscles at rest and during abdominal drawing-in manoeuvre in adolescent physically active girls: A case-control study. *J Sport Heal Sci*. 2015.
- Gray J, Aginsky KD, Derman W, Vaughan CL, Hodges PW. Symmetry, not asymmetry, of abdominal muscle morphology is associated with low back pain in cricket fast bowlers. *J Sci Med Sport*. 2016;19(3):222-6.
- Tayashiki K, Maeo S, Usui S, Miyamoto N, Kanehisa H. Effect of abdominal bracing training on strength and power of trunk and lower limb muscles. *Eur J Appl Physiol*. 2016;116(9):1703-13.
- Noormohammadpour P, Hosseini Khezri A, Linek P, et al. Comparison of lateral abdominal muscle thickness and

- cross sectional area of multifidus in adolescent soccer players with and without low back pain: a case control study. *Asian J Sports Med.* 2016.
20. Rankin G, Stokes M, Newham DJ. Abdominal muscle size and symmetry in normal subjects. *Muscle Nerve.* 2006;34(3):320-6.
 21. Myśliwiec A, Kuszewski M, Saulicz E, et al. Assessment of transverse abdominal muscle symmetry by ultrasonography | Ocena symetrii mięśnia poprzecznego brzucha w badaniu ultrasonograficznym. *Ortop Traumatol Rehabil.* 2014;16(4):427-34.
 22. Rasouli O, Arab AM, Amiri M, Jaberzadeh S. Ultrasound measurement of deep abdominal muscle activity in sitting positions with different stability levels in subjects with and without chronic low back pain. *Man Ther.* 2011;16(4):388-93.
 23. Manshadi FD, Parnianpour M, Sarrafzadeh J, et al. Abdominal hollowing and lateral abdominal wall muscles' activity in both healthy men & women: An ultrasonic assessment in supine and standing positions. *J Bodyw Mov Ther.* 2011;15(1):108-13.
 24. Critchley DJ, Pierson Z, Battersby G. Effect of pilates mat exercises and conventional exercise programmes on transversus abdominis and obliquus internus abdominis activity: pilot randomised trial. *Man Ther.* 2011;16(2):183-9.
 25. Linek P, Saulicz E, Wolny T, Myśliwiec A. Intra-rater reliability of B-mode ultrasound imaging of the abdominal muscles in healthy adolescents during the active straight leg raise test. *PM R.* 2015;7(1):53-9.
 26. Do Y-C, Yoo W-G. Comparison of the thicknesses of the transversus abdominis and internal abdominal obliques during plank exercises on different support surfaces. *J Phys Ther Sci.* 2015;27(1):169-70.
 27. Miura T, Yamanaka M, Ukishiro K, et al. Individuals with chronic low back pain do not modulate the level of transversus abdominis muscle contraction across different postures. *Man Ther.* 2014;19(6):534-40.
 28. Costa LOP, Maher CG, Latimer J, Smeets RJEM. Reproducibility of rehabilitative ultrasound imaging for the measurement of abdominal muscle activity: a systematic review. *Phys Ther.* 2009;89(8):756-69.
 29. Blanchard TW, Smith C, Grenier SG. In a dynamic lifting task, the relationship between cross-sectional abdominal muscle thickness and the corresponding muscle activity is affected by the combined use of a weightlifting belt and the Valsalva maneuver. *J Electromyogr Kinesiol.* 2016;28:99-103.
 30. Rabello LM, Gagnon D, da Silva RA, Paquette P, Larivière C. External abdominal oblique muscle ultrasonographic thickness changes is not an appropriate surrogate measure of electromyographic activity during isometric trunk contractions. *J Back Musculoskelet Rehabil.* 2015;28(2):229-38.
 31. Whittaker JL, McLean L, Hodder J, Warner MB, Stokes MJ. Association between changes in electromyographic signal amplitude and abdominal muscle thickness in individuals with and without lumbopelvic pain. *J Orthop Sports Phys Ther.* 2013;43(7):466-77.
 32. Tahan N, Arab AM, Arzani P, Rahimi F. Relationship between ultrasonography and electromyography measurement of abdominal muscles when activated with and without pelvis floor muscles contraction. *Minerva Med.* 2013;104(6):625-30.
 33. Ferreira PH, Ferreira ML, Nascimento DP, Pinto RZ, Franco MR, Hodges PW. Discriminative and reliability analyses of ultrasound measurement of abdominal muscles recruitment. *Man Ther.* 2011;16(5):463-9.
 34. Brown SHM, McGill SM. A comparison of ultrasound and electromyography measures of force and activation to examine the mechanics of abdominal wall contraction. *Clin Biomech (Bristol, Avon).* 2010;25(2):115-23.
 35. John EK, Beith ID. Can activity within the external abdominal oblique be measured using real-time ultrasound imaging? *Clin Biomech (Bristol, Avon).* 2007;22(9):972-9.
 36. McMeeken JM, Beith ID, Newham DJ, Milligan P, Critchley DJ. The relationship between EMG and change in thickness of transversus abdominis. *Clin Biomech (Bristol, Avon).* 2004;19(4):337-42.
 37. Hodges PW, Pengel LHM, Herbert RD, Gandevia SC. Measurement of muscle contraction with ultrasound imaging. *Muscle Nerve.* 2003;27(6):682-92.
 38. Kopenhagen SL, Hebert JJ, Parent EC, Fritz JM. Rehabilitative ultrasound imaging is a valid measure of trunk muscle size and activation during most isometric sub-maximal contractions: a systematic review. *Aust J Physiother.* 2009;55(3):153-69.
 39. Urquhart DM, Barker PJ, Hodges PW, Story IH, Briggs CA. Regional morphology of the transversus abdominis and obliquus internus and externus abdominis muscles. *Clin Biomech (Bristol, Avon).* 2005;20(3):233-41.
 40. Okubo Y, Kaneoka K, Imai A, et al. Comparison of the activities of the deep trunk muscles measured using intramuscular and surface electromyography. *J Mech Med Biol.* 2010;10(4):611-20.
 41. Marshall P, Murphy B. The validity and reliability of surface EMG to assess the neuromuscular response of the abdominal muscles to rapid limb movement. *J Electromyogr Kinesiol.* 2003;13(5):477-89.
 42. McGill S, Juker D, Kropf P. Appropriately placed surface EMG electrodes reflect deep muscle activity (psoas, quadratus lumborum, abdominal wall) in the lumbar spine. *J Biomech.* 1996;29(11):1503-7.
 43. Whittaker JL, Stokes M. Ultrasound imaging and muscle function. *J Orthop Sports Phys Ther.* 2011;41(8):572-80.
 44. Peschers UM, Gengelmaier A, Jundt K, Leib B, Dimpfl T. Evaluation of Pelvic Floor Muscle Strength Using Four Different Techniques. *Int Urogynecol J.* 2001;1(12):27-30.
 45. Delaney S, Worsley P, Warner M, Taylor M, Stokes M. Assessing contractile ability of the quadriceps muscle using ultrasound imaging. *Muscle Nerve.* 2010;42(4):530-8.
 46. Cresswell AG, Thorstensson A. The role of the abdominal musculature in the elevation of the intra-abdominal pressure during specified tasks. *Ergonomics.* 1989;32(10):1237-46.