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Examination of the diaphragm using ultrasonography and elastography: a literature review

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Abstract:

The diaphragm is the respiratory muscle that plays the largest role among other respiratory muscles. Due to the structure and anatomical connections, it also performs several other functions. Among many roles, diaphragm contributes to the stability of spine, supports digestive processes, prevent the development of oedema and varicose veins. The diaphragm is examined by various diagnostic tools. Due to the availability, simplicity and non-invasive examination the greatest potential has ultrasound imaging. Therefore, the purpose of the review is to introduce the reader the methods of diaphragm imaging using elastography and ultrasonography. The review of the literature includes articles discribing the exact methodology, reliability and repeatability of results. The analysis included 17 studies which measured the diaphragm thickness and 2 studies in which the diaphragm elasticity was examined. The examination was most often performed in a supine position. The ultrasound probe was usually applied in 8th, 9th or 10th intercostal spaces on the anterior axillary line or between the anterior and midaxillary line. Due to the difficult measurement of the left hemidiaphragm, in 58% works examined only right hemidiaphragm. The aspect of reliability was tested in 42% of works. Intraobserver and interobserver reliability in these publications was high. The review of the work resulted several discrepancies in methodology of research. Therefore further researchs are necessary to standardise the methodology of procedure.

Keywords: ultrasound imaging, shear wave elastography, diaphragm thickness, breath

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Introduction

Respiratory muscles are essential for life because they provide the driving force for breathing. Among respiratory muscles, the diaphragm plays the greatest role in breathing [1,2]. This dome-shaped muscle separates the abdominal cavity from the chest. During inhalation, the diaphragm shrinks and lowers, reducing the pressure in the chest and increasing the pressure in the abdominal cavity. It is responsible for three quarters of lung volume increase during quiet breathing [2-5]. Due to the structure of the diaphragm and its extensive anatomical connections, it performs several other functions apart from its role in breathing [6]. It contributes to the stability of the spine through increased intra-abdominal pressure and provides an anatomical connection with the lumbar region. Reduced diaphragm movements have been observed in patients with chronic low back pain compared to healthy individuals [7,8]. The diaphragm also affects digestive processes. [9]. The diaphragm contributes to preventing of gastroesophagal reflux because the diaphragm muscle is considered as two muscle in one. Diaphragm cruras during rhythmic breathing can squeeze the esophagus and oppose the work of the rib part of the diaphragm, which can squeeze acid from the stomach into the esophagus [10]. The rhythmic action of the diaphragm also supports the flow of venous blood and lymph from the lower extremities, thus preventing the development of oedema and varicose veins [6,9]. There is also information in the literature concerning the association of diaphragm function with the activity and pain of pelvic floor muscles and the cervix [6]. Despite its importance, the diaphragm is often overlooked as a possible cause of other dysfunctions [5].

There are numerous research and diagnostic tools to evaluate the diaphragm, and each tool has its strengths and weaknesses [11-13]. X-rays may show asymmetries of the diaphragm, but do not reflect its mobility [13-15].

Fluoroscopy assesses the inspiratory movement of the diaphragm during a short inspiratory effort (fluoroscopic sniff test) [13,14]. If one hemidiaphragm is unilaterally weakened during the test, an upward movement occurs. This test is useful in the diagnosis of unilateral diaphragm paralysis, but in the case of bilateral diaphragm paralysis it is no longer useful [14]. Fluoroscopy is not considered a reliable examination as false results are sometimes observed [12,14,16]. False positive results have been recorded in healthy patients, in whom rapid relaxation of abdominal muscles during inspiration follows abdominal muscle contraction during expiration, which could be incorrectly interpreted as a diaphragm contraction [16]. Additionally, this test is invasive, time consuming and involves exposure to ionizing radiation [17,18].

We can also assess the structure of the diaphragm by computed tomography (CT) and magnetic resonance imaging (MRI). However, such examinations are limited by the availability of equipment and high cost of their performance [5,11,19]. Moreover, they require a great deal of anatomical knowledge on the part of the examiner [20]. An additional disadvantage of CT examination is the involvement of ionizing radiation.

Aside from traditional MRI, the literature also reports diaphragm tests performed with dynamic MRI [20,21]. Compared to CT or traditional MRI, dynamic MRI does not require breath holding and provides more information on diaphragm movement [22,23]. However, the availability of this test tool is limited and the cost of examination is high. Other possible hindrances to MRI examination include obesity and claustrophobia, preventing the patient from being placed in the machine [23].When examinations such as X-ray or fluoroscopy are inconclusive, patients are sometimes referred for nerve conduction studies and electromyography (EMG). This method may detect possible neuromuscular respiratory impairment [5,24]. Surface EMG is simple and non-invasive, but it has some limitations. The signals from the superficial electrodes can be contaminated from adjacent structures, [25]. Therefore, diaphragm examination by superficial EMG may originated from the intercostal muscles or heart. However, diaphragm examination with needle electrodes may be difficult due to the risk of lung, liver, spleen and colon injury [13,24].

At present, it is not possible to directly assess the strength of the diaphragm. In the literature, the best indicator of diaphragm strength is the transdiaphragmatic pressure [1,16]. The examination of pressure on both sides of the diaphragm requires the placement of balloon catheters into the stomach and lower oesophagus. The transdiaphragmatic pressure is the difference between the gastric and oesophageal pressures. This method is invasive, which limits its wider use and carries the risk of infection [14].

Currently, shear wave elastography (SWE) is considered the best alternative to transdiaphragmatic pressure measurement [1,26]. Studies by Bachasson et al. [26] showed that changes in diaphragm elasticity reflect changes in transdiaphragmatic pressure. Both SWE and classical ultrasonography allow non-invasive examination of the diaphragm in real time [5,3,11,13,26]. Many studies demonstrate the simplicity and reproducibility of the method in the assessment of motion, velocity of contraction, or thickness change under various conditions [12,15,24,27]. Goligher et al. [28] demonstrated that ultrasonography is helpful in monitoring and assessing diaphragm dysfunction during ventilation. It may also be particularly useful when transporting the patient to the radiology ward would endanger their health. Ultrasonography enables the examination of the diaphragm using different modes (B-mode, M-mode, SWE), which allows its examination under resting conditions and during various postural or respiratory actions [1,2,26]. Additionally, ultrasonography can be useful to assess the relaxation of the diaphragm [12].

Due to its simplicity and availability, ultrasonography imaging currently has the greatest potential for non-invasive and painless examination of diaphragm morphology, which plays a significant role in various dysfunctions. Thus, analysis of studies concerning ultrasonographic evaluation of diaphragm morphology and function in healthy individuals, as well as in those with various dysfunctions, may contribute to a better understanding of the pathophysiological mechanisms of these abnormalities and their relation to the diaphragm, as well as facilitating investigations of changes that occur during therapy. Evaluating the different imaging methods reported in the literature may assist in the development of clinical trials using these procedures. Therefore, the present paper aims to introduce the reader to different methods of diaphragm imaging by elastography and ultrasonography. In this review, the emphasis is placed on presenting the method of diaphragm evaluation and the reliability and repeatability of the presented methods.

Materials and Methods

Search strategy

Electronic search of the “Medline” database using the PubMed search engine was conducted by two independent researchers. All articles that were published in English up to January 2020 were qualified. There was no exclusion criterion based on the type of paper. Additionally, the reference lists of all downloaded articles were checked for potentially relevant research papers. The search strategy included the use of the following keywords identifying the population ("people" OR "adult" OR "children"), research tool ("US" OR "Ultrasonography" OR "Elastography" OR "SWE") and the subject of the study ("diaphragm").

Study selection

One reviewer (MP) examined the titles and abstracts resulting from the electronic search to exclude articles that did not relate to the topic under examination. The remaining publications were analysed in their entirety by both reviewers. The criteria for inclusion were as follows: (1) published human study, (2) evaluation of the diaphragm by ultrasonography or elastography, and (3) description of the exact procedure for ultrasonography or elastography. The exclusion criteria were (1) no information on the examination method and (2) studies not involving the diaphragm.

Data extraction

The authors collected and arranged the data based on details reported in the text. In order to facilitate interpretation, data concerning the study group (age, sex, dysfunction), the position of the examined person, the position of the transducer during the examination, the measured ultrasound parameters and the examination mode, the examined side and the reliability of the examination method are presented in Tables 1 and 2.

Results

Thickness

The analysis included 17 studies which measured the thickness of the diaphragm by means of an ultrasound. The diaphragm was examined in different positions. Most of the researchers stated the exact location of the probe together with its position in relation to the vertical line of the chest. The intraobserver and interobserver reliability were reported in eight studies. Detailed data concerning the study group, methodology and reliability of the examinations are presented in Table 1.

Elasticity

The analysis included two studies that used an elastograph as the working tool. Data concerning the study group and the methodology of the conducted examinations are presented in Table 2. Unfortunately, none of the studies examined the reliability of diaphragm elasticity assessment.

Discussion

From the literature search, 19 studies reporting diaphragm imaging by ultrasound and elastograph were selected. The diaphragm was examined in standing, sitting, semi-recumbent and supine positions. The supine position was the most frequently used position, which seems to be suitable for analysis of the full mobility of the diaphragm because it is more mobile in this position than in the sitting or standing position [2,17]. Additionally, Gerscovich et al. [18] claim that the supine position of the diaphragm is more reliable and reproducible between the sides. However, the assessment of diaphragm contraction in a sitting or standing position is of greater functional importance given that most everyday activities are performed in a vertical position [2]. A study by Hellyer et al. [2] showed that the position in which the diaphragm is examined influences its thickness. It has been observed that the diaphragm is 20% thicker in the sitting and standing positions compared to the supine position. Posture may affect the diaphragm thickness due to the close proximity of internal organs of the abdomen. In the lying position, the viscera are located higher in the abdomen, which stretches the

Table 1. Selected studies of diaphragm visualization using an ultrasound scanner

Author	Research group	Subject's position	Probe's position	US measurments	Mode	Examined side	Reliability analyses
Brown et al. [32]	10 male world-class powerlifters	upright position	– 7th-10th intercostal space, – mid-axillary line	– Tdi	lack	Right	lack
Boon et al. [24]	150 normal subjects (20-83 years old)	supine position	– 8th or 9th intercostal space – anterior to the anterior axillary line	– Tdi – TR	b-mode	Both	Intra-rater reliability <u>DT-exp</u> ICC=0.94; (95% CI 0.79–0.98) <u>DT-insp</u> ICC=0.89; (95% CI 0.69–0.97) Inter-rater reliability <u>DT-exp</u> ICC=0.98; (95% CI 0.91– 0.99) <u>DT-insp</u> ICC=0.99; (95% CI 0.96–1.0)
Boussuges et al. [17]	210 healthy adult (150 male, 60 female)	standing position	<u>Right:</u> – subcostal area – between the midclavicular and anterior axillary lines <u>Left:</u> – subcostal or low intercostal – between the anterior and mid axillary lines	– EXdi – DM	m-mode	Both	lntraobserver Variability (diaphragmatic motion) <u>right:</u> QB: r = 0.96; P< 0.0(1); VS: r =0.96; P<0.001; DB: r=0.96; P< 0.001 <u>left:</u> QB: r =0.91; P < 0.001; VS: r =0.93; P < 0.001 lnterobserver Variability(diaphragmatic excursion) <u>right:</u> QB: r = 0.95; P <0.001; VS: r = 0.96; P < 0.(01); DB: r = 0.94; P <0.0(1) <u>left:</u> QB: r =0.91; P < 0.001; VS: r =0.93; P <0.001 Intraobserver reproducibility of the diaphragmatic motion <u>right:</u> QB 0.3 ± 7%; VS 0.3 ± 6%; DB 0 ± 6.2% <u>left:</u> QB 0.67 ± 5%; VS 0.2 ± 6% Interobserver reproducibility of the diaphragmatic motion <u>right:</u> QB 0.5 ± 7%; VS 0.4 ± %; DB 1 ± 7% <u>left:</u> QB 1.1 ± 8.6%; VS 1.4 ± 6%
Gerscovich et al. [18]	45 subjects (1 day of	supine position	– subcostal or low intercostal approach	– EXdi	m-mode	Both	lack

Table 1. Cont.

	life- 66 years old)		– between midaxillary and midclavicular lines				
Khurana et al. [11]	100 patients (52 females, 48 males; 21-94 years)	semirecumbent position	– ABCDE technique: Anterior axillary line(below the level of the nipple), watch for Breathing (lung sliding), and then move the probe Caudally to identify the Diaphragm for Examination	– Tdi	b-mode	Both	Interrater reliability Right: Cohen K coefficient = 1 Left: Cohen K Coefficient = 0,99
Ueki et al. [33]	13 healthy men (29-54 year old)	seated position	– intercostal space – between the anteroaxillary and midaxillary lines	– Tdi – TR	b-mode	Right	lack
Viver et al. [31]	12 ICU patients	semi-recumbent position	– above the 10th rib - midaxillary or anteroaxillary line,	– Tdi – TF	m-mode	Right	Intra-analyser reproducibility ICC=0.987; CR=7.3 Inter-analyser reproducibility ICC=0.985; CR=7.9 Intra-observer reproducibility ICC=0.985; CR=15.2 Inter-observer reproducibility ICC=0.978; CR=17.8
Goligher et al. [28]	96 mechanically ventilated patients	lack	– 9th or 10th intercostal space – midaxillary line	– Tdi – TGdi – TF	m-mode	Both	Tdi: mean ± SD 2.4 ± 0.8 mm; CR=0.2 mm, reproducibility coefficient 0.4 mm TFdi: median 11 %; IQR=3–17 %; CR=17 %, reproducibility coefficient 16 %
Dülger et al. [7]	21 women with low back pain	supine position	– 9th intercostal space – -anterior axillary line	– Tdi – DM	-b-mode -m-mode	Right	lack
Miyagi et al. [29]	77 patients with heart failure (about 72 years old)	lack	– 8th or 9th intercostal space – between anteroaxillary and midaxillary lines	– Tdi	lack	Right	Intra-observer Variability DT-insp r = 0,862; mean differences 0.16 mm; SD=0,51 mm DT-exp r=0,883; mean differences 0.02 mm; SD=0,15 mm P <0,05

Table 1. Cont.

							Interobserver Variability DT-insp r = 0,707; mean differences 0.06 mm; SD=0,59 mm DT-exp r=0,736; mean differences 0.08 mm; SD=0,25 mm P <0,05
Noda et al. [34]	-37 patients with various neuromuscular disorders -10 control group	supine position	– intercostal space (the most and easily visualized) – anterior axillary line	– Tdi	b-mode	Both	lack
Farghaly et al. [30]	54 ICU patients	semi-recumbent position	– 8th or 9th intercostal space – between the anterior axillary and the midaxillary lines (Tdi, TF) – mid-clavicular line (diaphragmatic excursion)	– EXdi – Tdi – TF	-b-mode (Tdi,TF) -m-mode (EXdi)	Right	lack
Dube et al. [27]	112 ICU patients (49-71 years old)	lack	– 9th and 10th intercostal spaces, – midaxillary line	– Tdi – EXdi – TF	m-mode	Right	lack
Hellyer et al. [2]	24 healthy subjects (12 men, 12 women; 22-35 years old	supine, seated, standing postures	– 8th or 9th intercostal space, – anterior axillary line	– Tdi – TR	b-mode	Right	ICC for repeat measurements Supine: Expiration ICC=0.95; CI 0.90-0.98 Inspiration ICC=0.93; CI 0.88-0.97 Sitting: Expiration ICC=0.95; CI=0.91-0.98 Inspiration ICC=0.96; CI 0.91-0.98 Standing: Expiration ICC=0.96; CI 0.93-0.98 Inspiration ICC= 0.95; CI 0.90-0.98
Sahin et al. [3]	-45 MS patients (11 males, 34 females; mean age-36)	lack	– anterior axillary line	– Tdi – TF	lack	Right	lack

Table 1. Cont.

	-36 healthy subjects (3 males, 33 females; mean age-35)						
El-Halaby et al. [4]	400 healthy participants (1 month - 16 years old; 221 male and 179 female)	supine position	Right: – subcostal area – between the midclavicular and anterior axillary lines Left: – subcostal or lower intercostal area – anterior and midaxillary lines	– EXdi – Tdi	m-mode b-mode (to find the diaphragm)	Both	Intraobserver variability right EXDI: bias -0,1; 95% confidence limits -0,36 to 0,17 left EXDI: bias 0,04; 95% confidence limits -0,16 to 0,24 right Tdi: bias -0,03; 95% confidence limits -0,17 to 0,1 left Tdi: bias 0.09; 95% confidence limits -0,03 to 0,2 Interobserver Variability right EXDI bias 0,08; 95% confidence limits -0,22 to 0,37 left EXDI bias 0,14; 95% confidence limits -0,09 to 0,37 right Tdi bias -0,07; 95% confidence limits -0,2 to 0,07 left Tdi bias -0.09; 95% confidence limits -0,28 to 0,1
Kocjan et al. [8]	142 patients (62-lung cancer, 40-after lobe resection, 40-non-clinical control group)	supine position	– 7th - 9th intercostal space – b-mode: – anterior axillary lines – m-mode: – between the mid-clavicular and anterior axillary lines	– Tdi – TF – DM	b-mode (Tdi) m-mode (DM)	Right (Tdi) Both (DM)	lack

Legend: Tdi - diaphragm thickness; TF - thickening fraction; TR - thickenning ratio; EXdi - diaphragm excursion; TGdi - diaphragm thickening; DM - diaphragmatic motion / diaphragm movement; QB - quiet breathing; VS - voluntary sniffing; DB - deep breathing; SD - Standard Deviation; DT - insp thickness at the end of inspiration; DT-exp thickness at resting expiration; CR - repeatability coefficient; ICC - Intra-class correlation coefficient; IQR - interquartile range; CI - Confidence Interval; MS-multiple sclerosis; ICU - intensive care unit; SWE - shear wave elastography

Table 2. Selected studies of diaphragm visualization using an elastography

Author	Research group	Subject's position	Probe's position	US measurements	Mode	Examined side	Reliability analyses
Chino et al. [1]	14 healthy men (about 25 years old)	sitting on a reclined chair (75°)	–8th intercorsal space, –between the anteroaxillary and midaxillary	–diaphragmatic shear modulus	swe	Right	lack
Bachasson et al. [26]	15 healthy subjects (18-43 years old)	semirecumbent position (40°)	–8th-10th intercostal space –posterior axillary line	–diaphragmatic shear modulus	swe b-mode	Right	lack

diaphragm, increasing its length. In the vertical position, the internal organs are located lower in the abdomen, which may result in greater thickness during ultrasound examination [2].

The ultrasound probe was usually applied in the eighth, ninth or tenth intercostal space [1,2,7,26-31]. However, in the two studies the space between the seventh and eighth ribs was also taken into account [8,32]. In seven studies, the intercostal space in which was the examination conducted was not precisely determined. Instead, these authors used the liver as the reference point on the right side and the spleen on the left side [3,4,11,18,26,33,34]. The methodology of each paper described the vertical lines determining the area in which the transducer was applied to the chest. In six studies, the anterior axillary line was used [2,3,7,11,24,34]. The line between the anterior axillary line and midaxillary line was used in five studies [1,29-31,33]. In three studies, the transducer was applied on the midaxillary line [27,28,32], and only the study by Bachasson et al. [26] used the posterior axillary line. Gerscovich et al. [19] placed the transducer between the midclavicular line and midaxillary line. In the publications by Boussuges et al. and El-Halaby et al., the left and right hemidiaphragm was examined in relation to other lines of the chest [4,17]. For the right hemidiaphragm, the transducer was placed between the midclavicular line and the anterior axillary line, and for the left hemidiaphragm, between the anterior axillary line and midaxillary line. Kocjan et. al. [8] placed the transducer in the anterior axillary lines during the b-mode test, and in m-mode between the mid-clavicular and anterior axillary lines. Diaphragm thickness measurements can vary widely depending on the selected intercostal space (up to 0.6 cm difference in resting thickness from one position to another). For repeated measurements, it is recommended that the examiner pay attention to a specific intercostal space, the distance from the selected vertical chest line and the measurement position [24]. According to Goligher et al., for correct reproducibility, it is recommended that the first examiner mark the examination site [28].

In the majority of studies (58%), only the right hemidiaphragm was examined as the opposite hemidiaphragm was more difficult to measure [1-3,7,26,27,29-33]. Eight publications studied both sides [4,11,17,18,24,28,34]. Kocjan et al. [8] studied only the right hemidiaphragm thickness, because the literature has shown that there is no significant difference between the sides.

The articles included in this review comprise various research populations, for example children [4,18], athletes [32] and healthy volunteers [2,17,24,33], as well as mechanically ventilated patients [27,28,30,31] and people with heart failure [29]. In the articles on diaphragm elasticity testing, the study group only comprised healthy individuals [1,26].

The ultrasonography research used the b-mode, m-mode or swe. The b-mode is mainly used to assess thickness, m-mode to assess diaphragm excursion or diaphragm movement, and swe mode to assess flexibility. According to the literature, m-mode examination is technically more difficult than b-mode, especially when imaging the left hemidiaphragm or obese individuals [24,34]. El-Halaby et al. [4] recommend that b-mode examination should be used prior to m-mode to find a suitable image.

The basic measurement of the diaphragm was its thickness. This measurement is useful in studies on disease progression [34]. However, according to Boon et al. [24], the thickening ratio (thickness at maximal inspiration/thickness at resting end expiration) may be more reliable than the thickness measurement itself.. Several articles use the thickening fraction, which is calculated from the equation: (thickness at end inspiration - thickness at end expiration)/thickness at end expiration [27,28,30,31]. This measurement is an effective tool for identifying diaphragm dysfunction, monitoring its changes over time and predicting the possibility of extubating [26,28]. In contrast, the examination of SWE as a new imaging method may be helpful in assessing the mechanical properties of the tissue [26]. In the study by Chino et al., the diaphragm shear wave module increased with inspiratory mouth pressure [1].

An important aspect of research is to determine the reliability. Unfortunately, reliability was only mentioned in a limited number of articles [2,4,11,17,24,28,29,31]. In half of these studies, Bland-Altman analysis was used to assess the repeatability of results [4,17,29,31]. In the study by Miyagi et al. [29], the results of intraobserver variability measured on 20 patients with heart failure was on high level. In three studies, intraobserver and interobserver repeatability were confirmed [4,17,31]. In the study by Boussuges et al., Pearson correlation analysis was performed in addition to Bland-Altman analysis. In the publication by Goligher et al. [28], the reproducibility of the study was checked based on the results of three investigators with different ultrasound experience. Before the examination, the diagnosticians had to demonstrate their ability to perform this technique on six patients. However, after these initial examinations, the diaphragm thickness measured by these investigators remained heterogeneous. The variability may be due to inadequate training of the investigators and different methods of application of the transducer. Consequently, the examination was repeated in 15 patients and the site of the transducer application was marked by the first researcher, which resulted in repeatable results. Two articles used the interclass correlation coefficient (ICC) to assess the reliability [2,24]. Hellyer et al. [2] observed that the relative reliability in three different positions (standing, lying, sitting) was high. The lowest coefficient was obtained in the supine position. In the study by Boon et al. [24], interobserver and intraobserver reliability were high in all breathing trials. Khurana et al. [11] checked the reliability between investigators using the Kappa-Cohen coefficient. The results of consistency of measurements of both the right and left hemidiaphragm indicated a high level of reliability between investigators.

Many authors report difficulties in imaging the left hemidiaphragm [17, 18, 27, 28]. Dube et al. [27] initially tried to measure both hemidiaphragms, but examination of the left hemidiaphragm was discontinued after the first 25 patients due to poor consistency between observers. Although both hemidiaphragm sides were assessed in seven studies, three of these publications reported difficulty in obtaining an image of the left hemidiaphragm during deep breathing [17,18,28]. Thus, the left hemidiaphragm was only measured in 21–79% of patients [17,18,28]. The difficulties in obtaining a reliable image of the left hemidiaphragm are due to it being covered by the left lung, especially during deep breathing [7]. Moreover, the spleen constitutes a smaller acoustic window on the left side compared to the liver on the right side [17,18].

Another aspect is that both the test group and the control group should have similar anthropometric characteristics. In the study by Dülger et al. [7], people in the control group had a higher body mass index (BMI) than those in the study group. This may have had an impact on the lack of variation in diaphragm thickness in the control group (compared to the study group), which was not subjected to stabilisation exercises. In studies on ultrasound measurements of muscle thickness, body mass is considered a significant disturbing variable [35,36].

Diaphragm examination in children was limited by a disturbance in the breathing pattern after the transducer was applied to the abdomen [4]. El-Halaby et al. [4] state that after the transducer is applied, breathing should be regulated before the measurement is collected. Moreover, for greater reliability, it is recommended that several breathing cycles be recorded [4]. Scientists point out that the diagnostic experience is significant in reliability results of research [28,30,31]. However, in all studies, consistency between researchers with different levels of experience was acceptable. Another limitation may be obesity among the subjects. In some studies, obesity was one of the exclusion criteria. In the study by Khurana et al. [11], the examination of subjects with a BMI equal to or higher than 30 kg/m^2 took longer. In ultrasound examinations, higher BMI may result in the rejection of images due to low quality. In SWE tests, greater thickness of adipose tissue may cause inability to collect the elasticity results [37]. A similar problem has previously been highlighted in other studies that analysed abdominal muscle elastography in children and adults [37,38].

There have been very few studies on diaphragm SWE [1,26]. So far, these studies have only been performed on healthy adults. Chino et al. [1] suggested that it seems important to determine the relationship between transdiaphragmatic pressure and diaphragm shear wave module, as transdiaphragmatic pressure is now considered the best available indicator of diaphragm strength.

In summary, a review of the work on ultrasound examination of the diaphragm suggests that it is a reliable examination method. However, discrepancies arise in relation to the specific location of transducer placement. Further investigations are necessary to standardise the examination procedure. In addition, further testing in different age groups (e.g., children) is important as only two studies on diaphragm ultrasonography are currently available. Due to the multifunctional role of the diaphragm for the whole organism, it is recommended that examinations be performed on different populations (healthy, clinical, subclinical). It should also be noted that the reliability of diaphragm elasticity evaluation using SWE was not specified in any studies.

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