Sonography indicators of diaphragm and their correlation with spirometry data in healthy individuals: a prospective study

Сонографические показатели диафрагмы и их корреляции со спирометрическими данными у здоровых лиц: проспективное клиническое исследование

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Abstract

OBJECTIVE: Revealing the correlation between sonography indicators of diaphragm performance and spirometry data of healthy persons. **MATERIALS AND METHODS:** The study was conducted at the Almazov National Medical Research Centre. The structural (thickness) and functional (thickening fraction and excursion of diaphragm) state of diaphragm of 50 healthy individuals (female — 30) was assessed with an ultrasound machine, and the spirometry characteristics of the external breathing apparatus were assessed with a ventilator. Afterwards the statistical and correlation analysis was conducted. **RESULTS:** It was possible to assess the thickness of diaphragm on both sides and the diaphragm excursion on the right in all subjects, the diaphragm excursion on the left — only in 20 % of subjects. Spirometry has been performed in all subjects. The obtained data are consistent with the literature. In particular, sonography and spirometry indicators of the healthy individuals are within reference values. Inspiratory muscles strength has also proved to be consistent with the literature data. Correlation analysis has revealed no statistically significant relationship between the examined sonography and spirometry parameters. In addition, no relation between age and sonography indicators of diaphragm has been found. There are weak statistically significant relations revealed between the structural and functional state of diaphragm and such anthropometric characteristics of the subjects as body mass and body mass index. **CONCLUSIONS:** Sonography indicators of diaphragm performance do not correlate or correlate poorly with spirometry data. There is no reason to use sonography of diaphragm in healthy individuals since it does not practically provide any additional information about the state of external respiratory apparatus.

Реферат

ЦЕЛЬ ИССЛЕДОВАНИЯ: Выявить корреляционные взаимосвязи сонографических показателей функционирования диафрагмы со спирометрическими данными у здоровых лиц. **МАТЕРИАЛЫ И МЕТОДЫ:** На базе ФГБУ «НМИЦ им. В.А. Алмазова» у 50 здоровых добровольцев (женщин — 30) оценили структурное (толщину) и функциональное (индекс утолщения и экскурсию) состояние диафрагмы с помощью ультразвукового исследования, а также спирометрические характеристики аппарата внешнего дыхания с помощью аппарата искусственной вентиляции легких. После чего провели статистическую обработку и корреляционный анализ. **РЕЗУЛЬТАТЫ:** Толщину диафрагмы (слева и справа) и ее экскурсию (справа) удалось оценить у всех испытуемых; экскурсию диафрагмы слева — только у 20 % испытуемых. Спирометрию выполнили у всех испытуемых. Полученные данные согласуются с литературными. В частности, ультразвуковые и спирометрические показатели для здоровых лиц находились в рамках референтных значений. Сила инспираторных мышц также оказалась сопоставимой с литературными данными. Корреляционный анализ не выявил статистически значимых взаимосвязей между изученными ультразвуковыми и спирометрическими параметрами. Также не было выявлено взаимосвязи между возрастом и ультразвуковыми показателями диафрагмы. Найдены слабые статистически значимые связи между структурно-функциональным состоянием диафрагмы и антропометрическими характеристиками обследованных: массой тела и индексом массы тела. **ВЫВОДЫ:** Ультразвуковые показатели работы диафрагмы не коррелируют или плохо коррелируют со спирометрическими. У здоровых нет оснований использовать ультразвуковое исследование диафрагмы, так как оно практически не дает дополнительной информации о состоянии аппарата внешнего дыхания.

KEYWORDS: sonography, diaphragm, lungs, spirometry, lung ventilation

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Introduction

Attention to the diaphragmatic function has remained high over the years [1–4]. Redundancy or insufficiency in the diaphragm's work contributes significantly to the development (aggravation) of some pathological conditions and diseases such as bronchial asthma, chronic obstructive pulmonary disease, heart failure, pneumonia, sepsis, and abdominal cavity pathologies which lead to increased intra-abdominal pressure [2, 5–7].

The most appealing assessment method of the diaphragm's bedside morphofunctional state is ultrasonography (US) [2, 8] which is well-proven as a lung examination assessment. It may be helpful in diagnostic and monitoring in the intensive care unit [2, 10, 11], particularly in invasive mechanical ventilation (IMV) settings, weaning off mechanical ventilation, and so forth. Along with well-established lung-protective ventilation [12], diaphragm protection solutions — diaphragm protective ventilation — are still being sought [13].

Therefore, it is relevant and promising to identify correlations and their dependence on spirometric and sonographic indications initially based on healthy people.

The present study was performed to identify a link between sonographic indications of diaphragm function and spirometric data in healthy patients in the supine position.

Materials and methods

The cohort study of an external respiratory system structural-functional state in healthy volunteers in the supine position was conducted at the Almazov National Medical Research Centre, St. Petersburg, Russia. The study corresponded to the Declaration of Helsinki (2000) and was approved by the Local Ethical Committee (Minutes of the meeting dated 30.04.2022. Chairman of the LEC — Zagorodnikova K.A.).

The presence of diseases that can change diaphragm function in either direction was an exclusion criterion for this study.

Subjects' age ranged from 22 to 30 years old, body weight 67.9 ± 14.5 kg, height 173.1 ± 11.0 cm, body mass index 22.4 ± 3.3 kg/m^2.

The study of sonographic and spirometric indications of external respiration was performed on 50 volunteers (30 females).

Structural and functional parameters of the diaphragm included thickness, thickening fraction, diaphragm excursion, and rate indications during calm and deep inspiration/expiration, assessed using an ultrasound device provided by Philips CX 50 (Philips Ultrasound, Inc production, USA).

The diaphragm thickening fraction during calm breathing was calculated as the following:

TFc = (*diaphragm thickness at the end of calm inspiration – – diaphragm thickness at the end of calm expiration*)/ *diaphragm thickness at the end of calm inspiration* × 100.

The diaphragm thickening fraction during deep breathing was calculated as the following:

TFd = (*diaphragm thickness at the end of deep inspiration – – diaphragm thickness at the end of deep expiration*)/ *diaphragm thickness at the end of deep inspiration* × 100.

This sort of digitization of the diaphragm function may provide practical assistance in deciding on the necessity of the mechanical respiratory support or weaning off a ventilator.

The spirometric evaluation was performed via parallel measurement of tidal volumes during the calm and deep breathing, inspiration and expiration time, respiratory drive, and respiratory muscle strength measured by P. 01 — airway pressure reduction in the first 100 msec of a patient's spontaneous breath attempt during a respiratory circuit occlusion and Negative Inspiratory Force — maximal inspiratory effort — minimal pressure under the end-expiratory pressure level within «inhalation retention» maneuver.

The spirometric measurements were performed by the "Bellavista 950e" ventilator machine (Russia, registration No РЗН 2021/13644, registration date 31.03.2022) with a constant positive airway pressure mode. It allows using the ventilator only as a spirometer while the continuous positive airway pressure is 0 cm H_2O without any additional impacts from the ventilator and with a fraction of inspired oxygen of 21 %. The ventilator choice was determined by the ability to measure the required parameters with high discretion and the ability to transport data collected from three seconds to one year to an external storage media.

Statistical analysis

Mathematical analysis of the collected data was performed by using a STATISTICA-10 program (StatSoft Inc, USA) and Microsoft Excel supplement — Real Statistics Resource Pack. The distribution pattern was defined by Kolmogorov-Smirnov and Shapiro-Wilk tests. After assessing the distribution pattern, the correlation criterion suggested by Spearman's programs was used. Further assessment continued with the Chaddock scale: weak correlation — 0.1–0.3; moderate correlation — 0.5–0.7; strong correlation — 0.7–0.9; very strong correlation — 0.9–1.0. The study description presented part results as an average and standard deviation (M ± SD). Relations validity was taken as $p \leq 0.05$.

Results

The research representativeness assessment at the designed stage revealed a required sample of at least 100 subjects to achieve 80 % power. According to calculations after the pilot study, the minimal required number appeared to be 34 subjects. Eventually, the study involved 50 subjects which provided power equal to 0.93.

The study easily provided imaging of the diaphragm thickness from both sides, but clear imaging of the diaphragm excursion on the left is often unavailable [8, 14, 15]. Of the total observations number (50), the best diaphragm excursion from the left side was only received in 10 studies (20 %). The data are presented as average deviation (Av), minimal (Min), and maximal (Max) values. Table 1 shows the results of the diaphragm ultrasound diagnostic.

Table 1. Sonographic structural and functional indicators of the diaphragm excursion on the right (*n* = 50, descriptive statistics)

Value	Av (M ± SD)	Min	Max	Literature data
Tc-inh (mm)	2.0 ± 0.4	1.1	3.1	2.1 ± 0.3 [16]
Tc-exh (mm)	1.5 ± 0.3	0.9	2.3	1.7 ± 0.2 [17] 1.6 ± 0.4 [18]
Td-inh (mm)	4.5 ± 0.3	3.0	6.7	4.5 ± 0.9 [17]
Td-exh (mm)	1.2 ± 0.3	0.6	1.7	1.6 ± 0.2 [17]
TFc-inh (%)	29.0 ± 8.5	14.5	46.7	32 ± 15 [16]
TFd-inh (%)	283.3 ± 81.1	161.5	483.3	—
Ec-br (cm)	1.8 ± 0.4	1.1	2.9	1.6 ± 0.3 [19]
Lcntr, c-br (s)	1.5 ± 0.4	0.5	2.8	1.27 ± 0.1 [20]
R. contr, c-br (cm/s)	1.1 ± 0.3	0.6	1.9	1.12 ± 0.4 [20]

Table 1 of end

Value	Av (M ± SD)	Min	Max	Literature data
L. relaxation, c-br (s)	1.5 ± 0.4	0.5	2.6	1.8 ± 0.3 [20]
R. relaxation, c-br, (cm/s)	1.3 ± 0.5	0.6	3.3	1.05 ± 0.3 [20]
AvLcontr : AvLrelaxation, c-br	1 : 1 (1.5 ± 0.4 : 1.5 ± 0.4)	—	—	—
Ed-br (cm)	7.0 ± 1.5	5.1	11.9	6.9 ± 1.4 [20]
L. contr, d-br (s)	2.6 ± 0.6	1.5	4.0	—
R. contr, d-br (cm/s)	2.8 ± 0.9	1.5	5.4	—
L. relaxation, c-br (s)	2.6 ± 0.9	1.1	6.1	1.5 ± 0.4 [20]
R. relaxation, d-br (cm/s)	2.6 ± 0.9	1.0	6.1	—
AvLcontr : AvLrelaxation, d-br	1 : 1 (2.6 : 2.6)	—	—	—

Note: Av — average; Br — breathing; c — calm; cm — centimeter; Cntr — contraction; d — deep; E — excursion; Exh — exhalation; Inh — inhalation; L — length; Max — maximum; Min — minimum; mm — millimeter; R — rate; s — second; T — thickness; TF — thickening fraction.

Table 2. Sonographic structural and functional indicators of the diaphragm excursion on the left (*n* = 10, descriptive statistics)

Value	Av (M ± SD)	Min	Max	Literature data
Tc-inh (mm)	1.8 ± 0.4	1.2	3.2	—
Tc-exh (mm)	1.4 ± 0.3	1.0	2.8	—
Td-inh (mm)	3.9 ± 0.3	2.1	6.2	—
Td-exh (mm)	1.1 ± 0.3	0.7	1.8	—
TFc-inh (%)	26.2 ± 8.9	15.3	45.8	30 ± 14 [16]
TFd-inh (%)	259.2 ± 98.9	111.8	529.2	—
Ec-br (cm)	1.4 ± 0.3	1.0	1.9	1.6 ± 0.3 [19]
Lcntr, c-br (s)(c)	1.5 ± 0.4	0.9	2.1	—
R. contr, c-br (cm/s)	1.4 ± 0.5	0.9	2.2	—
L. relaxation, c-br (s)	1.3 ± 0.5	0.8	2.0	1.8 ± 0.3 [20]
R. relaxation, c-br, (cm/s)	1.5 ± 0.5	0.9	2.3	—
AvLcontr : AvLrelaxation, c-br	1.1 : 1.0 (1.5 : 1.3)	—	—	—
Ed-br (cm)	6.3 ± 0.9	5.1	7.9	6.9 ± 1.4 [20]
Lcontr, d-br (s)	2.9 ± 1.3	1.5	6.0	—
R. contr, d-br (cm/s)	2.6 ± 0.7	1.5	3.8	—
Lrelaxation, c-br (s)	2.6 ± 0.9	1.6	4.5	1.5 ± 0.4 [20]
R. relaxation, d-br (cm/s)	2.6 ± 0.7	1.4	3.5	—
AvLcontr : AvLrelaxation, d-br	1.1 : 1.0 (2.9 : 2.6)	—	—	—

Note: Av — average; Br — breathing; c — calm; cm — centimeter; Cntr — contraction; d — deep; E — excursion; Exh — exhalation; Inh — inhalation; L — length; Max — maximum; Min — minimum; mm — millimeter; R — rate; s — second; T — thickness; TF — thickening fraction.

Tables 1 and 2 outcomes broadly support literature data [17–20]. The spirometric study results are presented in Table 3.

The average outcomes of the spirometric assessment of external respiration presented in Table 3 were within healthy people's acceptable limits [21, 22].

Obtained spirometric, sonographic, and anthropometric indications were analyzed for correlations (Table 4). The possibility of regression analysis use was also assessed.

According to the data in Table 4, correlation links between spirometric and sonographic parameters were not statistically significant. Only a weak direct relation between a deep breath and the diaphragm thickness at the height of inhalation on the left was observed as statistically significant, as well as the negative relation between a deep breath and the diaphragm thickening fraction on the left.

A statistically significant correlation between gender and sonographic indicators of the diaphragm function was observed in assessing the following pairs: gender and the diaphragm thickness on the right at the end of the deepest inhalation and exhalation ($rs = 0.33$, $p = 0.01$, $rs = 0.39$, $p = 0.008$ accordingly); gender and the diaphragm thickness on the left at the end of calm inhalation and exhalation ($rs = 0.39$, $p = 0.005$, $rs = 0.31$, $p = 0.02$ accordingly); gender and the diaphragm thickness on the left at the end of the deepest exhalation ($rs = 0.36$, $p = 0.01$); gender and the diaphragm contraction length on the right during calm breathing ($rs = 0.31$, $p = 0.02$); gender and maximal amplitude of the diaphragm movement on the right during deep breathing ($rs = 0.28$, $p = 0.04$); gender and maximal amplitude of the diaphragm movement on the left during calm breathing ($rs = 0.7$, $p = 0.02$); gender and the thickening fraction for a left hemisphere during calm breathing ($rs = 0.29$, $p = 0.03$).

Interrelation between age and the diaphragm sonographic parameters wasn't revealed in any of the studied features.

Table 3. Spirometry functioning indicators of the external breathing apparatus in the CPAP mode ($n = 50$)

Value	Av (M ± SD)	Min	Max	Literature data
TV c-Br (ml)	572 ± 118	385	780	300–900 [21, 22]
L_{inh} c-Br (s)	1.5 ± 0.1	1.0	1.7	1.0–2.0 [23]
L_{exh} c-Br (s)	3.0 ± 0.9	1.0	5.3	—
L_{inh} : L_{exh} (c-Br)	1 : 2 (1.5 ± 0.1: 3.0 ± 0.9)	—	—	1 : 2 [23, 24]
TV d-Br (ml)	3829 ± 526	3100	5600	3500–5000 [21, 22]
L_{inh} d-Br (s)	1.6 ± 0.5	0.3	3.7	—
L_{exh} d-Br (s)	4.0 ± 1.8	1.5	8.0	—
L_{inh} : L_{exh} , d-Br	1 : 2.5 (1.6 : 4.0)	—	—	—
P 0.1 (cm H_2O)	–2.6 ± 0.7	–1.1	–4.0	–2 … –4 [23, 25]
NIF (cm H_2O)	–53.23 ± 3.4	–48.1	–60.0	Is not defined for NIV. variable in research [26]

Note: **Av** — average; **Br** — breathing; **c** — calm; **d** — deep; **Exh** — exhalation; **Inh** — inhalation; **L** — length; **Max** — maximum; **Min** — minimum; **ml** — milliliter; **s** — second; **TV** — tidal volume.

Table 4. Results of the correlation analysis of the spirometry and sonography parameters (on the right $n = 50$, on the left $n = 10$)

Compared indicators	Spearman's correlation index(rs)	Significance level (p)
Calm inhale and exhale		
TV and T on the right (c-inh)	–0.06	0.64
TV and T on the right (c-exh)	0.014	0.91
TV and T on the left (c-inh)	0.15	0.26

Table 4 of end

Compared indicators	Spearman's correlation index(rs)	Significance level (p)
TV and T on the left (c-exh)	0.17	0.21
TV and TF on the right (c-inh)	–0.17	0.22
TV and TF on the left (c-inh)	0.06	0.66
Calm breathe		
TV and E on the right (c-br)	–0.01	0.92
TV and L. cntr on the right (c-br)	0.17	0.22
TV and R. cntr. on the right (c-br)	0.13	0.34
TV and L. relaxation on the right (c-br)	–0.02	0.8
TV and R. relaxation on the right (c-br)	0.14	0.3
TV and E on the left (c-br)	0.6	0.06
TV and L. cntr. on the left (c-br)	0.14	0.69
TV and R. cntr. on the left (c-br)	0.08	0.81
TV and L. relaxation on the left (c-br)	0.32	0.35
TV and R. relaxation on the left (c-br)	0.16	0.64
L. Inh. and L. Cntr. on the right (c-br)	0.15	0.29
L. Inh. and L. Cntr. on the left (c-br)	0.43	0.21
L. Exh. and L. relaxation on the right (c-br)	0.07	0.58
L. Exh. and L. relaxation on the left (c-br)	–0.14	0.68
The deepest inhale		
TVd and T on the right (d-inh)	–0.02	0.87
TVd and T on the right (d-exh)	0.02	0.85
TVd and T on the left (d-inh)	0.01	0.91
TVd and T on the left (d-exh)	0.3	0.03*
TVd and TF on the right (d-inh)	–0.03	0.82
TVd and TF on the left (d-inh)	–0.3	0.03*
Deep breathe		
TVd and E on the right (d-br)	–0.03	0.83
TVro and L. Cntr. on the right (d-br)	–0.25	0.07
TVd and R. Cntr. on the right (d-br)	0.08	0.54
TVd and L. relaxation on the right (d-br)	–0.13	0.34
TVd and R. relaxation on the right (d-br)	0.04	0.74
TVd and E on the left (d-br)	0.49	0.14
TVd and L. Cntr. on the left (d-br)	0.24	0.49
TVd and R. Cntr. on the left (d-br)	0.14	0.68
TVd and L. relaxation on the left (d-br)	0.46	0.17
TVd and R. relaxation on the left (d-br)	0.21	0.54

* Indications correlation of which attained statistical significance ($p < 0.05$).

Note: Br — breathing; c — calm; Cntr — contraction; d — deep; E — excursion; Exh — exhalation; Inh — inhalation; L — length; R — rate, relaxation, right, left; T — thickness; TF — thickening fraction; TV — tidal volume.

Among anthropometric indicators, a statistically significant relation was observed between body mass and the diaphragm thickness at the end of calm and maximal inhalation on the right (rs = 0.28, $p = 0.04$), relaxation length of the diaphragm's right hemisphere during deep breathing ($rs = -0.29$, $p = 0.03$), the relaxation rate of the diaphragm's right hemisphere during deep breathing ($rs = 0.28$, $p = 0.04$), the diaphragm contraction length on the left during deep breathing (rs = 0.66, $p = 0.03$).

Interrelation analysis of the body mass index revealed a statistically significant relation with followed indicators: the diaphragm right hemisphere thickness at the height of calm inhalation and the end of calm exhalation ($rs = 0.31$, $p = 0.02$, $rs = 0.28$; $p = 0.04$, accordingly), the relaxation rate of diaphragm right hemisphere during calm breathe ($rs = 0.32$, $p = 0.02$), the relaxation length of diaphragm right hemisphere during deep breathing ($rs = -0.43$, $p = 0.001$), the relaxation rate of diaphragm right hemisphere during deep breathing ($rs = 0.39$, $p = 0.004$), the contraction length of diaphragm left hemisphere during deep breathing ($rs = 0.67$, $p = 0.03$).

As there were no statistically significant correlation links between most of the compared parameters, regression analysis wasn't performed.

Discussion

The lack of statistically significant interrelations between tidal volumes and the diaphragm sonographic indications was quite unexpected. At the same time, correlation among other indicators was highly variable and seldom attained a high relation level. Other studies also did not discover a strong correlation between diaphragm action and spirometric indications. When such a correlation was pointed out, its force only reached a weak or average level, not a high one as expected [8, 17, 27].

Our study results did not reveal the interrelation between age and the sonographic indicators of diaphragm function. Body mass and gender have the most statistically significant but not high-level correlation link with the diaphragm sonographic indicators, which also agrees with other studies [2, 18]. Some authors noted that body mass possibly affects the diaphragm action indicators less than muscle mass. The diaphragm thickness may be greater in trained people, especially if training is related to respiratory muscle development [28]. It potentially explains the greater men's muscle mass influence on the diaphragm's sonographic indicators [29]. The same «noise» may likely be found in physically active women with well-defined muscles.

Our study results draw attention to several points. First, to inconsistency and to statistically insignificant relations. If such relations were present, we discovered a low correlation between sonographic indicators of the diaphragm (length contraction/relaxation indicators and respiratory cycle) and functional lung volumes. Evidently, there should be no direct association between diaphragm contraction and the amount of air entering the lungs. Instead, they must be considered sequential. The diaphragm contracts prior to the air entering the lungs. At that point, negative pressure forms in a pleural cavity. The same happens with diaphragm relaxation and following air exhalation from the lungs.

These considerations would explain the fact of inconsistency between spirometric and sonographic inspiration and expiration ratio time. The spirometric ratio was approximately 1 : 2, which accords with literature data [10, 23], whereas the sonographic ratio was closer to 1 : 1. Therefore, the spirometer use helps to state the time required to fill the lungs with air — the inspiration time — but not the diaphragm contraction time. Therefore, the spirometry and ultrasonography study helps to monitor different processes at different times. The precise moment when the air starts to fill the lungs after the diaphragm contraction can be explored in a more detailed physiological study.

In our opinion, the absence of the intuitively expected highest correlation between tidal volumes and diaphragm excursion is no less important. Without finding such a correlation we, just like other authors [17], have determined the possible reasons. First, auxiliary muscles; second, different types of breathing (abdominal and thoracic). Some other factors — tidal volume and diaphragm changes mismatch, for example, can be explained by the diaphragm's specific geometry and its attachment at a particular point which makes it difficult for ultrasonography [28, 30].

An analysis of the literature data also revealed different and even opposite results: from the positive correlation with tidal volumes [18] to the absence of it [17]. Ultrasonography diaphragm features of gender disparities also differ: some indicate significant gender and diaphragm ultrasound parameters correlation [6, 14, 16, 18], some presume that correlation depends on other parameters [28] and do not find the difference between female and male diaphragm ultrasound indicators. Ambiguous correlations are also found between the diaphragm thickness and the maximal inspiration pressure [31], functional residual lung capacity [17] and total lung capacity.

The dissent of the diaphragm ultrasound studies literary results in healthy people can be explained as the following: its operator dependency [2, 8, 17] despite good reproducibility of the results [20]; the impact of the subjects' anthropometric features; methodological aspects of the study, such as body position and ultrasound probe setting; dimensions, group diversity, etc. [18, 27, 28].

In studies of patients with different pathologies, such as chronic obstructive pulmonary disease or bronchial asthma, for example, the correlation was revealed between a one-way decline of the external respiratory function during calm and deep breathing and the diaphragm's ultrasound parameters, i.e, a one-way decline of tidal volume and diaphragm excursion [2, 27, 32], including unilateral diaphragm lesion [32, 34, 35].

Looking at the abovementioned inconsistencies found in both our own research and other literature, we can assume the following: the diaphragm is a nonlinear muscular structure. It's a dome-shaped fibromuscular organ, i. e. studies of the thickness of the diaphragm's muscular part at different points of the respiratory cycle do not consider its anatomical heterogeneity. This may explain weak correlations between the contraction of the diaphragm's muscular part and the amount of air entering the lungs. During contraction, the muscular part shifts the fibrotic part, which generates the required rarefaction in the pleural cavity. The abovementioned process explains the preservation of external respiratory function with a unilateral diaphragm lesion and the assessment of the accepted parameters in each study: thickness and excursion.

However, the weak correlation among studied indicators does not mean that the ultrasonography of the diaphragm should be the only method to assess the condition of external respiration. The comprehensive assessment rather requires using both methods, keeping in mind that the diaphragm is not the only muscle providing external respiration but also a muscle functioning in different ways depending on its configuration and the type of breathing [30].

The ultrasonography of the diaphragm can be successfully applied in clinical practice to assess its dynamic function in a course of a disease and concomitant spirometric changes [32, 32], which is especially important in case of unilateral diaphragm lesion [2, 32].

Such ultrasound indicators as diaphragm length and contraction/relaxation may be important diagnostic, prognostic, and monitored indicators for intensive care unit patients in the context of timely initiation of respiratory support and choice of its settings with a focus on the diaphragm's optimal load and unload ratio. Such conclusions [28, 37] are based on the well-known advantages of the sonography: affordability at the patient's bedside, non-invasiveness and ease of use, the possibility of assessment of the diaphragm's dysfunction and its contribution to respiratory failure development, and IMV weaning prediction. Much of the above, however, requires further research.

Conclusion

According to this study we can conclude the following:

1. The ultrasound structural-functional indicators of the diaphragm do not correlate or correlate badly with spirometric indicators, i. e. tidal volumes.
2. There is no reason to use diaphragm ultrasonography in healthy people since it does not provide further information about the external respiratory system.
3. The inconsistencies between diaphragm sonographic indicators and spirometric data are determined by many reasons such as methodological features of the research, and, apparently, the unknown contribution of the auxiliary muscles, and the types of breathing.

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Author contribution. All authors according to the ICMJE criteria participated in the development of the concept of the article, obtaining and analyzing factual data, writing and editing the text of the article, checking and approving the text of the article.

Ethics approval. This study was approved by the local Ethical Committee of Almazov National Medical Research Centre (reference number: 30.04.2022).

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