ORIGINAL RESEARCH ARTICLE

Diaphragmatic excursion by ultrasound: reference values for the normal population; a cross-sectional study in Egypt

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ABSTRACT

Background: Measurement of diaphragmatic motion by ultrasound is being utilized in different aspects of clinical practice. Defining reference values of the diaphragmatic excursion is important to identify those with diaphragmatic motion abnormalities. This study aimed to define the normal range of diaphragmatic motion (reference values) by M-mode ultrasound for the normal population.

Methods: Healthy volunteers were included in this study. Those with comorbidities, skeletal deformity, acute or chronic respiratory illness were excluded. Diaphragmatic ultrasound in the supine position was performed using a low-frequency probe. The B-mode was applied for diaphragmatic identification, and the M-mode was employed for the recording of the amplitude of diaphragm contraction during quiet breathing, deep breathing and sniffing.

Results: The study included 757 healthy subjects [478 men (63.14%) and 279 women (36.86%)] with normal spirometry and negative history of previous or current respiratory illness. Their mean age and BMI were 45.17 ±14.84 years and 29.36±19.68 (kg/m²). The mean right hemidiaphragmatic excursion was 2.32±0.54, 5.54±1.26 and 2.90±0.63 for quiet breathing, deep breathing and sniffing, respectively, while the left hemidiaphragmatic excursion was 2.35±0.54, 5.30±1.21 and 2.97±0.56 cm for quiet breathing, deep breathing and sniffing, respectively. There was a statistically significant difference between right and left diaphragmatic excursion among all studied subjects. The ratio of right to left diaphragmatic excursion during quiet breathing was (1.009±0.19); maximum 181% and minimum 28%. Only 19 cases showed a right to left ratio of less than 50% (5 men and 14 women). The diaphragmatic excursion was higher in males than females. There was a significant difference in diaphragmatic excursion among age groups. Age, sex and BMI significantly affected the diaphragmatic motion.

Conclusions: Diaphragmatic excursion values presented in this study can be used as reference values to detect diaphragmatic dysfunction in clinical practice. Diaphragmatic motion is affected by several factors including age, sex and body mass index.

Key words: diaphragmatic ultrasound; diaphragmatic excursion; diaphragmatic motion; M-mode ultrasound; reference values; normal values.

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Introduction

The diaphragm is the main muscle of respiration [1]. Diaphragmatic excursion is 1-2 cm during tidal breathing and 7-11 cm during deep inspiration [2]. The assessment of diaphragmatic function is important for diagnosis and follow up of various physiologic and pathologic conditions [1-4]. Several methods exist for the evaluation of diaphragmatic function. These methods include fluoroscopy [3], computed tomography [4], magnetic resonance imaging [2], and ultrasonography [5]. Thoracic ultrasound has been reported to be a useful tool for the examination of diaphragmatic function [6]. It is a bedside non-invasive tool that provides various techniques for evaluation of diaphragmatic function including measurement of diaphragmatic excursion and thickness as well as changes during different phases of inspiration [7]. Ultrasonography has been proved to be superior to fluoroscopy and can provide accurate measurement of diaphragmatic excursion [3]. Previous studies highlighted the lack of reference values for diaphragmatic excursion in the normal population which complicates diagnosing abnormal diaphragmatic motion in certain diseases. No data is available about diaphragmatic motion in the normal Egyptian population and no reference data are available to compare with. This study aimed to explore the normal diaphragmatic excursion in the Egyptian population by M-mode ultrasonography.

Methods

This is a cross-sectional study that initially included 780 participants. Twenty-three subjects were excluded due to poor images or failed visualization of one hemidiaphragm, rendering the finally included number 757 individuals (478 males and 279 females), all had normal lung functions with no history of chest disease. Smokers, those with acute respiratory illness, chronic respiratory disease, associated comorbidities, physical disability, abnormal pulmonary function tests or history of anesthesia within the past six months were excluded from the study.

Spirometry

Pulmonary functions were done using spirometry (Spirosift 5000; Fukuda Denshi, Beijing, China). The operator encouraged all subjects verbally to exhale as fast and as deep as possible. Each subject performed at least three technically accepted measurements, and the best of them was selected for statistical analysis. All measurements were performed according to ERS/ATS standards [7].

Diaphragmatic ultrasound

All sonographic examinations were done by the research team. Inter-operator and intra-operator variability were excellent (data not shown). Examinations were performed at quiet temperature (22-25C°). All subjects were asked to rest for 30 min before sonography. Ultrasonography was done using an ultrasound device (SSI6000; Sonoscape, Nanshan, China), while subjects located in the supine position. Examinations were performed using 3.5 MHz curvilinear probe. Each hemidiaphragm was first visualized by B-mode, then M-mode was used to evaluate diaphragmatic excursion in tidal breathing, deep breathing and sniff. The right hemidiaphragm was measured by positioning the probe between the midclavicular and midaxillary lines below the right costal margin (subcostal approach), using the liver as an acoustic window. The probe was directed medially, cephalic and dorsally. When the hemidiaphragm was well visualized, the M-mode was applied to measure the excursion [8]. The left hemidiaphragm was visualized using the spleen as an acoustic window. The probe was positioned between

the left midclavicular and midaxillary lines below the left costal margin. The probe was directed in the same way as the right side [8]. Targeting to improve visualization of the left hemidiaphragm, and overcome the small acoustic window of spleen, the probe was sometimes displaced caudally in the abdomen to obtain a better angle for visualization. The diaphragm was seen as a single echogenic line (Figure 1), moving towards the probe during inspiration and away from the probe during expiration [5]. Diaphragmatic excursion was defined as the difference between the highest point and steep point (amplitude). The diaphragmatic excursion was recorded in different respiratory phases; tidal breathing (normal quiet inspiration), deep inspiration (holding up breathing after maximal inspiration), and sniffing (quick nasal inspiration with a closed mouth) (Figure 2). The direction of movement was also observed (normal or paradoxical), as absent or paradoxical motion may indicate diaphragm paralysis.

Statistical analysis

All data were analyzed by SPSS (Statistical Package for Social Sciences) software version 19 (IBM corp., Armonk, NY, USA) after data cleaning and check. Numerical data were presented as mean ±SD, while categorical data were presented as number (percentage). Independent sample t-test and ANOVA were used for comparisons, Pearson correlation coefficient for testing the relationship between diaphragmatic excursion and demographic parameters, and linear regression analysis for the detection of factors affecting diaphragmatic motion. The significance level was set at a $p \leq 0.05$.

Results

Totally, 757 healthy subjects with normal spirometry were included in this study [478 men (63.14%) and 279 women (36.86%)]. The mean age of the study population was 45.17±14.84 years. Men were significantly older, had significantly higher FVC% and VT%, while women had significantly higher body mass index (BMI) and better FEF25-75% (Table 1). There was a statistically significant difference between right and left diaphragmatic excursion among all studied subjects (Table 2). The ratio of right to left diaphragmatic excursion during quiet breathing was (1.009±0.19); maximum 181% and minimum 28%. Only 19 cases showed a right to left ratio less than 50% (5 men and 14 women). Right diaphrag-

Figure 1. Right diaphragm visualization by B-mode ultrasound. The diaphragm is seen as a thick white line moving with respiration. The liver is used as an echogenic window.

matic motion was significantly higher in men than in women (Table 3). There were significant differences in diaphragmatic excursion among age groups (Table 4). However, there were no statistically significant differences among BMI categories (Table 5). A statistically significant positive correlation was found between age and right diaphragmatic excursion during both deep breathing and sniffing, and between age and left hemidiaphragmatic excursion during deep breathing (r=0.045, p<0.001, r=0.117, p=0.001, r=0.190, p<0.001, respectively). A statistically significant negative correlation was observed between age and left hemidiaphragmatic excursion during quiet breathing (r=-0.098, p=0.007). On the other hand,

a statistically significant negative correlation was detected between BMI and right hemidiaphragmatic excursion during deep breathing and sniffing, and between BMI and left hemidiaphragmatic excursion during deep breathing (r = 0.182, p<0.001; r = -0.094, p=0.009; r = -0.142, p<0.001, respectively). A positive correlation between BMI and left hemidiaphragmatic excursion was found during quiet breathing (r = 0.148, p<0.001) (Table 6). Regression analysis revealed that sex, age, BMI and pulmonary functions affect diaphragmatic motion (good predictors). Age, sex and BMI index significantly affect diaphragmatic motion by variable extents during different types of breathing.
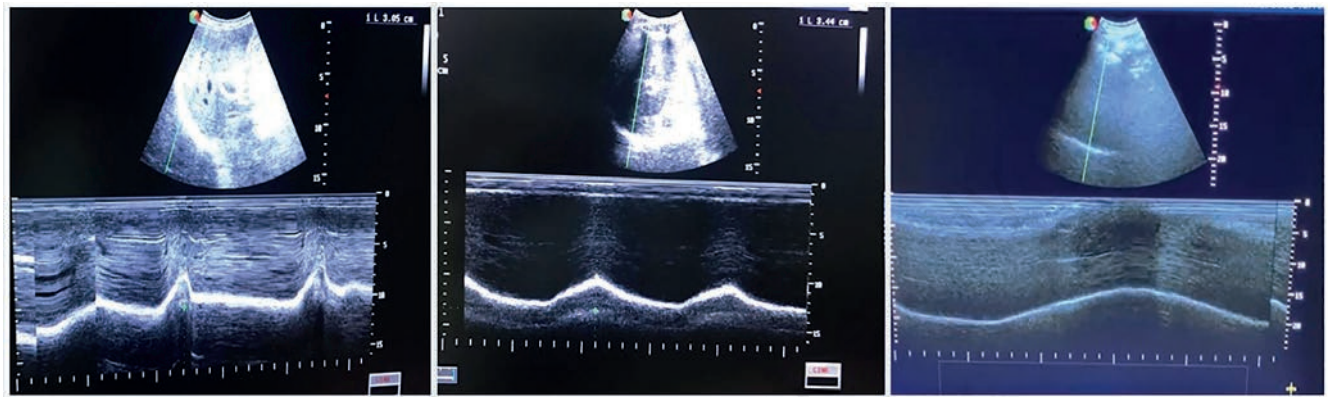
Figure 2. Visualization and measurement of right diaphragmatic excursion by M-mode ultrasound. The diaphragm is seen as a white line moving with respiration. The diaphragmatic excursion is measured as the amplitude of wave seen in M-mode during breathing.

Table 1. Demographic data and pulmonary functions of the studied population.

	Total (n=757)	Men (n=478)	Women (n=279)	p#
Age (year)	45.17±14.84	49.21±14.99	38.25±11.707	0.001*
BMI (kg/m^2)	28.36±5.2	27.26±4.43	29.63±6.03	0.001*
FEV$_1$%	88.22±9.06	87.80±8.65	88.94±9.69	0.067
FVC%	87.64±11.14	87.99±12.31	87.03±8.75	0.023*
VT (L)	0.57±0.53	0.60±.0.66	0.052±0.099	0.001*
VT%	90.41±7.70	90.43±8.43	90.38±6.27	0.013*
FEF25-75%	81.67±10.63	80.27±10.31	84.07±10.75	0.001*

#Comparison between men and women; *p<0.05.

Table 2. Diaphragmatic excursion in the normal population.

	Right hemidiaphragm		Left hemidiaphragm		p
	mean±SD	min-max	mean±SD	min-max	
Quiet breathing (cm)	2.32±0.54	0.72-3.90	2.35±0.54	1.26-3.95	0.009
Deep breathing (cm)	5.54±1.26	2.28-8.80	5.30±1.21	2.4-7.74	<0.001
Sniffing (cm)	2.90±0.63	1.01-4.90	2.97±0.56	1.40-4.88	0.001

Table 3. Diaphragmatic excursion according to sex.

		Men (n=478)	Women (n=279)	p#
Right hemidiaphragm	Quiet breathing	2.37±0.53	2.22±0.54	0.004*
	Deep breathing	5.74±1.26	5.20±1.19	<0.001*
	Sniffing	3.02±0.54	2.69±0.71	0.001*
Left hemidiaphragm	Quiet breathing	2.33±0.54	2.38±0.55	0.436
	Deep breathing	5.46±1.21	5.03±1.15	0.077
	Sniffing	2.98±0.53	2.96±0.59	0.201

#Comparison between men and women; *p<0.05.

Discussion

Diaphragm accounts for three fourths of lung ventilation [9]. Diaphragmatic imaging is important for the diagnosis of diaphragmatic dysfunction or paralysis [3,9]. Normal values of diaphragmatic excursion are important to evaluate abnormalities in different diseases [8]. Diaphragmatic dysfunction (weakness or paralysis) is usually underdiagnosed in clinical practice [10]. Normal values can be used to detect either hypokinesia or hyperkinesia [11]. In this study we found that the mean diaphragmatic excursion for right hemidiaphragm during quiet breathing was 2.32±0.54 cm, while that for the left one was 2.35±0.54 cm. The mean diaphragmatic excursion during deep breathing was 5.54±1.26 cm for the right side and 5.30±1.21 cm for the left, whereas the excursion during sniffing was 2.90±0.63 cm for the right side and 2.97±0.56 cm for the contralateral hemidiaphragm. These results are in line with the results of previous reports [5-7]. Normal diaphragmatic excursion in tidal breathing in previous studies was reported to be from 1-2.5 cm [8]. These values can be affected by age, sex, body composition [12,13], scanning position, and phase of inspiration [14]. Right diaphragmatic excursion was shown to be significantly better in men than in women (Table 3). The same results were reported by Kantarci *et al.* who in their study reported a significant difference in diaphragmatic motion between male and female subjects [13]. In their study, sex was the most significant factor affecting diaphragmatic function. In our study, there was a significant difference in diaphragmatic excursion among age groups (Table 4). Similar results were reported in previous studies [6,8]. Boussuges *et al.* [8] reported a higher diaphragmatic excursion in men than women in all types of breathing. This can be attributed to differences in height, weight, age [6,8], diaphragmatic mass, diaphragmatic fiber type property, metabolic activity, contractile properties and environmental factors [9].

In the current study, a statistically significant positive correlation was observed between age and diaphragmatic excursion during both deep breathing and sniffing in the right side, and during deep breathing only in the left one. Besides, a statistically significant negative correlation was revealed between age and left hemidiaphragmatic excursion during quiet breathing (Table 4). Kantarci *et al.* [13] found that diaphragmatic function is significantly lower in the individuals below 30 years when compared to those aged more than 30 years.

We did not find any significant statistical differences among BMI categories (Table 5). However, there was a significant positive correlation between BMI and left hemidiaphragmatic excursion during quiet breathing (Table 6). Moreover, regression analysis showed that age, sex and BMI are the main factors that significantly affect diaphragmatic excursion. Kantarci *et al.* [13] reported a significant difference in diaphragmatic motion according to BMI categories and explained this by the difference in fat and muscle composition. In the same context, Scarlata *et al.* [12] reported a significant correlation between diaphragmatic motion and gender, age, weight and height. This difference is clinically important for the identification of those with a risk of low diaphragmatic function to include them in rehabilitation programs. This discrepancy between studies may be due to different demographic characters and distribution of population in different body mass index categories. Increased diaphragmatic motion with increased BMI may be attributed to differences in height or the increased diaphragm weight with increased body weight [10]. This can be confirmed through the assessment of diaphragmatic thickness by

Table 4. Diaphragmatic excursion according to age groups.

Age in groups	Right hemidiaphragm			Left hemidiaphragm		
	Quiet breathing	Deep breathing	Sniffing	Quiet breathing	Deep breathing	Sniffing
<30 year (n=129)	2.34±0.55	5.51±1.16	2.87±0.74	2.39±0.56	5.22±1.19	3.03±0.59
31-50 year (n=292)	2.26±0.55	5.33±1.17	2.83±0.69	2.38±0.58	5.10±1.11	2.98±0.62
51-65 year (n=277)	2.37±0.54	5.67±1.35	2.96±0.52	2.32±0.50	5.42±1.31	2.95±0.47
>65 year	2.31±0.41	6.10±1.19	3.04±0.46	2.20±0.46	5.91±1.03	2.96±0.55
p	0.003*	0.001*	0.579	0.001*	0.001*	0.000*

*p<0.05.

Table 5. Diaphragmatic excursion according to BMI.

BMI in groups	Right hemidiaphragm			Left hemidiaphragm		
	Quiet breathing	Deep breathing	Sniffing	Quiet breathing	Deep breathing	Sniffing
<18.5 (n=11)	2.12±0.50	6.47±0.73	2.98±0.37	1.90±0.62	6.13±0.66	2.67±0.29
>18.5-24.9 (n=183)	2.26±0.56	5.73±1.08	2.89±0.60	2.24±0.60	5.44±1.10	2.94±0.56
25-29.9 (n=302)	2.33±0.54	5.62±1.24	2.94±0.61	2.33±0.54	5.34±1.21	2.99±0.57
≥30 (n=261)	2.35±0.52	5.28±1.36	2.85±0.67	2.45±0.48	5.12±1.28	3.00±0.55
p	0.089	≤0.001	0.55	≤0.001	0.005	0.056

Table 6. Correlation with body mass index and age and diaphragmatic excursion.

BMI in groups		Right hemidiaphragm			Left hemidiaphragm		
		Quiet breathing	Deep breathing	Sniffing	Quiet breathing	Deep breathing	Sniffing
BMI (n=757)	Pearson Correlation	0.031	-0.182**	-0.094**	0.148**	-0.143**	0.040
	Significance (2-tailed)	0.395	≤0.001	0.009	≤0.001	≤0.001	0.273
Age (n=757)	Pearson Correlation	0.045	0.164**	0.117**	-0.098**	0.190**	0.041
	Significance (2-tailed)	0.221	≤0.001	0.001	0.007	≤0.001	0.266

BMI, body mass index; **correlation is significant at the 0.01 level (2-tailed).

ultrasonography.

The strengths of this study include the large number of studied populations, different age groups and body composition. This study reflects the normal distribution of diaphragmatic excursion in the normal population in Egypt. Knowing normal references for diaphragmatic ultrasound measurements can be of clinical value in identifying and diagnosing diaphragmatic paralysis, as well as exploring the cause and predicting the prognosis of diaphragm paralysis [15]. Diaphragmatic ultrasound normal values can be also used to predict the response to treatment as in rehabilitation programs, in addition to setting cut-off values to predict successful weaning parameters from mechanical ventilation. Likewise, it can be used to evaluate diaphragmatic function before and after surgeries. Furthermore, these values can also predict diaphragmatic dysfunction and deconditioning [15]. They can be applied as a predictor of mechanical ventilation-induced diaphragm dysfunction, too [16]. The unequal distribution of age groups, the disparity of BMI among different age groups, together with the inability to perform a simultaneous assessment of pulmonary functions and diaphragmatic motion by ultrasound due to technical difficulties are the main limitations of this study. The study included only Egyptian volunteers, which may be considered another limitation, so large worldwide studies are recommended to reach worldwide normal values that can be applied to all countries. Also, further studies are needed for assessments of diaphragmatic functions in patients with chronic respiratory diseases.

Conclusions

Diaphragmatic excursion values presented in this study can be used as reference values to detect diaphragmatic dysfunction in clinical practice. There is a significant statistical difference between right and left hemidiaphragmatic movement during all types of breathing (quiet, deep and sniffing). Age, sex and BMI significantly affect diaphragmatic motion with variable extents during different types of breathing. The assessment of diaphragmatic motion by ultrasound could be a useful indicator for the diagnosis and follow up of respiratory diseases, and could be added to outcomes in clinical trials. Further studies to assess other factors that may affect the diaphragmatic motion including metabolic factors and other anthropometric parameters are required.

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