Assessment of diaphragmatic mobility by chest ultrasound in relation to BMI and spirometric parameters

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Context Ultrasound of the diaphragm is an evolving diagnostic modality with several techniques and measurements that can be used for structural and functional assessment of the diaphragm. Weight may have effects on pulmonary function tests including its impairment. Assessment of the diaphragm is one of these important measures of function by measuring the diaphragmatic thickness, excursion, and diaphragmatic thickness fraction (DTF).

Aim Assessing the relation between these sonographic diaphragmatic indices with spirometry and BMI.

Settings and design This was a prospective clinical study in which 107 normal healthy volunteers with different age, height, and weight were enrolled; most of them were coming for routine preoperative assessment at the Ain Shams University Chest Department Pulmonary Function Unit.

Patients and methods It included 107 healthy persons who came for routine preoperative lung function assessment or normal volunteers. Full medical and smoking history, BMI, chest radiography spirometry, and diaphragmatic assessment by ultrasound for excursion, thickness, and DTF were done. All persons were divided into obese individuals of BMI more than or equal to 25 and nonobese individuals of BMI less than 25.

Statistical analysis Statistical package for the social sciences program (SPSS) software version 18.0.

Results In obese individuals, forced expiratory volume in the first second (FEV_1%) and right diaphragmatic excursion show a significant decrease when BMI increases. There was a statistically significant increase in right and left diaphragmatic excursion and DTF in men rather than women. There was a highly significant increase in both right and left diaphragmatic thickness and excursion when forced vital capacity increases. There was a highly significant increase in right diaphragmatic excursion and both right and left diaphragmatic thickness when FEV_1 increases. A significant increase in left excursion and DTF was also noticed with increased FEV_1. However, there was a significant decrease in DTF with increased percent of forced vital capacity.

Conclusion Spirometric parameters and right diaphragmatic excursion show a significant decrease when BMI increases. Different relations were found between spirometric parameters and ultrasonographic measurements regardless of the BMI.

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Introduction

Diaphragm is the major respiratory muscle used for quiet breathing. Different structural and functional techniques are available for evaluating the diaphragm [1].

This evaluation is accomplished through history, physical examination, fluoroscopic sniff test, nerve conduction studies, and electromyography. Nerve conduction studies and electromyography in this setting are challenging and can cause serious complications such as pneumothorax [2].

Ultrasound of the diaphragm is an evolving diagnostic modality with several measurements that can be used for structural and functional assessment of the diaphragm. It is now commonly used for the evaluation of diaphragm structure and function [3].

Ultrasound focuses mainly on the posterior and lateral parts of the diaphragm, which are the muscular components innervated by the phrenic nerve, rather than the anterior central tendon seen in fluoroscopy, which moves 40% less with respiration. Its position and motion depend on the position of the patient [4].

Muscle fibers shorten with contraction and cause muscle thickening. Increase in diaphragmatic thickness during inspiration has been used as an indirect measurement of muscle fiber contraction [5].

Age-related changes in body composition and fat distribution may be associated with pulmonary impairment observed in elderly persons. Some studies found a direct relationship between BMI and lung function determined by spirometric examination [6].

Healthy participants with smaller BMI (<18.5) showed a decreased amount of diaphragmatic motion, and as the

BMI increased, the diaphragmatic motion increased. This increase in motion, however, is not linear, and as the BMI increases, the diaphragmatic motion does not show a parallel increase [7,8].

This study was to assess the relation between diaphragmatic measurements by chest ultrasonography in relation to BMI and spirometric parameters.

Patients and methods

Patients

Inclusion criteria

Normal healthy volunteers coming to the pulmonary function unit for functional assessment.

Exclusion criteria

Physical disability, cigarette smoking, signs and symptoms suggesting respiratory tract disease, diabetes mellitus and hypertension, any disease process involving the thorax (heart and lung), abdominal, and retroperitoneal organs, and associated neuromuscular disorders.

Methods

Every included participant will be subjected to the following: demographic data include age, sex, BMI (weight/height^2 in meters), smoking history. Full history taking included recording the presence of any comorbidity, coexisting pulmonary, or abdominal diseases. Clinical examination: pelviabdominal ultrasound to exclude any associated abdominal problem, chest radiographs to exclude any associated lung problems and to assess the level of the diaphragm.

Spirometry

A Viasys FlowScreen spirometer (VAISYAS Healthcare, Hoechberg, Germany) present in the pulmonary function laboratory in Ain Shams University Hospitals, Chest Department was used. according to the guidelines of American Thoracic Society/European Thoracic Society, 2005 [9] of usage and interpretation of spirometric indices to use forced expiratory volume in the first second (FEV_1%), forced vital capacity (FVC%), FEV_1/FVC, FEV_1(L), FVC(L) in this study results.

Diaphragm ultrasound was for the assessment of diaphragmatic mobility, thickness, and diaphragmatic thickness fraction (DTF) on both sides [10].

Patient position

The patient would be in supine position, and the researcher sat down on a chair at the right side of the bed at the level of the patient's abdomen; the ultrasound device was beside him at the level of the head of the patient and then the same was repeated on the left side.

Advantages of supine position

Less overall variability, less side-to-side variability, greater reproducibility, and excursion were known to be greater in the supine position for the same volume inspired than in sitting or standing positions.

Device used: Mindray DP-1100 (2015) Shanghi, China.

For diaphragmatic excursion

Examination was done using a 3.5C (bandwidth 2–5 MHz) convex-phased array probe (low-frequency probe with greater depth and allowing to assess excursion), with B mode set as the default mode on the device screen.

The probe of the ultrasound was put at an anterior axillary line, right subcostal after application of the ultrasound gel and is directed medially, cephalic, and dorsally using the liver as an acoustic window for better illustration of the diaphragm.

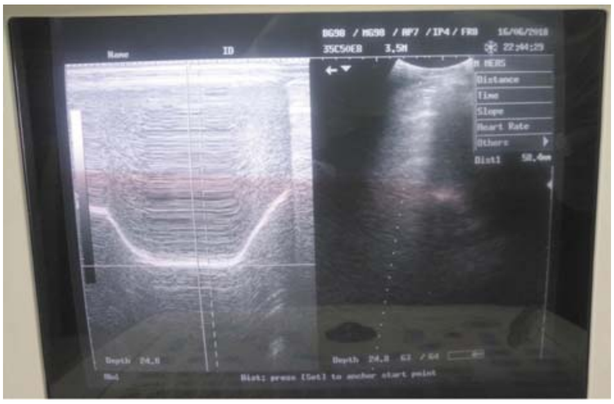
Then switch to M mode observing the diaphragmatic movement during inspiration and expiration during quiet breathing, then the freeze button on the ultrasound device is pressed, followed by measurement of the difference between the diaphragmatic position during inspiration and expiration and then the diaphragmatic excursion during quiet breathing is recorded which corresponds to diaphragmatic excursion during rest.

The same steps were followed, but with asking the patient to take a deep inspiration followed by a deep expiration to measure diaphragmatic excursion during forced respiration which corresponds to diaphragmatic excursion during patient exercise (Fig. 1).

Figure 1

Diaphragmatic excursion by M mode ultrasound during forced inspiration using Mindray DP-1100 Device.

Figure 2



Diaphragmatic thickness by B mode.

For diaphragmatic thickness

A linear array probe (bandwidth 5–13 MHz) was put at the right anterior axillary line at the seventh or eighth intercostal space, obtaining an image showing the liver and the lung and a zone of apposition between them using the B mode. Both pleural lining and peritoneal lining appeared clearly as two approximately parallel echogenic lines. The space between them resembling diaphragmatic thickness was measured during inspiration. Diaphragmatic thickness corresponds to muscle endurance.

DTF: calculated as a percentage from the formula (thickness at end inspiration−thickness at end expiration)/thickness at end expiration×100.

Data analysis was done in line of the objectives by using the statistical package for the social sciences program (SPSS) software version 18.0 (Tronto, Canada). Qualitative variables were presented as percentage and quantitative variables were presented as mean±SD. Student's *t*-test and Pearson's correlation coefficient was used as the test of significance; *P* value less than 0.05 was considered as significant (Fig. 2).

Results

The present study was conducted on 107 healthy persons coming to Ain Shams University Chest Department Pulmonary Function Unit for any purpose or on normal volunteers. Patients of different ages, sex, and BMI were subjected to full medical history, chest radiograph, spirometry, and chest ultrasound for diaphragmatic mobility and thickness for the right and left couple. All collected data were analyzed by using the SPSS program software version 18.0 as in the following: the studied populations were 60 (56.1%) men and 47 (43.9%) women with a mean age and BMI of 37.39±14.10 and 32.64±9.51, respectively. Of them, 85% showed normal spirometry; the rest show restrictive pattern (mild and moderate), and no obstruction was shown as the within normal ratio (FEV_1/FVC). Mean right and left diaphragmatic excursion (cm) was 5.01±1.53 and 4.83±1.58, respectively. The median right and left diaphragmatic thickness was (mm) 2.1 (1.7–2.8) and 2 (1.5–2.5), respectively. Median DTF was 0.55 (0.47–0.65 as in Table 1).

In this study, there was highly significant statistical increase in BMI along the studied female population (P=0.008). Moreover, the studied female population showed a highly significant increase in age than the studied men (Table 2).

In all the studied population, there was a significant increase in BMI when the age increases. Also, FEV_1 and FVC show a highly significant decrease when the BMI increases (P=0.001 and 0.009, respectively). In obese individuals, FEV_1% and right diaphragmatic excursion show a significant decrease when the BMI increases (P=0.014 and 0.010, respectively). Nonobese individuals show no significant difference between BMI and spirometric or diaphragmatic ultrasound parameters (Table 3).

In this study, there was a statistically significant increase in severity of restrictive pattern of spirometry when the BMI increases in obese persons (Fig. 3). As regards this relation with sonographic diaphragmatic indices in obese individuals, there was no significant statistical difference between the degree of restrictive pattern and ultrasonographic diaphragmatic indices (Table 4).

Also, there was a statistically significant decrease in the ratio between FEV_1 and FVC when the BMI increases (P=0.022), but there was no significant difference between it and other spirometric indices (Table 5). On the contrary, there was no significant statistical difference between obese and nonobese as regards ultrasonographic diaphragmatic indices (Table 6).

This study showed that there was a highly statistical significant increase in FEV_1 and FVC in men (mean FEV_1 and FVC in men 3.89±0.75 and 4.53±0.85, respectively) than in women (Table 7). As regards sonographic diaphragmatic indices, there was a statistically significant increase in right diaphragmatic excursion in men rather than women (mean 5.33±1.75 in

Table 1 Demographic data and spirometric and sonographic diaphragmatic indices of the studied population

Demographic data	*N*=107
Age	
Mean±SD	37.39±14.10
Range	15–87
Sex [*n* (%)]	
Female	47 (43.9)
Male	60 (56.1)
BMI	
Mean±SD	32.64±9.51
Range	16.2–70.9
Nonobese [*n* (%)]	15 (14.0)
Obese [*n* (%)]	92 (86.0)
Spirometric indices	
FVC%	
Mean±SD	93.40±10.97
Range	70–149
FEV_1%	
Mean±SD	90.96±11.14
Range	66–148
Ratio	
Mean±SD	84.53±6.37
Range	70–100
Degree of restriction [*n* (%)]	
Normal	91 (85.0)
Mild	14 (13.1)
Moderate	2 (1.9)
FEV_1	
Mean±SD	3.52±0.86
Range	1.59–6.95
FVC	
Mean±SD	4.14±0.96
Range	2–8.39
Diaphragmatic indices	
Right excursion (cm)	
Mean±SD	5.01±1.53
Range	2–11.4
Left excursion (cm)	
Mean±SD	4.83±1.58
Range	1.1–10
Right thickness (mm)	
Median (IQR)	2.1 (1.7–2.8)
Range	0.75–8.6
Left thickness (mm)	
Median (IQR)	2 (1.5–2.5)
Range	0.57–8.3
DTF	
Median (IQR)	0.55 (0.47–0.65)
Range	0.33–0.9

DTF, diaphragmatic thickness fraction; FEV_1, forced expiratory volume in the first second; FVC, forced vital capacity; IQR, interquartile range.

men, *P*=0.013). Also, there was a highly significant statistical increase in left diaphragmatic excursion in men more than women (mean 5.24±1.75 in men, *P*=0.002). DTF shows a statistically significant decrease in men rather than women (Table 8).

This study shows that in all the studied population, there was a highly significant increase in both right and left diaphragmatic thickness and excursion when FVC increases. Also, there was a highly significant increase in right diaphragmatic excursion and both right and left diaphragmatic thickness when FEV_1 increases. A significant increase in left excursion and DTF was also noticed with increased FEV_1. However, there was significant decrease in DTF with increase in FVC% (Table 9).

In the nonobese population of this study, there was highly significant increase in right diaphragmatic excursion when FVC increases. A significant increase in right excursion and left excursion was also noticed with increased FEV_1% and FVC, respectively. However, there was significant decrease in DTF with increase in FVC% (Table 10). Similarly, in obese individuals, there was highly significant increase in both right and left diaphragmatic thickness and right diaphragmatic excursion when FEV_1 increases. Also, there was a highly significant increase in both right and left diaphragmatic excursion and diaphragmatic thickness and when FVC increases. A significant increase in left excursion was also noticed with increased FEV_1. But no correlations were found as regards DTF (Table 11).

Discussion

The diaphragm is the principal muscle of respiration and its contraction along with accessory muscles causes inspiration and relaxation causing expiration. Along with respiration, diaphragmatic contractions also increase intra-abdominal pressure that helps in urination, defecation, and prevention of gastroesophageal reflux [11].

The diagnostic tools traditionally used to study the diaphragmatic dysfunction like fluoroscopy, phrenic nerve conduction study, and transdiaphragmatic pressure measurement present some limitations and disadvantages including: the usage of ionizing radiations, low availability, invasiveness, the need for patient transportation and skilled or specifically trained operators. Recently, ultrasound has been used to evaluate the diaphragmatic function. Advantages of ultrasound include safety, avoidance of radiation hazards, and availability at the bedside [12].

The aim of this study was to evaluate chest ultrasound as a simple, noninvasive test in the assessment of diaphragmatic mobility in relation to spirometric parameters in different BMI.

Table 2 Comparison between men and women as regards age and BMI

	Female (*N*=47)	Male (*N*=60)	Test value[b]	*P*-value	Significance
Age					
Mean±SD	41.81±15.14	33.93±12.28	–2.971	0.004	HS
Range	19–87	15–71			
BMI					
Mean±SD	35.38±10.70	30.50±7.90	–2.713	0.008	HS
Range	22.03–70.9	16.2–62.7			

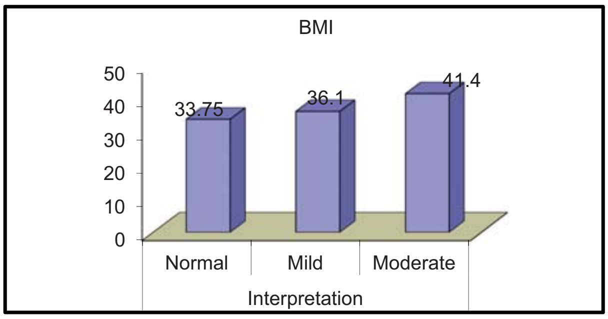
$P>0.05$: NS; $P<0.05$: significant; $P<0.01$: highly significant. HS, highly significant. [b]One-way analysis of variance test.

Table 3 Correlations between BMI in all, obese and nonobese persons with age, spirometric indices, ultrasonographic diaphragmatic measurements

	BMI					
	All persons (*N*=107)		Nonobese (*N*=15)		Obese (*N*=92)	
	r	*P*-value	*r*	*P*-value	*r*	*P*-value
Age	0.238*	0.013	0.399	0.141	0.159	0.129
FVC%	–0.111	0.254	0.405	0.135	–0.175	0.095
FEV_1%	–0.191	0.048	–0.013	0.965	–0.256	0.014
Ratio	–0.118	0.225	–0.179	0.524	0.017	0.872
FEV_1	–0.320	0.001	–0.206	0.462	–0.183	0.080
FVC	–0.251	0.009	–0.130	0.643	–0.153	0.146
Right excursion (cm)	–0.168	0.083	–0.048	0.864	–0.267	0.010
Left excursion (cm)	–0.019	0.848	–0.136	0.629	–0.195	0.063
Right thickness (mm)	–0.119	0.222	0.192	0.494	–0.196	0.061
Left thickness (mm)	–0.120	0.218	0.332	0.227	–0.123	0.243
DTF	0.061	0.530	–0.069	0.807	0.198	0.059

$P>0.05$: NS; $P<0.05$: significant; $P<0.01$: highly significant. DTF, diaphragmatic thickness fraction; FEV_1, forced expiratory volume in the first second; FVC, forced vital capacity; Ratio, FEV_1/FVC; *r*, Pearson's correlation.

Figure 3



Relation between BMI in obese persons and degree of restrictive pattern

Relation between BMI and degree of restrictive spirometric pattern in obese persons.

This study was conducted on one hundred and seven patients of normal volunteers. The exclusion criteria were smoking history, current chest disease, abnormal chest radiograph, associated comorbidity such as diabetes mellitus, hypertension, ischemic heart disease, old stroke). All patients were subjected to full medical history, chest radiograph, spirometry, and diaphragmatic ultrasound measurement of thickness and excursion.

The current study was done on 60 men and 47 women of mean age 37.39±14.10 ranging from 15 to 87 of different BMI ranging from 16.2 to 70.9. BMI was differentiated into nonobese (BMI<25) and obese (BMI≥25).

The current study shows a significant increase in age when the BMI increases. The mean of age in the nonobese population is 28.93±12.24 but in the obese population it is 38.77±13.96.

This was matched with the results of Donald [13] who studied (sex and age differences in the relationship between BMI and perceived weight) in a sample of 3000 men and 3000 women who found that for both men and women, there is a steady age-related increase in the percentage of BMI .

This was not matched with Al-Awadhi *et al.* [14], who conducted a cross-sectional study on adolescent girls in Kuwait and reported an inverse association between age at menarche and obesity or overweight. They found that there was gradual decrease in the age of menarche in case of overweight and obese girls; this may be

Table 4 Relation between degree of restrictive pattern and sonographic diaphragmatic indices in obese persons

Obese	Interpretation			Test value	*P*-value	Significance
	Normal	Mild	Moderate			
Right excretion (cm)						
Mean±SD	5.03±1.66	5.19±1.02	4.55±1.63	0.157[a]	0.855	NS
Range	2–11.4	3.5–7.2	3.4–5.7			
Left excretion (cm)						
Mean±SD	4.86±1.61	4.92±1.3	4.45±1.63	0.079[a]	0.924	NS
Range	2–10	3.42–8.1	3.3–5.6			
Right thickness (mm)						
Median (IQR)	2.2 (1.8–2.8)	1.9 (1.09–2.8)	2 (1.9–2.1)	1.790[b]	0.409	NS
Range	1.1–7	0.89–3.9	1.9–2.1			
Left thickness (mm)						
Median (IQR)	2.05 (1.6–2.55)	1.75 (1.1–2.5)	1.75 (1.5–2)	1.129[b]	0.569	NS
Range	0.78–8	0.57–3.7	1.5–2			
DTF						
Median (IQR)	0.53 (0.46–0.65)	0.64 (0.55–0.68)	0.53 (0.41–0.65)	5.571[b]	0.062	NS
Range	0.33–0.81	0.47–0.8	0.41–0.65			

$P>0.05$: NS; $P<0.05$: significant; $P<0.01$: highly significant. IQR, interquartile range. [a]One-way analysis of variance test. [b]Kruskal–Wallis test.

Table 5 Comparison between obese and nonobese as regard spirometric indices

	Nonobese (*N*=15)	Obese (*N*=92)	Test value	*P*-value	Significance
FVC%					
Mean±SD	94.43±8.41	93.23±11.36	0.392[b]	0.696	NS
Range	79–112	70–149			
FEV_1%					
Mean±SD	92.42±5.51	90.72±11.81	0.548[b]	0.585	NS
Range	83–102	66–148			
Ratio					
Mean±SD	88.00±6.99	83.96±6.12	2.324[b]	0.022	S
Range	74–99	70–100			
Interpretation [*n* (%)]					
Normal	15 (100.0)	7 6 (82.6)	3.067[a]	0.216	NS
Mild	0 (0)	14 (15.2)			
Moderate	0 (0)	2 (2.2)			
FEV_1					
Mean±SD	3.87±0.56	3.46±0.89	1.726[b]	0.087	NS
Range	2.9–4.83	1.59–6.95			
FVC					
Mean±SD	4.29±0.72	4.11±1.00	0.666[b]	0.507	NS
Range	3.1–5.4	2–8.39			

$P>0.05$: NS; $P<0.05$: significant; $P<0.01$: highly significant. FEV_1, forced expiratory volume in the first second; FVC, forced vital capacity; Ratio, FEV_1/FVC. [a]χ^2-Test. [b]One-way analysis of variance test.

attributed to local and national variation of the studied population.

This study shows that there is highly significant increase in BMI of women than men; the mean BMI of women was 35.38±10.70 but the mean BMI in men was 30.50±7.90.

This was matched with Yang and Colditz [15], who designed a cross-sectional estimate of the prevalence of major diseases, nutritional disorders, and potential risk factors among the US population and found that women are more obese than men (39.96%) (weighted *n*=36 325 297) and 29.74% (weighted *n*=28 894 630) of women were overweight and 35.04% (weighted *n*=31 847 198) of men and 36.84% (weighted *n*=35 792 733) of women were obese. But it was not matched with the results of Kuan *et al.* [16] who studied sex differences in BMI, body weight perception, and weight loss strategies among undergraduates in Universiti Malaysia Sarawak and found that men have more BMI than

Table 6 Comparison between the obese and nonobese as regards ultrasonographic diaphragmatic indices

	Nonobese (*N*=15)	Obese (*N*=92)	Test value	*P*-value	Significance
Right excursion (cm)					
Mean±SD	4.80±1.33	5.04±1.57	−0.572[a]	0.569	NS
Range	2.1–6.6	2–11.4			
Left excursion (cm)					
Mean±SD	4.60±1.75	4.86±1.55	−0.604[a]	0.547	NS
Range	1.1–8.2	2–10			
Right thickness (mm)					
Median (IQR)	2.1 (1.5–3.1)	2.2 (1.8–2.8)	−0.283[a]	0.777	NS
Range	0.75–8.6	0.89–7			
Left thickness (mm)					
Median (IQR)	2 (1.2–2.8)	2 (1.55–2.5)	−0.368[b]	0.713	NS
Range	0.83–8.3	0.57–8			
DTF					
Median (IQR)	0.64 (0.54–0.7)	0.54 (0.47–0.65)	−1.534[b]	0.125	NS
Range	0.36–0.9	0.33–0.81			

$P>0.05$: NS; $P<0.05$: significant; $P<0.01$: highly significant. DTF, diaphragmatic thickness fraction; IQR, interquartile range. [a]One way analysis of variance test. [b]Kruskal–Wallis test.

Table 7 Comparison between males and females as regard spirometric indices

	Female (*N*=47)	Male (*N*=60)	Test value	*P*-value	Significance
FVC%					
Mean±SD	91.52±9.77	94.88±11.69	1.582[b]	0.117	NS
Range	70–115	71–149			
FEV_1%					
Mean±SD	88.91±9.98	92.56±11.80	1.694[b]	0.093	NS
Range	66–114	69–148			
Ratio					
Mean±SD	84.36±6.14	84.66±6.59	0.244[b]	0.808	NS
Range	73.1–100	70–99			
Interpretation					
Normal	36 (76.60)	55 (91.70)	5.033[a]	0.081	NS
Mild	10 (21.30)	4 (6.70)			
Moderate	1 (2.10)	1 (1.70)			
FEV_1					
Mean±SD	3.05±0.76	3.89±0.75	5.666[b]	0.000	HS
Range	1.59–4.83	2.3–6.95			
FVC					
Mean±SD	3.63±0.87	4.53±0.85	5.381[b]	0.000	HS
Range	2–5.32	3.1–8.39			

$P>0.05$: NS; $P<0.05$: significant; $P<0.01$: highly significant. FEV_1, forced expiratory volume in the first second; FVC, forced vital capacity; HS, highly significant. [a]χ^2-Test. [b]Independent *t*-test.

women. The mean BMI was 21.1 kg/m^2 for women and 22.0 kg/m^2 for men. That was because in that study volunteers are subjected to self-administered questionnaires.

In this study, FEV_1 and FVC show highly significant decrease when BMI increases (P=0.001 and 0.009, respectively). In obese individuals, FEV_1% and right diaphragmatic excursion show significant decrease when BMI increases (P=0.014 and 0.010, respectively).

Comparable results were reported by Banerjee *et al.* [17] who studied 424 test results of nonasthmatic patients and found that in obese patients in Kolkata, India, there was significant negative correlation between BMI and FEV_1 (P=0.009).

Similarly, Wang *et al.* [18], who studied the effects of BMI on spirometry tests among adults in Xi'an, China on 803 volunteers (aged 18–80 years) who had lived in there for more than 2 years found that FVC notably decreased in obese people (P=0.037).

Table 8 Comparison between men and women as regards ultrasonic diaphragmatic indices

	Female (*N*=47)	Male (*N*=60)	Test value	*P*-value	Significance
Rt. excursion (cm)					
Mean±SD	4.60±1.08	5.33±1.75	2.537[a]	0.013	S
Range	2.4–7.2	2–11.4			
Left excursion (cm)					
Mean±SD	4.30±1.13	5.24±1.75	3.203[a]	0.002	HS
Range	1.29–6.7	1.1–10			
Right thickness (mm)					
Median (IQR)	2 (1.5–2.8)	2.25 (1.8–3)	−0.785[b]	0.432	NS
Range	0.98–4.2	0.75–8.6			
Left thickness (mm)					
Median (IQR)	1.9 (1.4–2.4)	2 (1.65–2.55)	−1.279[b]	0.201	NS
Range	0.78–3.8	0.57–8.3			
DTF					
Median (IQR)	0.53 (0.46–0.64)	0.61 (0.51–0.66)	−2.046[b]	0.041	S
Range	0.33–0.8	0.34–0.9			

$P>0.05$: NS; $P<0.05$: significant; $P<0.01$: highly significant. DTF, diaphragmatic thickness fraction; HS, highly significant; IQR, interquartile range; S, significant. [a]Independent *t*-test. [b]Mann–Whitney test.

Table 9 Relation between spirometric parameters and ultrasound diaphragmatic parameters in all persons

	Right excursion (cm)		Left excursion (cm)		Right thickness (mm)		Left thickness (mm)		DTF	
	r	*P*-value	*r*	*P*-value	*r*	*P*-value	*r*	*P*-value	*r*	*P*-value
FVC%	−0.011	0.908	−0.001	0.992	0.160	0.100	0.114	0.243	−0.212	0.028
FEV_1%	0.073	0.457	0.064	0.510	0.091	0.352	0.048	0.624	−0.151	0.121
Ratio	0.051	0.602	0.022	0.823	0.031	0.754	0.063	0.517	0.047	0.633
FEV_1	0.319	0.001	0.247	0.010	0.266	0.006	0.287	0.003	0.194	0.046
FVC	0.377	0.000	0.322	0.001	0.318	0.001	0.311	0.001	0.184	0.058

$P>0.05$: NS; $P<0.05$: significant; $P<0.01$: highly significant. DTF, diaphragmatic thickness fraction; FEV_1, forced expiratory volume in the first second; FEV_1%, percent of FEV_1 of the predicted; FVC, forced vital capacity; FVC%, percent of FVC of the predicted; Ratio, FEV_1/FVC; *r*, Pearson's correlation.

Table 10 Relation between spirometric parameters and ultrasound diaphragmatic parameters in nonobese persons

Nonobese	Right excursion (cm)		Left excursion (cm)		Right thickness (mm)		Left thickness (mm)		DTF	
	r	*P*-value	*r*	*P*-value	*r*	*P*-value	*r*	*P*-value	*r*	*P*-value
FVC%	0.072	0.798	−0.110	0.696	0.195	0.485	0.151	0.591	−0.566	0.028
FEV_1%	0.533	0.041	0.352	0.198	−0.246	0.378	−0.341	0.213	−0.163	0.561
Ratio	−0.200	0.474	−0.211	0.450	0.094	0.739	0.156	0.580	0.182	0.515
FEV_1	0.260	0.349	0.150	0.593	−0.402	0.137	−0.333	0.226	0.240	0.390
FVC	0.704	0.003	0.558	0.031	−0.290	0.294	−0.361	0.186	0.080	0.776

$P>0.05$: NS; $P<0.05$: significant; $P<0.01$: highly significant. DTF, diaphragmatic thickness fraction; FEV_1, forced expiratory volume in the first second; FEV_1%, percent of FEV_1 of the predicted; FVC, forced vital capacity; FVC%, percent of FVC of the predicted; Ratio, FEV_1/FVC; *r*, Pearson's correlation.

Nearly the same results were obtained by Jain and Golmohamed [19] who studied the impact of BMI on FEV_1% and quality of life in asthma patients in Liverpool, UK in a sample of 63.8% (348) women versus 36.2% (199) men with a mean age of 52.8 years of average BMI was 31.3 kg/m^2 and they found that the greater the BMI, the lower the FEV_1%.

On the contrary, Xugui and Chen [20] who studied the relationship between obesity and forced vital capacity among university students in China in 2617 (1131 men and 1486 women) patients, with an age range from 19 to 23 years in a university student who was admitted for routine health screening, found that obesity has a higher FVC in both male and female university students. The effects of obesity on spirometric values are not consistent in most of the studies. This discrepancy between studies could be explained by the wide variations in ethnicity of different populations in pulmonary fuction test (PFT) values

Table 11 Relation between spirometric parameters and ultrasound diaphragmatic parameters in obese persons

Obese	Right excursion (cm)		Left excursion (cm)		Right thickness (mm)		Left thickness (mm)		DTF	
	r	*P*-value	*r*	*P*-value	*r*	*P*-value	*r*	*P*-value	*r*	*P*-value
FVC%	–0.015	0.884	0.019	0.855	0.158	0.133	0.113	0.285	–0.200	0.056
FEV_1%	0.025	0.814	0.042	0.689	0.142	0.177	0.099	0.348	–0.184	0.079
Ratio	0.091	0.388	0.048	0.652	0.049	0.645	0.068	0.517	–0.025	0.813
FEV_1	0.320	0.002	0.259	0.013	0.395	0.000	0.404	0.000	0.160	0.128
FVC	0.335	0.001	0.296	0.004	0.424	0.000	0.416	0.000	0.190	0.070

$P>0.05$: NS; $P<0.05$: significant; $P<0.01$: highly significant. DTF, diaphragmatic thickness fraction; FEV_1, forced expiratory volume in the first second; FEV_1%, percent of FEV_1 of the predicted; FVC, forced vital capacity; FVC%, percent of FVC of the predicted; Ratio, FEV_1/FVC; *r*, Pearson's correlation.

or this may be a result of methodological differences in these studies.

This study shows that there was a statistically significant increase in the severity of restrictive pattern of spirometry when BMI increases in obese individuals. An adequate pulmonary function needs harmonic cooperation of the structure that composes the respiratory system. Obesity and increasing BMI cause more structural changes with different degrees of disruption of this harmony leading to more restriction of pulmonary function.

In this study, there was a statistically significant decrease in the ratio between FEV_1 and FVC when BMI increases the mean of the ratio in nonobese persons is 88.00±6.99 and in obese persons is 83.96 ±6.12.

Similar results were reported by Tantisira *et al.* [21] who studied the association of body mass with pulmonary function in the Childhood Asthma Management Program in USA on 1041 children with asthma and found that significant decrements in the FEV_1/FVC ratio were noted in association with increasing BMI. But Banerjee *et al.* [17] did not agree with these previous results and they found that there is a significant positive correlation of BMI with FEV_1/FVC (r=0.603, P=0.002) in non-asthmatics obese which was suggested by the restrictive effects of BMI.

In this study, there was a highly statistical significant increase in FEV_1 and FVC in men than women. Mean FEV_1 in men is 3.89±0.75 but in women it is 3.05±0.76 (P=0.000); the mean FVC in men is 4.53±0.85 but in women it is 3.63±0.87 (P=0.000).

This was comparable with Brooks and Strohl [22] who studied the size and mechanical properties of the pharynx in 23 healthy men and 34 women and found that men had significantly larger mean values for all pulmonary variables, but this was not matched with Banerjee *et al.* [17], who studied 232 men and 192 women and found that the mean of FEV_1, FEV_1/FVC, was significantly more in women than men. This may be attributed to the different ethnic local variations between men and women.

In this study, there was no significant statistical difference between obese and nonobese individuals as regards ultrasonographic diaphragmatic indices. In obese only, right diaphragmatic excursion shows a significant decrease when BMI increases (P=0.010).

This was nearly in agreement with Carrillo-Esper *et al.* [23] who studied the Standardization of Sonographic Diaphragm Thickness Evaluations in Healthy Volunteers in 109 healthy individuals and found that there was no correlation between BMI and diaphragmatic thickness.

It also agrees with Boon *et al.* [24] who studied two-dimensional ultrasound imaging of the diaphragm: quantitative values in normal participants of at least 10 patients per sex who were recruited for each decade, starting at the age of 20–29 years up to the age of 70–79 years, with a final group aged 80 years and older in the USA and found that diaphragm thickness is minimally affected by age, sex, and body habitus.

It disagrees with Kantarci *et al.* [25] who studied Normal Diaphragmatic Motion and the Effects of Body Composition of 183 volunteers selected from healthy participants during a 6-month period in Istanbul and found healthy participants with smaller BMI showed decreased diaphragmatic motion and as BMI increases the diaphragmatic motion increases; however, the relation is not linear.

In this study, there was a statistically significant increase in right diaphragmatic excursion in men rather than women. Also, there was a highly significant statistical increase in left diaphragmatic excursion in men more than women. DTF shows a statistically significant decrease in men rather than women.

This was not matched with Harper *et al.* [26] who studied the Variability in Diaphragm Motion During Normal Breathing, assessed with a B mode ultrasound on a minimum of 10 patients per sex who were recruited for each decade, from ages 20 to 29 years up to 70 to 79 years. With a final group aged 80 years and older it was found that there was no significant difference in the thickening ratio (DTF) between men and women.

There is lack of data about the difference between sex and diaphragmatic excursion.

In this study among all persons there was a highly significant statistical increase in right diaphragmatic excursion and both right and left diaphragmatic thickness when FEV_1 increases. A significant increase in left excursion and DTF was also noticed with increased FEV_1. However, there was a significant decrease in DTF with increased FVC%.

This was in concordance with Youssufa *et al.* [27] who studied the role of transthoracic ultrasound in evaluating patients with chronic obstructive pulmonary disease on 60 male participants in El-Kasr El-Aini Hospital, Cairo and found a statistically significant positive correlation that was observed between FEV_1 and diaphragmatic excursion, but that study worked on the right side only. Similar results were observed by Eman *et al.* [28] who studied Ultrasonography Assessment of Diaphragm in Asthmatic Children and the Effects of Diaphragm Strengthening Exercise on Angiogenin Level and Pulmonary Functions at Ain Shams University Hospital, Cairo, on 45 (23 male and 22 female children) asthmatic children and found that there was a positive correlation between FEV1 and diaphragmatic excursion and thickness.

In this study among all persons, there was a highly significant increase in both right and left diaphragmatic thickness and excursion when FVC increases.

This was in agreement with Fantini *et al.* [29], who studied ultrasound assessment of diaphragmatic function in patients with amyotrophic lateral sclerosis on 41 (30 men and 11 women) patients, in Italy and found that diaphragmatic thickness evaluation by ultrasound is feasible and a significant positive correlation with FVC was found.

But it partially correlated with Santana *et al.* [30] who studied diaphragmatic mobility and diaphragm thickening in interstitial lung disease and found no correlation between DTF and spirometric parameters on 40 consecutive patients in Brazil, but found positive correlations between diaphragmatic mobility during deep breathing and FVC as a percentage of the predicted value. This is could be explained by the associated sonographic pleural signs of ILD ranging from pleural thickening, nodularities, and interrupted pleural line which surely affect the measured sonographic indices of the diaphragm.

This study shows that in nonobese population, there was a highly significant increase in right diaphragmatic excursion when FVC increases. A significant increase in right excursion and left excursion was also noticed with increased FEV_1% and FVC, respectively. However, there was a significant decrease in DTF with increased FVC%.

In this study in obese persons, there was a highly significant increase in both right and left diaphragmatic thickness and right diaphragmatic excursion when FEV_1 increases. Also, there was a highly significant increase in both right and left diaphragmatic excursion and diaphragmatic thickness and when FVC increases. A significant increase in left excursion was also noticed with increased FEV_1.

Ali and Mohamad [31] who studied diaphragm ultrasound as a new functional and morphological index of outcome, prognosis, and discontinuation from mechanical ventilation in critically ill patients and evaluating the possible protective indices against VIDD and Osman and Hashim [32] who studied diaphragmatic and lung ultrasound application as new predictive indices for the weaning process in ICU patients were the only Egyptian researchers who studied DTF, but it was not correlated to spirometric parameters and BMI measurements as this study did.

In this study in obese persons, there was no significant statistical difference between the degree of restrictive pattern and ultrasonographic diaphragmatic indices. This could be explained by the presence of no significant relation between BMI and sonographic diaphragmatic indices except that previously mentioned with right excursion.

Stud limitations

The current study as any other studies has its own limitations that should be noted. Obesity make the evaluation of the diaphragm by ultrasound so difficult due to poor echogenicity. Left side is far more difficult in the evaluation by ultrasound. Given the relatively small size of this study sample with the wide age, BMI and sex variations, there was limited power to assess how these variables affect sonographic diaphragmatic and spirometric indices. However, this is the largest study in Egyptian volunteers assessing all diaphragmatic sonographic indices.

Conclusion

This study shows that there is a negative correlation between BMI and both spirometric parameters and only one ultrasonic diaphragmatic parameter (right diaphragmatic excursion). Regardless of the BMI, different correlations were found between spirometric and ultrasonographic diaphragmatic indices. Positive correlation between different spirometric parameters and ultrasonic diaphragmatic parameters except DTF as previously mentioned. Men have a stronger diaphragm that is obvious in the diaphragmatic excursion and thickness and also in spirometric parameters. BMI affects the grade of restriction in spirometry above a limit of obesity.

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Conflicts of interest

There are no conflicts of interest.

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