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Ultrasonographic findings of the normal diaphragm: thickness and contractility

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Background: Neuromuscular ultrasound can be used to assess the diaphragm. Before it can be used clinically, the reference ranges of diaphragm thickness and contractility must be determined.
Methods: We measured the thickness of the diaphragm and the diaphragmatic thickening fraction (DTF) in 80 healthy volunteers with ultrasound and collected their demographic information to determine if age, sex, and body mass index (BMI) influence these measures.
Results: The thickness of the diaphragm at resting end expiration was 0.193 ± 0.044 cm on the right side and 0.187 ± 0.039 cm on the left. The DTF was 104.8 ± 50.6% on the right side and 114.9 ± 49.2% on the left. Sex, weight, height, and BMI significantly affected the thickness of the diaphragm, but had little effect on the DTF.
Conclusions: Normal reference values for the diaphragm should be helpful when evaluating the diaphragm. The DTF appears more useful than resting diaphragm thickness because it is affected less by individual variation.

Key words: Ultrasonography; Reference values; Diaphragm

INTRODUCTION

The diaphragm is the major muscle of respiration and its dysfunction is associated with problems ranging from orthopnea to prolonged recovery from surgery or ventilator management. Common causes of diaphragm dysfunction include phrenic neuropathy, motor neuron disease, neuromuscular junction disorders, and myopathy.[1-3]

Although there are several diagnostic tests available for evaluating the diaphragm, each of them has limitations.[4,5] Chest x-rays are relatively insensitive. Fluoroscopy is difficult to quantitate, and, like computed tomography, involves radiation exposure and transportation need. Magnetic resonance imaging presents challenges for patients in the intensive care unit and

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is costly. Electromyography is invasive and risks pneumothorax. Neuromuscular ultrasound has recently emerged as a useful tool for the evaluation of muscles and nerves. Ultrasound is painless, portable, and poses no radiation hazards. In this study, healthy Korean volunteers underwent ultrasound of the diaphragm to establish reference values and to further investigate demographic factors influencing diaphragm thickness.

MATERIALS AND METHODS

Subjects

We recruited 80 healthy volunteers between 20 and 60 years of age through advertisements placed on bulletin boards. The participant pool consisted of an equal number of men (n = 40) and women (n = 40), with 10 men and 10 women from each age decade. Participants were excluded from this study if they were diagnosed with a neuromuscular disorder that could cause diaphragm dysfunction (peripheral neuropathy, myopathy, motor neuron disease, or central nervous system disease), were abusers of alcohol, had been exposed to tuberculosis medication or an antineoplastic agent, or had a history of dyspnea. Chest x-rays were used to exclude asymptomatic diaphragm palsy.[6] This study was approved by our institutional review board and all subjects provided informed consent.

Methods

Demographic data were collected, including age, sex, height, and weight; body mass index (BMI) was calculated from height and weight.

High-resolution ultrasound scans were obtained using a Philips iU22 scanner (Philips Medical Systems, Bothell, WA, USA) with a 12-MHz linear array transducer. All measurements were made by a single ultrasonographer with more than 3 years of experience in musculoskeletal ultrasound. Ultrasound scans of the diaphragm bilaterally were obtained while the participant was in a supine position (Fig. 1) following a previously described approach[7] as subsequently detailed. To obtain an intercostal view in the zone of apposition, the transducer was placed at the anterior axillary line between the seventh and eighth or eighth and ninth ribs. In this view, real-time movement of the diaphragm was recorded in B mode, and the diaphragm was outlined by the two hyperechoic lines of the pleural and peritoneal membranes. Diaphragm thickness was measured by placing electronic calipers just inside the two hyperechoic lines where the lines were most parallel (usually at the midline between the two ribs). Two images for each measurement were averaged to give a thickness at resting end expiration, resting end inspiration, and maximal inspiration. The thickness at maximal inspiration was measured at the point of maximal inspiration or at the point which the diaphragm became obscured by the lung. Then, the diaphragm

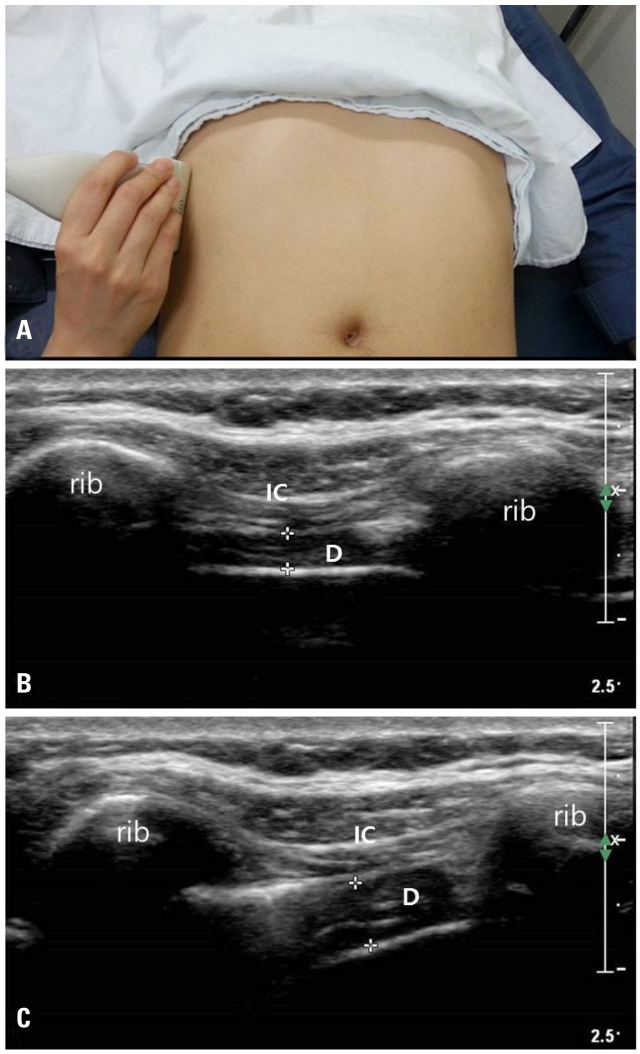

Fig. 1. Measurement of diaphragm thickness. (A) The transducer is positioned on the intercostal space in the anterior axillary line. (B) At the end of quiet expiration, the diaphragm is seen as a hypoechoic structure between two hyperechoic fascia bands. (C) At maximal inspiration, the diaphragm is seen 'peeling away' from the chest wall. The distance between the two marks (+) is the muscle thickness. D, diaphragm; IC, intercostal muscle.

thickness fraction (DTF) was calculated as a percentage using the following formula:

DTF = (thickness at maximal inspiration – thickness at resting end expiration)/(thickness at resting end expiration)

Statistical analysis

The paired *t*-test or Wilcoxon signed-rank test was used to evaluate the differences between both sides in diaphragm thickness and the DTF. Two-sample *t*-test or Mann-Whitney U test was used to compare muscle thickness and DTF between men and women. One-way analysis of variance (ANOVA) or Kruskal-Wallis test was used to compare among the different age. The correlations between the diaphragm thickness and height, weight and BMI among the participants were assessed using Pearson's correlation coefficients. Correlation coefficients between the DTF and height, weight and BMI among the participants were also calculated.

All analyses were performed using SPSS ver. 19.0 (SPSS Inc., Chicago, IL, USA). All data are presented as the means ± standard deviation (SD) and a *p*-value < 0.05 was considered statistically significant.

RESULTS

This study included 80 healthy Korean volunteers (40 men, 40 women; mean age 38.5 ± 8.3 years [range 20–60]). The mean height, weight, and BMI were 166.2 ± 8.3 cm, 62.1 ± 11.1 kg, and 22.3 ± 2.4 kg/m^2, respectively. The diaphragm was easily visualized and measured with ultrasound on both sides. Table 1 shows the reference values for the thicknesses of the diaphragm and the DTF. The lower limit of normal resting thickness was 0.11 cm on both sides. The lower normal limit of DTF was 28% for the right side and l7% for the left. There was no significant difference in thickness or DTF between the both sides.

The thickness of the diaphragm was significantly greater in men than in women and was significantly correlated with weight, height, and BMI (Table 2). In contrast, there was no significant difference in the DTF between men and women for the group as a whole, although the DTF was greater in men on the right side. The DTF was not related to weight, height, or BMI on either side.

DISCUSSION

This study determined normal reference values for the thickness of the diaphragm and the DTF in a Korean population. Several studies have obtained the normal range of diaphragm thickness or thickening ratio in healthy subjects. One large study on normal diaphragm values was done by Boon et al., who studied 150 healthy individuals in the USA.[8,9] In their study, the mean diaphragm thickness was 0.33 cm and the lower limit of the normal resting thickness was 0.15 cm, which are much larger than the reference values in

Table 1. Normal reference values for diaphragm thickness and the diaphragm thickness fraction (DTF)

	Side	Mean	SD	Percentiles 2.5th, 97.5th	Reference range
Diaphragm thickness (cm)					
Resting	Rt	0.19	0.04	0.11, 0.32	0.11-0.28
	Lt	0.19	0.04	0.11, 0.26	0.11-0.27
Maximal inspiration	Rt	0.39	0.13	0.21, 0.66	0.14-0.65
	Lt	0.39	0.10	0.22, 0.60	0.20-0.60
DTF (%)	Rt	105	51	28, 258	28-258
	Lt	115	49	36, 216	17-213

The reference range was determined as the mean ± 2 SD for normally distributed data and from the 97.5th percentile for non-normally distributed data. Diaphragm thickness and DTF for the left side are distributed normally.
Rt, right; Lt, left; SD, standard deviation.

Table 2. Diaphragm thickness and the diaphragm thickness fraction (DTF) according to demographic factors

	DT, resting		DT, maximal inspiration		DTF[c]	
	Rt	Lt	Rt	Lt	Rt	Lt
Age, mean (SD)						
3rd decade	0.19 (0.04)	0.18 (0.04)	0.40 (0.09)	0.41 (0.11)	107 (41)	134 (47)
4th decade	0.20 (0.06)	0.18 (0.04)	0.38 (0.13)	0.39 (0.10)	90 (43)	115 (54)
5th decade	0.19 (0.04)	0.20 (0.04)	0.40 (0.13)	0.42 (0.09)	106 (48)	119 (44)
6th decade	0.19 (0.03)	0.19 (0.04)	0.40 (0.15)	0.37 (0.09)	116 (66)	91 (45)
p-value	0.77	0.31	0.97	0.34	0.44	0.04[b]
Sex, mean (SD)						
Male	0.22 (0.05)	0.21 (0.03)	0.47 (0.12)	0.44 (0.10)	118 (56)	118 (50)
Female	0.17 (0.03)	0.17 (0.04)	0.32 (0.08)	0.35 (0.08)	92 (41)	112 (49)
p-value	<0.001[b]	<0.001[b]	<0.001[b]	<0.001[b]	0.02[b]	0.56
Height						
CC	0.659	0.567	0.512	0.340	0.071	−0.137
p-value	<0.001[b]	<0.001[b]	<0.001[b]	<0.001[b]	0.53	0.22
p-value[a]	<0.05[b]	0.15	0.16	0.99	0.48	0.38
Weight						
CC	0.596	0.454	0.540	0.380	0.164	0.013
p-value	<0.001[b]	<0.001[b]	<0.001[b]	<0.001[b]	0.15	0.90
p-value[a]	<0.001[b]	<0.05[b]	0.12	0.65	0.08	0.06
BMI						
CC	0.513	0.496	0.339	0.213	−0.026	−0.222
p-value	<0.001[b]	<0.001[b]	<0.05[b]	0.06	0.82	0.05
p-value[a]	<0.001[b]	<0.05[b]	0.24	0.52	0.08	0.07

DT, diaphragm thickness in cm; Rt, right; Lt, left; SD, standard deviation; CC, correlation coefficient; BMI, body mass index.
[a]*p*-value adjusted for age and sex.
[b]Significant values ($p < 0.05$).
[c]Diaphragm thickness fraction as a %.

our study. Higher BMI (27.9 ± 5.3 kg/m^2) than those of our study (22.3 ± 2.4 kg/m^2) may partly explain these differences. Other studies of reference values in smaller populations found mean diaphragm thickness to be 0.16–0.27 cm.[10-12] These differences may be secondary to the ethnic background of subjects or differences in ultrasound devices or technique.

A chronically paralyzed diaphragm is thin and does not thicken during inspiration. In such cases, both the diaphragm thickness and thickening ratio are useful. However, the thickness can be normal in an acutely paralyzed diaphragm, and it may even be paradoxically increased in Duchenne muscular dystrophy despite intrinsic muscle weakness.[13] To identify acute onset diaphragm paralysis, the degree of diaphragm thickening is thought to be more sensitive than measuring thickness. A change in diaphragm thickness of 28–96% has been reported in healthy volunteers.[11] Another report proposed that diaphragm thickening of <20% is consistent with paralysis.[14] Boon et al. suggested that a decrease in thickening ratio below 1.2 (DTF = 20%) may help to identify an abnormality.[8,9]

Prior studies have shown a relationship of diaphragm thickness and body size and gender, similar to the findings in this study.[8,9] In our study, DTF was relatively unaffected by demographic factors compared with diaphragm thickness. Although DTF was affected by age for the left side and by sex for the right side, the findings were not consistent for both sides and were minimal compared with thickness.

This study had some limitations. It is possible that M-mode imaging in addition to B-mode imaging may have provided additional useful information. Secondly, two parameters including diaphragm thickness and DTF were measured in this study. Future studies looking at echointensity and echo homogeneity of the diaphragm, as well as estimating diaphragm volume may be informative. Thirdly, we did not assess the effects of physical activity on DTF. It is possible that the degree of physical activity could influence DTF and this may be relevant in future studies. Our study is also limited somewhat by the sample size, in that it is possible that a larger or somewhat older sample might have enhanced the data. Also, it is possible that genetic, dietary, or environmental factors present in more heterogeneous populations may influence the reference ranges of diaphragm parameters. Finally, body posture may affect diaphragm thickness.[15] In this study, the measurements were made with the subjects supine, but when upright, the diaphragm thickness may be increased.[15]

In conclusion, these normal reference values may be helpful for evaluating diaphragm pathologies. BMI, weight, height, and gender correlated significantly with diaphragm thickness. Correcting for these factors may enhance the diagnostic relevance of these painless, non-invasive measures. DTF was affected less by demographic factors. Therefore, DTF may be useful, especially in individuals who exceed the age or BMI ranges of the subjects in this study.

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Conflicts of Interest
The authors have no conflicts to disclose.

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