UNIVERSITY of MARYLAND SCHOOL OF MEDICINE

PHYSICAL THERAPY AND REHABILITATION SCIENCE

Diaphragm Thickness Correlates with Breathing Performance on the Six-Minute Walk Test in Healthy Children and Adolescents

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Introduction

- The diaphragm is the primary muscle of ventilation and has been associated with exercise capacity[1] and perceived exertion.[2] However, the underlying mechanisms for how the diaphragm affects these areas is not fully understood, especially in children and adolescents. Although previous studies have shown that the regulation of breathing parameters such as respiratory frequency (f_R) and tidal volume (V_T) during exercise play a major role in performance,[3] whether diaphragm structure and function impact these parameters is not clear.
- **Purpose:** To explore relationships between diaphragm structure and function and breathing performance during the six-minute walk test (6MWT) in healthy children and adolescents.
- **Hypothesis:** Measures of diaphragm structure and function will be correlated with breathing performance on the 6MWT.

Methods

Inclusion Criteria:
- 6–17 years of age
- No history of cardiovascular, pulmonary or neuromuscular disease

Procedures:
- Respiratory mouth pressure tests were performed using a MicroRPM respiratory pressure meter (Vyaire, Mettawa, IL, USA) with a flanged mouthpiece to obtain maximal inspiratory pressure (MIP) and maximal expiratory pressure (MEP) according to American Thoracic Society guidelines.[4]
- Diaphragm thickness was measured via two-dimensional B-mode ultrasonography (figure 2) as described by Spiesshoefer et al.[5] using a 7.5–10 MHz frequency 45-mm linear transducer (SonoQue C4PL Dual Head Probe, O2 Lifecare, Inc., Yorba Linda, CA, USA).
- The six-minute walk test (6MWT) was used to measure functional capacity.[6] Participants were instructed to walk continuously as fast as possible without running along a 50-foot (15.24 m) out-and-back course marked with cones for 6 minutes (figure 3). The Borg category ratio (CR-10) scale was used to assess rate of perceived exertion (RPE) on a 0–10 scale[7] at the end of the 6MWT.
- Breathing performance (f_R, V_T and minute ventilation [$\dot{V}_E$]) during the 6MWT was measured via breath-by-breath expired gas analysis using the VO_2 Master Pro Metabolic Analyzer (VO2 Master Health Sensors Inc., Vernon, BC, Canada).
- Pearson's correlation coefficient (r) was used to assess the relationships between diaphragm structure and function and breathing performance. Statistical significance was set at $p \leq 0.05$.

Measurements

Diaphragm Thickness Measurements:
At the *zone of apposition* (figure 1), the diaphragm was visualized as three distinct layers on B-mode ultrasonography (figure 2):
(1) echogenic outer layer representing the diaphragmatic pleura;
(2) hypoechoic layer representing the fibrous muscular layer; and
(3) echogenic inner layer representing the peritoneal membrane.

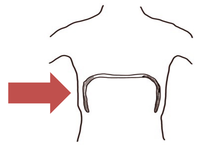
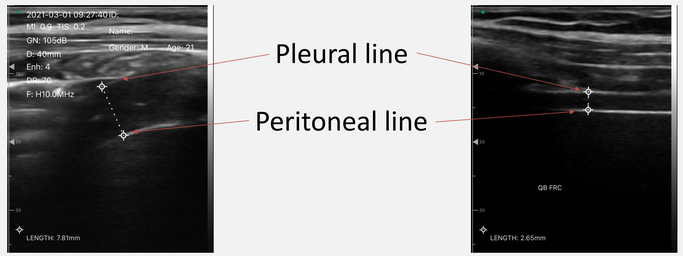


Figure 1. *Zone of Apposition*

Figure 2. *Thickness in mm was defined as the perpendicular distance from the middle of the pleural line to the middle of the peritoneal line.*



Total Lung Capacity (TLC) | Functional Residual Capacity (FRC)

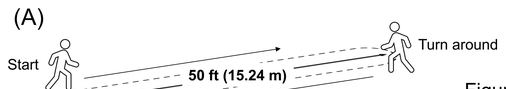
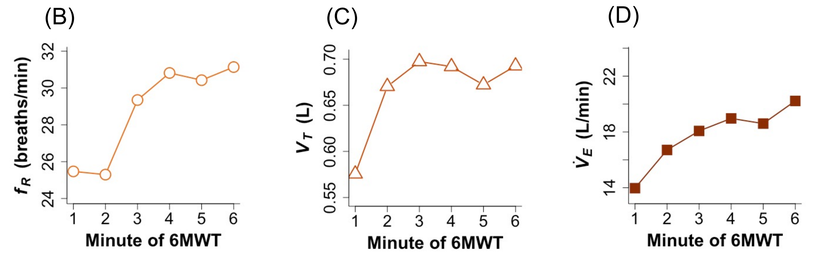


Figure 3. *Schematic of Six-Minute Walk Test (6MWT) **(A)**; average breathing performance during each minute of the 6MWT **(B–D)**; f_R, respiratory frequency; V_T, tidal volume; $\dot{V}_E$, minute ventilation.*



Results

Table 1
Participant characteristics (n = 10)

	Mean	SD
Age, years	10.40	± 2.22
Female/Male	5/5	
Height, cm	148.45	± 17.55
Weight, kg	40.48	± 11.60
BMI (kg/m²)	17.96	± 1.88
MIP, cmH_2O	93.7	± 17.46
MEP, cmH_2O	104.8	± 10.43
Th_{TLC}, mm	2.41	± 0.62
Th_{FRC}, mm	1.58	± 0.24
TF	0.52	± 0.29
Distance, m	574.95	± 69.64

BMI = body mass index; Th_{TLC} = thickness at total lung capacity; Th_{FRC} = thickness at functional residual capacity; TF = thickening fraction; SD = standard deviation

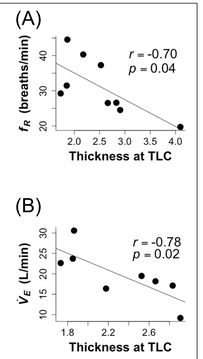


Figure 4. *Relationship between diaphragm thickness and breathing performance. Thickness at total lung capacity (TLC) and respiratory frequency (f_R) **(A)**; thickness at TLC and minute ventilation ($\dot{V}_E$) **(B)**.*

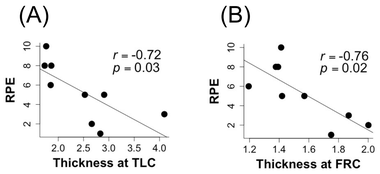


Figure 5. *Relationship between diaphragm thickness and rate of perceived exertion (RPE). Thickness at total lung capacity (TLC) and RPE **(A)**; thickness at functional residual capacity (FRC) and RPE **(B)**.*

Conclusions

- These findings suggest that greater diaphragm thickness was associated with lower ventilatory demand, yet diaphragm strength was not related. Greater diaphragm thickness might be associated with changes in chest wall mechanics, which can potentially alter the sensation of dyspnea and the control of breathing. Thus, the structure and function of the diaphragm muscle may have a mechanistic role that affects the regulation of the respiratory rhythm and ultimately exercise performance.

References

1. Welch JF et al. *J Appl Physiol* (1985). 2018;125(6):1987-1996. doi:10.1152/japplphysiol.00630.2018
2. Boyle KG et al. *J Physiol.* 2020;598(15):3223-3237. doi:10.1113/JP279755
3. Nicolò A et al. *Physiol Rep.* 2018;6(21):e13908. doi:10.14814/phy2.13908
4. ATS/ERS Statement on Respiratory Muscle Testing. *Am J Respir Crit Care Med.* 2002;166(4):518-624. doi:10.1164/rccm.166.4.518
5. Spiesshoefer J et al. *Respiration.* 2020;99(5):369-381. doi:10.1159/000506016
6. ATS Committee on Proficiency Standards for Clinical Pulmonary Function Laboratories. *Am J Respir Crit Care Med.* 2002;166(1):111-117. doi:10.1164/ajrccm.166.1.at1102
7. Pianosi PT et al. *Respir Physiol Neurobiol.* 2014;199:34-40. doi:10.1016/j.resp.2014.04.003