# Body Position Affects Ultrasonographic Measurement of Diaphragm Contractility

*Christopher Brown, PT, PhD(c), DPT, CSCS; Shih-Chiao Tseng, PT, PhD; Katy Mitchell, PT, PhD; Toni Roddey, PT, PhD*

School of Physical Therapy, Texas Woman's University, Houston, TX

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***This study (protocol #18513) was approved by the Texas Woman's University—Houston Institutional Review Board (IRB) on September 9, 2015, and renewed on September 24, 2016, prior to involvement with study participants.***

**Purpose:** (1) Determine whether ultrasonography can detect differences in diaphragm contractility between body positions. (2) Perform reliability analysis of diaphragm thickness measurements in each test condition. **Methods:** We used a repeated-measures experimental design with 45 healthy adults where 3 B-mode ultrasound images were collected at peak-inspiration and end-expiration in supine, sitting, and standing. Mean diaphragm thickening fractions were calculated for each test position. Statistical significance was tested using 1-way repeated-measures analysis of variance with planned comparisons. For reliability analysis, the intraclass correlation coefficient (3, 3) was calculated. **Results:** Mean diaphragm thickening fraction increased from 60.2% (95% confidence interval [CI] 53.0%, 67.9%) in supine, to 96.5% (95% CI 83.2%, 109.9%) while seated and to 173.8% (95% CI 150.5%, 197.1%) while standing. Body position was a significant factor overall ($P < .001$), as were comparisons between each individual position ($P < .001$). Intraobserver reliability was excellent (>0.93) for all body positions tested. **Conclusions:** Ultrasound imaging detected positional differences in diaphragm contractility. The effect of gravitational loading on diaphragm length-tension, and body position-mediated changes in intra-abdominal pressure may explain the differences found. Future research should address methodological concerns and apply this method to patients participating in early mobilization programs in the intensive care unit. **(Cardiopulm Phys Ther J. 2018;29:166–172)** *Key Words: ultrasonography, diaphragm, patient positioning*

## INTRODUCTION AND PURPOSE

Diaphragm dysfunction is a frequent problem on admission to the intensive care unit (ICU),[1] and as a consequence of interventions while there.[2–5] Mechanical ventilation (MV) is frequently required to offload and support the diaphragm when in acute respiratory failure,[2] but failure to liberate the patient in a timely manner may result in a loss of force-generating capacity for the diaphragm known as ventilator-induced diaphragm dysfunction (VIDD).[3–5] Receiving MV also places one at a high risk of physical decline from excessive, prolonged bed rest and immobility.[6,7]

Physical therapists (PTs) use ICU early mobilization rehabilitation programs to ameliorate the effects of bed rest and improve physical function.[6,8] These programs are safe, feasible, and provide at least short-term improvements in physical function.[9–13] They also contribute to reduced ICU and hospital lengths of stay, fewer days on MV, and lower in-hospital mortality rates.[14] Recommendations have been made as to which tests and measures should be used during these programs,[15,16] and a significant volume of research has been conducted measuring the effects of VIDD.[17] Yet, guidance on respiratory muscle testing in the context of



**Correspondence:** Christopher Brown, PT, PhD(c), DPT, CSCS, School of Physical Therapy, Texas Woman's University, 6700 Fannin Street, Houston, TX 77030 (chris.brown.dpt@gmail.com).

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early mobilization has been limited to methods lacking specificity for the diaphragm,[18–20] and measurement of diaphragm dysfunction during early mobilization programs, specifically, is yet to be reported in the literature.

This is despite the emergence of using diaphragm ultrasound imaging to quantify its motion or muscle contractility during the ICU admission.[21–23] This imaging modality has shown broad applicability in the ICU,[24–39] and demonstrated strong methodological properties.[24,31–33,37,40] It may be applied repeatedly at bedside[23,27,34,37] while avoiding the exposure to ionizing radiation associated with conventional radiographs or fluoroscopy.[21–23,30] In addition, it negates the impracticality of transporting critically ill patients for computed tomography or magnetic resonance imaging.[21,30] Successful training programs for novice diaphragm ultrasonographers have been reportedly brief,[24,33,41,42] suggesting accessibility to PTs working in the ICU.

When diaphragm ultrasound imaging is applied in the ICU, it is typically done in the supine, or semi-recumbent position;[22] yet, during early mobilization programs, patients often progress by moving to upright positions, then walking.[42,43] Knowing the position-dependent demand on the diaphragm may assist a PT's decision-making during early mobilization interventions. The validity of ultrasound imaging during rehabilitation may be context-dependent, where the muscle studied, contraction intensity, and activation strategy used must be considered.[44] It is hypothesized that this supposition applies to diaphragm contractility, and differences occur when moving to upright positions.

Thus, this study's purpose is to detect whether differences in diaphragm contractility may be reliably measured with changes in body position. To the best of our knowledge, the diaphragm thickening fraction (ie, a measure of diaphragm contractility; the relative increase in muscle thickness on inspiration) has not been contrasted between the supine, seated, and standing positions. We propose 2 research questions. Using an intercostal approach,[45] can B-mode ultrasound detect differences in diaphragm contractility between these 3 body positions? Additionally, can diaphragm thickness be reliably measured at end-expiration, and peak-inspiration, in each test position?

## METHODS

### Participants

This prospective study was performed at Texas Woman's University (TWU) Institute of Health Sciences–Houston Center in the cardiopulmonary laboratory during October and November of 2015. The Texas Woman's University Institutional Review Board approved this study before involvement of participants. No specific data are available as a reference for expected effect size; thus, sample size was based on an assumed small to medium effect size of $f = 0.2$. Thus, statistical power analysis (G*Power, Dusseldorf, Germany), assuming 80% power, suggested 42 participants be recruited. An additional 3 subjects were available for testing, resulting in a convenience sample of 45 healthy graduate students. Participant characteristics are summarized in Table 1.

Inclusion criteria were being apparently healthy, 18 years or older, and having the ability to sit and stand independently. Participants were excluded from the study if they had any neuromuscular disease potentially affecting the diaphragm, pulmonary or respiratory disease, any disease involving the abdomino-pelvic compartment, smoking history, obesity (ie, a body mass index [BMI] greater than 30), lack of English language proficiency, or were pregnant. An informed consent form explaining the purpose, procedures, risks, and benefits of the study was provided and signed by each participant. In addition, a medical history form was filled out to confirm meeting inclusion and exclusion criteria.

### Ultrasound Imaging

This single-factor, repeated-measures experiment involved testing in 3 body positions of interest: supine, supported sitting, and free standing. The test positions had been randomized a priori to eliminate any potential order effects. All ultrasound images were acquired in B-mode using an 8.0 MHz linear array transducer (GE Logiq Book; GE Medical Systems, Milwaukee, WI). One novice ultrasonographer (ie, a PT), who previously received 8 hours of training in ultrasonography, collected all images.

The image acquisition procedure, in brief, is as follows.[45] A mark was placed at the intersection of the right anterior axillary line and the ninth intercostal space (ie, at the "zone of apposition") to ensure consistent, transverse planar application of the transducer. Three images were acquired at the end of 3 nonconsecutive breaths during quiet expiration (ie, at the functional residual capacity [FRC]) and stored. Participants were then cued to breathe as deeply as possible, and 3 images were acquired at the peak of inspiration during nonconsecutive breaths. The timing of image acquisition was done visually, in real-time, by viewing the phasic changes in diaphragm muscle thickness on the

**TABLE 1**

Participant Demographics

| Characteristic (n = 45) | Mean (SD) |
|---|---|
| Age (yrs) | 26.0 (3.4) |
| Sex, *n* female (%) | 31 (69) |
| Height (cm) | 168 (9.8) |
| Weight (kg) | 66 (12) |
| BMI (kg/m$^2$) | 23.4 (2.9) |

BMI, body mass index.

ultrasound machine's monitor during cine mode as participants breathed. This was done to ensure that image acquisition, and subsequent diaphragm thickness measurements, were made at the discrete moments of end-expiration or peak-inspiration. The entire process of image acquisition was repeated in the second and third body positions. Image acquisition ranged from 15 to 20 minutes per participant and was completed in only one testing session.

Image diaphragm muscle thickness measurements and processing were made using ImageJ software, version 1.49 (Bethesda, MD: National Institutes of Health). The diaphragm was identified as the deepest hypoechoic (ie, dark) 3-layered muscle encased within 2 hyperechoic (ie, bright) layers (superficially, the parietal pleura, and deeply, the peritoneum). For the purposes of muscle thickness measurements, the diaphragm muscle layer was identified per Ueki et al[45] as being the perpendicular distance between the middle of the parietal pleura fascial layer and the middle of the peritoneal fascial layer. All measurements are accurate to 0.01 cm. Using the ruler (in centimeters) within the raw ultrasound image, the set scale function in ImageJ was used to convert the number of pixels measured by the line tool to centimeters. To ensure that diaphragm muscle thickness measurements were made at the same location, the 3 images for given position were overlaid, and a mark was made to ensure consistent application of the line tool. The mean of the 3 measurements of diaphragm muscle thickness were calculated for both peak-inspiration and end-expiration, for each body position tested.

Diaphragm contractility was operationally defined as the diaphragm thickening fraction, or the increase in diaphragm thickness at peak-inspiration relative to end-expiration. Using these data, the diaphragm thickening fraction was calculated, for each participant, using the formula: ([peak-inspiration − end-expiration]/[end-expiration]) × 100.[46]

## Data Analysis

Statistical analysis was conducted using IBM SPSS Statistics for Macintosh, Version 21.0 (Armonk, NY: IBM Corp.). The assumption of normality was met, and parametric statistical methods were used exclusively. The assumption of sphericity was examined using Mauchly test and, ultimately, Greenhouse-Geisser corrections were made for violation of this assumption. A 1-way repeated-measures analysis of variance was used to look for differences in the diaphragm thickening fraction with body position as the only factor. Planned comparisons of supine versus sitting, supine versus standing, and sitting versus standing were conducted using a *t* test with Bonferroni correction for multiple comparisons. Statistical significance, for all tests, was set at $P < .05$ with 2-tailed distributions.

For intrarater reliability, the intraclass correlation coefficient (3, 3) were calculated from the 3 measurements of diaphragm muscle thickness at both peak-inspiration and end-expiration, in each test position. The time interval between the capture of these 3 images was 30 seconds, and the conditions of image capture remained entirely unchanged during this sequence.

## RESULTS

### Diaphragm Contractility by Position

Figure 1 depicts processed ultrasound images from a 22-year-old woman at end-expiration and peak-inspiration in the standing position. As portrayed in

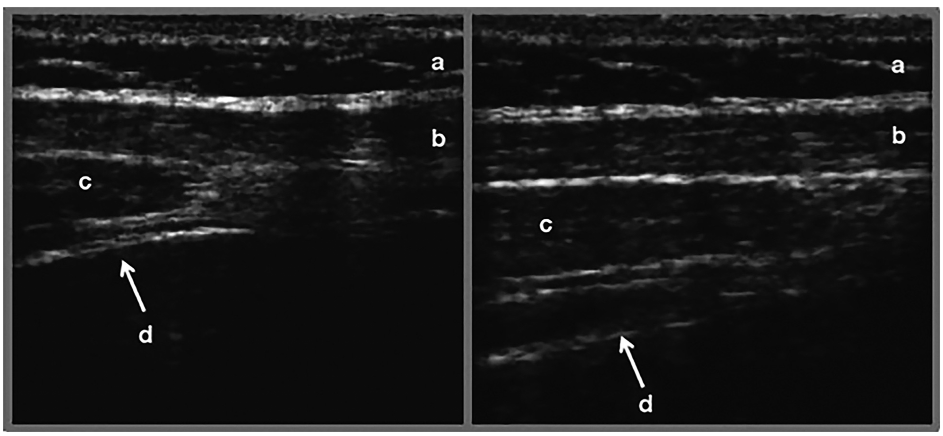


**Fig. 1.** Processed ultrasound image of the diaphragm. These images were acquired from a 22-year-old woman while standing. At the moment of end-expiration (left panel), the muscle thickness measured 0.17 cm, and at peak-inspiration (right panel) measured 0.60 cm. Note the difference in diaphragm muscle thickness between the 2 conditions. The layers of tissue are as follows (from superficial to deep): (A) subcutaneous tissue layer, (B) anterolateral abdominal wall muscles (ie, external oblique, internal oblique, and transversus abdominis), (C) intercostal muscles (external intercostal, internal intercostal, and innermost intercostal), and (D) the diaphragm, bordered superficially by the pleural membrane, and deeply by the peritoneal membrane.

**TABLE 2**

Mean (95% CI) Diaphragm Muscle Thicknesses, Thickening Fractions, and Thickening Fraction Differences by Position

| | Supine | Seated | Standing |
|---|---|---|---|
| Peak-inspiration diaphragm thickness (cm), mean (95% CI) | 0.35 (0.34–0.37) | 0.46 (0.44–0.48) | 0.65 (0.61–0.69) |
| End-expiration diaphragm thickness (cm), mean (95% CI) | 0.22 (0.21–0.24) | 0.24 (0.23–0.26) | 0.25 (0.23–0.28) |
| Diaphragm thickening fraction (%), mean (95% CI) | 60 (53–68) | 97 (83–110) | 174 (151–197) |

CI, confidence interval.

Table 2, a trend was found where the mean diaphragm muscle thickness at peak-inspiration increased as participants moved from supine to seated and to the standing position, whereas remaining essentially the same at end-expiration across these 3 body positions. In terms of the diaphragm thickening fraction, we found a similar trend (Fig. 2 and Table 2) such that it was significantly affected by body position, $F_{1.50,\ 66.18} = 66.08$, $P < .001$, and that each planned comparison (ie, supine vs seated, supine vs standing, and seated vs standing) was found to be statistically significant, $P < .001$.

## Intrarater Reliability

The intrarater reliability values at both peak-inspiration and end-inspiration, which are summarized in Table 3, were excellent, ranging from 0.93 to 0.98 for each body position tested.

## DISCUSSION

Ultrasound imaging using intercostal approach in B-mode detected a statistically significant difference in diaphragm contractility when healthy participants moved from supine to supported sitting to a free-standing body position. This study had a large sample size and excellent power to show these differences. In addition, the intrarater reliability of measurements of peak-inspiration and end-expiration diaphragm muscle thickness measurements were excellent, with all values greater than 0.9 for each test position, thus lending support for using the method described here in future research studies. There were several novel aspects to this study. To the best of our knowledge, this is the first study to use ultrasound imaging to have tested for differences in this variable across body positions, and to report the magnitude of these differences.

Although alternative approaches, modes, and methods are available to study diaphragm function, we chose to use an intercostal approach in B-mode to measure diaphragm muscle contractility. This method, originally proposed by Ueki et al,[45] and replicated by Cohn et al,[46] was subsequently used in several studies.[24,31,34,35,37–39,48] As the subcostal approach only views the diaphragm's dome, we decided to use an intercostal approach due to the often cited advantage of direct visualization of the costal diaphragm's zone of apposition.[21,22,24,31,45–48] Here, soft tissue layers are quite superficial affording better resolution, bracket the muscle for clearer identification, and the orientation of the diaphragm muscle is approximately parallel to the site of application of the transducer, thus avoiding anisotropy.[21,22,24,31,45–49] Although M-mode does have the advantage of capturing multiple breaths within one image allowing for easier comparison,[33,47] its limitations include wider variability in measuring muscle thickness,[47] the potential to overestimate diaphragm muscle thickness,[46] and an inability to discriminate between excursion resulting from extrinsic mechanical positive pressure and intrinsic diaphragm contractility.[21,24,33] Although reportedly technically more challenging,[23] B-mode provides a more detailed visualization of the diaphragm in 2 dimensions, and morphometry overcomes the limitations of displacement ambiguities by representing only active diaphragm contraction.[21,24,33] In addition, we submit that our methodology overcomes the advantages of M-mode over B-mode by using a clear, precise, and consistent method to ensure the same portion of diaphragm was measured.

Our finding of 0.24 cm thickness at end-expiration FRC in sitting, and 0.46 cm at peak-inspiration is similar to the results from Ueki et al[45] and Wait et al[47] (both studies had

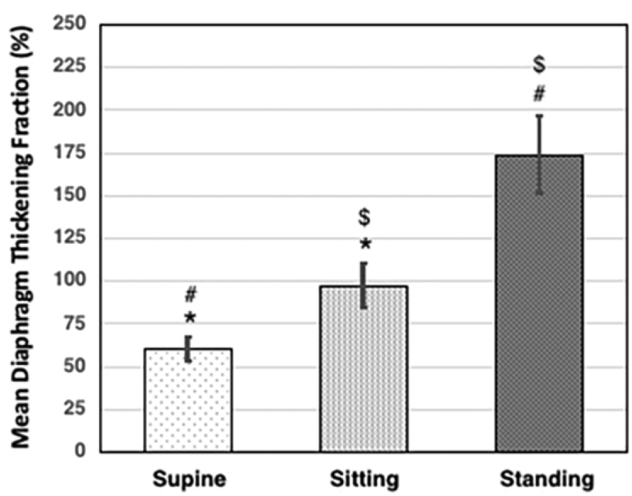


**Fig. 2.** Mean diaphragm thickening fractions (including 95% confidence interval bars), by position. # Statistically significant difference, $P < .001$.

**TABLE 3**

Intraclass Correlation Coefficients (95% CI) for Diaphragm Muscle Thickness Measurements

| | Supine | Seated | Standing |
|---|---|---|---|
| Diaphragm muscle thickness at peak-inspiration | 0.93 (0.88–0.96) | 0.93 (0.88–0.96) | 0.98 (0.97–0.99) |
| Diaphragm muscle thickness at end-expiration | 0.95 (0.92–0.97) | 0.96 (0.93–0.98) | 0.98 (0.97–0.99) |

Data represent intraclass correlation coefficient (3, 3).
CI, confidence interval.

participants seated). In our study, we found the mean end-expiration diaphragm muscle thickness to be 0.22 cm, and 0.35 cm at peak-inspiration in supine. Although the mean, supine peak-expiration diaphragm thickness of 0.35 cm calculated in our study is similar to the 0.40 cm found by Boon et al,[48] they found a much larger end-expiration measurement at the FRC in this position (0.33 vs 0.22 cm in our study). The factors contributing to this difference are not certain. It is important to note that there are methodological challenges to timing image capture at a discrete moment, such as end-expiration. In our study, the use of cine mode provided a means to accomplish this with greater facility. Without the ability to review a continuous representation of the changes in diaphragm muscle thickness, it would be expected that image capture at discrete moments in the breathing cycle would not be possible with fidelity and would introduce greater systematic measurement error.

The differences in diaphragm contractility by position are attributable to gravitational forces on the diaphragm and abdominal viscera, and the physiological response of the diaphragm and abdominal wall muscles to these forces. Gravity displaces both the diaphragm, and abdominal viscera, to a more inferior position when sitting upright or standing.[50,51] In terms of its length-tension relationship, the diaphragm now exists in a shortened state, and experiences decreased resting, muscular tension, and mechanical efficiency. A compensatory increase in neural activation of the diaphragm occurs to offset reduced mechanical efficiency on inspiratory effort, which allows for transdiaphragmatic pressures to be preserved in the upright individual relative to one who is supine.[50] The response to gravitational displacement of abdominal viscera on moving to an upright position is an active, tonic contraction of the abdominal wall muscles.[51] This reduces abdominal wall compliance, which increases intra-abdominal pressure. Diaphragm contractility must further increase to overcome increased intra-abdominal pressure in its mechanically less efficient position to preserve transdiaphragmatic pressures.[50,51]

Finally, regarding the observed increase in diaphragm contractility when participants moved from sitting to standing, one must note the details of our test conditions. In this study, participants sat supported in a backed chair, and were free of any support when standing, as this was considered more representative of the specific positional conditions a patient might experience while in the ICU. Although the upright, seated position involves the same gravitational loading on the diaphragm and abdominal viscera as one would experience while standing,[50] the physiological response of these muscles to gravitational loading would be expected to vary depending on the level of positional support. Because of trunk support against the back of the chair, the positional demands on abdominal wall muscles and, indirectly, on the diaphragm would be less than what was observed when standing without support.

## Study Limitations

This study carries several limitations, reducing its generalizability. The results describe young, healthy people, and represent an important first step in studying the effects of body position on diaphragm contractility. It is envisioned that the study would need to be replicated in the ICU setting with patients suffering from critical illness, who may be on some form of invasive MV, to ascribe any clinical significance to the results.

Subgroup analysis by sex was not done in this study. Although a previous study by Thurlbeck,[52] using cadaver studies, concluded that the diaphragm is typically larger in males when factoring in body weight, it is unclear that this necessarily supports the notion that diaphragm contractility is higher in males in vivo. More recent studies[48,53] have not found a difference in diaphragm thickening ratios between sexes, which supports our decision to not split analysis of the participants by sex. These same studies also failed to find a difference between the right and left hemidiaphragms' thickening ratios;[48,53] thus, only the right hemidiaphragm was imaged. Several studies have reported the difficulties in obtaining clear imaging of the left hemidiaphragm;[23,33,39] thus, it was not attempted.

The approach at the zone of apposition requires visualizing beneath subcutaneous adipose tissue; thus, there is concern with respect to feasibility of this method with patients who are obese,[23,49] and in terms of how to control the degree of pressure applied to the transducer against the skin.[49] Considering this technical challenge, and that BMI has previously been found to be somewhat correlated with diaphragm muscle thickness measurements,[48,53] participants in the obese BMI range (≥30 kg/m$^2$) were excluded. Keeping this as a criterion for exclusion from study participation certainly limits generalizability, as patients who are obese certainly will be encountered in the ICU.

Finally, although the intrarater reliability was excellent, which establishes repeatability, reproducibility was not established with other operators and/or observers.

## Future Studies

Future studies should address methodological issues associated with diaphragm ultrasound in ideal circumstances before study in the ICU during early mobilization programs. If this instrument is to be accepted in this context, generalizability must be improved. Factors such as age, sex, type and severity of illness, body composition, and adipose tissue thickness must be inserted into the analysis of position-dependent diaphragm contractility. Overcoming the difficulties in imaging the left hemidiaphragm would be helpful as well. Repeatability and reproducibility results should be reported, as should the protocol by which reliability analysis was conducted.

The application of ultrasound imaging to early mobilization programs in the ICU represents an important research agenda. Diaphragm thickening fraction may be a biomarker serving to (1) identify readiness for participation in early mobilization programs, (2) readiness to progress in the program, (3) develop position-dependent normative data, (4) track morphological and functional changes in the diaphragm at select time points, and (5) predict a variety of outcomes, such as ICU or hospital length of stay, or long term postadmission physical function levels after patient participation in early mobilization programs.

## CONCLUSIONS

Ultrasound imaging of the diaphragm in the supine, seated, or standing position is unobtrusive to the patient, time-efficient, and allows for calculation of an easily interpretable and comparable variable (ie, the diaphragm thickening fraction). This study showed that a PT with minimal training can achieve results with excellent reliability. Second, the results support proof of concept that diaphragm contractility is not only dependent on respiratory demands, but also on the demands of maintaining the body position one is in.

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