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Original Research

Comparison of Diaphragm Thickness Measurements Among Postures Via Ultrasound Imaging

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Abstract

Background: Assessment of diaphragm contraction may be useful for identifying impairments in patients with movement dysfunction involving trunk stabilization, respiration, or both. Real-time ultrasound imaging is a readily available technology that can be used to quickly assess this aspect of diaphragm activity. Although previous studies have examined diaphragm contraction in the supine posture, a comparison of measurements between supine and upright postures has not been made.

Objective: To examine whether diaphragm thickness measurements differ among 3 different body postures in healthy subjects.

Design: Descriptive repeated measures.

Setting: Clinical laboratory.

Patients (or Participants): Twenty-four healthy subjects (12 male and 12 female) aged 22-35 years old were recruited and completed the study.

Method: Diaphragm thickness was assessed in via B-mode ultrasound imaging in supine, seated, and standing postures. Measurements of diaphragm thickness were taken in the zone of apposition during maximal inspiration to total lunge capacity (TLC) and end-tidal expiratory lung volume (EELV). A thickness ratio (inspiration thickness/expiration thickness) was calculated to compare relative diaphragm contraction during each condition.

Main Outcome Measurements: The primary dependent variable was diaphragm thickness (mm).

Results: Average diaphragm thickness at EELV and maximum TLC were more than 20% greater in the seated and standing postures than in supine ($P < .05$). Moreover, the diaphragm was approximately 205% thicker at TLC than at EELV ($P < .05$). Relative inspiratory to expiratory thickness ratios (TLC/EELV) did not differ among postures ($P = .24$).

Conclusions: The diaphragm is thicker when the body is in more upright postures (standing and sitting versus supine) perhaps due to greater vertical gravitational load on the muscle and associated change in the resting length of the muscle fibers. Thus it appears that ultrasound imaging may be a sensitive tool to examine changes in diaphragm contraction during varying postural tasks.

Introduction

The diaphragm muscle is the primary inspiratory muscle, acting as a piston to expand thoracic volume, drawing air into the lungs. In addition, the diaphragm stabilizes the axial skeleton by descending into the abdominal cavity and increasing abdominal pressure [1]. Therefore, diaphragmatic impairment may not only impact breathing but postural stability as well [2]. Despite differing physiologic functions, both respiratory and stabilizing roles of the diaphragm are presumed to be mediated by graded muscle contraction across ventilatory and nonventilatory behaviors [3]. Therefore, visualization of diaphragm contraction provides valuable information regarding the functional status of the diaphragm. Real-time ultrasound imaging is a readily available technology that can be used to quickly assess and relatively quantitate diaphragm thickening, providing useful insight into diaphragm function. Many investigators have used thickness measurements of the diaphragm as a surrogate measure of muscle contraction [4-7].

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Although most investigators have examined the diaphragm via ultrasonography with individuals in either supine or sitting postures [4-7], a comparison of diaphragm thickness between supine and sitting postures apparently has not been made. Assessment of diaphragm contraction in sitting or standing postures may be of functional importance as activities of daily living are carried out in these positions. In the supine position, the diaphragm exhibits greater excursion during breathing than in the seated position [8]. Diaphragm excursion is expected to change, along with diaphragm thickness, as the length of the muscle changes. As the body assumes an upright posture such as sitting, the diaphragm displaces caudally as the result of decreased pressure from the abdominal contents and subsequently is expected to demonstrate less excursion, as has been observed [8].

In this regard, the resting and contracting thickness measures of the diaphragm are hypothesized to change with differing postures in relation to observed changes in excursion with known reductions in vital capacity in the supine posture [9]. Whether posture changes absolute thickness or inspiratory-to-expiratory thickness ratios of the diaphragm is unknown. Therefore, the primary purpose of the current study was to compare diaphragm thickness between 2 different lung volumes among 3 different body postures in healthy subjects.

Methods

Subjects

The use of human subjects and all procedures of this study were approved by the Mayo Clinic Institutional Review Board. Informed consent was received from each patient, and the rights of the subjects were protected. To detect a 0.1-mm difference in diaphragm thickness with an assumed standard deviation of 0.1 mm in subjects, a statistical power of 0.80 necessitated at least 10 subjects per gender group ($\alpha = .05$). Twenty-four healthy subjects, 12 male and 12 female, with an age range of 22-35 years volunteered for the study. Subjects were excluded if they had a history of dyspnea or generalized neuromuscular disease, such as peripheral neuropathy, myopathy, motor neuron disease, or central nervous system disease. Each subject signed an approved consent form before testing began.

Procedures

The diaphragm of each subject was imaged with subjects in 3 different postures, namely supine, seated, and standing. In each position the diaphragm thickness was measured 3 times at maximal inspiration to total lung capacity (TLC) and at end-tidal expiratory lung volume (EELV). TLC was defined as the lung volume after instruction to the patient to maximally inhale, whereas EELV was defined as the lung volume when the subject had exhaled a tidal breath. Ultrasound measurements of the diaphragm were performed as described previously [4]. Palpation just anterior to the anterior axillary line on the right side of the subject was used as a starting point to identify the intercostal space providing the best visualization of the diaphragm—typically the eighth or ninth intercostal space. Real time B-mode ultrasound (Nemio US machine model SSA-550A, with an 8 MHz linear transducer; Toshiba, Tokyo, Japan) was then used to identify the intercostal space at which the diaphragm was most easily visualized (either the eighth or ninth intercostal space) with least encroachment of the lungs during inspiration.

Diaphragm thickness was measured at the end of quiet expiration and at maximum inspiration. EELV was chosen as the point of diaphragm relaxation because it was technically difficult to keep the transducer in place to measure diaphragm thickness at maximal expiration (residual volume). The diaphragm was identified by a hypoechoic layer of muscle tissue encased between 2 hyperechoic lines of pleural and peritoneal fascia (Figure 1). Diaphragm images were captured during quiet breathing, where the subject was instructed to breathe normally and maximum inspiratory measurements were taken as the subject was instructed to inhale as deeply and slowly as possible. An electronic caliper was used to measure the thickness of the diaphragm muscle where the fibers were parallel, yet as close to the caudal aspect of the rib as possible (Figure 1). The measurements were then repeated 2 more times with a return to the originally identified intercostal space and the examiner adjusting the calipers blinded to previous values.

For the seated posture, each subject was positioned in 90° of hip flexion and 90° of knee flexion, as measured with a goniometer, and with their feet flat on the floor. Subjects were asked to rest their arms on their thighs to ensure an unsupported trunk throughout. For the standing posture, subjects were instructed to stand

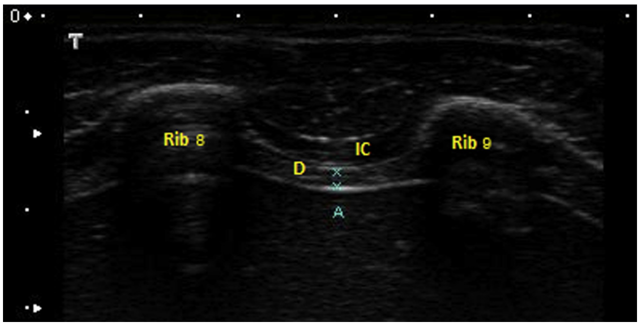

Figure 1. Representative ultrasound image of the diaphragm at EELV. The x notations along the hyperechoic line represent the electronic caliper with the A distance being 1.5 mm. D = diaphragm; IC = intercostal muscles; A = abdominal muscles; EELV = and end-tidal expiratory lung volume.