Heart & Lung ■■ (2018) ■■–■■

Contents lists available at ScienceDirect

Heart & Lung

journal homepage: www.heartandlung.com

An investigation into the use of ultrasound as a surrogate measure of diaphragm function

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A R T I C L E I N F O

Article history:
Received 4 December 2017
Accepted 26 April 2018
Available online

Keywords:
Diaphragm function
Ultrasonography
Ventilator induced diaphragm dysfunction
Respiratory muscle strength
Diaphragm thickness

A B S T R A C T

Purpose: Sonographic assessment of the diaphragm may be a surrogate for interpretation of diaphragm function in mechanically ventilated patients. This study aimed to determine the correlation between respiratory muscle function and diaphragm thickness in a healthy population.
Methods: A descriptive study was conducted. Diaphragm thickness was determined by sonographic measurement. Respiratory muscle strength, fatigue and endurance was determined using a mouth pressure manometer.
Results: 55 subjects with a mean (SD) age 21.16 ± 1.55 years were studied. Diaphragm thickness was moderately correlated with strength ($r = 0.52$; r^2=0.27; $p < 0.001$). Respiratory muscle fatigue was not correlated with thickness (r=–0.15; r^2=0.02; $p = 0.29$) or strength (r=–0.19; r^2=0.04; $p = 0.16$).
Conclusion: Diaphragm thickness was moderately correlated to strength but not to fatigue or endurance in healthy individuals. Sonography may be a surrogate measure of volitional respiratory muscle strength and requires confirmation in critically ill patients.

Introduction

In the intensive care unit population, approximately 40% of patients require mechanical ventilation and 20–25% of these patients will encounter difficulties in the discontinuation of mechanical ventilation.[1] Diaphragm dysfunction, as a result of mechanical ventilation, may contribute significantly to these difficulties.[2–4] Ventilator induced diaphragmatic dysfunction (VIDD) is defined as a reduction in the force generating capacity of the diaphragm.[5] Animal and human studies have shown diaphragmatic inactivity associated with mechanical ventilation may contribute to this observed dysfunction.[2,6,7] The diaphragmatic weakness that occurs with mechanical ventilation is also associated with a significant increase mortality and duration of mechanical ventilation, making it important to identify and manage this dysfunction early.[8]

While maximal diaphragm or inspiratory muscle strength is commonly measured, muscle endurance and its relationship to the duration of mechanical ventilation have also been described.[9] Mechanical ventilation for more than 48 hours was shown to reduce inspiratory muscle endurance, which becomes worse with the increasing duration of mechanical ventilation.[9] This suggests that patients who require prolonged mechanical ventilation are at risk of both respiratory muscle fatigue and weakness, which are often still present after successful discontinuation of mechanical ventilation.[7,10,11] Despite inspiratory muscle training having shown some benefit in selected patient populations,[12] questions still remain as to how such patients are identified; when should training be initiated; what type of training should be initiated; and how it should be prescribed?

A major challenge in determining VIDD/respiratory muscle dysfunction is the ability to accurately evaluate respiratory muscle function in critically ill mechanically ventilated patients.[6] The gold standard of measuring diaphragmatic strength is by measuring the transdiaphragmatic twitch pressure via phrenic nerve stimulation,[13] which is an invasive test specific to the diaphragm. This technique, however, requires considerable skill, is uncomfortable for the patient and may be difficult to achieve in clinical settings.[13] Alternatively, volitional tests of respiratory muscle strength give an estimate of inspiratory and expiratory muscle strength, are relatively easy to perform and are often well tolerated by patients.[13] However, a disadvantage of volitional tests is that they require full patient co-operation and are poorly reproducible, particularly in the intubated critically ill population.[1,13]

Conflict of interests: No conflict of interest to declare.
Disclosures: None.
Funding: None.
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0147-9563/$ – see front matter © 2018 Elsevier Inc. All rights reserved.
https://doi.org/10.1016/j.hrtlng.2018.04.010

Ultrasonography (US) is non-invasive and can easily be performed at the bedside, which may make it a suitable alternative for interpreting diaphragm function.[1,14–17] Diaphragm ultrasonography shows excellent reproducibility and can reliably detect changes in diaphragm structure in mechanically ventilated patients.[14,15] However, the relationship between changes in diaphragm thickness and respiratory muscle strength and endurance, particularly in the critically ill population, is unclear. Several small studies in patients with cerebral palsy have shown associations between muscle thickness determined by US and strength.[18,19] Strong correlations were found in healthy individuals and weight-lifters between diaphragm thickness, diaphragm cross-sectional area and diaphragm strength using oesophageal and gastric balloons and an experimental inspiratory manoeuvre.[17] Whether a correlation exists between US measures of diaphragm thickness and non-invasive, volitional measures of respiratory muscle strength and particularly fatigue and endurance is still unclear.

Given the effects of mechanical ventilation and critical illness on respiratory muscle function, early identification of "at risk" patients may help earlier, targeted interventions to optimise respiratory muscle function and improve outcomes. To understand what happens in illness, we first need to understand what happens in health. To inform future research in this area, the correlation between diaphragm thickness, respiratory muscle strength and fatigue, must be established. Since little is known about the correlation between the abovementioned factors, the primary aim of this paper is to describe the correlation between diaphragm thickness, strength and fatigue in a healthy population.

Materials and methods

Sample

A sample of convenience was used. We recruited university students between the ages of 18 – 24 years during September 2013 – October 2013. University students were categorised into three activity levels. They were included if they took part at university level in 1) endurance type sports; 2) strength type sports or 3) lead a sedentary lifestyle. This was done to obtain a range within the a normal population to allow for better generalisability. Students in each category were matched for age and BMI. Students were excluded if they had any type of surgical procedure within 12 months prior to the study; were on any medication or were suffering from any type of neurological condition (e.g. Myasthenia Gravis); respiratory condition (e.g. Cystic Fibrosis, Asthma) or orthopaedic condition (e.g. Ankylosing Spondylitis) affecting mobility of the thorax or hindering respiratory function. The Human Research Ethics Committee at Stellenbosch University (S13/05/111) approved this correlational study. All subjects provided written informed consent.

Procedure

Subjects were asked to refrain from strenuous physical activity and food intake two hours prior to testing to ensure maximal comfort. Baseline measurements (height, weight, age, activity level) were recorded and diaphragm thickness, strength and fatigue were measured. Measurements were completed in the same order by the primary investigator. Inter-rater reliability of diaphragm thickness using ultrasonography (ICC agreement=0.99) was established in the pilot study prior to the commencement of the main study. The laboratory temperature and equipment set-up remained standardized and all equipment was calibrated daily prior to testing.

Diaphragm thickness

Imaging was performed using the Acuson P300 ultrasound system (Siemens, Münich, Germany), with a 12mHz high resolution linear transducer probe[15,16] in two-dimensional B-mode.[1,20] Subjects were in a 30-degree head up supine position during measurements, with the arms relaxed at their sides, and instructed to relax and breathe quietly. The probe was placed in the right mid-axillary line at the level of the right eighth or ninth intercostal space, whichever gave the clearest image,[1,20] and the diaphragm was imaged through the zone of apposition (Fig. 1).[1,16,20] The right diaphragm[21] was identified as a structure made of three distinct layers: A non-echogenic central muscular layer bound by echogenic membranes, the peritoneum and the diaphragmatic pleura. The ultrasound beam was directed perpendicular to the diaphragm[16,21] and a sine-loop of three consecutive breathing cycles were recorded.[1,17] Images were coded and stored (Fig. 2) (Fig. 3).

After collecting all the images, the primary investigator measured the coded images. Three still images were obtained at end-expiration, to establish reproducibility of the measurements.

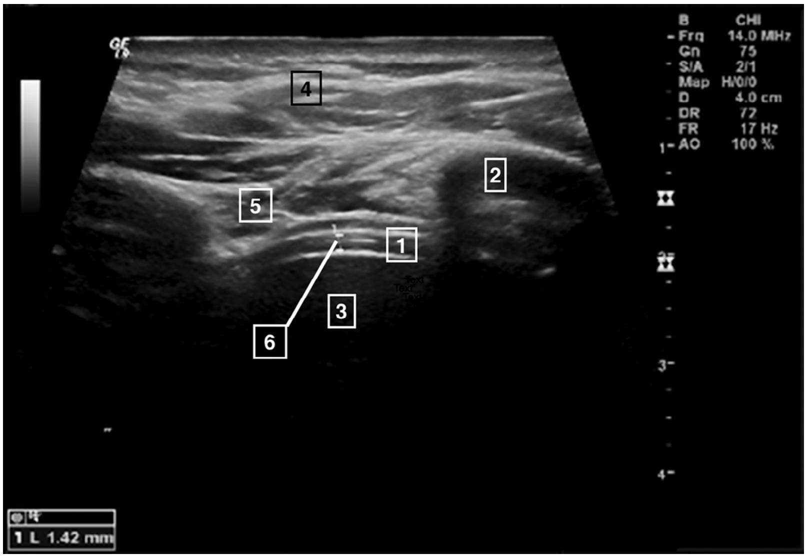

Fig. 1. Measurement of diaphragm thickness using ultrasound, 1- diaphragm; 2 – rib; 3 – liver; 4 – subcutaneous tissue; 5 – intercostal muscle; 6 – calipers used to measure end-expiratory thickness.