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● *Original Contribution*

DIAPHRAGMATIC ULTRASOUND CORRELATES WITH INSPIRATORY MUSCLE STRENGTH AND PULMONARY FUNCTION IN HEALTHY SUBJECTS

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Abstract—Diaphragm ultrasound (DUS) has been used to identify diaphragm dysfunction. However, its correlations with respiratory strength and lung function are unclear, even in healthy patients. A total of 64 healthy patients (30 males) had lung function and inspiratory strength (maximal inspiratory pressure and sniff nasal inspiratory pressure) measured. Gastric and oesophageal pressures were measured in a subgroup (n = 40). DUS was characterized by mobility (quiet breathing [QB] and deep breathing [DB]) and thickness (at functional residual capacity [Th_{FRC}] and total lung capacity [Th_{TLC}]). We calculated the thickening fraction (TF). During QB, DUS was similar between sexes. However, during DB, females had lower mobility, thickness and TF than males. Mobility at DB, Th_{TLC} and TF significantly correlated with lung function and inspiratory strength. These correlations were affected by sex. DUS correlated with inspiratory gastric pressure. In healthy patients, DUS correlated with lung function and inspiratory strength during DB. Significant differences between genders were noticeable when DUS was performed during DB. (E-mail: letscardenas@gmail.com)

Key Words: **Diaphragm, Inspiratory muscles, Ventilatory muscle strength, Ultrasound, Lung function, Gender.**

INTRODUCTION

Diaphragm ultrasound (DUS) is a simple, reproducible method for evaluating diaphragmatic mobility and thickness (Boon et al. 2013; Boussuges et al. 2009; Cohn et al. 1997; Kantarci et al. 2004; Testa et al. 2011; Ueki et al. 1995). DUS has been increasingly used to evaluate diaphragmatic function in many clinical situations because its advantages (absence of radiation, portability, real-time imaging and non-invasiveness) eliminate many of the limitations of previous standard imaging techniques (Matamis et al. 2013; Sarwal et al. 2013).

Despite these advantages, the correlation between DUS variables and inspiratory muscle strength is controversial in healthy patients (Brown et al. 2013; McCool et al. 1997; Summerhill et al. 2007; Ueki et al. 1995). Some authors (McCool et al. 1997; Summerhill et al. 2007) found a correlation between maximal inspiratory pressure (MIP) and diaphragm thickness at functional residual capacity (FRC) (Th_{FRC}). However, Ueki et al. (1995) conversely found a correlation between MIP and diaphragm thickness at total lung capacity (TLC) (Th_{TLC}) and between MIP and thickening ratio, but not between MIP and Th_{FRC}. Methodologic issues such as a small number of patients, different ages and non-uniform distribution of sexes may explain the controversial findings among these studies. Considering that the strength of a muscle depends in part on its effective cross-sectional area (Freilich et al. 1995; Verdijk et al. 2010) and that muscle strength is greater in males than in females (Chen and Kuo 1989; Wilson et al. 1984), sex in particular may represent a key factor in examining the relationship between diaphragm thickness and inspiratory strength.

Describing the characteristics of DUS in healthy individuals is clinically relevant as a reference value so that diaphragm dysfunction can be diagnosed using a non-invasive method. Furthermore, whether or not the mobility and thickness of the diaphragm have a correlation with inspiratory strength, DUS might represent a tool for the evaluation of patients unable to perform the manoeuvres of maximal ventilatory strength and even lung function tests.

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This study aimed (i) to investigate the influence of sex on the mobility and thickness of the diaphragm; (ii) to characterize the relationships between mobility and thickness of the diaphragm evaluated by ultrasound and inspiratory muscle strength in healthy males and females; (iii) to obtain the mean values and the lower limit of normality (LLN) in both sexes.

We hypothesized that inspiratory muscle strength may be related to diaphragm mobility and thickness displayed on ultrasound, mainly during deep breathing (DB) and at TLC, respectively, with possible differences between sexes.

METHODS

We performed a cross-sectional study that consecutively evaluated 64 healthy volunteers. The study was approved by the Research Ethics Committee of the University of São Paulo School of Medicine Hospital das Clínicas (protocol number 0835/11).

Patients

All participants gave written informed consent. We recruited the controls from the staff and students of our laboratory (Respiratory Muscles) and healthy relatives of patients involved in other studies of our group. Eligibility criteria were age 18–82 y, forced expiratory volume 1 (FEV_1) and forced vital capacity (FVC) ratio >80%; not participating in physical activities or sports more than 4 times per wk; and for the elderly, we asked for a self-report of no difficulty in daily activities. Exclusion criteria were the presence of any cardiopulmonary or neuromuscular disease and former smokers with more than 20 pack-y or current smokers (a flowchart is included the supplemental material).

Measurements

All patients underwent a lung function test (LFT), DUS and ventilatory muscle strength measurement on the same day.

LFT. We used a calibrated pneumotachograph (MGC Diagnostics, St. Paul, MN, USA) to perform forced manoeuver, according to the European Respiratory Society/American Thoracic Society (ERS/ATS) Statement (Brusasco et al. 2005), and measured FVC and FEV_1. Predicted values were those derived for the Brazilian population (Pereira et al. 2007).

DUS. Ultrasound imaging of the diaphragm was done using a portable ultrasound system (Nanomaxx, Sonosite, Bothell, WA, USA) or another machine (M-Turbo, Sonosite), according to availability of the device. The ultrasound system was used, setting-up depth 210 mm, appropriate total gain and slowest sweep speed (10 s per screen). Patients were in a semi-recumbent position with the bed slope at 45° (Fig. 1). For the evaluation of diaphragmatic mobility, we used a 2–5 MHz convex transducer. The probe was placed over the right anterior subcostal region between the midclavicular and anterior axillary lines. The transducer was directed medially cephalad and dorsally so that the ultrasound beam reached perpendicularly to the posterior third of the right hemidiaphragm. First, the 2-D mode was used to visualize and obtain the best approach, with the liver serving as an acoustic window to the right, to select the exploration line. The M-mode then was used to display and measure the amplitude of the craniocaudal diaphragmatic excursion during quiet breathing (QB) and DB (Boussuges et al. 2009; Testa et al. 2011). We recorded the averaged value of three consecutive measurements. The mobility of the diaphragm during a sniff test was done to exclude paradoxical movement.

Diaphragm thickness was measured in B-mode with a 6–13 MHz linear transducer placed over the zone of apposition (ZA) of the diaphragm to the rib cage, between the right anterior and medial axillary lines. In the ZA, the diaphragm is observed as a structure made of three distinct layers: a non-echogenic central layer bordered by two echogenic layers, the peritoneum and the diaphragmatic pleurae. The thickness was measured from the middle of the pleural line to the middle of the peritoneal line (Boon et al. 2013; Ueki et al. 1995). We measured the thickness of the diaphragm during quiet spontaneous breathing at FRC and at breath holding after a maximal inspiratory effort, at TLC. Again, the averaged value of three consecutive measurements was recorded for each. We also calculated the thickening fraction (TF), as the proportional thickening of the diaphragm from FRC to TLC. TF represents an index of diaphragmatic thickening as is defined by the following equation: $TF = ([Th_{TLC} - Th_{FRC}] / Th_{FRC}) \times 100$, where Th_{FRC} is the thickness of the diaphragm measured at the end of a quiet expiration (at FRC) and Th_{TLC} is the maximum thickness of the diaphragm measured at the end of DB (at TLC).

Ventilatory muscle strength

All measurements (MIP and sniff nasal inspiratory pressure [SNIP]) were made with patients in the sitting position, using a nose clip for MIP. The manoeuvers of MIP were done according to ATS recommendations (American Thoracic Society/European Respiratory Society 2002) repeated three times or more (because the last value was not higher than 10% from the previous), and the highest value was recorded for analysis (Caruso et al. 2015). Predicted values were those derived for the Brazilian population for maximal respiratory pressures (Neder et al. 1999) and for SNIP (Araújo et al. 2012).