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Diaphragmatic regional displacement assessed by ultrasound and correlated to subphrenic organ movement in the critically ill patients—an observational study

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ABSTRACT

Introduction: The objectives of the study are to identify the most reliably imaged regions of the diaphragm, to evaluate the correlation of movement between different parts of each hemidiaphragm, and to assess the agreement between liver or spleen displacement and movement of the ipsilateral hemidiaphragm.
Methods: Images of the diaphragm, liver, and spleen were obtained using 2-dimensional ultrasound. Acceptable agreement between regions of the diaphragm, liver, and spleen was defined as an absence of fixed or proportional bias using Deming regression analysis and limits of agreement of 2 SDs of the difference less than 30% of the mean value.
Results: We included 90 critically ill patients. The medial (87%) and middle (73%) regions of the right hemidiaphragm, liver (87.7%), and spleen (81%) and medial (71%) and middle regions (51%) of the left hemidiaphragm were most frequently imaged. In nonintubated patients, acceptable agreement was present for comparisons of the left middle and medial, right middle and medial, and left middle regions and spleen displacement. In intubated patients and in all patients when combined, acceptable agreement was only present for comparisons of the left middle and medial and right middle and medial regions of the diaphragm. Acceptable agreement was not present for intubated and all patients for diaphragmatic and solid organ movement.
Conclusion: The diaphragm medial part is visualized in the majority of studied patients. The medial and middle thirds may be used interchangeably to assess hemidiaphragm movement. Acceptable agreement does not exist for diaphragm and solid organ movement, other than for the left middle region and the spleen.

1. Introduction

Measurement of diaphragmatic excursion may be useful in assessing respiratory sufficiency, ensuring adequate ventilation, and evaluating respiratory complications [1-5]. Normally, diaphragmatic excursion during quiet breathing is 0.9 to 2 cm and may increase to 7 to 9 cm during forced breathing [1,6-9]. There are also regional differences in diaphragmatic movement [10,11] with the greatest movement occurring in the middle and the posterior thirds [11].

Ultrasound is used to evaluate diaphragmatic function and to estimate work of breathing [12]. The approach to diaphragmatic ultrasound imaging depends on the position of the patient, the location and orientation of the transducer on the chest, and the region of interest of the diaphragm. The literature describes different techniques in imaging the diaphragm. There are variations in probe location on the chest wall, landmarks of the site of exploration, and the selection of the ultrasound mode of imaging. Moreover, assessment of degree of diaphragmatic movement depends on adequate viewing, operator experience, and the angle of incidence. The angle of incidence is the angle between the beam incident on a surface and the line perpendicular to the surface at the point of incidence. To achieve an accurate quantitative assessment, the orientation of the probe in relation to craniocaudal movement axis should aim for an angle of incidence not more than 20°.

Ultrasound of the diaphragm using B-mode alone [8,11,13-19] or combined with M-mode has been described in literature [4,9,20-22].

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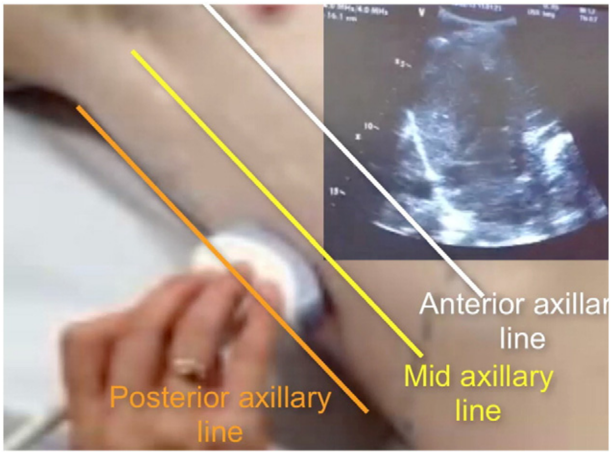

Fig. 1. Scanning plane, lateral approach. The probe is placed perpendicularly to the lateral chest wall of a supine patient in a lower intercostal space between the mid and posterior axillary lines with the probe oriented cranially.

B-mode is a 2-dimensional imaging, which is used to identify the diaphragm at the interface between the lung and the subphrenic solid organ. It is also useful in identifying diaphragmatic structural abnormalities. Two-dimensional imaging allows a better assessment of possibly related pathologies in the neighboring subphrenic or supraphrenic structures. It has also been used in conjunction with M-mode to identify the exploration site for M-mode assessment of the diaphragm. M-mode, on the other hand, is a monodimesional time-dependent imaging mode that records successive positions of the diaphragm vs time. It allows easier measurement of the thickness of the diaphragm and allows easier quantification and the velocity of its excursion.

Identifying the hemidiaphragm through an anterior ultrasound approach may be difficult for reasons such as presence of bowel gas, lung interposition, movement of the underlying ribs, or surgical wounds and surgical dressings. This is particularly difficult in left hemidiaphragmatic imaging due to interposition of lung and bowel gas. Displacement of the liver and spleen has, therefore, been suggested as surrogates for diaphragm movement [23,24]. A previously published study showed that displacement of the liver or the spleen is an acceptable predictor of successful extubation [25]. However, in this study, a precise correlation in movement between the diaphragm and liver or splenic displacement was not determined. Moreover, the degree of solid organ displacement may vary due to other factors such as organ deformation and lateral or anteroposterior displacement, which is not usually measured [26].

The posterior part is the most muscular and mobile region of the diaphragm. Nonetheless, it may not be visible in critically ill patients. Furthermore, the comparison of movement between different regions of diaphragm or between the diaphragm and the liver or the spleen is not clear.

In this study, we aimed to evaluate the correlation of movement between different parts of each hemidiaphragm, assess the agreement between liver or spleen displacement and movement of the ipsilateral hemidiaphragm, and identify the most reliably imaged regions of the diaphragm.

2. Materials and methods

The study is single-center prospective observational study in a 13-bed level III university-affiliated adult intensive care unit. Patients with known diaphragm paralysis were excluded. The Peninsula Health Human Research and Ethics Committee (Chair Dr DR) approved the study in May 2102 as an audit of an existing study where patients received ultrasound examination of the heart and lungs, Impact of transthoracic echocardiography and respiratory ultrasound assessment in critical care study, Human Research and Ethics Committee Project No. HREC/12/PH/34. All patients or the person responsible for their care if they were sedated provided informed consent for the primary study.

A Vivid q GE Healthcare ultrasound machine (GE Healthcare, Wauwatosa, WI) with a curved array 4C-RS probe was used. The probe has a footprint of 17 to 65 mm with a scanner frequency range of 1.8 to 6.0 MHz and provides a field depth of 30 cm. All ultrasound examinations were performed by the same physician (KH). The patients were examined in a horizontal supine position. The same landmarks and technique were used for both hemidiaphragms. The probe was placed laterally and perpendicularly on each lateral chest wall in a lower intercostal space between the mid and posterior axillary lines. Therefore, the direction of the beam was perpendicular or near perpendicular to the craniocaudal axis during breathing (Fig. 1). By using this technique, a longitudinal plane of the maximal possible length of the hemidiaphragm and the adjacent subphrenic solid organ including a maximal bipolar renal length possible was obtained [8,27] (Fig. 2). After a brief period of quiet consistent breathing, we obtained multiple video clips of each hemidiaphragm with a minimum of 2 to 3 successive respiratory cycles. We recorded at least 3 video clips that contained the maximum possible length of the hemidiaphragm and the ipsilateral subdiaphragmatic solid organ. The images during forced breaths, sighs, and coughing were excluded. The recorded clips were stored in digital format (DICOM), and all measurements were performed off-line.

The stored clips were replayed, and the ultrasonographic measurements were performed in 3 different regions of the diaphragm. The anterior ultrasonographic third represented the lateral anatomical region of the diaphragm, the middle third represented the middle anatomical region of the diaphragm, and the posterior third represented the medial anatomical region of the diaphragm (Fig. 2). With this lateral approach, we predominantly assessed the movement of the posterior diaphragm,

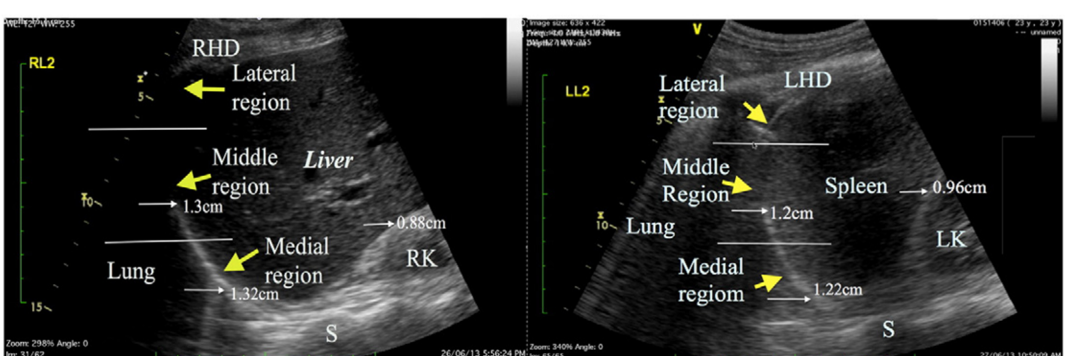

Fig. 2. Two-dimensional mode ultrasound of the right hemidiaphragm, liver, left hemidiaphragm, and spleen. The ultrasonographic images of the diaphragm divided in 3 different regions, the anterior ultrasonographic middle and medial third, spleen, and liver. RHD indicates right hemidiaphragm; RK, right kidney; LHD, left hemidiaphragm; LK, left kidney; S, spines.