SPECKLE TRACKING AS A METHOD TO MEASURE HEMIDIAPHRAGM EXCURSION

STEPHEN A. GOUTMAN, MD, MS,[1] JAMES D. HAMILTON, PhD,[2] BLAKE SWIHART, MA,[1] BRADLEY FOERSTER, MD, PhD,[3,4] EVA L. FELDMAN, MD, PhD,[1,5] and JONATHAN M. RUBIN, MD, PhD[3]

[1] Department of Neurology, University of Michigan, 1500 East Medical Center Drive, Ann Arbor, Michigan 48109, USA
[2] Department of Internal Medicine, University of Michigan, Ann Arbor, Michigan, USA
[3] Department of Radiology, University of Michigan, Ann Arbor, Michigan, USA
[4] Ann Arbor Veterans Administration Healthcare System, Ann Arbor, Michigan, USA
[5] A. Alfred Taubman Medical Institute, University of Michigan, Ann Arbor, Michigan, USA

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ABSTRACT: *Introduction:* Diaphragm excursion measured via ultrasound may be an important imaging outcome measure of respiratory function. We developed a new method for measuring diaphragm movement and compared it to the more traditional M-mode method. *Methods*: Ultrasound images of the right and left hemidiaphragms were collected to compare speckle tracking and M-mode measurements of diaphragm excursion. Speckle tracking was performed using EchoInsight (Epsilon Imaging, Ann Arbor, Michigan). *Results*: Six healthy subjects without a history of pulmonary diseases were included in this proof-of-concept study. Speckle tracking of the diaphragm is technically possible. Unlike M-mode, speckle tracking carries the advantage of reliable visualization and measurement of the left hemidiaphragm. *Conclusions*: Speckle tracking accounted for diaphragm movement simultaneously in the cephalocaudad and mediolateral directions, unlike M-mode, which is 1-dimensional. Diaphragm speckle tracking may represent a novel, more robust method for measuring diaphragm excursion, especially for the left hemidiaphragm.

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M-mode ultrasonography can quantify diaphragm excursion,[1–4] although there are limitations, such as: (1) the left hemidiaphragm is rarely visible due to the smaller acoustic window in the left upper quadrant[3–5]; and (2) M-mode is a 1-dimensional (1D) measurement of tissue passing through the ultrasound beam. Therefore, although tissue moving towards and away from the ultrasound probe can be measured, if tissue concurrently moves laterally, this vector cannot be captured and consequently the M-mode does not reflect true motion.

Speckle tracking is used in echocardiography[6,7] and can evaluate organ motion.[8] Speckle is created when ultrasound signals are reflected from microstructure within tissue and other scattering media. Because these microscatterers are in slightly different positions in an ultrasound beam, their contributions to the backscattered ultrasound signal may be positive or negative depending on the phase of the ultrasound wave at each scatterer position. The result is an overlying pattern of a light and dark (referred to as salt and pepper) textured appearance on ultrasound images. This pattern, which looks like noise, is often stable within small displacements, and can be tracked during motion using computer-based image processing techniques. Such tracking can be performed in 2 or 3 dimensions (2D or 3D), in contrast to M-mode, which instead measures 1D tissue motion and does not track a fixed region of tissue. We hypothesized that speckle tracking could robustly measure diaphragm movement, as it accounts for the 2D motion vector rather than 1D motion with M-mode imaging.

METHODS

Participants. The healthy participants had no history of pulmonary or neuromuscular disease. All subjects provided written informed consent, and the study received institutional review board approval. Age and gender were recorded.

Ultrasound Protocol. Imaging was performed in a semirecumbent position on an ultrasound machine (Epic; Philips Ultrasound, Bothell, Washington) with a standard abdominal imaging curved array transducer (C5-1). For speckle tracking loops, the probe was oriented coronally at the mid-axillary line, and each corresponding hemidiaphragm was imaged between the ribs. Ultrasound images recorded the right and left hemidiaphragms during both normal and deep breathing. For M-modes, the same probe was oriented sagittally subcostally. The M-mode sampling line was directed so that the motion would be oriented directly toward the probe, that is, in a cephalocaudad direction. At least 3 B- and M-mode samples for the right and left hemidiaphragms were performed during both

Additional Supporting Information may be found in the online version of this article.

Abbreviations: 1D, 1-dimensional; 2D, 2-dimensional; 3D, 3-dimensional; ROI, region of interest

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Key words: diaphragm excursion; diaphragm ultrasound; imaging biomarker; M-mode; respiratory imaging biomarker; speckle tracking

Correspondence to: S.A. Goutman; e-mail: sgoutman@med.umich.edu

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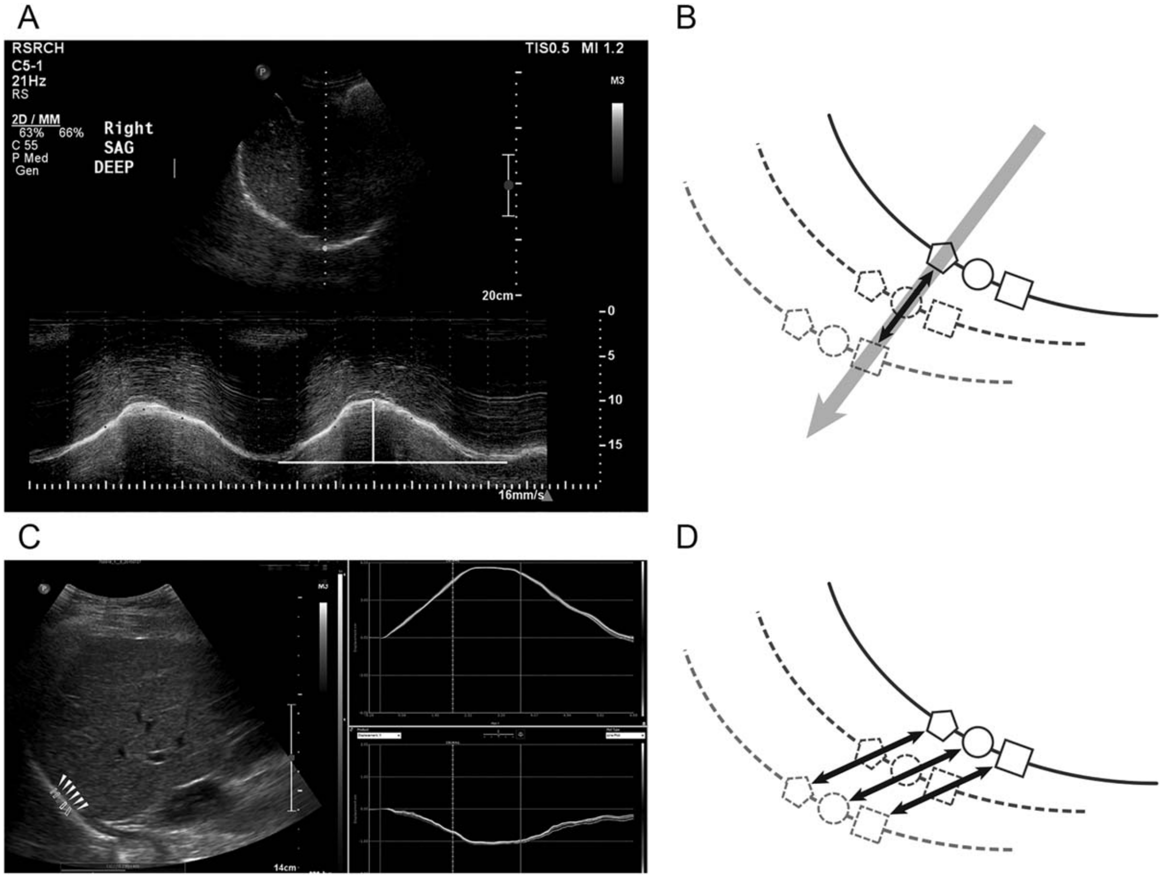

FIGURE 1. M-mode and speckle tracking overview. **(A)** M-mode. The lower panel represents tissue displacement passing through the M-mode beam over time. Vertical white line indicates diaphragm displacement. **(B)** M-mode does not track the same region of tissue over time due to simultaneous lateral movement. The solid curved line represents initial diaphragm position. During breathing, there is cephalocaudad excursion of tissue represented by dashed curved lines and lateral diaphragm movement, as shown by the geometric shapes shifting from right to left. The M-mode beam (large gray arrow) passes through different points on the tissue during breathing; thus, displacement measurement (small black arrow) represents different points on the tissue. **(C)** Speckle tracking. B-mode ultrasonography in the left panel shows regions of interest (ROIs) on the diaphragm tissue (small white boxes, indicated by white arrowheads). Movement of the ROIs in the X and Y planes are shown in the right upper and lower panels, respectively (refer to Fig. S1 in Supplementary Material, available online, for additional details). **(D)** Speckle tracking measures displacement in 2 dimensions and therefore can better characterize true motion. The actual measurement (black arrows) is fixed relative to tissue position.

normal and deep inspiration. M-mode displacements were averaged for analysis.

Speckle Tracking. Speckle tracking was performed using EchoInsight (Epsilon Imaging, Ann Arbor, Michigan), commercially available software designed to track 2D speckle motion in cardiac echograms and other applications. After import of DICOM files into EchoInsight, a region-of-interest (ROI) curve was placed over the diaphragm, utilizing the *define wall* tool (Fig. 1; see also Videos SV1–4 and Fig. S1 in the Supplementary Material, available online). The ROI width was 0.5 cm. As shown in Figure 1, EchoInsight creates 6 individual measurement regions, or segments, from the ROI curve. To create evenly spaced ROI segments, the center of the ROI curve was set visually using the control+left mouse click. The image loop was reviewed to ensure the ROI did not drift from the diaphragm tissue and, if so, the tracking operating mode was switched (see below). Each ROI curve measured cephalocaudad displacement, defined as the square root of the X displacement squared plus the Y displacement squared, averaged over the 6 ROI segments for each loop. For analysis, the diaphragm was visualized for a complete respiratory cycle; if a shadow obscured the speckle over the diaphragm, the image was excluded from analysis.

The EchoInsight speckle tracking algorithm was modified to have 2 operating modes, which controlled the resolution of the image data before tracking. In fine resolution mode, B-mode images were spatially filtered using a 2D, 5-point Hanning filter before tracking. Coarse resolution mode used a 15-point Hanning filter. The 2 modes allow the operator of EchoInsight to trade off between robustness and precision of the tracking algorithm by adjusting the spatial frequency content of the tracked data. The fine resolution algorithm was used on diaphragm loops with a sharp and clearly visualized diaphragm border. For noisier data and image loops with a diffuse appearance of the diaphragm border, the coarse tracking algorithm was used. The operator determined which mode to implement by visually assessing the tracking of the ROI curve throughout the respiratory cycle.

Statistical Analysis. All analyses were performed using SAS 9.4 (SAS Institute, Cary, North Carolina).

RESULTS

Six subjects (3 women) underwent ultrasound assessment. Mean age was 57.7 (standard deviation 9.1) years. M-mode ultrasonography and speckle tracking each visualized all 6 subjects' right hemidiaphragms during both normal and deep inspiration. On the left, M-mode captured 2 subjects' hemidiaphragms during normal inspiration and none during deep inspiration, whereas speckle tracking captured all 6 hemidiaphragms during normal breathing and 5 of 6 during deep breathing. Table S1 (online) highlights displacements by subject. The average difference between right speckle tracking and M-mode for normal and deep inspiration was 0.30 cm ($n = 6$) and −0.65 cm ($n = 6$), respectively, and on the left it was 1.00 cm ($n = 2$) for normal inspiration. No M-modes were available on the left for comparison during deep inspiration.

DISCUSSION

In this study we have provided an initial description of speckle tracking for evaluating diaphragm motion. This technique has 2 distinct advantages. First, it more accurately evaluates diaphragm movement compared with M-mode, because speckle tracking measures the motion of a defined point or region on the diaphragm through the image loop, whereas M-mode records motion of variable regions of tissue passing through the M-mode line. Second, speckle tracking can quantify left hemidiaphragm displacement, a nearly impossible task with M-mode.

One limitation of speckle tracking is the additional time needed for software processing of ultrasound studies. In some circumstances, displacement magnitudes were larger for M-mode compared with speckle tracking. The diaphragm does not move uniformly,[1] and speckle tracking can measure a larger region of tissue, including segments without peak displacements. In contrast, M-mode focuses on peak displacement. Analysis of individual speckle segments showed displacement variability of up to 0.5 cm, suggesting that the speckle tracking averages out motion over a wider range of tissue. Speckle tracking can also capture peak displacements; future studies should focus on whether bulk or peak motion is more clinically meaningful. Importantly, as speckle tracking clearly demonstrates displacements in the X and Y directions, we have identified major limitations of M-mode for diaphragm displacement measurements. If speckle tracking is further validated, it may prove to be a more useful and reliable method for longitudinal assessment of diaphragm movement with ultrasound compared with the currently used techniques.

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