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Tissue Doppler Imaging of the Diaphragm: A Novel Approach but Too Early for Clinical Implementation?

To the Editor:

Tissue Doppler imaging (TDI) is a robust ultrasound technique used in cardiology to quantify myocardial motion velocity, but the validity and clinical applications of diaphragm TDI are as yet uncertain. We read with great interest the work of Soilemezi and colleagues (1) on TDI to describe diaphragm motion properties of critically ill patients during ventilator weaning. The authors mention that diaphragm pulsed-wave (PW)-TDI is a straightforward method with a fast learning curve. Although we agree that these are essential features for any ultrasound method, we would like to address some important challenges that should be taken into account before implementing this technique in clinical practice.

First, PW-TDI results are very dependent on ultrasound settings and probe position. Doppler signals within a region of interest ("sample volume," or "gate") are converted into an average velocity signal. However, increasing the gain broadens the velocity spectrum and results in higher peak velocities (2, 3). Furthermore, as TDI measures the motion vector that is parallel to the ultrasound beam, the insonation angle must be kept as low as possible and changes in angle will affect both pulse length and spectral width. Angle correction can be applied but only for angles $<60^{\circ}$ because this correction is nonlinear. In addition, reverberation artifacts may occur, resulting in a clutter band along the baseline. This is presented in Figure E1B in the online supplement of Reference 1, where the concept of "smoothing" is introduced. Although smoothing improves visualization of the contour of the velocity signal, peaks are directly affected by the gain and too much smoothing results in signal loss. The authors mentioned that different filters and gains were set to obtain the best velocity images according to the speed of the diaphragmatic motion and the subject under examination. It would be great if they could address how this method was standardized (i.e., quantify "best"), as PW-TDI results can be manipulated easily by adjusting settings on the ultrasound machine.

Furthermore, despite high reliability of results reported in healthy volunteers, it is not entirely clear if PW-TDI results represent what they are intended to. As the velocity–time integral (VTI) reflects diaphragm displacement, VTI should match M-mode displacement (less sensitive to measurement errors compared with PW-TDI), but a large discrepancy was reported in patients (mean 1.27 vs. 0.78 cm for M-mode displacement vs. VTI, respectively; *see* Table 2 of Reference 1). Also, inspiratory and expiratory VTI should be similar over a large number of breaths, as end-expiratory diaphragm position should not change. Based on our own experience with PW-TDI, and in line with the presented examples (1), VTI inspiration is often larger than VTI expiration. Therefore, reporting a direct comparison of M-mode displacement versus VTI, and VTI inspiration versus VTI expiration, would be valuable to address the validity of PW-TDI results. If there is a systematic underestimation of VTI (and thus also of velocity results), it should be explored whether differences can be minimized sufficiently by adapting ultrasound settings or by performing offline correction.

Noninvasive measures to quantify diaphragm mechanics are highly needed, and correlations between transdiaphragmatic pressure (Pdi) and PW-TDI were evaluated. No relationship between VTI and diaphragm pressure–time product (PTPdi) was found. The authors assumed that VTI could possibly represent diaphragmatic work, because it is defined as the area under the inspiratory PW-TDI curve, similarly to PTPdi being the area under the Pdi–time waveform. This lack of relationship is not surprising given the poor correlation between diaphragm displacement and breathing effort (4, 5). A correlation was found between TDI-maximal relaxation rate (MRR) and Pdi-MRR. TDI-MRR was defined as the slope of the steepest part of the PW-TDI signal during expiration. From a physiological perspective, however, TDI-MRR represents diaphragm deceleration as the signal is already a derivative of displacement. Hence, peak relaxation velocity better reflects MRR and it would be of clinical interest to evaluate its relationship with Pdi-MRR.

Undoubtedly, diaphragm TDI is an exciting approach. However, standardization of the method and further understanding of the capabilities and limitations is important before using this technique for clinical decision-making. ■

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Reply to Jonkman *et al.*

From the Authors:

We thank Dr. Jonkman and colleagues for their comments concerning our paper on diaphragmatic tissue Doppler imaging (TDI) (1).

We agree that the echo settings (angle correction, filters, and gains) may affect the TDI measurements; our ultrasound settings can be seen in the videos and images provided in our paper.

The comment that velocity–time integral (VTI) should match M-mode displacement is theoretically correct; however, because simultaneous recording of TDI and M-mode displacement is not feasible, this assumption is impossible to prove because VTI and displacement will be measured during different breaths. Moreover, to our knowledge, there is no study demonstrating that M-mode displacement is less sensitive to measurement errors compared with TDI. Furthermore, it is also an assumption that inspiratory and expiratory VTI should be similar; in normal individuals this seems correct over a large number of breaths. However, in ICU patients, the presence of various levels of intrinsic positive end-expiratory pressure during weaning can affect the end-expiratory position of the diaphragm from breath to breath, making this assumption also particularly false and misleading.

Additionally, according to the authors' suggestion, we looked into the relationship between the mean values of the peak relaxation velocity and transdiaphragmatic pressure (Pdi)-derived maximal relaxation rate (MRR); the relationship is indeed better compared with TDI-MRR and Pdi-MRR (Figure 1).

Finally, we share Dr. Jonkman's concern about the early clinical implementation of TDI. However, we provide a large number of data in normal individuals and in ICU patients to stimulate further clinical investigation to assess diaphragmatic function. We believe that TDI is a fascinating, bedside, noninvasive, real-time tool in the hands of the intensivists and physiologists. We should not forget that so far, the contractile and relaxation properties of the diaphragm were investigated with invasive, cumbersome, and indirect methods. ■

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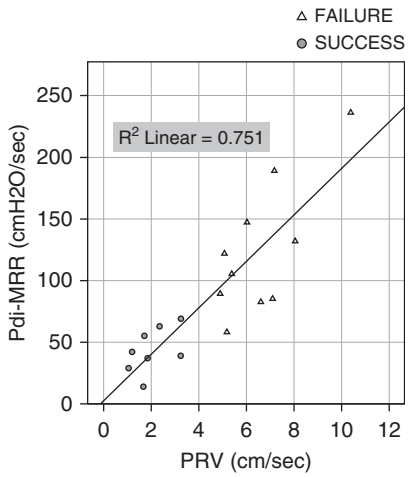

Figure 1. Relationship between Pdi-MRR and PRV. Pdi-MRR = transdiaphragmatic pressure–derived maximal relaxation rate; PRV = peak relaxation velocity.

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