

Ultrafast Ultrasound Plane Wave Imaging As a Novel non-Invasive Technique to Assess Diaphragm Contractility in Response to Phrenic Nerve Magnetic Stimulation

Rationale

Measuring twitch transdiaphragmatic pressure ($P_{di_{tw}}$) elicited by cervical magnetic stimulation (CMS) is considered as the reference method for the standardized evaluation of diaphragm function. Yet, the measurement of P_{di} requires esophageal and gastric catheter-balloons that are rarely used because of their invasiveness. Ultrafast ultrasound (US) is a non-invasive imaging technique enabling frame rates high enough to capture transient events such as evoked muscle contractions. More specifically, ultrafast US allows the quantification of transient velocities using radio frequency-based speckle tracking. Previous works have shown that **maximal tissue velocity** linearly increased with **stimulation intensity**^{a,b}. This technique is yet to be applied on the diaphragm. Also, the relationship between diaphragm tissue velocity and the **pressure** it generates during stimulation is unknown.

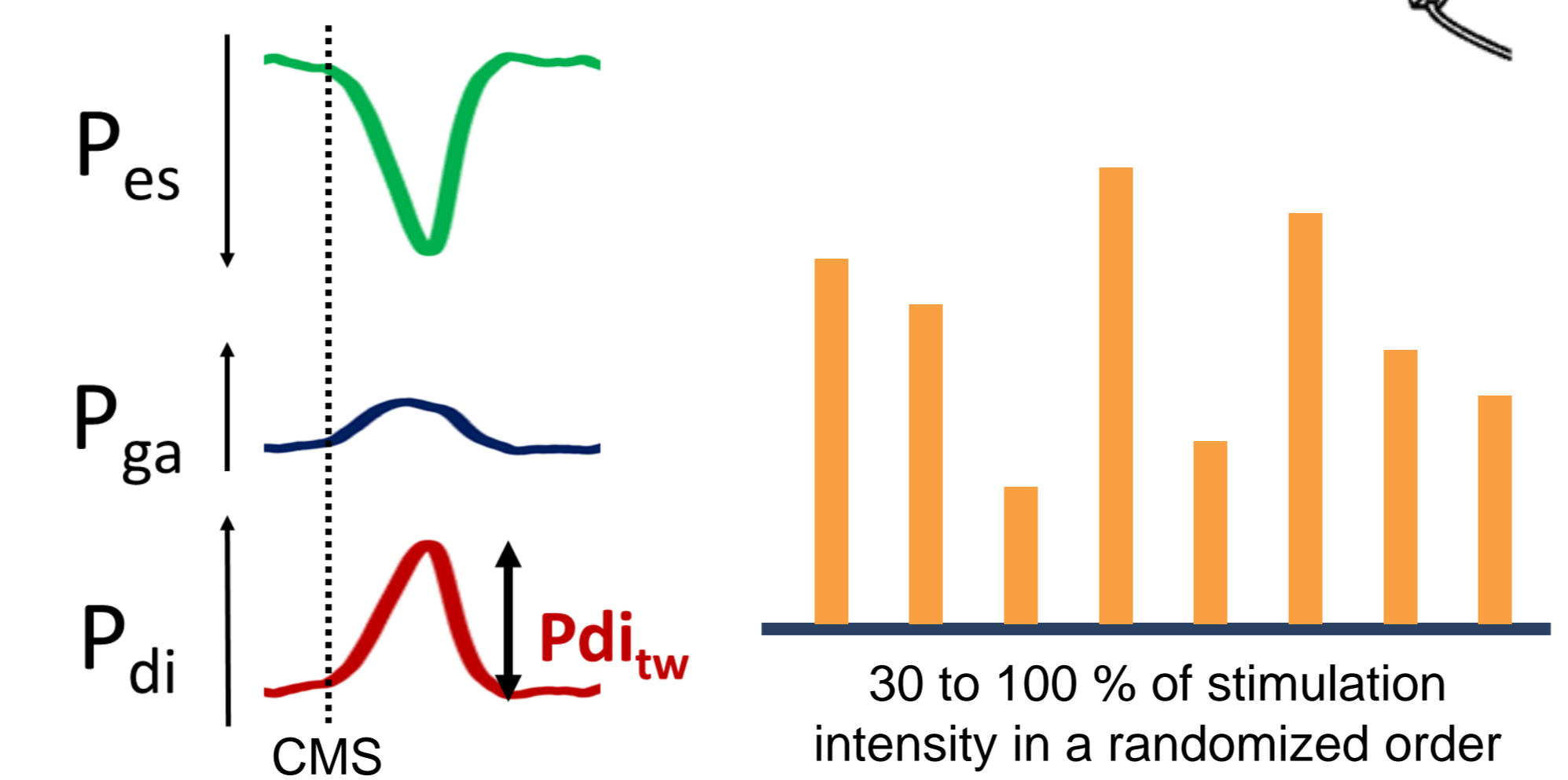
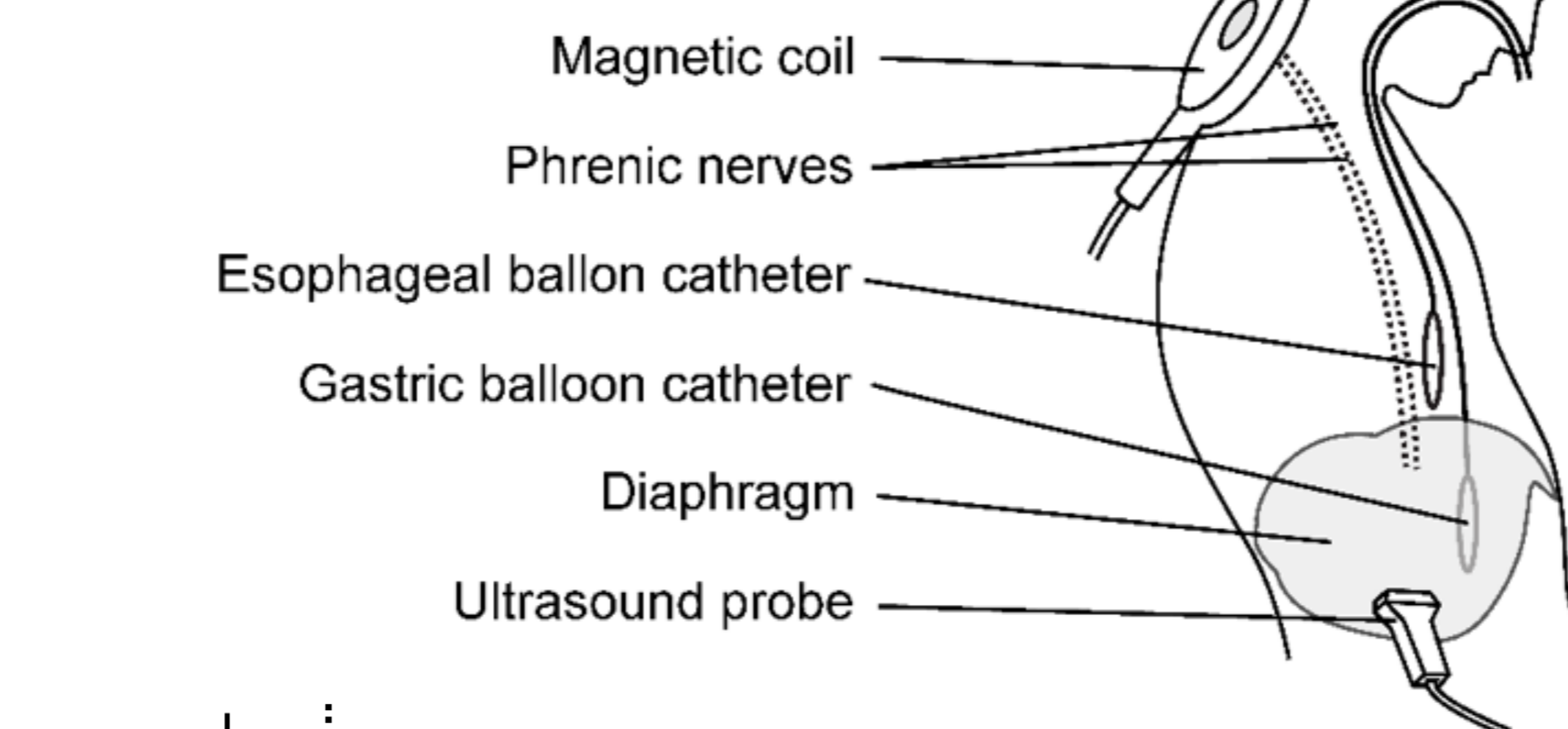
Aims

Investigate the effect of **stimulation intensity** on **diaphragm tissue velocity** ($V_{di_{max}}$)
 Determine the relationship between **diaphragm tissue velocity** and $P_{di_{tw}}$

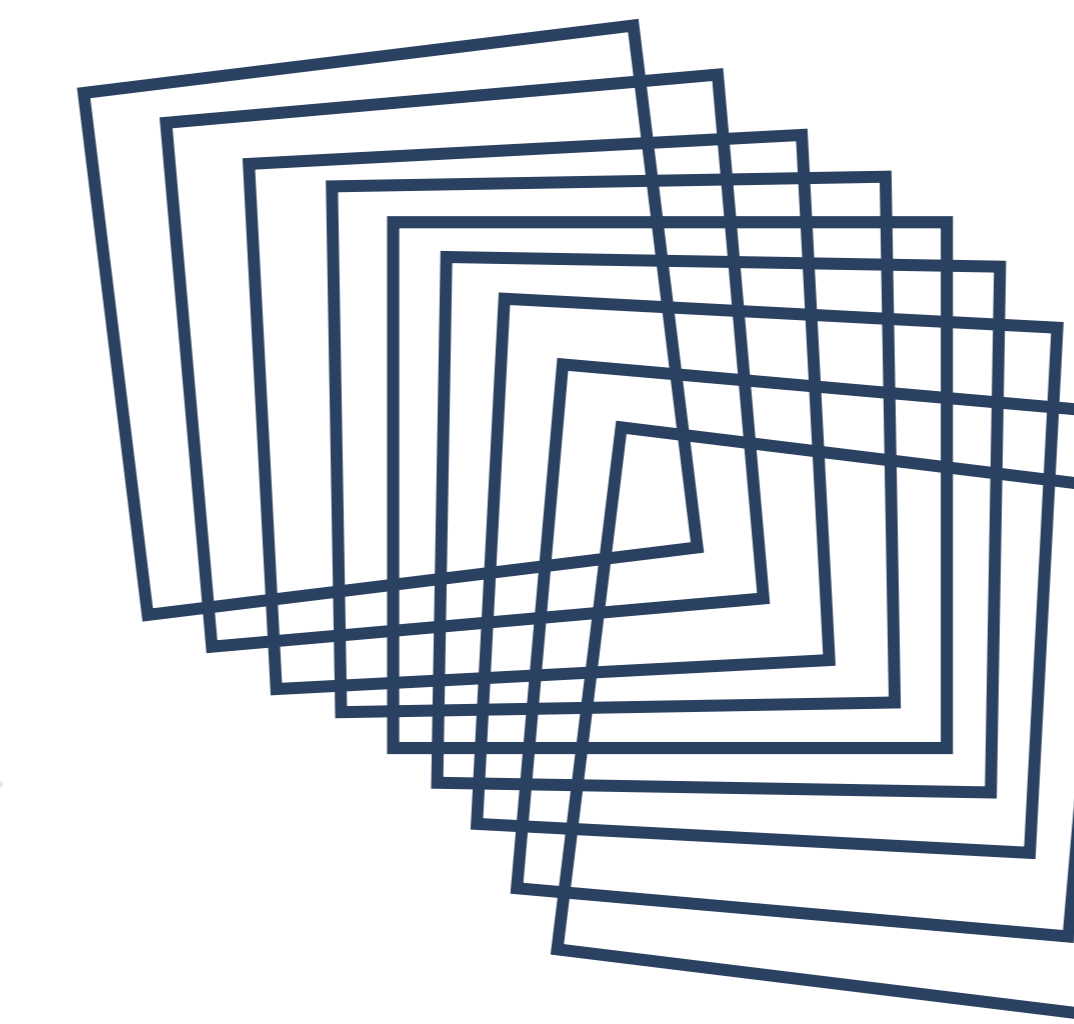
Methods

Thirteen healthy adults

♀ x8 ♂ x5

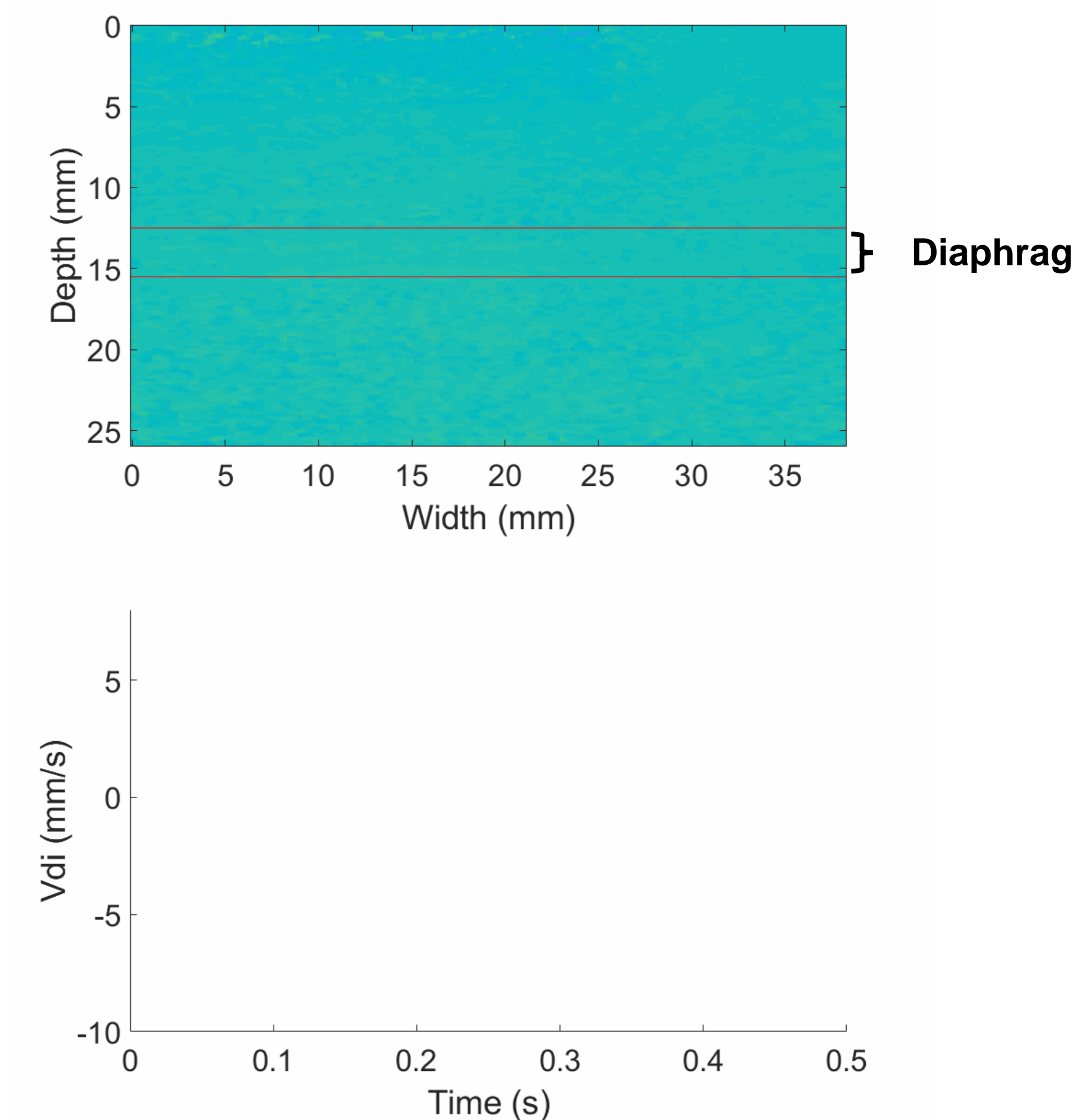
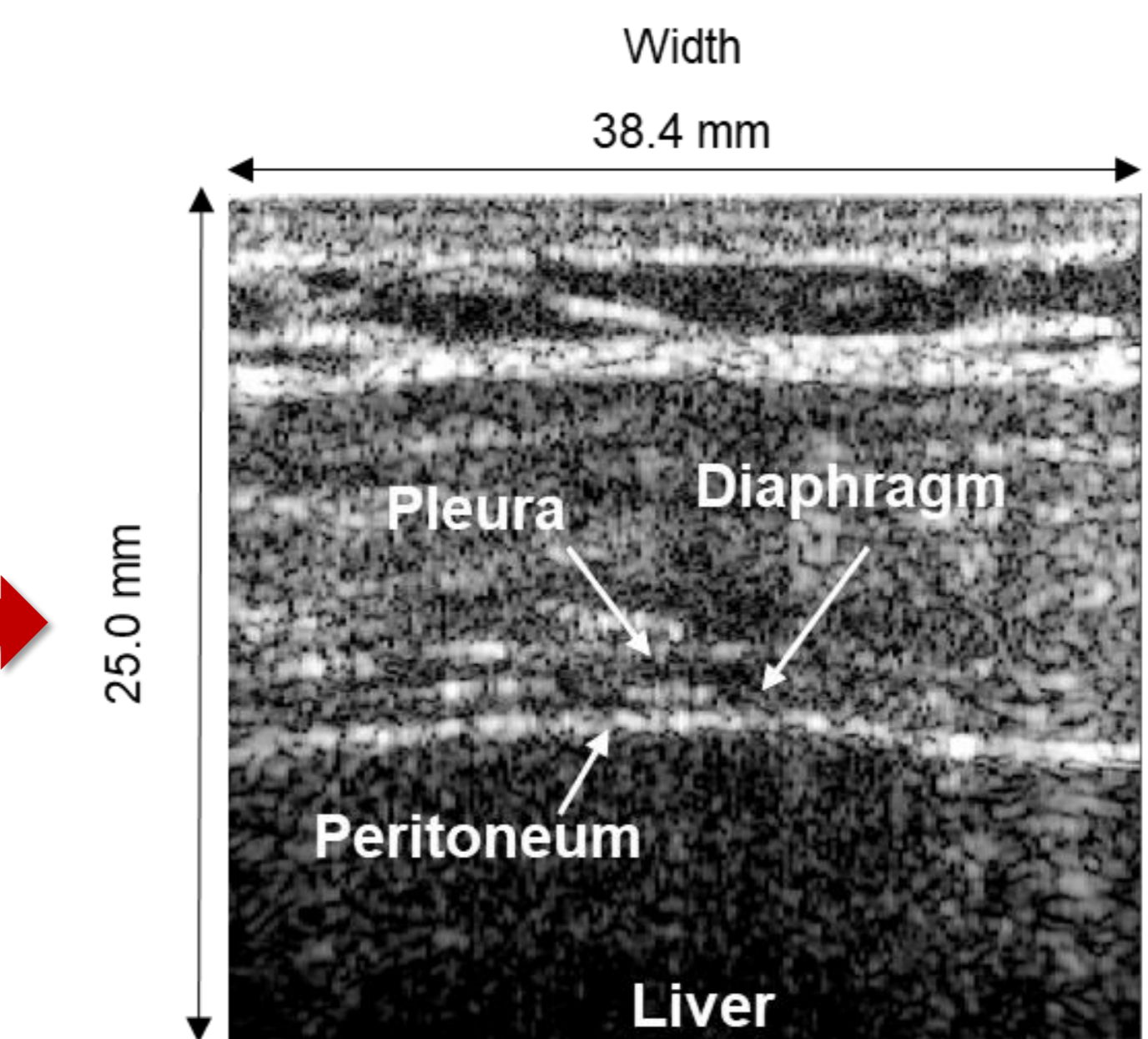


9 angles (-7° to 7° with a 2° incremental step)



9 kHz frame rate

1 kHz compounded frame rate^c
500 ms acquisition

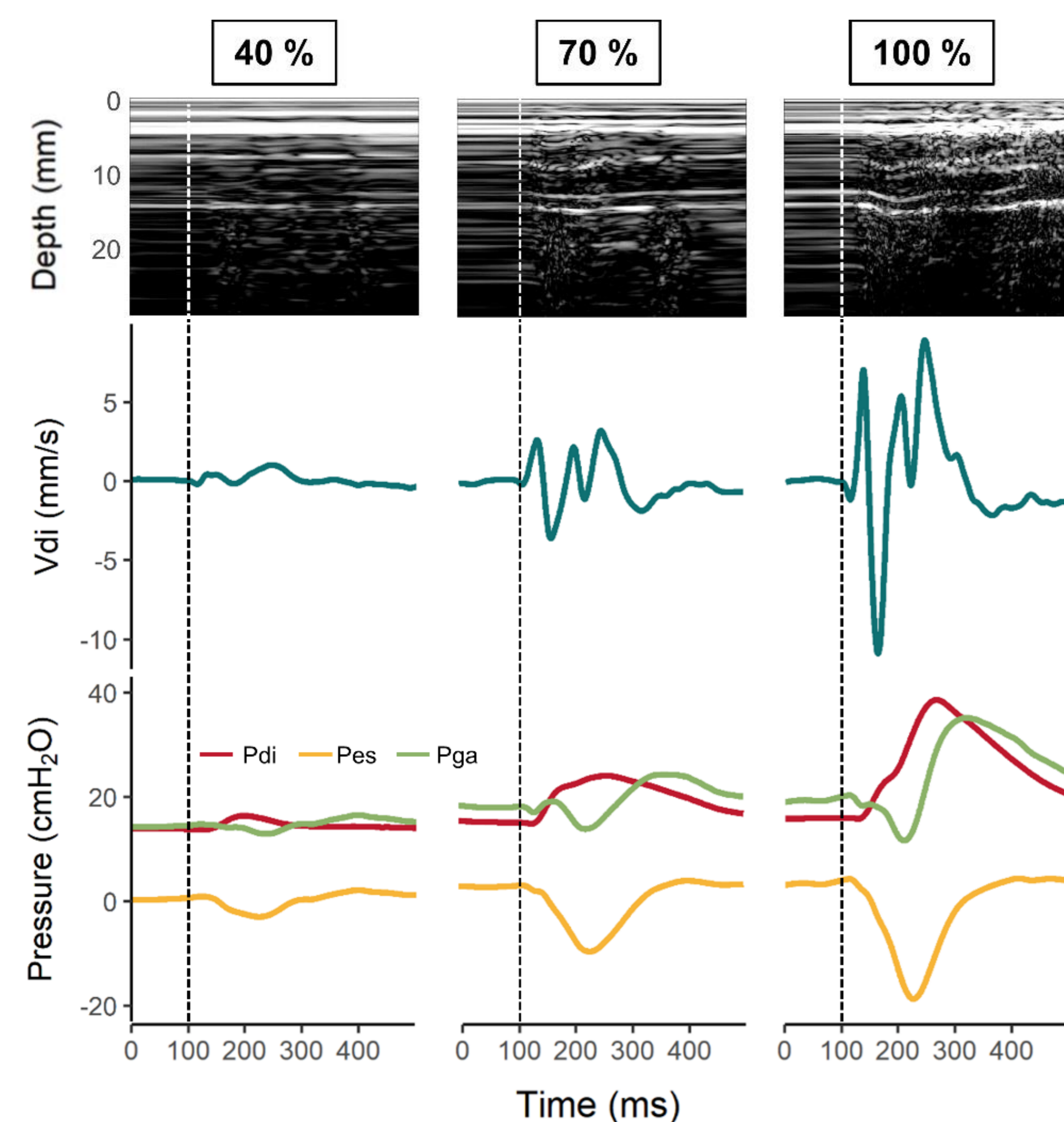


- Imaging of the zone of apposition of the right hemidiaphragm
- CMS during an end-expiratory breath hold
- One minute rest interval between stimulations

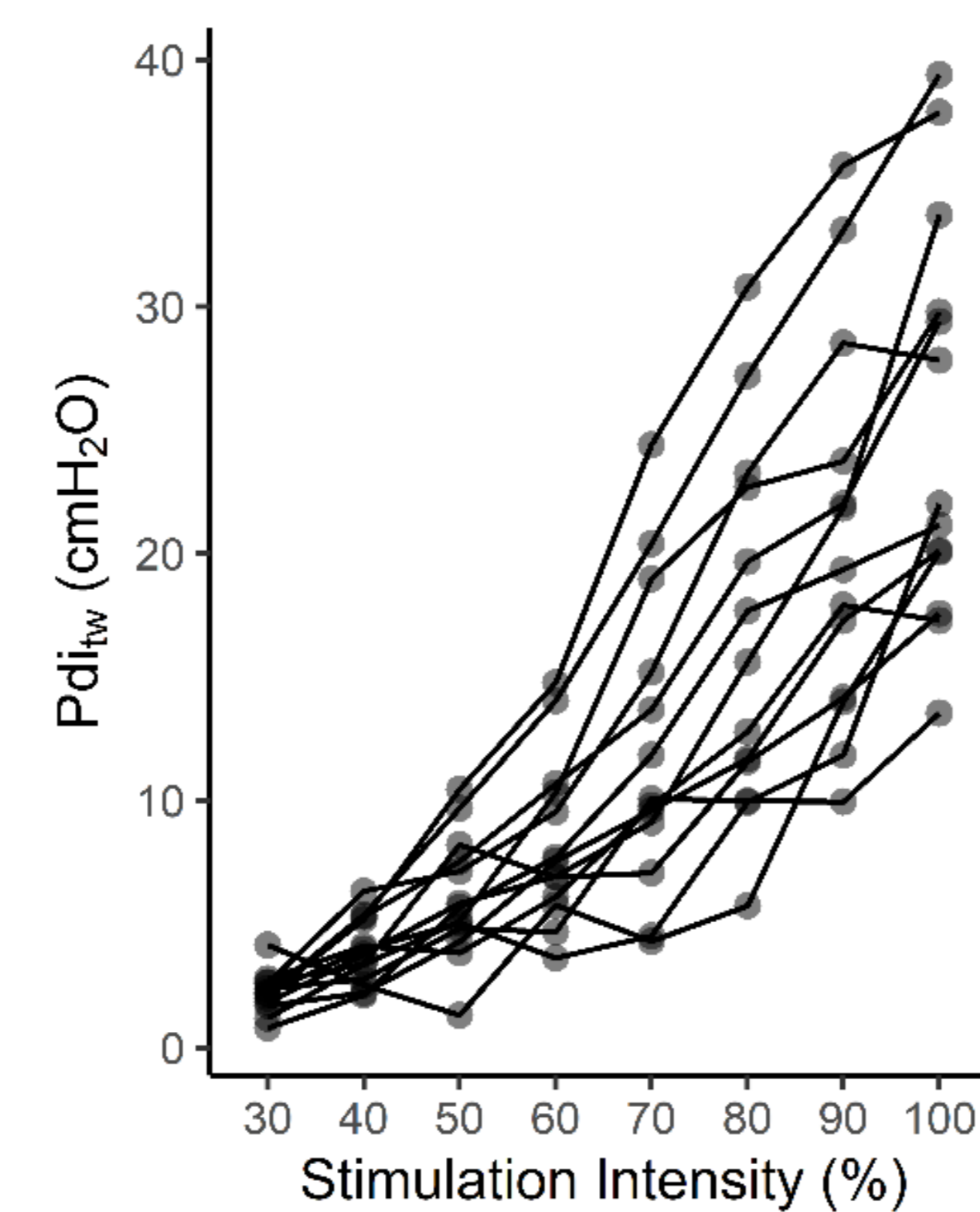
ANOVAs were used to assess the effect of **stimulation intensity** on $P_{di_{tw}}$ and $V_{di_{max}}$. **Spearman correlation coefficient** (ρ) were used to determine **within-individual relationships** between $P_{di_{tw}}$ and $V_{di_{max}}$.

Results

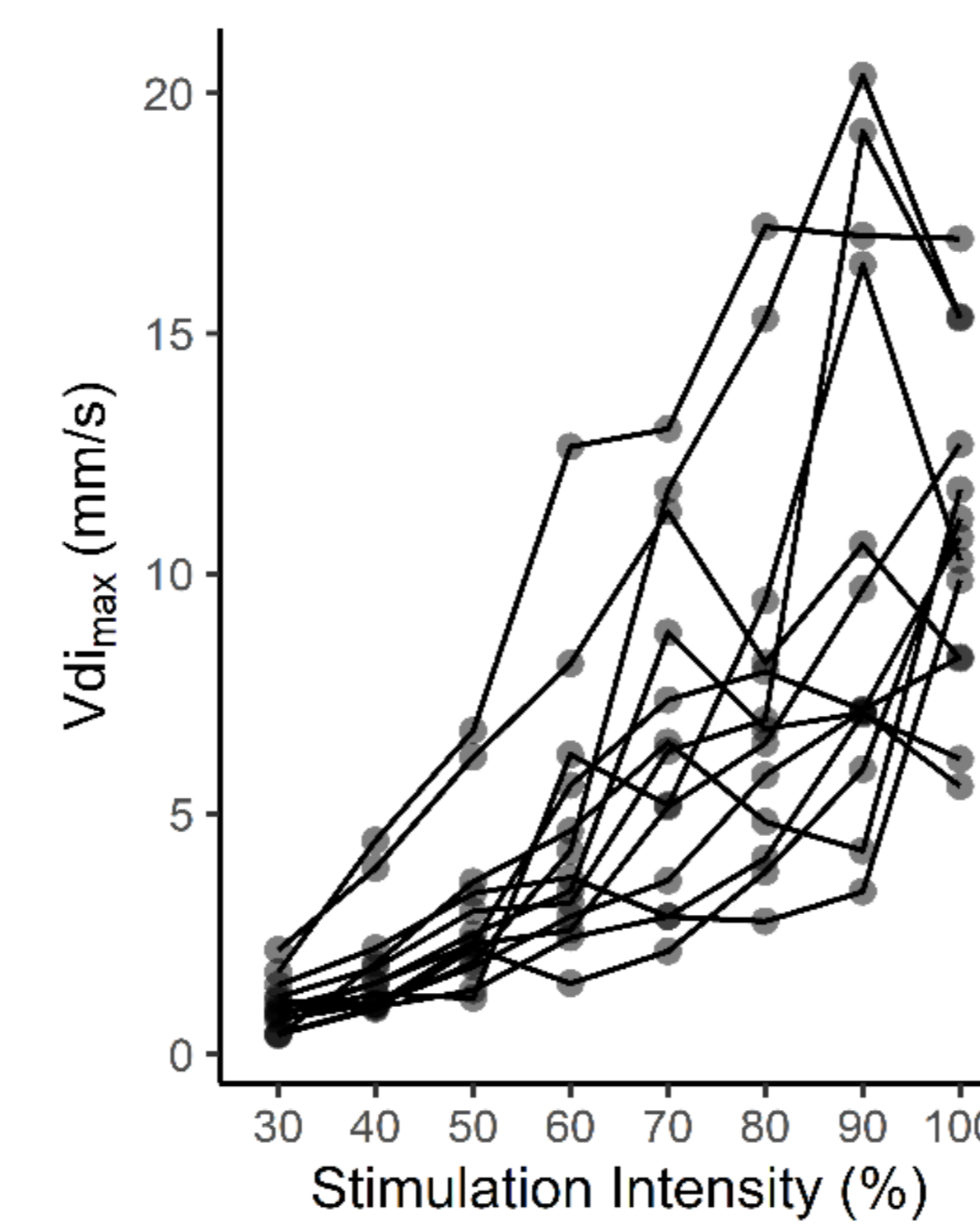
Typical M-Mode images at three intensity levels are presented. $V_{di_{max}}$ and $P_{di_{tw}}$ were similarly affected by the increase in stimulation intensity.



Both $P_{di_{tw}}$ and $V_{di_{max}}$ were significantly related to stimulation intensity in all subjects.

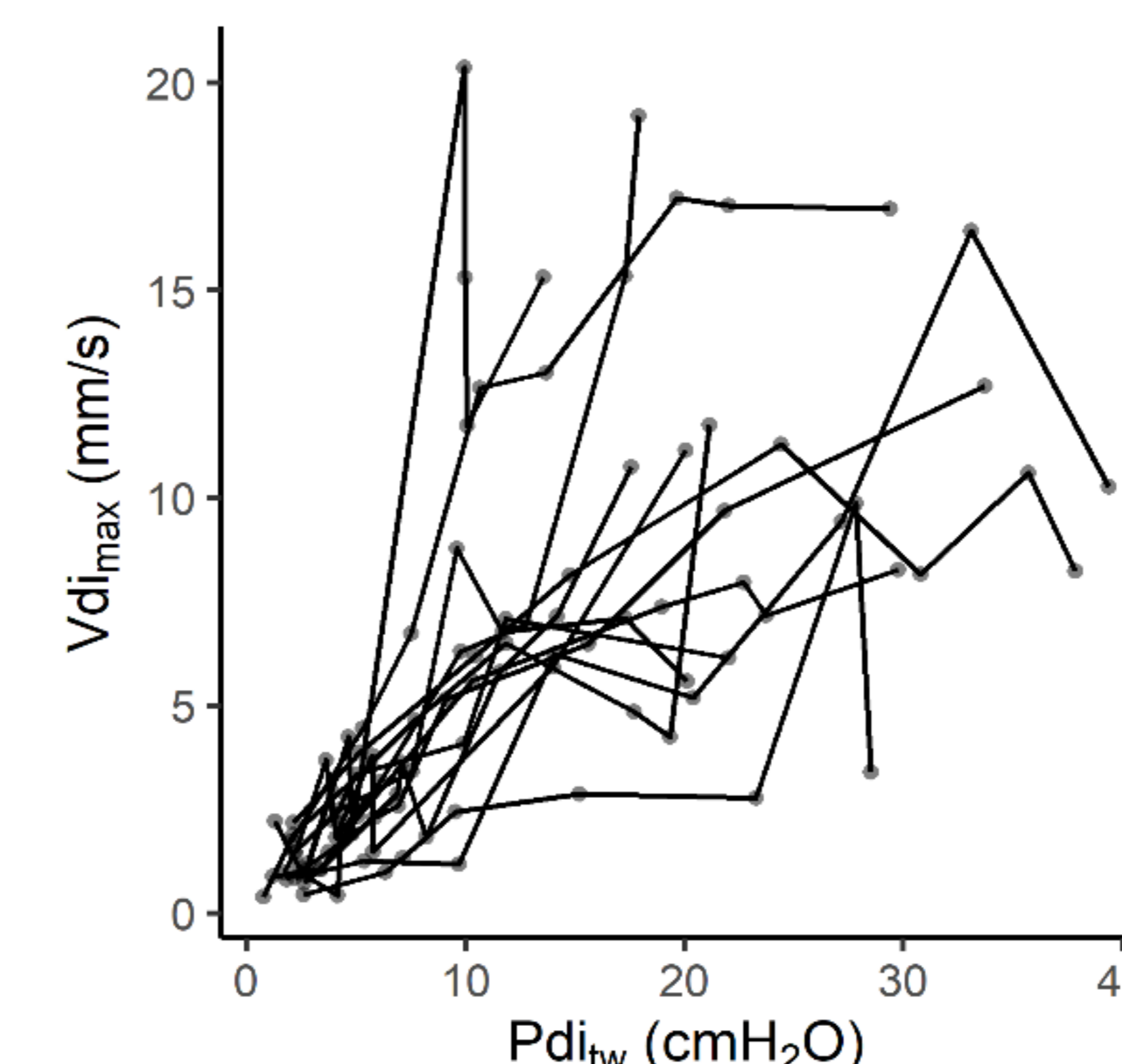


$0.83 < \rho < 1.00$, all $p < 0.01$



$0.79 < \rho < 1.00$, all $p < 0.05$

Similarly, $V_{di_{max}}$ was significantly related to $P_{di_{tw}}$ in all subjects.



$0.64 < \rho < 1.00$, all $p < 0.05$

Discussion & Conclusion

We demonstrated that ultrafast US may be used to image diaphragm behavior following CMS. Diaphragm tissue velocity is **strongly correlated** with twitch transdiaphragmatic pressure. This non-invasive approach opens prospect for a **fully non-invasive assessment** of diaphragm contractility in **clinical populations**. Indeed, the relative decrease or increase in $P_{di_{tw}}$ over time could be **predicted** thanks to the **ultrasound-derived metrics** such as **diaphragm tissue velocity**.

References:

- ^a Deffieux *et al.* Assessment of the mechanical properties of the musculoskeletal system using 2-D and 3-D very high frame rate ultrasound. IEEE Trans Ultrason Ferroelectr Freq Control
^b Gronlund *et al.* Imaging two-dimensional mechanical waves of skeletal muscle contraction. Ultrasound Med Biol
^c Loupas *et al.* An axial velocity estimator for ultrasound blood flow imaging, based on a full evaluation of the Doppler equation by means of a two-dimensional autocorrelation approach. IEEE Trans Ultrason Ferroelectr Freq Control

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