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LETTER

Diaphragmatic ultrasound and esophageal pressure in COVID-19 pneumonia during helmet CPAP

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Dear Editor,

Diaphragmatic thickening fraction was reported to correlate with inspiratory effort [1, 2]. In this prospective study, we investigated whether ultrasound-measured diaphragmatic excursion and thickening may surrogate esophageal pressure swing during Continuous Positive Airway Pressure (CPAP).

From December 2020 to August 2021, 46 consecutive patients admitted to the High-Dependency Unit (HDU) of San Carlo University Hospital (Milan, Italy) for pneumonia related to coronavirus disease 2019 (COVID-19) (confirmed by acute respiratory failure, positive test and infiltrates at lung computed tomography [CT]) were prospectively enrolled. The study was approved by the ethical committee (Comitato Etico Milano Area I; 17263/2020-2020/ST/095) and written informed consent was obtained. At HDU admission, according to the local protocol of clinical monitoring in COVID-19 patients, an esophageal balloon catheter was inserted. Esophageal pressure, ultrasound and blood gas analysis were simultaneously obtained during helmet CPAP. Measurements were repeated at zero end-expiratory pressure (ZEEP). The ultrasounds were performed by ultrasound-experienced physicians with good reproducibility of measures.

The study population had a median [interquartile range (IQR)] age of 58 [54;65] years and 61% were male, body mass index (BMI) was 27 [25;28]. PaO_2/FiO_2 ratio and $PaCO_2$ at admission were 184 [136;243] mmHg and 39 [36;42] mmHg. Charlson Comorbidity Index was 1 [1;2] and Sequential Organ Failure Assessment (SOFA) score was 3 [2;3]. Thirty-nine patients had a positive outcome, 7 underwent mechanical ventilation and 3 of them ultimately died.

As shown in Fig. 1, no association was observed between esophageal pressure swings and: (1) thickening fractions (Panel A) and (2) diaphragmatic excursions (Panel B). The correlation between changes in esophageal pressure swing and thickening fraction between PEEP and ZEEP was significantly positive but moderate ($p = 0.038$, Spearman's rho 0.35) (Panel C).

The main finding of the present study is that neither thickening fraction nor diaphragmatic excursion were able to estimate esophageal pressure swing in patients with COVID-19 pneumonia. Despite previous positive studies [1, 2], also Poulard et al. [3] observed a poor correlation between thickening fraction and change in transdiaphragmatic pressure. The two variables were repeatedly tested in a single subject and a correlation was found only in few of them. This suggests a non-fixed relationship between diaphragm contraction and change in transdiaphragmatic pressure and agrees with the dispersion we observed in the relationship between changes in esophageal pressure swing and thickening fraction between PEEP and ZEEP.

The change in transpulmonary pressure results from the applied pressure and the muscular inspiratory effort according to the following equation [4]:

$$\Delta P_{es} = \Delta P_{aw} \cdot \frac{E_w}{E_{TOT}} - \Delta P_{musc} \cdot \frac{E_L}{E_{TOT}},$$

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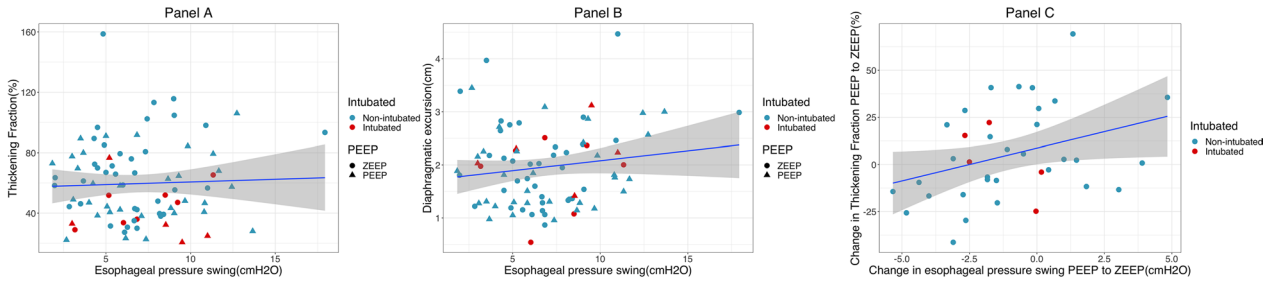

Fig. 1 **A** Correlation between esophageal pressure swing and thickening fraction both at ZEEP (circles, $p = 0.72$, Spearman's rho − 0.08) and PEEP (triangles, $p = 0.73$, Spearman's rho 0.05). **B** Correlation between esophageal pressure swing and diaphragmatic excursion both at ZEEP (circles, $p = 0.32$, Spearman's rho 0.17) and PEEP (triangles, $p = 0.99$, Spearman's rho − 0.001). **C** Correlation between the change in esophageal pressure swing and the change in thickening fraction, between PEEP and ZEEP ($p = 0.038$, Spearman's rho 0.35)

where ΔP_{es} is the esophageal pressure swing, ΔP_{aw} is the applied airway pressure, ΔP_{musc} is the pressure generated by the patient's muscles, E_W is the chest wall elastance, E_L is the lung elastance and E_{TOT} is the total elastance. Therefore, a different ratio between chest wall and lung elastance, at the same ΔP_{musc}, causes different changes in esophageal pressure and the variability of this ratio may account for the lack of correlation between diaphragmatic contraction, a manifestation of diaphragmatic ΔP_{musc}, and esophageal pressure. Moreover, ΔP_{musc} is the sum of the pressure generated by the diaphragm (as revealed by the thickening fraction) and the pressure generated by the intercostal muscles and during increasing inspiratory effort the contribution of the intercostal muscles increases progressively more in comparison to the activity of the diaphragm [5]. Therefore, we may hypothesize that, at least in COVID-19 patients, an increased inspiratory effort, as measured by esophageal pressure swings, is poorly related to the pressure generated by the diaphragm and inferred by the thickening fraction.

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Conception and design: IS, EC, and DC. Analysis and interpretation: IS, EC, SG, SCB, and DC. Drafting the manuscript for important intellectual content: IS and DC. Guarantor of this paper and responsible for the integrity of the work: IS and DC.

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Declarations

Conflicts of interest
The authors report no conflicts of interest.

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