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Volume–OXygenation Index to Predict High-flow Nasal Cannula Failure: How to Capture the Tidal Volume Matters

To the Editor:

We read with great interest the article by Chen and colleagues (1) in which they proposed a modified novel index volume–OXygenation (VOX), as calculated using the tidal volume (VT), as compared with the original ROX index [SpO_2 (pulse oximetry)/FiO_2 over respiratory rate (RR)] with RR. Better performance with higher sensitivity and specificity and a larger area under the receiver operating curve at an earlier phase (2 h and 6 h) after high-flow nasal cannula (HFNC) was initiated. We congratulate the authors for the nicely conducted pilot study demonstrating the important role of VT in the failure of HFNC in patients with acute hypoxemic failure. Nevertheless, as pointed out by Chen and colleagues, the VT measurement with noninvasive ventilation (NIV) and interruption of HFNC was not ideal. We would like to continue the discussion on this topic.

VT Occurring During HFNC May Not Be the Same as the VT Measured During NIV

To illustrate our concern, we have conducted a similar measurement as described in the study (1). A patient with acute hypoxemic failure was treated with HFNC (Optiflow, Fisher and Paykel). HFNC was interrupted and switched to NIV (Respironics V60, Philips) with inspiratory support of 5 cm H_2O and positive end-expiratory pressure amount of 5 cm H_2O. To compare the VT during HFNC and NIV, electrical impedance tomography (EIT; PulmoVista500, Draeger Medical) was used, and the ventilation changes were tracked (2). VT during noninvasive ventilation was 640 ml on average. When the impedance changes normalized to volume, it yielded VT 472 $\pm$ 65 ml for HFNC and 640 $\pm$ 74 ml for NIV. VOX was 30.4 instead of 41.2 if VT from NIV was used instead of HFNC. The cut-off values proposed in the study by Chen and colleagues were optimized for VT measured during NIV but not for HFNC.

For the Calculation of VOX, the Absolute VT Might Not Be Necessary

One disadvantage of HFNC interruption is that the "positive pressure" effect induced by HFNC will disappear within 10 seconds (as indicated with end-expiratory lung impedance in EIT).

On the other hand, EIT can be used to identify overdistention via monitoring VT distribution during HFNC continuously (3). This provides an objective measure for real-time VT changes and respiratory rate. In a previous study, we attempted to use EIT for

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early prediction (within 1 h) of HFNC failure (4). As inspired by the work (1), we combined ROX and VOX indices and retrospectively analyzed the data from the previous study (4) using EIT-based VT and RR (EIT-based min volume [MV]) at 1 hour after HFNC. This parameter ΔEMOX was calculated as follows:

$$\Delta\text{EMOX} = [\text{SpO}_{2,1h}/(\text{FiO}_{2,1h} \times \text{MV}_{\text{EIT},1h}) - \text{SpO}_{2,0h}/(\text{FiO}_{2,0h} \times \text{MV}_{\text{EIT},0h})] \times \text{MV}_{\text{EIT},0h}.$$

ΔEMOX at 1 hour after HFNC was able to distinguish HFNC failure ($P < 0.05$). The area under the receiver operating characteristic curve was 0.72 (same as ROX_{1h}). The sensitivity and specificity were 51.4 and 100, respectively, versus 77.1 and 63.6 for ROX_{1h}.

The VT calculation in the study (1) averaged the volume within 1 minute during stable NIV, whereas MV combines both VT and respiratory rate that reflects the respiratory drive within 1 minute. Given that respiratory efforts during spontaneous breathing could be assessed by EIT (5) and EIT data might be connected to the centralized ICU system, the combination of ROX and VOX with EIT-based MV might be more practical in clinical routine, that requires further validation. ■

Author disclosures are available with the text of this letter at www.atsjournals.org.

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Reply to Li *et al.*

From the Authors:

We read with great interest the letter by Li and colleagues and thank them for their interest in our work (1).

We fully agree that tidal volume (VT) that occurred during high-flow nasal cannula (HFNC) may not be the same as the VT measured with noninvasive ventilation (NIV) used at low degrees of support. However, this does not affect VT measured with NIV response to an early increase in respiratory drive in each patient. Although the accuracy of VT remains controversial, it should be pointed out that our study is merely a proof of concept to demonstrate that an index incorporating VT performs better than an index relying on respiratory rate.

To the best of our knowledge, there does exist only a few monitoring techniques that enable VT measurement under HFNC, such as a time-of-flight camera (2). However, it has not been widely used at the bedside. Tidal impedance change measured by electrical impedance tomography (EIT) correlates well with VT in individuals. However, such a correlation is not constant among patients. A universal cutoff value reflecting respiratory drive cannot be derived from EIT data alone. Although this method is not perfect, monitoring VT with low support level NIV in patients with HFNC is thus far a clinically acceptable and simple method. If well prepared, switching HFNC to NIV takes only a few seconds and may not result in derecruitment of the alveoli. Nevertheless, alternative ways to evaluate VT in patients under HFNC should be explored.

The second point raised by Li and colleagues is that for the calculation of Volume-OXygenation (VOX), the absolute VT might not be necessary. It is our opinion that the absolute value of VT is essential to estimate the absolute value of an early increase in the respiratory drive during HFNC. The parameter ΔEMOX proposed by Li and colleagues, that uses EIT-based VT and respiratory rate (EIT-based min volume [MV]) at 1 hour after HFNC, only reflects the change in respiratory drive before and 1 hour after HFNC but not the absolute increase in respiratory drive in each patient. Therefore, it is not surprising that ΔEMOX has only a moderate value in predicting HFNC failure (area under the receiver operating characteristic curve [AUROC], 0.72).

To verify that absolute elevation of VT rather than changes in VT after HFNC is a better predictor of HFNC failure, we retrospectively analyzed the data from our previous study, mimicking Dr. Li and colleagues' ΔEMOX formula. The parameter ΔMOX (MV-OXygenation) at 2 hours and 6 hours after HFNC was calculated as follows (Sp_{O_2} = oxygen saturation as measured by pulse oximetry):

$$\Delta\text{MOX}_{2h} = ([\text{Sp}_{\text{O}_2,2h} / (\text{Fi}_{\text{O}_2,2h} \times \text{MV}_{2h})] - [\text{Sp}_{\text{O}_2,0h} / (\text{Fi}_{\text{O}_2,0h} \times \text{MV}_{0h})]) \times \text{MV}_{0h}$$

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