On the Road to Surface Monitoring of Diaphragmatic Activity in Mechanically Ventilated Patients

In 1999, Sinderby et al[1] published the first paper on neurally adjusted ventilatory assist (NAVA). This publication clearly excited the respiratory care community because it was the first legitimate demonstration that the inspiratory diaphragmatic electromyography (EMG) signal, also called the electrical activity of the diaphragm (EA_{di}), could be used in a practical manner to manage gas delivery and improve patient–ventilator interaction.[2,3] NAVA delivers pressure to the airways proportional to the EA_{di}; the proportionality factor is set on the ventilator by the clinician. Since that first paper, there has been an abundance of data addressing how the EA_{di} could be used in the management of patients with respiratory failure. NAVA has been used as a ventilatory mode for neonates,[4,5] pediatric patients[6,7] and adults,[8,9] and it has clearly demonstrated improved patient–ventilator interaction compared to the classic ventilatory modes.[2,3] Detection of inspiratory efforts is important to individualize the ventilatory assistance for patients requiring ventilatory support. Recently, a number of groups have demonstrated the potential use of the EA_{di} signal to evaluate the liberation of patients from mechanical ventilation.[10–12] Dres et al[10] demonstrated that the maximum EA_{di} during spontaneous breathing, the maximum EA_{di}/tidal volume (V_T), the area under the maximum EA_{di} curve (AUC EA_{di}), and the AUC EA_{di}/V_T, all were improved in subjects successfully weaned from ventilatory support compared to those failing spontaneous breathing trials. Muttini et al[12] were able to derive regression equations that clearly separated those subjects who were weaned successfully from ventilatory support from those who failed a spontaneous breathing trial by comparing maximum $EA_{di_{max}}$ to AUC EA_{di}. Bellani et al[13] also reported that the EA_{di} could be used to assess the level of autoPEEP. Colombo et al[14] demonstrated that the EA_{di} provided an excellent tool to monitor a patient's ventilatory drive. In a subsequent publication, Bellani et al[15] found a linear relationship between EA_{di} and the pressure generated by the ventilatory muscles during inspiration (P_{mus}), and they showed that EA_{di} measured in microvolts could be converted to P_{mus} in cm H_2O. However, the major problem with the use of EA_{di} is that its measurement is invasive, requiring the placement of a catheter via the esophagus across the diaphragm. Not only is the catheter difficult to place in some patients, but it is even more difficult to maintain it in its proper position. This problem has minimized the enthusiasm for the use of NAVA and the continuous measurement of EA_{di}.

In this issue of the Journal, Bellani et al[16] report a solution to this problem. They used surface EMG electrodes to record the diaphragm EA_{di} on the skin surface (surface EA_{di}) and the EMG activity of the intercostal and sternocleidomastoid muscles, and they measured simultaneously the esophageal pressure, airway pressure, airway flow, and the EA_{di} using esophageal electrodes. Subjects in their study were either intubated or tracheostomized and received pressure-support ventilation. A total of 14 selected subjects participated in the study. Their average duration of ventilation at the time of the study was 12 ± 19 d. Subjects were ventilated with a mean PEEP of 10 ± 2 cm H_2O and mean F_{IO_2} 0.42 ± 0.19, and had a mean P_{aO_2}/F_{IO_2} of 235 ± 60 mm Hg at a pressure support level of 7 ± 2 cm H_2O. Unfortunately, V_T was not provided. Body mass index was 25 ± 4 kg/m^2, and subjects were mostly ventilated for hypoxemic respiratory failure: 6 with pneumonia, 4 with the ARDS, 3 with sepsis, 1 trauma victim, and 1 post-cardiac arrest subject. They found a very good correlation between EA_{di} and surface EA_{di} based on single breaths, although when considering all aggregated breaths, the correlation increased to a mean $R = 0.93 \pm 0.12$. They also found that P_{mus} measured from the esophageal pressure correlated well with both EA_{di} ($R = 0.72$, $P < .001$, slope 0.81) and surface EA_{di} ($R = 0.64$, $P < .001$, slope 1.01).

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Although the investigators should be congratulated on a very well designed and performed study, there are some concerns with the findings. First, because this was a short-term study, more data are needed to determine whether the same reliability of measurement will exist if the surface EA_{di} electrodes are left in place continuously over a longer period of time. Second, we have had misguided enthusiasm over the use of surface electrodes to trigger inspiration in the past. The Infrasonics pediatric ventilator in the 1970s and 1980s used a motion sensor to trigger inspiration in mechanically ventilated neonates.[17] The sensor was placed on the abdomen between the umbilicus and the xiphisternum, but it proved to be unreliable. This technology, referred to as the Graseby capsule, is now being used in the Infant Flow SiPAP, nCPAP system (Vyaire, Lake Forest, Illinois).[18] It has been demonstrated that the Graseby capsule is capable of triggering SiPAP flow at essentially

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the same reliability as a transcutaneously applied EA_{di} electrode.[18] Third, this small, selected patient series is not representative of the entire population of interest in the ICU. None of the subjects studied had chronic pulmonary disease, and, most importantly, all subjects had a lean body mass. The greater the body mass index, the more difficult it is to obtain a reliable surface EMG signal from the diaphragm.[19] The greater the layer of adipose tissue between the electrode and the muscle, the less likely the signal will be reliable. Considering the increasing worldwide obesity epidemic,[20] this is a major concern with the use of surface EA_{di} that must be addressed.

Certainly, these data from Bellani and colleagues[16] should generate enthusiasm for the use of the surface EA_{di} signal, both to manage gas delivery and to monitor patient response to mechanical ventilation, as well as to assess patient efforts and probability of weaning from ventilatory support. However, there is a long way to go before we will see this technology available for everyday use. Nevertheless, the data from Bellani et al[16] indicate that there is a high probability that patients receiving patient-triggered ventilation can have gas delivery initiated and regulated noninvasively by the patient's diaphragmatic EMG signal, thus allowing easily obtained monitoring data that are not available at the bedside today. We are clearly on the road to having surface EMG diaphragmatic monitoring and gas delivery regulation.

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