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The Paradox of Power: Dynamic Tools to Predict Respiratory Failure in Spontaneously Breathing Patients

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The impressionist artist, Claude Monet, painted a series of haystacks, "*Les Meules à Giverny.*" He famously produced 14 paintings in a single day as he noted that the sun changed position every 7 minutes [1]. Much as observations of color are subject to the influence of atmospheric conditions on the refraction of light, our assessments of complex biologic systems may also change with differences in perspective. While static measurements, such as PaO2 or Plateau pressure, are heavily relied upon for their diagnostic value, dynamic measurements can reveal additional insights into disease trajectory or treatment response.

In this issue of the *Journal*, Gattarello and colleagues provide thought provoking data on the value of mechanical power and other dynamic measures of respiratory function in spontaneously breathing COVID-19 patients in acute respiratory failure[2]. They performed a secondary analysis of a prospective cohort of 111 patients hospitalized with COVID-19 pneumonia at a single center between September 2020 to December 2021. All patients were supported with continuous positive airway pressure (CPAP). An esophageal balloon catheter estimated the pleural pressure (ΔP_{pl}, ΔP_{pl} = esophageal inspiratory pressure – esophageal expiratory pressure), and tidal volume (V_T) and respiratory rate (RR) were measured with a novel non-invasive impedance device[3].

It is well established that limiting V_T to 6-8 mL/Kg of ideal body weight improves survival during acute respiratory distress syndrome (ARDS), but it is unclear if these targets are appropriate for all patients given heterogeneity in regional lung compliance[4]. Recently, mechanical power has emerged as a potential *unifying* predictor of ventilator induced lung injury. Mechanical power is a measurement, in Joules/minute, of the energy required to move the lungs from rest to a given point on the respiratory system pressure-volume curve. During mechanical ventilation, airway pressure is delivered to overcome the resistive and elastic forces of the respiratory system to generate thoracic expansion. Ventilator induced lung injury is associated with mechanical power, potentially dependent on V_T, in experimental models, [5-7] and increased mechanical power is associated with mortality among mechanically ventilated patients with ARDS, independent of driving pressure[8,9]. However, among spontaneously breathing patients, it has been unknown whether differences in mechanical power may identify patients at risk for progression of acute lung injury.

To address this gap, Gattarello and colleagues estimated mechanical power with a validated equation using RR, V_T and ΔP_{pl}. The authors offered a novel definition of *ideal mechanical power* as the power needed for a normal minute ventilation, figured as 0.1 times the ideal body weight (kg). Two recently introduced indices, the ratio of oxygen (ROX) index and the pressure-rate index, were also measured, with the former more easily applied at the bedside[10,11]. The primary outcome of treatment escalation, defined as any increase in respiratory support beyond CPAP, was left to the discretion of the attending physician with institutional guidance based on the COVID-19 pandemic. The authors used the area under the receiver operating characteristic curve (AUROC) to test the association between each predictor and the binary need for respiratory treatment escalation.

Gattarello and colleagues report clear differences in initial ventilatory parameters in the group of patients eventually requiring respiratory treatment escalation above CPAP characterized by lower PaO2, worse PaO2/fraction of inspired oxygen (FiO2), higher minute ventilation, higher RR, higher ΔP_{pl} and higher lung elastance on the first day of hospitalization. All values of the tested dynamic parameters were worse in patients requiring more respiratory support; mechanical power, in absolute and relative values, ROX and the pressure-rate index. Mechanical power and the pressure-rate index had the highest AUROC for determining need of respiratory treatment escalation, but the ROX index had a similar but smaller AUROC. These findings identify mechanical power as a potentially sensitive instrument for discerning which spontaneously breathing patients with acute respiratory failure are at risk for escalation in care.

A strength of this study is that it is a secondary analysis of prospective data collected with sophisticated tools and carefully applied to the latest existing mathematical constructs of mechanical power. Stated limitations by the authors included that the statistical approach was not selected to assess superiority of the various indices in predicting the primary outcome. Thus, questions remain of whether mechanical power performs better in identifying an at-risk group than less complex indices of respiratory failure, more readily applied at the bedside, such as the ROX index. Of particular concern, the primary study outcome of respiratory escalation is quite broad, inclusive of other non-invasive support, and may not be clinically meaningful; although, the authors' justification that guidelines developed specifically for the COVID-19 pandemic were widely applied appears sound. Further, acknowledging resource limitations during the COVID-19 pandemic, patients in this study were supported on CPAP whereas high flow nasal canula is a more accepted initial therapy for respiratory failure[12]. Therefore, additional work is required to best establish the association between mechanical power in spontaneously breathing patients and important clinical outcomes such as the need for mechanical ventilation or, of primary importance, mortality. Broad adoption of this complex approach hinges on evidence of relevance in other common non-COVID-19 causes of respiratory failure, such as sepsis, and with models adjusted for potentially confounding demographic variables, such as age or comorbid respiratory disease.

Based on these findings, one immediate question is whether the clinician should incorporate mechanical power measurements into practice? One potential barrier is the challenge of how best to normalize mechanical power between patients who vary in baseline differences in the measured parameters given age, sex, and body size. The authors showed no differences in distributions of gas-volume or tissue-mass on CT chest imaging between the cohorts of patients. However the question remains of how to account for lung disease heterogeneity within individual patients. Others have proposed normalizing mechanical power to dynamic lung compliance, which would better control for these differences [13]. Here, the authors derived a novel and untested value, *ideal mechanical power* as a function of height and sex, which would control for thoracic size. Which normalization approach will ultimately allow broad clinical application of mechanical power remains to be answered.

There are additional technical considerations regarding the measurement and application of mechanical power. Gattarello and colleagues measure mechanical power with a validated equation that largely reflects inspiratory power. Experts debate whether to include the expiratory component of mechanical power, which may be especially important in spontaneously breathing patients. Quantifying mechanical power as the area under the pressure-volume loop may more comprehensively capture the ventilation cycle as others have shown discrepant values when comparing these two approaches[14]. Additional work is also needed to ascertain how widely used treatment modalities, such as proning or high flow nasal canula, may influence mechanical power in spontaneously breathing patients. Finally, data from experimental models are needed to establish whether mechanical power is a marker of lung disease severity or a mediator of lung injury during spontaneous breathing.

As Claude Monet showed in the French countryside, serial observations of complex systems yield novel insights. Intriguingly, mechanical power may be a more dynamic assessment of lung injury; though, practical questions remain to be answered before it may supplant conventional clinical approaches and more established indicators of disease severity.

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