Lung Mechanics of the Obese Undergoing Robotic Surgery and the Pursuit of Protective Ventilation

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Protective mechanical ventilation characterizes a strategy aimed at preventing lung overdistension (volutrauma), derecruitment (atelectrauma), and dysfunctional inflammation (biotrauma). It is usually implemented with physiologic tidal volumes, for which there is strong evidence of outcome benefits, and lung expansion including positive end-expiratory pressure (PEEP) and recruitment maneuvers, with persisting controversy. Protective ventilation has been mostly studied in critical care, despite the known effects of intraoperative ventilatory settings on postoperative pulmonary outcomes.[1] Current laparoscopic robotic surgery techniques challenge the anesthesiologist to optimize mechanical ventilation in conditions where the patient's physiologic complexity (*e.g.*, obesity) frequently compounds with surgical physiologic burden (pneumoperitoneum, unphysiological Trendelenburg position).[2] Unfortunately, objective data are scarce to guide clinical practice in these procedures.

"Current laparoscopic robotic surgery techniques challenge the anesthesiologist to optimize mechanical ventilation…"

In this issue of Anesthesiology, the article by Tharp *et al.* regarding 91 patients with body mass index (BMI) ranging from normal to greater than 40 kg/m^2 undergoing laparoscopic robotic surgery brings valuable data to the field.[3] The authors report significantly worse lung mechanics—compliance, driving pressures, and transpulmonary pressures—with increased BMI at different surgical stages. Lungs of severely obese patients were twice as rigid than those of patients with normal BMIs. Tharp *et al.* estimated optimal PEEP from lung mechanics measurements and showed this to be substantially higher than the applied PEEP in most patients in the different surgical stages and BMI categories, despite consistent use of currently proposed lung protective ventilation strategies.[3] Indeed, most patients presented mechanical evidence of atelectasis, suggesting that they were at risk for hypoxemia and atelectrauma.

Airway pressures are required to generate at least three processes during mechanical ventilation: airway flow, lung expansion, and chest wall expansion. This implies that total airway pressure applied by the ventilator is not entirely spent on the lungs (*i.e.*, is not equivalent to lung stretch or stress). In fact, during ventilation of a healthy, nonobese patient under general anesthesia, approximately 60 to 70% of the airway pressure is distributed to the lungs, and approximately 30 to 40% expands the chest wall.[3–5] This is because in those conditions, lung compliance is lower (40 to 70%) than chest wall compliance.[3–5] The concept is that the stiffer structure bears the higher fraction of airway pressure. That fraction of airway pressure distributed to the lung is the relevant component for ventilator-induced lung injury, as that is the pressure ultimately producing excessive lung stress and injury.[6] Assessment of this risk during robotic surgery is challenging because both lungs and chest wall mechanics change intraoperatively. Consequently, data are needed to guide practice.

A traditional physiologic method now clinically available to separate the pressure acting on the lungs (transpulmonary pressure) from that acting on the chest wall (pleural pressure) is esophageal balloon manometry. Transpulmonary pressure is calculated as the difference between airway and esophageal pressure, the latter used to estimate pleural pressures.[3–6] Tharp *et al.* document increases in tidal transpulmonary pressure of 1.9 ± 0.5 cm H_2O for each 5 kg/m^2 of BMI after anesthesia induction and before pneumoperitoneum. Such a finding emphasizes that susceptibility to stress injury during mechanical ventilation increases with BMI. Of note, that was not only due to higher airway pressures with BMI, but also because lung compliance, not chest wall compliance, worsened with BMI, increasing the fraction of airway pressure distributed to the lungs.

Image: A. Johnson, Vivo Visuals.

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Data presented by Tharp *et al.*[3] indicate remarkably worse stiffening of the chest wall (greater than 300%) than of the lungs (approximately 50%) in the surgical stage of Trendelenburg position with docked robotic arms, as compared to measurements immediately after intubation in all BMI categories. These values were similar to those from a recent study in American Society of Anesthesiologists physical class I to II nonobese patients undergoing laparoscopic robotic surgery,[4] but contrast with substantially milder mechanical worsening during nonrobotic laparoscopic surgery,[5] emphasizing the compromise in respiratory mechanics specific to robotic cases. Such higher chest wall stiffness results in a lower fraction of airway pressure distributed to the lungs during the Trendelenburg position and docked robot condition than after intubation: 48 to 49% in nonobese patients, down from 62 to 63%,[3,4] and 56 to 57% for those with BMI 30 to 40 kg/m^2, down from 78 to 80%.[3]

The clinical implication of these observations is very practical: absolute limits for airway plateau pressures, such as 30 cm H_2O,[7] are not necessarily accurate during robotic surgery, as a substantial fraction of the airway pressure is not applied to distend the lungs but to expand the rigid chest wall.[4] Overzealous limitation of PEEP or tidal volume to maintain plateau pressures less than 28 to 30 cm H_2O in such cases could expose patients to unnecessary hypoxemia, hypoventilation, and mechanical injury. Indeed, using electrical impedance tomography, Brandão *et al.*[4] found loss of dorsal aeration at the end of robotic surgery consistent with insufficient lung expansion despite use of conventional "protective" settings.[7] Dorsal ventilation was maintained in that condition (*i.e.*, the same tidal volume applied to a smaller lung), implying increased dorsal strain, driving pressure,[3,4] and risk for pulmonary complications.[1] Tharp *et al.* indicate that such unfavorable physiologic conditions worsen with BMI.[3]

Another contribution of the article by Tharp *et al.*[3] was the estimation of optimal PEEP, calculated as the applied PEEP added to the end-expiratory transpulmonary pressure. The latter represents the pressure across the lungs at end-exhalation, a positive value required for an open lung. End-expiratory transpulmonary pressures were negative in most patients throughout surgery, *i.e.*, most patients likely did not receive optimal protective settings. Furthermore, PEEP requirements increased with BMI, and they were the largest during Trendelenburg position.[3] At this stage, an optimal PEEP of 9.7 ± 3.7 cm H_2O was estimated for BMI less than 25 kg/m^2 and PEEP of 21.3 ± 7.4 cm H_2O for BMI greater than or equal to 40 kg/m^2. These estimates challenge the adequacy of the "high-PEEP" of 12 cm H_2O used in a recent major study showing no pulmonary outcome benefits in obese patients.[8] While there is substantial controversy about use of esophageal pressures to set PEEP,[6] Tharp *et al.*'s report provides a clear message on the shortcomings of current PEEP setting practices for the obese. Importantly, as noted by Dr. Wiener-Kronish in the Severinghaus Lecture during the 2019 Meeting of the American Society of Anesthesiologists, high PEEP levels optimized to lung mechanics have been safely applied in critical care settings to obese patients with significant cardiac compromise. This was recently confirmed in obese acute respiratory distress syndrome patients who benefitted from PEEP increases to approximately 20 cm H_2O with reduction of required hemodynamic support and no adverse effect on right ventricular function.[9]

Tharp *et al.* observed high variability in optimal PEEP depending on patient, surgical stage, and BMI.[3] Consequently, an empirical PEEP could be either insufficient to recruit atelectatic lung or excessive and produce overdistension. Here, the clinical message is also clear. Similar to hemodynamic monitoring, which is advanced from noninvasive to pulmonary artery catheter and transesophageal echocardiography as patient and surgical complexity increase, respiratory monitoring requires individualization. Usually, our respiratory monitoring allows for safe management, and new surgical challenges, as robotic surgery may require advanced techniques such as esophageal manometry in selected cases for best management. Conceptually, that appears appropriate: anesthesiologic innovation goes hand in hand with surgical innovation.

More still needs to be learned. The implications of high PEEP to intraocular and intracranial pressures in steep Trendelenburg position need better understanding, and could be influenced by worsened chest wall compliance.[10] Airway closure during surgical pneumoperitoneum observed in obese patients creates challenges for accurate estimation of transpulmonary pressures.[11] A recently completed observational study will bring data on pulmonary complications and ventilatory settings during laparoscopic robotic surgery.[12]

Tharp *et al.* add to the literature that associates risk of lung mechanical injury to BMI during mechanical ventilation for laparoscopic robotic surgery. The investigators teach us that we should be prepared to add respiratory monitors to our clinical armamentarium according to case and patient complexity, and apply ventilator settings not currently usual during robotic surgery in the obese if we are to follow protective principles to their physiologic meaning.

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Competing Interests

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