GE HealthCare

Carestation™ 600 Series Anesthesia Systems Lung Protective Tools

Clinical Focus Guide

Learn how simple implementing lung protective strategies can be using innovative GE HealthCare anesthesia technology to help reduce post-operative pulmonary complications.

Introduction

Although there have been significant advances in mechanical ventilation over the past several decades, the possibility of post-operative pulmonary complications (PPCs) and ventilator-induced lung injury (VILI) persists.[1,2] The prevalence of PPCs is frequent and associated with substantial morbidity and mortality. However, evidence suggests that intraoperative lung protective ventilation strategies can reduce the incidence of PPCs.[3] As a leader in healthcare technology, GE HealthCare is committed to providing lung protective ventilation tools that enable clinicians to safely manage patients requiring mechanical ventilation. The Carestation™ 600 Series Anesthesia Systems introduce important functionalities designed to help clinicians deliver lung protective ventilation to help improve patient-ventilator care and PPCs.

Predicted Body Weight

When determining the initial tidal volume setting for ventilation, clinicians often use the ideal body weight or predicted body weight (PBW) as a guide.[4] The purpose of using PBW instead of actual body weight is to ensure that adequate ventilation is delivered to the patient based on the size of their lung, which corresponds to patient height rather than the patient's actual weight. For this reason, lung protective ventilation guidelines suggest setting tidal volume based on the patient's ideal or predicted body weight.[5]

There are different methods for calculating a surrogate weight measurement. The model adopted on the Carestation 600 system implements the unisex PBW formula (PBWuf + MBW), which only requires the patient's height and not biological sex for calculation (Figure 1). The model applies the ARDSNet 'female' formula to both adult sexes while providing a tight fit to median body weight (MBW) to retain consistency with weight prediction over the adult range and those with small statures and is a closer approximation to lean body weight compared to traditional models.[6,7] In the case of a male patient, the initial proposed volume using the unisex formula would be up to 10% lower than if the conventional PBW male formula was applied at a height of 5 ft/152 cm, or 6% less volume at an average male height.

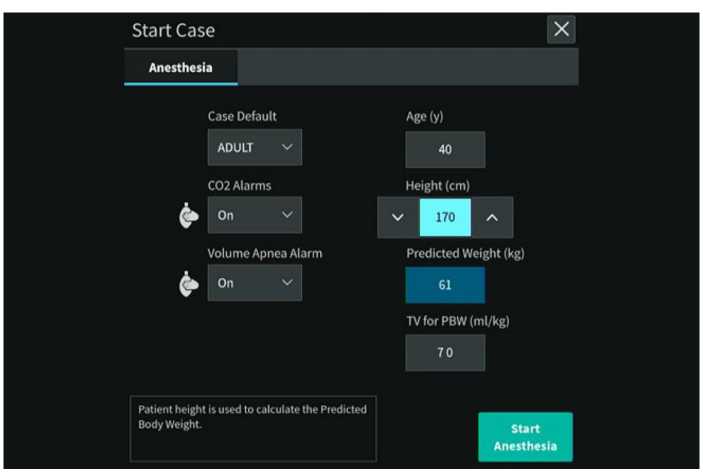

Figure 1. Predicted Body Weight calculator.

The implemented unisex model is different than the commonly used Devine 1974 PBW model, which has been used for calculating PBW at vary adult heights and gender[8] with the following formula:

50 + (0.91 × [ht − 152.4 cm]) for Adult Male

45.5 + (0.91 × [ht − 152.4 cm]) for Adult Female

The implemented unisex PBW, based on height, is compared to the Devine 1974 PBW, based on height gender (Table 1). The heights included in the table serve as a range of patients commonly observed in clinical practice, ranging from smaller stature patients (< 60 inches) to taller stature adults (> 74 inches). The PBW based on both calculated models are compared along with an applied tidal volume based on PBW at 6 ml/kg and 8 ml/kg, respectively. Both 6 ml/kg and 8 ml/kg are commonly used initial tidal volume ventilator settings observed in clinical practice.

By incorporating the unisex PBW model, the Carestation 600 system calculates PBW based on the height value either provided by the user or stored as a case default setting. PBW is used together with a ml/kg setting to calculate the proposed initial **Tidal Volume** setting in **Start Case** and **Patient Demographics** menus, which helps to simplify the workflow and manual calculation steps. Proposed initial **Respiratory Rate** setting is also derived from the PBW value.

The unisex PBW model also extends to the small pediatric population. This is significant as there currently exists no simple formula to estimate pediatric PBW, as the dominant PBW formula for lung protective ventilation is the Devine 1974 model for heights above 5 ft/152 cm, presenting challenges and complexities when considering extending lung protective ventilation to smaller pediatric patients.[7] Thus, the implemented PBW model found in the Carestation 600 software simplifies calculating PBW to one standard unisex formula from pediatric to adults.

Driving Pressure

Studies support the use of driving pressure as a marker of outcomes in mechanically ventilated patients. In a 2015 study by Amato et al, driving pressure was found to be the ventilation variable that best stratified risk.[9] The study further highlighted that individual changes in tidal volume or PEEP after randomization were not independently associated with survival; they were associated only if they were among the changes that led to reductions in driving pressure.

In the intraoperative setting, Neto et al and Douville et al also found that increased driving pressure is associated with PPCs, concluding that a high driving pressure, but not tidal volume or PEEP, is associated with adverse outcomes in critically ill patients receiving mechanical ventilation.[10,11]

Moreover, in a randomized controlled trial in the intraoperative setting, patients were randomly assigned to receive an individualized PEEP guided by minimum driving pressure or a fixed PEEP at 6 cmH_2O.

Table 1. Comparison of PBW models based on height to establish initial tidal volume settings.

	Devine 1974 PBW Model		Unisex PBW Model	Carestation 600
	Female	Male	Unisex	Initial proposed setting
42 in. / 106.68 cm	N/A	N/A	17.1 kg	
VT @ 6 ml/kg	N/A	N/A	103 ml	100 ml
VT @ 8 ml/kg	N/A	N/A	137 ml	140 ml
58 in. / 147.32 cm	40.9 kg	45.4 kg	40.8 kg	
VT @ 6 ml/kg	245 ml	272 ml	249 ml	250 ml
VT @ 8 ml/kg	327 ml	363 ml	326 ml	325 ml
64 in. / 162.56 cm	54.7 kg	59.2 kg	54.7 kg	
VT @ 6 ml/kg	328 ml	355 ml	328 ml	325 ml
VT @ 8 ml/kg	438 ml	474 ml	438 ml	450 ml
70 in. / 177.8 cm	68.6 kg	73.1 kg	68.6 kg	
VT @ 6 ml/kg	412 ml	439 ml	412 ml	425 ml
VT @ 8 ml/kg	549 ml	585 ml	549 ml	550 ml
76 in. / 193.04 cm	82.5 kg	87.0 kg	82.4 kg	
VT @ 6 ml/kg	495 ml	522 ml	494 ml	500 ml
VT @ 8 ml/kg	660 ml	696 ml	659 ml	650 ml

The study found that the incidence of clinically significant PPCs was significantly lower in the individualized PEEP group compared with that in the fixed PEEP group.[12]

The evidence from recent studies in the intraoperative setting underscores the critical role of driving pressure in predicting and mitigating PPCs. The association between high driving pressure and adverse outcomes, coupled with the reduction in clinically significant PPCs when implementing driving-pressure guided ventilation, clearly indicates clinical relevance. This reinforces the importance of including driving pressure as a key parameter in the management of patients undergoing intraoperative mechanical ventilation. Thus, monitoring the driving pressure is critical for clinicians who must carefully manage the balance of providing adequate ventilatory support while avoiding potential harm associated with excessive pressure to improve patient outcomes and reduce the risks of PPCs.

For the Carestation 600 anesthesia machines, the calculation of driving pressure (**P_{drive}**) requires a period of zero flow by an inspiratory hold maneuver to equalize the pressures throughout the patient airway. In this way, the P_{drive} measured during the inspiration pause is a surrogate measurement of the alveolar pressure. The pressure measured in a static state is called the plateau pressure. Therefore, in the Carestation 600 series, P_{drive} is derived as the difference between the plateau pressure and PEEP (Figure 2).

It is important to note that P_{drive} is only available in VCV mode. To ensure a paused state at the end of inspiration to achieve a plateau pressure, **T_{pause}** (inspiratory pause) must be set to a value other than "OFF" (Figure 3). In other ventilation modes, P_{mean} is shown instead of P_{drive}.

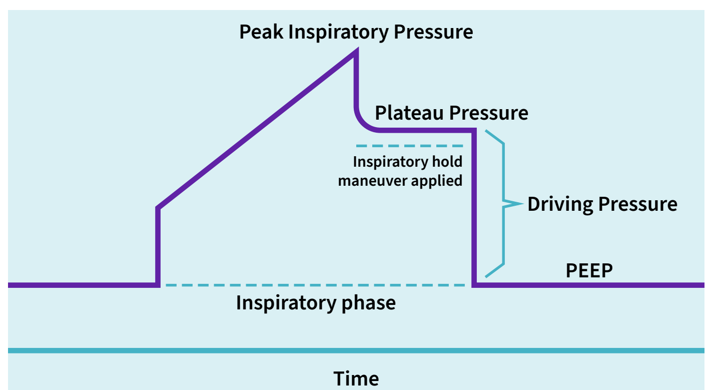

Figure 2. P_{drive} derived as the difference between the plateau pressure and PEEP.

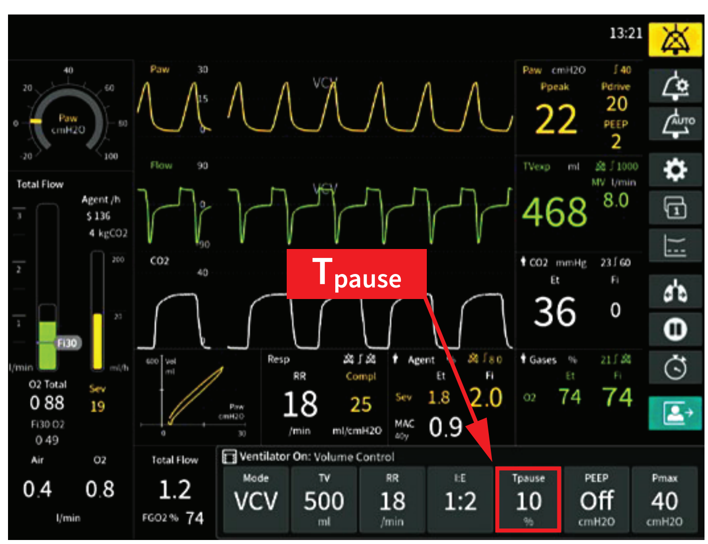

Figure 3. T_{pause} setting on Carestation 600 series anesthesia machine.

Pressure Control

In pressure-controlled modes the clinician selects the inspiratory pressure (P_{insp}) and the PEEP. The Pinsp selected is added over the PEEP and the total results in peak pressure (P_{peak}) (Figure 4). P_{drive} is not displayed in pressure-controlled modes since the inspiratory flow never reaches a paused and zero state. However, some clinicians use P_{insp} as a surrogate for P_{drive}.

Recruitment Maneuvers

Atelectasis appears in about 90% of all anesthetized patients, which is likely to be a focus of infection and may contribute to serious pulmonary complications.[13] **Recruitment Maneuvers** provide a way to execute lung recruitment procedures to address atelectasis. Clinicians perform these procedures to inflate collapsed alveoli and reduce atelectasis. The purpose of recruitment procedures is not only to improve oxygenation associated with recruited alveoli, but also to prevent shear injuries caused by repeated opening and closing of alveoli, which is a critical component of lung protective strategies.[14]

The **Single Step** recruitment maneuver (Figure 5) delivers a continuous set pressure breath for a user-determined set time. The maneuver provides an accurate and repeatable method as an alternative to the manual bag squeeze maneuver commonly observed in clinical practice, which is often associated with a lack of PEEP delivery and lacks the precise control of pressure.

The **Multi Step** recruitment maneuver (Figure 6) allows the user to configure a series of ventilation settings. During the procedure, as pressure is increased, dynamic compliance is measured and presented to the user (Figure 7). This enables the delivery of increasing pressures through a series of ventilation steps during mechanical ventilation without making multiple manual changes to the ventilator settings. The user may also ensure that a set PEEP is delivered upon the completion of the Recruitment Maneuver by adjusting the **PEEP on Exit** setting (Figure 6).

Some clinicians also use this tool to help identify the optimal PEEP setting to keep the alveoli open during inhalation and exhalation, to prevent injurious shear forces associated with repeated opening and closing of alveoli.

In a study published in 2017, Das et al observed that the implementation of gradual increments of PEEP followed by PEEP titration produced improvements in oxygenation, CO_2 elimination, and dynamic strain.[15]

For users upgrading from the Carestation 600 version 1, please note:

- "**Single Step**" procedure is identical to "**Vital Capacity**" procedure in Carestation 600 version 1.
- "**Multi Step**" procedure is identical to "**Cycling**" procedure in Carestation 600 version 1

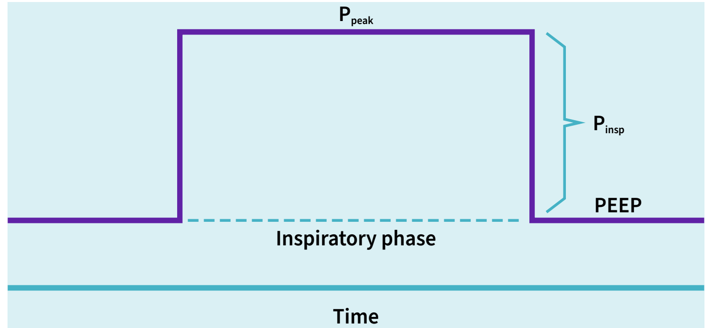

Figure 4. Peak pressure (P_{peak}) as a result of P_{insp} + PEEP.

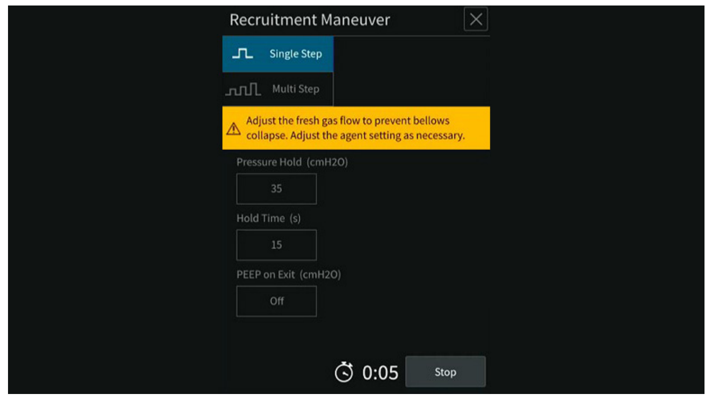

Figure 5. Single Step recruitment maneuver screen.

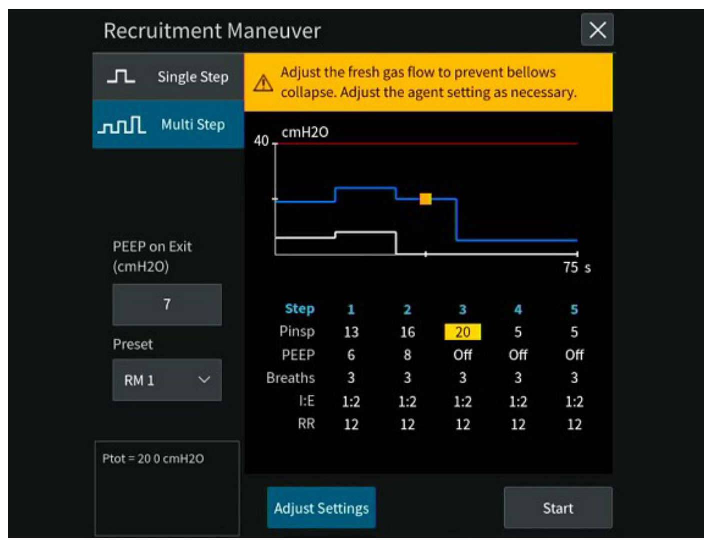

Figure 6. Multi Step recruitment maneuver screens

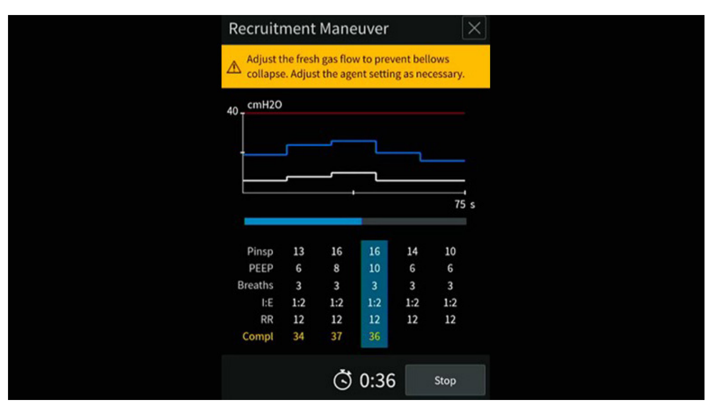

Figure 7. Dynamic compliance measurements.

Ventilation Modes

Carestation 600 series offers a comprehensive suite of ventilation modes, including Controlled modes (VCV, PCV and PCV-VG), Synchronized modes (SIMV VCV, SIMV PCV and SIMV PCV-VG) and Support modes (PSVPro and CPAP+PSV) (Figure 8). Depending on the patient's lung condition, the ability to select from a suite of ventilation modes helps clinicians implement the appropriate patient-ventilation strategy.

Please note that **Cardiac Bypass** is visible in the **Ventilation Modes** menu (Figure 9).

- There are two modes for Cardiac Bypass (Figure 9), for the manual ventilation option the mode suspends the audible patient-related ventilator alarms.

- The option of VCV **Cardiac Bypass** allows mechanical ventilation while in the VCV mode. Please note that the VCV mode is the only ventilation mode available while using VCV **Cardiac Bypass**. Note: In a prospective study published by Davoudi et al, continued delivery of low tidal volume ventilation during Cardiopulmonary Bypass (CPB) improved post-bypass oxygenation and lung mechanics.[16]

Maintain lung protection when transitioning between Ventilation Modes

When transitioning to a mode of ventilation, the system will calculate the measured value of airway pressure or tidal volume of the previous ventilation mode, then automatically propose settings for the new ventilation mode (Figure 10). Users can simply adjust or confirm the proposed settings, enabling clinicians to quickly focus on the care of their patients.

For details to how the system proposes settings when transitioning from modes, see Table 2.

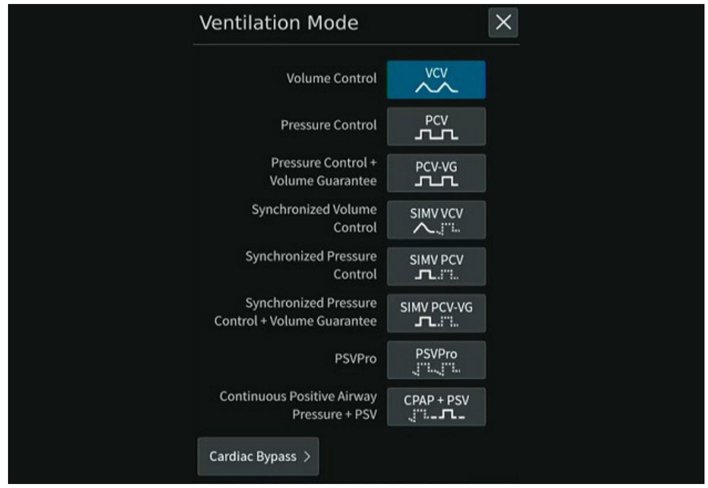

Figure 8. Ventilation mode selection menu.

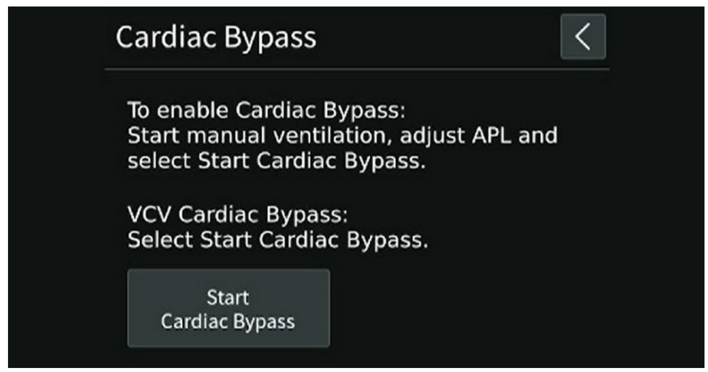

Figure 9. Cardiac Bypass screen.

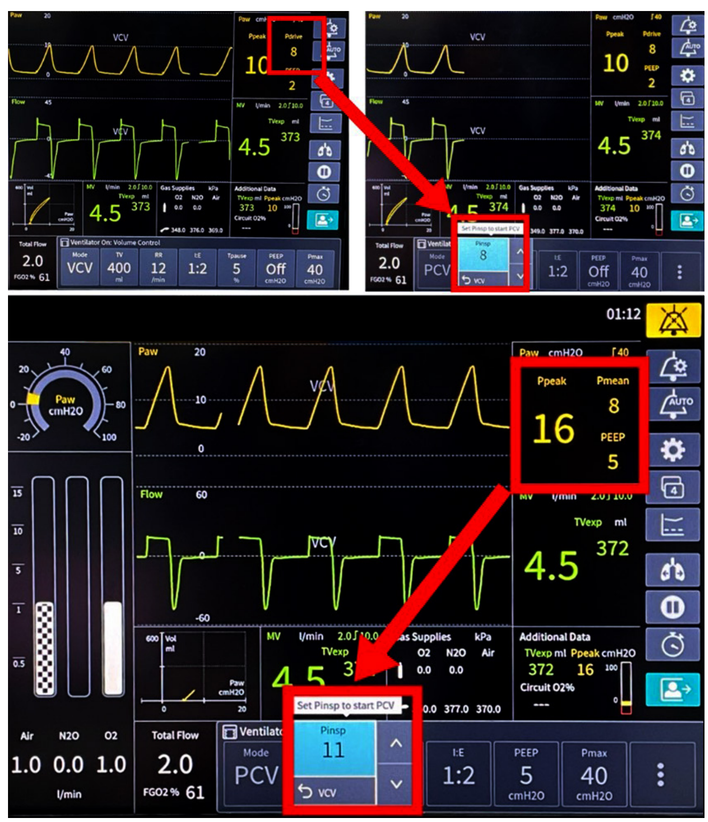

Figure 10. Automated ventilation settings proposed by the Carestation 600 system.

Conclusion

The use of lung protective strategies which include the use of tidal volumes between 6–8 ml/kg of PBW, individualized PEEP and recruitment maneuvers, along with maintaining driving pressures in an acceptable range may help decrease the incidence of post-operative pulmonary complications. GE HealthCare's Carestation 600 series anesthesia workstations offer lung protective tools to help clinicians individualize therapy during surgery, so that you can stay one step ahead in safeguarding and enhancing patient well-being.

Table 2. How Carestation 600 system automatically proposes ventilation settings.

From	To						
	VCV	PCV-VG	SIMV VCV	SIMV PCV-VG	PCV	SIMV PCV	PSV PRO
VCV	Set TV unchanged				P_{drive} → Set P_{insp} or P_{peak} – PEEP → Set P_{insp} (if P_{drive} unavailable)		
PCV-VG							
SIMV VCV							
SIMV PCV-VG							
PCV	VT_{insp} → Set TV (at least 1 mechanical breath is available)				Set P_{insp} unchanged		
SIMV PCV							
SIMV PCV Backup							
PSV PRO							
CPAP PSV							

References

1. Güldner A, Kiss T, Serpa Neto A, et al. Intraoperative Protective Mechanical Ventilation for Prevention of Postoperative Pulmonary Complications: A Comprehensive Review of the Role of Tidal Volume, Positive End-expiratory Pressure, and Lung Recruitment Maneuvers. Anesthesiology. 2015;123(3):692–713. doi:https://doi.org/10.1097/ALN.0000000000000754
2. Kelkar KV. Post-operative pulmonary complications after non-cardiothoracic surgery. Indian J Anaesth. 2015;59(9):599–605. doi:10.4103/0019–5049.165857
3. Young CC, Harris EM, Vacchiano C, et al. Lung-protective ventilation for the surgical patient: international expert panel-based consensus recommendations. British Journal of Anaesthesia. 2019;123(6):898–913. doi:https://doi.org/10.1016/j.bja.2019.08.017
4. L'her, E., Martin-Babau, J. & Lellouche, F. Accuracy of height estimation and tidal volume setting using anthropometric formulas in an ICU Caucasian population. Ann. Intensive Care 6, 55 (2016). https://doi.org/10.1186/s13613-016-0154-4
5. Acute Respiratory Distress Syndrome Network, Brower RG, Matthay MA, et al. Ventilation with lower tidal volumes as compared with traditional tidal volumes for acute lung injury and the acute respiratory distress syndrome. N Engl J Med. 2000;342(18):1301–1308. doi:10.1056/NEJM200005043421801
6. Linares-Perdomo, Olinto, et al. "Standardizing predicted body weight equations for mechanical ventilation tidal volume settings." Chest 148.1 (2015): 73–78.
7. Martin DC, Richards GN. Predicted body weight relationships for protective ventilation-unisex proposals from pre-term through to adult. BMC Pulm Med. 2017;17(1):85. Pub. 2017 May 23. doi:10.1186/s12890-017-0427-1
8. In inches, the formula is: 50.0 + 2.3 × (ht – 60 in) for Adult Male; 45.5 + 2.3 × (ht – 60 in) for Adult Female
9. Amato MB, Meade MO, Slutsky AS, et al. Driving pressure and survival in the acute respiratory distress syndrome. N Engl J Med. 2015;372(8):747–755. doi:10.1056/NEJMsa1410639
10. Neto AS, Hemmes SNT, Barbas CSV, et al. Association between driving pressure and development of postoperative pulmonary complications in patients undergoing mechanical ventilation for general anaesthesia: a meta-analysis of individual patient data. The Lancet Respiratory Medicine. 2016;4(4):272–280. doi:https://doi.org/10.1016/s2213-2600(16)00057-6
11. Douville NJ, McMurry TL, Ma JZ, et al. Airway driving pressure is associated with postoperative pulmonary complications after major abdominal surgery: a multicentre retrospective observational cohort study. BJA Open. 2022;4:100099. doi:https://doi.org/10.1016/j.bjao.2022.100099
12. Zhang C, Xu F, Li W, et al. Driving Pressure-Guided Individualized Positive End-Expiratory Pressure in Abdominal Surgery: A Randomized Controlled Trial. Anesth Analg. 2021;133(5):1197–1205. doi:10.1213/ANE.0000000000005575
13. Hedenstierna G, Edmark L. Mechanisms of atelectasis in the perioperative period. Best Pract Res Clin Anaesthesiol. 2010 Jun;24(2):157–69. doi: 10.1016/j.bpa.2009.12.002. PMID: 20608554.
14. Santos, Raquel S., et al. "Recruitment maneuvers in acute respiratory distress syndrome: The safe way is the best way." World Journal of Critical Care Medicine 4.4 (2015): 278.
15. Das, Anup, et al. "Hemodynamic effects of lung recruitment maneuvers in acute respiratory distress syndrome." BMC pulmonary medicine 17.1 (2017): 1–13.
16. Davoudi, Maryam, et al. "The effect of low tidal volume ventilation during cardiopulmonary bypass on postoperative pulmonary function." The Journal of Tehran Heart Center 5.3 (2010): 128.

JB27087XX | November 2023

GE HealthCare