

# Lung-Protective Ventilation Over 6 Years at a Large Academic Medical Center: An Evaluation of Trends, Adherence, and Perceptions of Benefit

**OBJECTIVES:** The main objective of this study was to evaluate trends in set tidal volumes across all adult ICUs at a large academic medical center over 6 years, with a focus on adherence to lung-protective ventilation ( $\leq 8$ -cc/kg ideal body weight). A secondary objective was to survey providers on their perceptions of lung-protective ventilation and barriers to its implementation.

**DESIGN:** Retrospective observational analysis (primary objective) and cross-sectional survey study (secondary objective), both at a single center.

**PARTICIPANTS:** Mechanically ventilated adult patients with a set tidal volume (primary objective) and providers rotating through the Medical and Neurosciences ICUs (secondary objective).

**INTERVENTIONS:** None.

**MEASUREMENTS AND MAIN RESULTS:** From 2013 to 2018, the average initial set tidal volume (cc/kg ideal body weight) decreased from  $8.99 \pm 2.19$  to  $7.45 \pm 1.34$  ( $p < 0.001$ ). The cardiothoracic ICU had the largest change in tidal volume from  $11.09 \pm 1.96$  in 2013 to  $7.97 \pm 1.03$  in 2018 ( $p < 0.001$ ). Although the majority of tidal volumes across all ICUs were between 6.58 and 8.01 (interquartile range) in 2018, 27% of patients were still being ventilated at volumes greater than 8-cc/kg ideal body weight. Most surveyed respondents felt there was benefit to lung-protective ventilation, though many did not routinely calculate the set tidal volume in cc/kg ideal body weight, and most did not feel it was easily calculable with the current electronic medical record system.

**CONCLUSIONS:** Despite a trend toward lower tidal volumes over the years, in 2018, over a quarter of mechanically ventilated adult patients were being ventilated with tidal volumes greater than 8 cc/kg. Survey data indicate that despite respondents acknowledging the benefits of lung-protective ventilation, there are barriers to its optimal implementation. Future modifications of the electronic medical record, including a calculator to set tidal volume in cc/kg and the use of default set tidal volumes, may help facilitate the delivery of and adherence to lung-protective ventilation.

**KEY WORDS:** low tidal volume ventilation; lung-protective ventilation; mechanical ventilation

Lung-protective ventilation (LPV;  $\leq 8$ -cc/kg ideal body weight [IBW]) has been demonstrated to reduce a host of adverse outcomes in mechanically ventilated patients both with (1) and without the acute respiratory distress syndrome (ARDS) (2). A randomized control trial of major abdominal surgery patients found that those treated with 6–8 cc/kg IBW had a lower requirement for ventilatory support in the postoperative period and shorter

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lengths of stay than those who received 10–12-cc/kg IBW (3). Furthermore, among patients undergoing general anesthesia, 6–8 versus greater than 10-cc/kg IBW decreased postoperative lung infection, atelectasis, acute lung injury, and hospital length of stay (4).

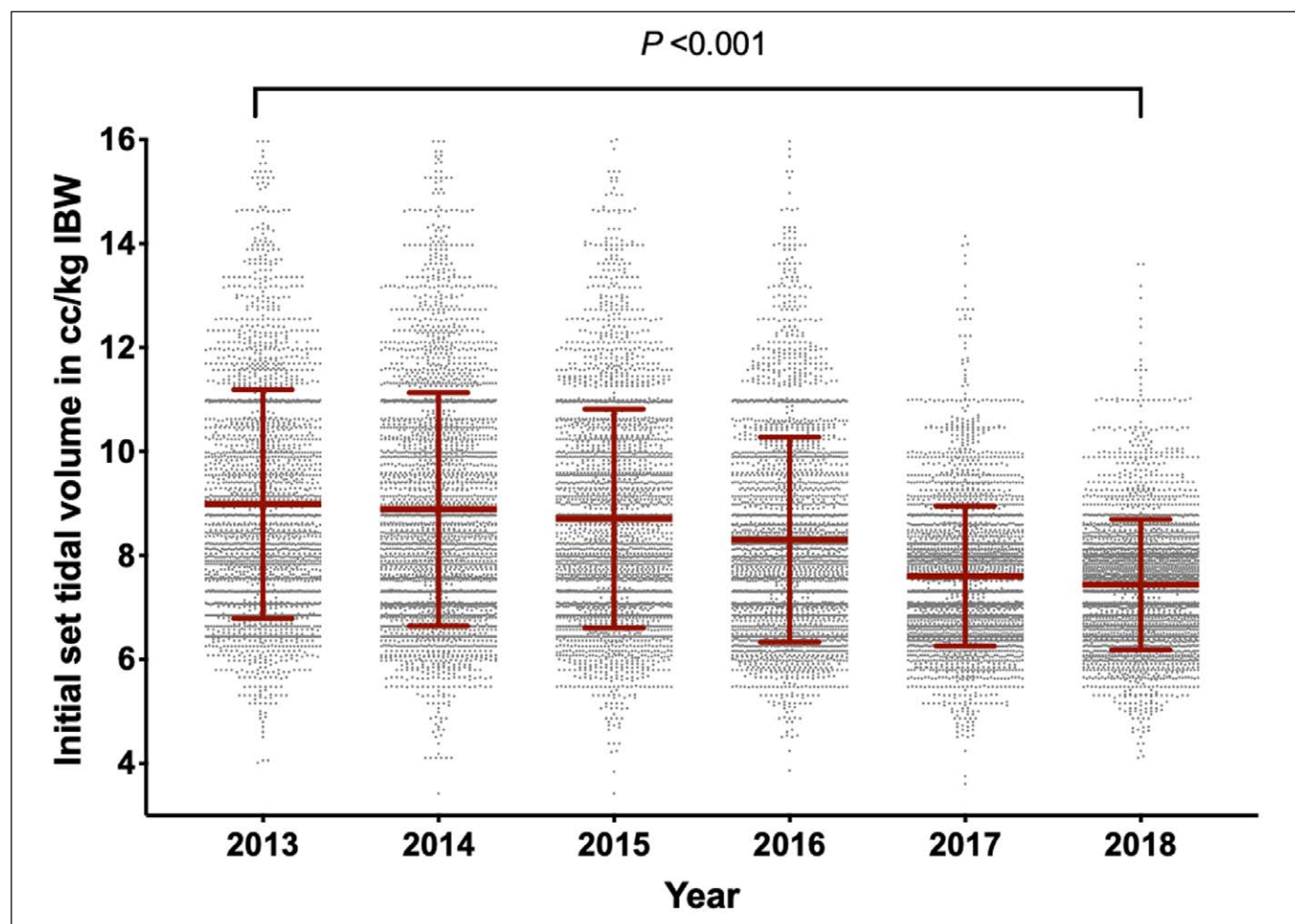
Despite strong evidence of the benefits of LPV, numerous studies have demonstrated variable adherence (3, 5). Surveys of critical care physicians, nurses, and respiratory therapists (RTs) demonstrated low utilization despite few perceived barriers and positive attitudes toward low tidal volume ventilation (LTVV) (6, 7). Our objective was to evaluate tidal volume (TV) trends over 6 years at a 1,541-bed academic medical center.

## MATERIALS AND METHODS

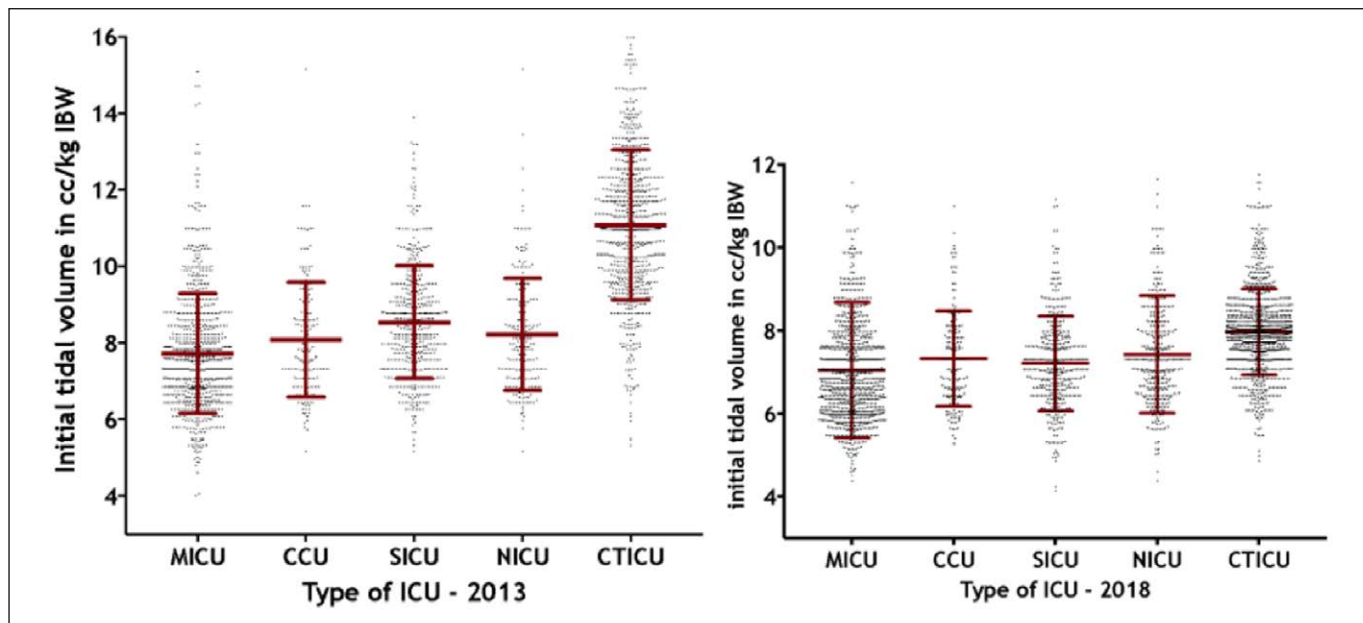
We reviewed all adult patient ventilation records with modes requiring set TVs (e.g., assist control volume control) at our institution from February 2013 (when

the current electronic medical record [EMR] was implemented) to December 2018, and evaluated data from all adult ICUs: medical ICU (MICU), surgical ICU, cardiothoracic ICU (CTICU), neurologic ICU (NICU), and cardiac ICU. A total of 18,563 ventilated admissions were identified. Data from patients on extracorporeal membrane oxygenation (ECMO) ( $n = 88$ , 0.005%) and with incomplete information ( $n = 1,382$ , 0.075%) were excluded, leaving 17,093 admissions in the analysis. A sample of greater than 100 admissions underwent manual spot checks to verify the accuracy of the data. We converted set TV in cc to cc/kg IBW based on patient height and gender, and evaluated the correlation between TV and type of ICU, gender, and height.

We surveyed attendings, fellows, residents, advanced practice providers (APPs), nurses, and RTs in the MICU and NICU from January 17, 2019, to February 6, 2019, collecting demographic data and perceived benefit of LPV in the cases with and without



**Figure 1.** Tidal volume (TV) changes over time. Each point represents a data point, with *red line* illustrating mean  $\pm$  sd. From 2013 to 2018, the initial set TVs across all ICUs (in cc/kg ideal body weight [IBW]) decreased from (mean  $\pm$  sd)  $8.99 \pm 2.19$  to  $7.45 \pm 1.34$  ( $p < 0.001$ ). In 2018, 27% of ventilator encounters still had a set TV  $> 8$  cc/kg IBW.



**Figure 2.** Tidal volume (TV) changes, by type of ICU, over time. Each point represents a data point, with *red line* illustrating mean  $\pm$  SD. The cardiothoracic ICU (CTICU) had the highest TVs, though decreased in average initial TV (cc/kg ideal body weight) from (mean  $\pm$  SD)  $11.09 \pm 1.96$  in 2013 to  $7.97 \pm 1.03$  in 2018 ( $p < 0.001$ ). CCU = cardiac ICU, MICU = medical ICU, NICU = neurosciences ICU, SICU = surgical ICU.

ARDS. We asked respondents about their approach to calculating TV and how difficult they found it in the current EMR (which asks the provider to enter TV in cc) on a 5-point Likert scale.

Our study was reviewed by the Yale University institutional review board and granted exemption with protocol ID 2000023894.

## RESULTS

From 2013 to 2018, the average initial set TV (cc/kg IBW) decreased from  $8.99 \pm 2.19$  to  $7.45 \pm 1.34$  ( $p < 0.001$  by *t* test) (Fig. 1). The CTICU had the largest change in TV (cc/kg IBW) from  $11.09 \pm 1.96$  in 2013 to  $7.97 \pm 1.03$  in 2018 ( $p < 0.001$ ) (Fig. 2). The MICU had the lowest TV (cc/kg IBW) with a mean of  $7.05 \pm 1.63$  in 2018 (range for other ICUs, 7.20–7.97). Although the majority of TVs across all ICUs were between 6.58 and 8.01 (interquartile range) in 2018, 27% of patients were still being ventilated at volumes greater than 8-cc/kg IBW. Of the patients being ventilated at greater than 8-cc/kg IBW in 2018, 58% were female and the average height was  $64.3 \pm 4.16$  inches, significantly lower than the average height of all patients,  $67.1 \pm 4.31$  inches ( $p < 0.001$ ). Of those ventilated at greater than 9-cc/kg IBW, 79% were female and the average height was  $61.8 \pm 3.83$  inches, also significantly lower ( $p < 0.001$ ).

We received 104 survey responses from 118 distributed (response rate 88%). Eight were from attendings, 11 fellows, 47 residents, 15 nurses, 12 APPs, and 11 RTs. Most respondents (85%) felt that there was benefit to LPV even in the cases without ARDS. However, 11 of the respondents (10%) reported not routinely calculating TV in cc/kg IBW, and six reported (6%) using an educated guess by looking at the patient. Some respondents incorrectly asked for the patient's actual weight, rather than attempting to determine IBW; only 32 (31%) reported looking up patient height and referring to the acute respiratory distress syndrome network (ARDSNet) table (1). Only 25 (24%) of respondents thought it was easy to calculate optimal TV with the current EMR; 40 (38%) found it difficult and 32 (31%) neither easy nor difficult.

## DISCUSSION

In this study, over 6 years at a major academic medical center, we found that TVs decreased significantly across all ICUs, even with exclusion of ECMO. This trend toward smaller TV is similar to what has been described in other studies (8, 9), reflecting the growing body of evidence in support of LPV and greater emphasis on adherence by ICU leadership. The CTICU's TV decreased the most during the study period, likely due to a TV initiative by CTICU leadership and the hiring of dedicated

intensivists. Though we did not directly survey the CTICU's rotators, this conclusion was reached in discussion with the CTICU's director and conversations with senior ICU leadership present during the years of interest.

Despite the movement toward safer TV, in 2018, 27% of ventilator encounters still had a set TV greater than 8-cc/kg IBW. Studies have shown significant variability in TV choices (10). Women and those of shorter height were disproportionately affected by overventilation, potentially due to the inappropriate use of "eyeball" estimates, the use of actual (rather than IBW) body weight, or the use of default TVs in cc. Others have reported similar risks of overventilation in women (11) (56% of women being ventilated at > 8-cc/kg IBW as compared with only 9% of men, in one study) (12). Similar to our findings, other studies have demonstrated up to a six-fold risk of overventilation in shorter patients (13).

Despite the vast majority of survey respondents acknowledging the benefits of LPV in both our results and in the literature (6, 7), many did not precisely calculate TV and found it challenging to use the EMR to do so. Respondents used a wide array of tools to estimate TV, including MD calculator, the ARDSnet table (14), and smart phone applications. Studies have shown that education, guidelines, and protocols improve LPV adherence (15, 16), as do simple interventions such as calculators attached to ventilators (17), reference cards (18), and screens displaying TV in units of cc/kg IBW (19). In some institutions, bedside staff such as nurses and RTs measure height and perform TV calculations, and they are an important audience for interventions as well.

We favor modifying the order set in the EMR so that providers may set TV in cc/kg IBW, with the initial default TV no higher than 8-cc/kg IBW, rather than the current standard of entering TV in cc. Changing the default order set has been shown to improve adherence to LPV (20). This approach would save time by eliminating the need for an external resource to calculate cc/kg IBW and increase adherence to best practices (21).

Limitations include the retrospective, single-center nature of our study. We also did not investigate the underlying reasons for intubation, nor did we evaluate outcomes of overventilation in the study population. Survey responses were collected on a voluntary basis, and we were not able to survey all the types of ICUs. Although it would have been interesting to evaluate the subgroup with ARDS, this is difficult to identify without direct adjudication, which was precluded by our large sample

size. To begin with, it is already known that physicians are poor at recognizing and documenting ARDS, and standard ICU monitoring systems are similarly inadequate (22). Studies of LTVV delivery in the cases of ARDS have required significant physician adjudication of each observation (23). There is development of sophisticated machine-learning algorithms to abstract the diagnosis of ARDS from patient charts (24), as well as programs to suspect ARDS based on a combination of lab work and imaging results (22), but these are not yet used in regular clinical practice. Although this was beyond the scope of this particular project to compare ARDS vs non-ARDS cases, others have shown that patients with ARDS do receive lower TV ventilation (10), and we do see lower TVs in the MICU, which is more likely to have cases of ARDS than the other types of ICUs.

## CONCLUSIONS

Despite trends toward lower TV in clinical practice, there are still many adult ICU patients being ventilated at higher-than-optimal TVs. Targeted education and the use of EMR defaults may facilitate the delivery of and adherence to LPV.

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An earlier version of these data was presented as an oral presentation during the CHEST 2019 Annual Meeting in New Orleans, LA, in October 2019.



Our study was reviewed by the Yale University IRB and granted exemption with protocol ID 2000023894.

Dr. Gao had full access to the data and takes responsibility for the integrity of the data, accuracy of analysis, and content of the article. She drafted the design of the study, gathered the survey data, performed analysis and interpretation of the data, and drafted the article. Dr. Howard performed analysis of the data and reviewed the article. Dr. Siner contributed to design of the study and revision of the article. Mr. Candido performed analysis of the data. Dr. Ferrante oversaw the design of the study, interpretation of the data, and revision of the article.

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