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Variability in the Use of Protective Mechanical Ventilation During General Anesthesia

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Abstract

BACKGROUND—The purpose of this study was to determine whether significant variation exists in the use of protective ventilation across individual anesthesia providers and whether this difference can be explained by patient, procedure, and provider-related characteristics.

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DISCLOSURES

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METHODS—The cohort consisted of 262 anesthesia providers treating 57,372 patients at a tertiary care hospital between 2007 and 2014. Protective ventilation was defined as a median positive end-expiratory pressure of 5 cm H₂O or more, tidal volume of <10 mL/kg of predicted body weight and plateau pressure of <30 cm H₂O. Analysis was performed using mixed-effects logistic regression models with propensity scores to adjust for covariates. The definition of protective ventilation was modified in sensitivity analyses.

RESULTS—In unadjusted analysis, the mean probability of administering protective ventilation was 53.8% (2.5th percentile of provider 19.9%, 97.5th percentile 80.8%). After adjustment for a large number of covariates, there was little change in the results with a mean probability of 51.1% (2.5th percentile 24.7%, 97.5th percentile 77.2%). The variations persisted when the thresholds for protective ventilation were changed.

CONCLUSIONS—There was significant variability across individual anesthesia providers in the use of intraoperative protective mechanical ventilation. Our data suggest that this variability is highly driven by individual preference, rather than patient, procedure, or provider-related characteristics.

The detrimental effects of anesthesia and mechanical ventilation on pulmonary function have been known for decades.^{1,2} Indeed, postoperative pulmonary complications remain 1 of the leading causes of increased perioperative morbidity, mortality, and resource utilization.^{3–6} Despite the incidence and impact of these complications, anesthesiologists have few interventions to prevent them or mitigate their impact.

Protective mechanical ventilation can broadly be defined as the use of low tidal volumes, low plateau pressures, and the application of positive end-expiratory pressure (PEEP). Both randomized controlled clinical trials and carefully controlled observational studies have demonstrated that a strategy of intraoperative protective ventilation is associated with a reduced risk of major postoperative respiratory complications in patients with healthy lungs, who are mechanically ventilated for a short time period in the operating room.^{7–11} Previous studies have examined patterns of intraoperative ventilation at an institutional level and demonstrated that a significant number of patients do not receive protective mechanical ventilation.^{12–16}

While data at the hospital-level provide some indication of the use of protective ventilation, there is no data regarding the practice patterns of individual anesthesia providers. Understanding the clinical behavior of providers is essential in devising and assessing quality improvement projects since it is individuals who determine ventilator settings, not institutions. Efforts to quantify and compare individual practice in the perioperative period are often hindered by the large number of patient and procedure-related factors that are involved in clinical decision making. Advanced analytic techniques to account for many covariates such as propensity scores exist but have not been routinely used when examining provider-related quality and safety metrics within anesthesia. The purpose of this study was to assess the variability between individual anesthesia providers in the use of intraoperative protective ventilation while using advanced statistical methods to adjust for differences in patient and procedure case mix.

METHODS

Study Design and Setting

This study received approval from the Partners Institutional Review Board (protocol number 2014P002179). Data were obtained for patients requiring general anesthesia performed at the Massachusetts General Hospital between January 2007 and October 2014. Data were extracted and combined from the Anesthesia Information Management System and the Research Patient Data Registry. The Anesthesia Information Management System contains a registry identification number of the anesthesia provider and prospectively records intraoperative, physiological data from all patients undergoing general anesthesia. The Anesthesia Information Management System registers the use of anesthesia equipment and techniques, records the ventilator parameters every minute, and contains data regarding drug and fluid therapy, transfusions, and adverse events during the operation. The Research Patient Data Registry is a centralized clinical data registry that compiles and saves data from various hospital systems for research objectives. The Research Patient Data Registry provides pre- and postoperative information about demographics, hospital billing data, medical history, laboratory results, postoperative outcome, and survival.

Study Cohort

We included all anesthesia providers who performed a minimum of 100 anesthetics for patients undergoing a surgical procedure during the study period. Anesthesia providers could be anesthesia residents, certified registered nurse anesthetists (CRNA), or attending anesthesiologists who managed no more than 1 patient at a time and did not supervise multiple rooms. Patients aged 18 years or older, undergoing a noncardiothoracic surgical procedure and requiring general anesthesia were considered for the study. Only cases where the patient was intubated with an endotracheal tube at the start and extubated at the end of the procedure were included in the analysis. Cases with missing data, and height <48 inches (calculations of predicted body weight become inaccurate at the extremes of height¹⁷) were excluded from the analysis. Patients with American Society of Anesthesiologists physical classification status of greater than 4 were not included since it was felt that these cases do not represent routine anesthetic care.

Exposure

In the primary analysis, protective ventilation was defined a priori, based on prior literature on mechanical ventilation in perioperative medicine.^{7,8,10,13} Patients were classified as being ventilated protectively if they had a median applied PEEP of ≥ 5 cm H₂O, a median expiratory tidal volume <10 mL/kg of predicted body weight, and a median plateau pressure (obtained from a 10% inspiratory pause during volume controlled ventilation, or the set pressure during pressure controlled ventilation) of <30 cm H₂O.⁸ Patients had to meet each of these criteria to be considered as receiving protective ventilation during the procedure. These ventilator variables are recorded every minute by the anesthetic record system. In the secondary analysis, we separately analyzed the variability in application of each of the individual components of protective ventilation: PEEP, tidal volume, and plateau pressure.

Covariates

Data regarding both patient and surgical characteristics that could affect the use of protective ventilation were obtained. Patient factors comprised of demographic variables including sex, age, height, body mass index, American Society of Anesthesiologists physical status classification, year of surgery, and whether the procedure was listed as emergent or ambulatory. The Score for Prediction Of Postoperative Respiratory Complications was calculated for every patient to establish the preoperative risk for postoperative pulmonary complications.¹⁸ We also determined whether the patient had any preexisting respiratory disease and also calculated the Charlson comorbidity index score to adjust for overall disease burden in the patient population.^{19,20} Data regarding type of surgical procedure were retrieved using the Current Procedural Terminology codes. We divided the surgical procedures into 14 different groups, as listed in Table 1.⁸ Work relative value units were used to represent and adjust for the complexity of the surgical procedure. Data regarding fluid therapy, transfusion of fresh frozen plasma, packed red blood cells and platelets, estimated blood loss, and use of epidural analgesia were also abstracted from the database. Finally, we included data regarding whether a provider was a resident, CRNA or attending anesthesiologist, as well as the cumulative number of cases of the provider as a continuous variable.

Statistical Analysis

For all individual anesthesia providers, we calculated the proportion of patients that received protective ventilation during the surgical procedure. The cohort was then divided into quartiles based on the overall proportion of protective ventilation usage by individual anesthesia providers to calculate descriptive statistics. Differences between the quartiles were assessed using the χ^2 test for categorical variables and analysis of variance and Kruskal–Wallis tests for continuous variables.

In the primary analysis, mixed-effects logistic regression models were used to assess the association between individual anesthesia provider and the use of protective ventilation during general anesthesia. First, we performed unadjusted mixed-effects logistic regression analysis with protective ventilation as the dependent binary variable and individual provider as a random effect. In the results of the unadjusted analysis, the intercept for each individual provider was then used to calculate the estimated probability of a patient receiving protective ventilation. Since the model accounts for random variation, the results of the unadjusted analysis differ slightly from the observed (crude) rates of protective ventilation use.

To account for covariates, we subsequently used adjusted mixed-effects logistic regression analysis. As a data reduction technique, we generated a propensity score to calculate an individual patient's probability of receiving protective ventilation accounting for demographics, comorbidities, procedure- and intraoperative-related predictors of protective ventilation.^{21–23} All covariates were included in the propensity score model without further selection. Continuous variables were divided into quartiles and then included into the model as categorical variables to account for nonlinear relationships. The propensity score was then centered on the mean. Thus, once the propensity score was added as a fixed effect into the regression model, it allowed for the individual intercept of a provider to be interpreted as the

estimated probability that an average patient would receive protective ventilation. An average patient is mathematically defined as one who has the average probability to receive protective ventilation. The propensity score was included as a continuous variable in the regression model. To ensure that the assumption of linearity between the propensity score and the log odds of receiving protective ventilation was valid, we included quadratic and cubic terms to the regression model. With these additional terms, there was no change in the variance for providers suggesting that our results were not sensitive to this assumption. In a sensitivity analysis, we used inverse probability of treatment weights in a mixed-effects model, as well as a multivariable model utilizing the same predictors as in the propensity model.

As a secondary analysis, we analyzed the variability in practice among individual providers separately for each of the 3 components of protective ventilation: application of PEEP (≥ 5 cm H₂O), low tidal volume (<10 mL/kg predicted body weight), and low plateau pressure (<30 cm H₂O). For each parameter (PEEP, tidal volume, and plateau pressure), a new propensity score was calculated and a separate mixed-effects logistic regression model was used.

We also performed additional sensitivity analyses to help with the interpretation of our results. To test whether the results were sensitive to the definition of protective ventilation, we altered the protective thresholds and repeated the primary analysis using a combination PEEP of ≥ 5 cm H₂O, plateau pressure < 20 cm H₂O, and tidal volume of ≥ 8 mL/kg predicted body weight. The secondary analysis was also repeated using different thresholds for the individual components of protective ventilation.

The primary analysis was performed with compliance (defined as median tidal volume divided the median plateau pressure subtracted from the median PEEP) as a covariate to determine if preexisting lung stiffness accounted for practice patterns. We also changed the cutoff for the minimum number of cases required to be included into the cohort to 50 to ensure that this did not bias the result. Additionally, the primary analysis was repeated using the supervising attending anesthesiologist as the random effect in the model to see whether that eliminated the variability among providers. Only supervising attending anesthesiologists with more than 100 cases performed in the sample were included. The covariates adjusted for were the same as the primary analysis. Given that provider handovers most often occur at 5 pm at the study institution, we performed a sensitivity analysis where we excluded cases that ended after 5 pm to eliminate potential contamination from multiple providers being involved in a single case.

To further investigate changes of practice over time, we divided the cohort into quartiles based on the usage of protective ventilation in 2007 to 2008. We then tracked the proportion of patients receiving protective ventilation in 2-year increments. Only providers who completed anesthetics in each period were included in this analysis. Finally, to see if the variation differed over the study time period, we created 2 new subcohorts defined by the year the patient received their anesthetic. The 2 time periods were early (2007–2009) and late (2012–2014) and the primary analysis was repeated and compared between these 2 cohorts.

Statistical tests were 2 tailed and a P value of <0.05 was considered to be significant. Predicted probabilities were calculated based on both the fixed and random effects components of the models and plotted. Before plotting these values, the assumption of linearity on the logit scale was checked to ensure that the results could be plotted conventionally. All analyses were performed in Stata (version 14; StataCorp, College Station, TX). Mixed-effects models were calculated using the GLAMM, XTMELOGIT, and XTLOGIT commands. The sample size was based on the available data and no a priori sample size calculation was performed. However, the large number of providers (ie, >250) each with a sizable number of treated patients (ie, >100) provided sufficient data to examine the distribution of protective ventilation usage across providers.

RESULTS

The cohort consisted of 262 individual anesthesia providers treating 57,372 patients undergoing general anesthesia in the operating room. A complete description of the cohort formation is displayed in Supplemental Digital Content 1, Figure 1, <http://links.lww.com/AA/B905>. The median number of cases per provider was 224 [interquartile range: 173–296]. The overall proportion of patients who received protective ventilation was 52%. We stratified individual anesthesia providers into quartiles based on the proportion of use of protective ventilation. The cutoffs for the quartiles in terms of usage of protective ventilation were 2% to 39%, 40% to 53%, 53% to 66%, and 66% to 87%. There were statistically significant differences across the individual provider quartiles for some of the covariates. For instance, those in the highest quartile of protective ventilation had a higher proportion of patients undergoing anesthesia during the later years of the study and tended to have longer duration of intraoperative ventilation. However, there were no differences noted across the quartiles with regards to body mass index and existing chronic pulmonary disease. A complete description of patient demographics and comorbidities, as well as procedure and provider characteristics and intraoperative factors can be found in Table 1.

Primary Analysis

The unadjusted and fully adjusted results of the mixed-effects logistic regression analysis for individual provider variability in the use of protective ventilation are shown in Table 2. The variance between individual anesthesia providers in the use of protective ventilation is described by σ_p^2 . In the unadjusted model, the variance (standard error) for use of protective ventilation was 0.59 (0.055) and the mean probability of use of protective ventilation was 53.8%. From this model, it was calculated that 95% of providers had an estimated probability of using protective ventilation between 19.9% and 80.8%. This amounts to 15.1% of the total variance in protective ventilation being accounted for by anesthesia provider. In the adjusted analysis, the variance and mean probability for use of protective ventilation across the individual providers were similar compared with the unadjusted analysis. Specifically, the mean probability was 51.1% and the variance (standard error) was 0.42 (0.041). This translated to 95% of providers having an estimated probability of using protective ventilation between 24.7% and 77.2%. After adjusting for the confounders, 11.4% of the variance in protective ventilation due to remained (ie, only 3.7% of the variance in protective ventilation use could be accounted for by measurable covariates). Similar results

were obtained when adjusting for confounders using inverse probability treatment weights in the model or a multivariable model (see Table 3 and Supplemental Digital Content 2, Figure 2, <http://links.lww.com/AA/B906>). The estimated probabilities for use of protective ventilation for every individual provider in rank-order for the unadjusted and adjusted models are presented in Figure 1.

Secondary Analysis

The secondary analysis examined the variability in the use of the individual components of protective ventilation. For all 3 components, there was little difference between the results of the adjusted and unadjusted analysis as displayed in Table 2. There was greater variability in the use of PEEP compared with low plateau pressure. The estimated probabilities for the application of PEEP, low tidal volume, and low plateau pressure for every individual provider in rankorder in the unadjusted and adjusted models are presented in Figure 2.

Sensitivity Analyses

In the sensitivity analysis, the definition of protective ventilation was changed with more conservative thresholds of tidal volume and plateau pressure. With this new definition, the overall usage of protective ventilation was lower compared with the primary analysis, with the adjusted mean probability of use of protective ventilation being 14.7%. The variation across providers persisted with 95% of providers having an estimated of probability of using protective ventilation between 5.1% and 29.6% as determined from the adjusted model. There was little difference between the adjusted and unadjusted models with regards to variation as can be seen in Supplemental Digital Content 3, Figure 3, <http://links.lww.com/AA/B907>. The primary analysis was repeated separately with compliance added to the model and with the minimum number of cases set to 50 and the results of both of these analyses were similar to the primary analysis (Table 3).

We repeated the secondary analysis with different protective thresholds for PEEP, plateau pressure, and tidal volume. When examining the use of a median PEEP of >0 cm H₂O, the mean probability of use from the fully adjusted model was 92.5%. While this proportion was higher than observed in the primary analysis, although there was still variation across practitioners with 95% of providers in the range of 62.5% to 98.9%. When the threshold for tidal volume was lowered to 8 mL/kg of predicted body weight, the mean was shifted to 36.4%, but the variation persisted with 95% of providers in the range of 20.2% to 57.2%. The results of this analysis can be found in Table 3 and are graphically depicted in Supplemental Digital Content 4, Figure 4, <http://links.lww.com/AA/B908>.

When switching the unit of analysis from anesthesia provider to supervising attending anesthesiologist, there were 129 anesthesiologists who cared for 65,787 patients during the study time period. A total of 50.2% of patients received protective ventilation. In the adjusted model, the mean predicted use of 50.0%. The variance was 0.19 (0.027) and 95% of attendings had a predicted usage rate between 33.9% and 66.7%. The full results from the sensitivity analysis are displayed in Table 3. Results from analyses excluding cases ending after 5 pm, adding compliance as a confounder and changing the inclusion criteria for the

number of cases by a provider from 100 cases to 50 cases were all similar to the primary analysis (Table 3).

Overall, the usage of protective ventilation increased over time (P value for trend: $<.001$). However, providers in the lowest quartile of use at the beginning of the study time period continued to have the lowest rate of usage of protective ventilation throughout the analysis. Similarly, the providers with the highest proportion of patients receiving protective ventilation continued to have the highest rate of usage throughout. This is displayed in Figure 3.

In the final sensitivity analysis, 2 new subcohorts were created for patients who received their anesthetics early in the study time period (2007–2009) and those who underwent anesthesia later in the study time period (2012–2014). The adjusted predicted proportion of patients receiving protective ventilation within each subcohort are displayed in Supplemental Digital Content 5, Figure 5, <http://links.lww.com/AA/B909> and Table 3. As can be seen in the figure, there was significant variation in both time periods suggesting that the initial results from the primary analysis cannot be attributed to residual confounding of time period.

DISCUSSION

In this study of 262 individual anesthesia providers treating 57,372 patients, we found significant interprovider variability in the use of intraoperative protective ventilation ranging from 25% to 77%. The variability in practice was not affected by adjustment for covariates including demographics, comorbidities, procedure type, and intraoperative factors. This suggests that the use of protective intraoperative mechanical ventilation is driven by the individual preference/practice of the anesthesia provider, rather than patient and/or procedural characteristics. When the definitions of the components of protective ventilation were changed in the sensitivity analyses, the pattern of variation across providers persisted with adjustment. While the utilization of protective ventilation increased during the 7-year observation period as a function of time, the high level of provider variability remained constant. The worst performing providers remained in the lowest category throughout the study time period.

Differences in the practice of anesthesia are likely common and often anecdotally observed.²⁴ Variations in the practice of perioperative medicine have been empirically identified in the practice of fluid administration and preoperative evaluations.^{25,26} While it may be that some variation in practice is benign, there is evidence that outcomes differ across anesthesiologists.²⁷ Thus, identifying differences in practice that can affect outcomes is essential to improving patient quality and safety. Previous studies have examined variability in the use of protective ventilation between institutions^{13,16,28}; however, this is the first study, to our knowledge, to examine practice patterns at the provider level. Our results suggest that the hospital should not be used as a surrogate for describing individual practice patterns and that doing so may underestimate the true amount of variation in practice. At the study institution, anesthesia is often delivered in a care team model with an attending anesthesiologist supervising multiple rooms. While we did not have data as to who made the

decision regarding ventilation patterns we found variation both at the provider and attending level. Thus, the results may be better interpreted as variation across care teams rather than individual providers.

When analyzing the individual components of protective ventilation, it appeared that the amount of variability differed by the component analyzed with PEEP having the greatest variation and plateau pressure demonstrating the least. Providers used protective plateau pressure much more frequently than protective PEEP (97% vs 66%) and thus it is not surprising that we find greater variability in the latter variable. An explanation for the decreased variability in tidal volume and plateau pressure is that the default ventilator settings at the study institution are volume control with a tidal volume of 500 mL and the majority of patients (87%) are ventilated using volume control ventilation. This means that as long as a patients' pulmonary compliance was normal, it was likely that the provider had protective settings. Additionally, the default tidal volume used may or may not be protective depending on a patient's sex, height, and weight.

This is contrasted to PEEP where the default ventilator setting is 0 cm H₂O. This meant that a provider would have to actively change the setting to deliver protective ventilation. At the same time, the role of PEEP in both the intensive care unit and the operating room is debated²⁹ and may be procedure specific,³⁰ which may account for some of the variation. With respect to its use in the operating room, 1 randomized controlled trial found that high PEEP was not beneficial compared with low PEEP,³¹ while a meta-analysis of individual patient data was inconclusive on the benefits of PEEP.⁹ Another study by members of our group found that PEEP was beneficial in preventing postoperative pulmonary complications⁸ and there is also data suggesting that low tidal volumes with minimal PEEP are harmful.^{32,33}

Despite disagreements over guidelines and thresholds to define intraoperative protective ventilation, there is growing evidence that intraoperative ventilation strategies matter^{7–10} and that ventilator settings should be individualized according to patient and procedure characteristics.³⁴ Our data showed that this is not the current practice. Therefore, implementing strategies such as protocols or educational initiatives to decrease the variation observed may improve outcomes. We did notice that there was an increase in the use of protective ventilation over time, particularly from 2011 to 2012 and 2013 to 2014. To the authors' knowledge, there was no quality improvement intervention such as an educational program or quality initiative that occurred over the study time period that could account for this change. It should be highlighted that when examining groups of providers over time, the worst performing providers remained in the lowest category throughout the study time period. Therefore, the type of analysis used in this study can help identify low performing providers that may be less likely to adopt standard practices so that any potential interventions can be targeted to them.

This study also provides an example of how to create a quality metric for anesthesia providers using a robust statistical technique that can adjust for differences in case mix. Within anesthesiology, there are currently no National Quality Forum performance measures that differentiate high-quality providers.³⁵ Thus, there is an opportunity to create metrics to not only help demonstrate the value of anesthesia care but also make the perioperative period

safer for patients. We would argue that any meaningful measure must appropriately account for differences in the populations cared for by anesthesiologists to make the inferences regarding performance stronger. The use of mixed-effects models, as done in this study, is one potential method to achieve this. Additionally, the implementation of propensity scores as a data reduction technique mitigates the issue of small numbers that is typically encountered when examining outcomes.³⁶ It is important to note that the techniques used are only practical in institutions that have an existing electronic anesthetic information management system and thus may not be implementable within certain health systems.

Our cohort consisted of a large number of anesthesia providers and surgical patients. Further, we had detailed clinical information for each patient which allowed us to adjust for several important covariates such as body mass index and underlying respiratory comorbidities that might influence the choice of an anesthesia provider to use protective ventilation. We performed several sensitivity analyses and the results were consistent across all of the statistical techniques used.

This study was limited by several factors that should be considered when interpreting the results. Our study was observational and despite our thorough confounder control, we cannot exclude residual confounding. For instance, we did not have data regarding years of practice or training background and thus could not adjust for these factors in our models. Additionally, we used administrative data to define patient comorbidities and thus errors in coding are possible, although we have no reason to suspect that the dataset contains errors that would differentially influence our results. We were not able to control for arterial blood gases or recruitment maneuvers which might influence the choice of a physician to use protective ventilation. However, we were able to adjust for several other important intraoperative factors. Driving pressure was not included in the analysis and has been shown to be an important component of protective ventilation.^{8,37} Given that this is a recent discovery though, it is unlikely to have affected behavior over the study time period. Finally, our study was conducted at a single center and variance in the practice of individual anesthesia providers may be different in other hospitals or settings.

CONCLUSIONS

The results of our study indicate that there is marked variability across individual anesthesia providers in the use of intraoperative protective mechanical ventilation. Our data suggest that this variability is highly driven by the individual preference of the anesthesia provider, rather than as a consequence of patient and procedural characteristics. This analysis cannot tell us why providers practice differently and thus future qualitative research using in-depth interviews should be conducted to better understand decision making of individual providers with regards to the choice of ventilation settings. Additionally, the methods used in this study can be applied in the future to other individual-level quality metrics to account for differences in procedure and patient factors across providers.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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REFERENCES

1. Bendixen HH, Hedley-Whyte J, Laver MB. Impaired oxygenation in surgical patients during general anesthesia with controlled ventilation. A concept of atelectasis. *N Engl J Med.* 1963;269:991–996. [PubMed: 14059732]
2. Nunn JF, Payne JP. Hypoxaemia after general anaesthesia. *Lancet.* 1962;2:631–632. [PubMed: 13939226]
3. Khuri SF, Henderson WG, DePalma RG, Mosca C, Healey NA, Kumbhani DJ; Participants in the VA National Surgical Quality Improvement Program. Determinants of long-term survival after major surgery and the adverse effect of postoperative complications. *Ann Surg.* 2005;242:326–341. [PubMed: 16135919]
4. Nafiu OO, Ramachandran SK, Ackwerh R, Tremper KK, Campbell DA Jr, Stanley JC. Factors associated with and consequences of unplanned post-operative intubation in elderly vascular and general surgery patients. *Eur J Anaesthesiol.* 2011;28:220–224. [PubMed: 21191304]
5. Smetana GW. Postoperative pulmonary complications: an update on risk assessment and reduction. *Cleve Clin J Med.* 2009;76(Suppl 4):S60–S65.
6. Dimick JB, Chen SL, Taheri PA, Henderson WG, Khuri SF, Campbell DA Jr. Hospital costs associated with surgical complications: a report from the private-sector National Surgical Quality Improvement Program. *J Am Coll Surg.* 2004;199:531–537. [PubMed: 15454134]
7. Futier E, Constantin JM, Paugam-Burtz C, et al.; IMPROVE Study Group. A trial of intraoperative low-tidal-volume ventilation in abdominal surgery. *N Engl J Med.* 2013;369:428–437. [PubMed: 23902482]
8. Ladha K, Vidal Melo MF, McLean DJ, et al. Intraoperative protective mechanical ventilation and risk of postoperative respiratory complications: hospital based registry study. *BMJ.* 2015;351:h3646. [PubMed: 26174419]
9. Serpa Neto A, Hemmes SN, Barbas CS, et al.; PROVE Network Investigators. Protective versus conventional ventilation for surgery: a systematic review and individual patient data metaanalysis. *Anesthesiology.* 2015;123:66–78. [PubMed: 25978326]
10. Severgnini P, Selmo G, Lanza C, et al. Protective mechanical ventilation during general anesthesia for open abdominal surgery improves postoperative pulmonary function. *Anesthesiology.* 2013;118:1307–1321. [PubMed: 23542800]
11. Wolthuis EK, Choi G, Dessing MC, et al. Mechanical ventilation with lower tidal volumes and positive end-expiratory pressure prevents pulmonary inflammation in patients without preexisting lung injury. *Anesthesiology.* 2008;108:46–54. [PubMed: 18156881]
12. Jaber S, Coisel Y, Chanques G, et al. A multicentre observational study of intra-operative ventilatory management during general anaesthesia: tidal volumes and relation to body weight. *Anaesthesia.* 2012;67:999–1008. [PubMed: 22708696]
13. Bender SP, Paganelli WC, Gerety LP, et al. Intraoperative lungprotective ventilation trends and practice patterns: a report from the multicenter perioperative outcomes group. *Anesth Analg.* 2015;121:1231–1239. [PubMed: 26332856]
14. Hess DR, Kondili D, Burns E, Bittner EA, Schmidt UH. A 5-year observational study of lung-protective ventilation in the operating room: a single-center experience. *J Crit Care.* 2013;28:533.e9–533.15.
15. Blum JM, Maile M, Park PK, et al. A description of intraoperative ventilator management in patients with acute lung injury and the use of lung protective ventilation strategies. *Anesthesiology.* 2011;115:75–82. [PubMed: 21552117]

16. Wanderer JP, Ehrenfeld JM, Epstein RH, et al. Temporal trends and current practice patterns for intraoperative ventilation at U.S. academic medical centers: a retrospective study. *BMC Anesthesiol.* 2015;15:40. [PubMed: 25852301]
17. Shah B, Sucher K, Hollenbeck CB. Comparison of ideal body weight equations and published height-weight tables with body mass index tables for healthy adults in the United States. *Nutr Clin Pract.* 2006;21:312–319. [PubMed: 16772549]
18. Brueckmann B, Villa-Urbe JL, Bateman BT, et al. Development and validation of a score for prediction of postoperative respiratory complications. *Anesthesiology.* 2013;118:1276–1285. [PubMed: 23571640]
19. Quan H, Sundararajan V, Halfon P, et al. Coding algorithms for defining comorbidities in ICD-9-CM and ICD-10 administrative data. *Med Care.* 2005;43:1130–1139. [PubMed: 16224307]
20. Ladha KS, Zhao K, Quraishi SA, et al. The Deyo-Charlson and Elixhauser-van Walraven Comorbidity Indices as predictors of mortality in critically ill patients. *BMJ Open.* 2015;5:e008990.
21. Bateman BT, Tsen LC, Liu J, Butwick AJ, Huybrechts KF. Patterns of second-line uterotonic use in a large sample of hospitalizations for childbirth in the United States: 2007–2011. *Anesth Analg.* 2014;119:1344–1349. [PubMed: 25166464]
22. Huybrechts KF, Rothman KJ, Brookhart MA, et al. Variation in antipsychotic treatment choice across US nursing homes. *J Clin Psychopharmacol.* 2012;32:11–17. [PubMed: 22198446]
23. Ladha KS, Paterno E, Huybrechts KF, Liu J, Rathmell JP, Bateman BT. Variations in the use of perioperative multimodal analgesic therapy. *Anesthesiology.* 2016;124:837–845. [PubMed: 26835644]
24. Wijeyesundera DN, Beattie WS. Facing the uncomfortable truth: your choice of anesthesiologist does matter. *Anesth Analg.* 2015;120:502–503. [PubMed: 25695564]
25. Wijeyesundera DN, Austin PC, Beattie WS, Hux JE, Laupacis A. Variation in the practice of preoperative medical consultation for major elective noncardiac surgery: a population-based study. *Anesthesiology.* 2012;116:25–34. [PubMed: 22185874]
26. Lilot M, Ehrenfeld JM, Lee C, Harrington B, Cannesson M, Rinehart J. Variability in practice and factors predictive of total crystalloid administration during abdominal surgery: retrospective two-centre analysis. *Br J Anaesth.* 2015;114:767–776. [PubMed: 25586725]
27. Slogoff S, Keats AS. Does perioperative myocardial ischemia lead to postoperative myocardial infarction? *Anesthesiology.* 1985;62:107–114. [PubMed: 3970360]
28. Karalapillai D, Weinberg L, Galtieri J, et al. Current ventilation practice during general anaesthesia: a prospective audit in Melbourne, Australia. *BMC Anesthesiol.* 2014;14:85. [PubMed: 25302048]
29. Vargas M, Sutherasan Y, Gregoretti C, Pelosi P. PEEP role in ICU and operating room: from pathophysiology to clinical practice. *ScientificWorldJournal.* 2014;2014:852356. [PubMed: 24719580]
30. de Jong MA, Ladha KS, Melo MF, et al. Differential effects of intraoperative positive end-expiratory pressure (PEEP) on respiratory outcome in major abdominal surgery versus craniotomy. *Ann Surg.* 2016;264:362–369. [PubMed: 26496082]
31. Hemmes SNT, Gama de Abreu M, Pelosi P, Schultz MJ; PROVE Network Investigators for the Clinical Trial Network of the European Society of Anaesthesiology. High versus low positive end-expiratory pressure during general anaesthesia for open abdominal surgery (PROVHILO trial): a multicentre randomised controlled trial. *Lancet.* 2014;384:495–503. [PubMed: 24894577]
32. Levin MA, McCormick PJ, Lin HM, Hosseinian L, Fischer GW. Low intraoperative tidal volume ventilation with minimal PEEP is associated with increased mortality. *Br J Anaesth.* 2014;113:97–108. [PubMed: 24623057]
33. Sato H, Nakamura K, Baba Y, Terada S, Goto T, Kurahashi K. Low tidal volume ventilation with low PEEP during surgery may induce lung inflammation. *BMC Anesthesiol.* 2016;16:47. [PubMed: 27473050]
34. Eikermann M, Kurth T. Apply protective mechanical ventilation in the operating room in an individualized approach to perioperative respiratory care. *Anesthesiology.* 2015;123:12–14. [PubMed: 25978325]

35. Hyder JA, Niconchuk J, Glance LG, et al. What can the national quality forum tell us about performance measurement in anesthesiology? *Anesth Analg*. 2015;120:440–448. [PubMed: 25602454]
36. Lane-Fall MB, Neuman MD. Outcomes measures and risk adjustment. *Int Anesthesiol Clin*. 2013;51:10–21. [PubMed: 24088885]
37. Neto AS, Hemmes SN, Barbas CS, et al.; PROVE Network Investigators. 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. *Lancet Respir Med*. 2016;4:272–280. [PubMed: 26947624]

Figure 1. Range of predicted probabilities of the use of protective ventilation across individual anesthesia providers obtained from unadjusted and adjusted mixed-effects models.

Figure 2.

Results of the secondary analysis demonstrating the range of predicted probabilities for the components of protective ventilation. Probabilities were obtained from unadjusted and adjusted mixed-effects models.

Figure 3.

Examining the use of protective ventilation over time. Providers were separated into quartiles based on the crude rate of using protective ventilation in 2007 to 2008. The collective rate of using protective ventilation was plotted as a function of time.

Table 1.

Patient Characteristics According to Provider Quartile of Protective Ventilation Use

	Entire Cohort	First Quartile	Second Quartile	Third Quartile	Fourth Quartile	P*
Total number of patients	57,372	14,460	14,324	14,476	14,112	
Proportion of patients receiving protective ventilation, mean $\pm$ SD	0.52 $\pm$ 0.18	0.28 $\pm$ 0.08	0.47 $\pm$ 0.04	0.59 $\pm$ 0.04	0.73 $\pm$ 0.05	<.001
Plateau pressure (cm H ₂ O), median [IQR]	19 [16, 22]	18 [15, 22]	19 [16, 22]	19 [16, 22]	19 [16, 22]	<.001
PEEP (cm H ₂ O), median [IQR]	5 [3.5, 5]	4 [1, 5]	5 [3, 5]	5 [4, 5]	5 [5, 5]	<.001
Tidal volume (mL/kg PBW), median [IQR]	8.4 [7.5, 9.5]	8.8 [7.8, 10]	8.5 [7.6, 9.5]	8.3 [7.4, 9.3]	8.0 [7.2, 9.0]	<.001
Provider type						<.001
Resident	30,214 (52.7)	3846 (26.6)	6160 (43.0)	9764 (67.4)	10,444 (74.0)	
CRNA	22,036 (38.4)	10,087 (69.8)	6640 (46.4)	3105 (21.4)	2204 (15.6)	
Attending anesthesiologist	5122 (8.9)	527 (3.6)	1524 (10.6)	1607 (11.1)	1464 (10.4)	
Demographic characteristics						
Sex, male, n (%)	25,822 (45.1)	6429 (44.5)	6405 (44.7)	6556 (45.3)	6492 (46.0)	.044
Age group (y), n (%)						<.001
<40	10,687 (18.6)	2689 (18.6)	2650 (18.5)	2758 (19.1)	2590 (18.4)	
40–49	9916 (17.3)	2566 (17.7)	2525 (17.6)	2415 (16.7)	2410 (17.1)	
50–59	12,836 (22.4)	3319 (23.0)	3145 (22.0)	3234 (22.3)	3138 (22.2)	
60–69	12,733 (22.2)	3275 (22.6)	3148 (22.0)	3197 (22.1)	3113 (22.1)	
70 and above	11,200 (19.5)	2611 (18.1)	2856 (19.9)	2872 (19.8)	2861 (20.3)	
Year, n (%)						<.001
2007	2040 (3.6)	537 (3.7)	506 (3.5)	702 (4.8)	295 (2.1)	
2008	5606 (9.8)	1372 (9.5)	2087 (14.6)	1387 (9.6)	760 (5.4)	
2009	6976 (12.2)	1640 (11.3)	2290 (16.0)	1999 (13.8)	1047 (7.4)	
2010	7811 (13.6)	2355 (16.3)	2237 (15.6)	1998 (13.8)	1221 (8.7)	
2011	10,582 (18.4)	2921 (20.2)	2854 (19.9)	2425 (16.8)	2382 (16.9)	
2012	10,633 (18.5)	2702 (18.7)	2060 (14.4)	2756 (19.0)	3115 (22.1)	
2013	9935 (17.3)	2240 (15.5)	1628 (11.4)	2294 (15.8)	3773 (26.7)	
2014	3789 (6.6)	693 (4.8)	662 (4.6)	915 (6.3)	1519 (10.8)	
Body mass index (kg/m ²), n (%)						.83
<20	3036 (5.3)	770 (5.3)	786 (5.5)	744 (5.1)	736 (5.2)	

	Entire Cohort	First Quartile	Second Quartile	Third Quartile	Fourth Quartile	P^*
20–24.9	15,526 (27.1)	3898 (27.0)	3901 (27.2)	3909 (27.0)	3818 (27.1)	
25–29.9	19,216 (33.5)	4900 (33.9)	4712 (32.9)	4863 (33.6)	4741 (33.6)	
30 and above	19,594 (32.4)	4892 (33.8)	4925 (34.4)	4960 (34.3)	4817 (34.1)	
Comorbidities						
Charlson comorbidity index, mean $\pm$ SD	2.17 $\pm$ 2.93	2.07 $\pm$ 2.89	2.19 $\pm$ 2.93	2.22 $\pm$ 2.96	2.21 $\pm$ 2.94	<.001
Existing chronic pulmonary disease, n (%)	7022 (12.2)	1793 (12.4)	1761 (12.3)	1781 (12.3)	1687 (12.0)	.68
SPORC, mean $\pm$ SD	1.69 $\pm$ 2.07	1.48 $\pm$ 1.96	1.72 $\pm$ 2.09	1.74 $\pm$ 2.08	1.82 $\pm$ 2.11	<.001
Procedure						
Surgery type, n (%)						<.001
Laparoscopic abdominal surgery	10,120 (17.6)	2852 (19.7)	2407 (16.8)	2399 (16.6)	2462 (17.4)	
Retropitoneal surgery	1980 (3.5)	410 (2.8)	504 (3.5)	542 (3.7)	524 (3.7)	
Hemia repair or minor abdominal surgery	1860 (3.2)	450 (3.1)	430 (3.0)	554 (3.8)	426 (3.0)	
Major abdominal surgery	5173 (9.0)	1095 (7.6)	1203 (8.4)	1405 (9.7)	1470 (10.4)	
Hip and knee arthroplasty	2858 (5.0)	589 (4.1)	684 (4.8)	757 (5.2)	828 (5.9)	
Neurosurgery (nonspine)	4555 (7.9)	755 (5.2)	1210 (8.4)	1295 (8.9)	1295 (9.2)	
Vascular surgery	2399 (4.2)	379 (2.6)	672 (4.7)	706 (4.9)	642 (4.5)	
Plastic surgery	2261 (3.9)	557 (3.9)	530 (3.7)	571 (3.9)	603 (4.3)	
Urologic surgery (nonabdominal)	4578 (8.0)	1482 (10.2)	1032 (7.2)	1069 (7.4)	995 (7.1)	
General surgery (nonabdominal)	4941 (8.6)	1676 (11.6)	1284 (9.0)	964 (6.7)	1017 (7.2)	
Orthopedic surgery (nonspine)	8999 (15.7)	2141 (14.8)	2389 (16.7)	2349 (16.2)	2120 (15.0)	
Spinal surgery	3064 (5.3)	629 (4.3)	798 (5.6)	817 (5.6)	820 (5.8)	
Breast surgery	2861 (5.0)	964 (6.7)	753 (5.3)	623 (4.3)	521 (3.7)	
Gynecologic surgery	1723 (3.0)	481 (3.3)	428 (3.0)	425 (2.9)	389 (2.8)	
Emergency/urgent, n (%)	5402 (9.4)	1153 (8.0)	1380 (9.6)	1407 (9.7)	1462 (10.4)	<.001
Ambulatory procedure, n (%)	10,667 (18.6)	3726 (25.8)	2536 (17.7)	2126 (14.7)	2279 (16.1)	<.001
Work RVU, mean $\pm$ SD	17.81 $\pm$ 11.36	16.47 $\pm$ 10.40	17.43 $\pm$ 11.00	18.46 $\pm$ 11.83	18.92 $\pm$ 12.00	<.001
Intraoperative factors						
Total resuscitation volume (mL), mean $\pm$ SD	2479 $\pm$ 8106	2083 $\pm$ 5652	2521 $\pm$ 8708	2621 $\pm$ 8259	2696 $\pm$ 9341	<.001
Estimated blood loss (mL), mean $\pm$ SD	173 $\pm$ 361	139 $\pm$ 304	172 $\pm$ 344	187 $\pm$ 416	195 $\pm$ 367	<.001
Platelets transfused (units), mean $\pm$ SD	0.04 $\pm$ 0.62	0.03 $\pm$ 0.61	0.03 $\pm$ 0.50	0.05 $\pm$ 0.73	0.04 $\pm$ 0.64	.006
Fresh frozen plasma transfused (units), mean $\pm$ SD	0.02 $\pm$ 0.33	0.03 $\pm$ 0.35	0.03 $\pm$ 0.31	0.02 $\pm$ 0.36	0.02 $\pm$ 0.31	.86

	Entire Cohort	First Quartile	Second Quartile	Third Quartile	Fourth Quartile	P*
Packed red blood cells transfused (units), mean ± SD	0.08 ± 1.40	0.08 ± 2.52	0.09 ± 0.96	0.09 ± 0.50	0.08 ± 0.46	.91
Duration of intraoperative ventilation (h), mean ± SD	2.95 ± 2.56	2.64 ± 2.22	2.91 ± 2.51	3.10 ± 2.68	3.16 ± 2.77	<.001
Epidural, n (%)	4154 (7.2)	823 (5.7)	948 (6.6)	1163 (8.0)	1220 (8.6)	<.001

Abbreviations: CRNA, clinical registered nurse anesthetist; IQR, interquartile range; PBW, predicted body weight; PEEP, positive end-expiratory pressure; RVU, relative value units; SD, standard deviation; SPORC, Score for Prediction Of Postoperative Respiratory Complications.

* Pvalue calculated from χ^2 , analysis of variance, or Kruskal–Wallis tests where appropriate with $P < .05$ deemed as statistically significant.

Table 2.
Rates of Protective Ventilation Across Individual Anesthesia Providers Determined From Mixed-Effects Models

	Usage Rates of Protective Ventilation			
	β_0 (SE) ^a	σ_0^2 (SE) ^b	Average Provider ^c (% of Cases)	97.5 Percentile ^d
Use of protective ventilation				
Unadjusted	0.15 (0.048)	0.59 (0.055)	53.8	19.9
Adjusted	0.044 (0.041)	0.42 (0.041)	51.1	24.7
Application of PEEP (> 5 cm H ₂ O)				
Unadjusted	0.74 (0.056)	0.77 (0.073)	67.7	31.0
Adjusted analysis	0.68 (0.052)	0.86 (0.04)	66.2	31.6
Use of low tidal volume (<10 mL/kg predicted body weight)				
Unadjusted	1.79 (0.038)	0.33 (0.034)	85.7	64.6
Adjusted	1.96 (0.033)	0.22 (0.024)	87.7	73.3
Use of low plateau pressure (< 30 cm H ₂ O)				
Unadjusted	3.30 (0.032)	0.11 (0.020)	96.4	94.5
Adjusted	3.80 (0.035)	0.26 (0.03)	97.8	97.3

Abbreviations: PEEP, positive end-expiratory pressure; SE, standard error.

^a β_0 : The marginal (averaged across providers) log odds of using protective ventilation for the average patient.

^b σ_0^2 : Estimate of the variation in performance between individual providers on the logistic scale. When covariates are adjusted for, σ_0^2 would be expected to decrease if the variation is explained by the covariates.

^c“Average provider”: The probability that the average patient (defined as a mean probability score of zero) would receive protective ventilation across all individual providers; it is estimated as: $\exp(\beta_0)/[1 + \exp(\beta_0)] \times 100$.

^dRange directly determined from distribution of predicted values.

Table 3.

Results of Sensitivity Analyses

	Usage Rates of Protective Ventilation			
	β_0 (SE) ^a	σ_b^2 (SE) ^b	Average Provider ^c (% of Cases)	97.5 Percentile ^d
Alternate methods to adjust for confounding				
Multivariable model	−.95 (0.11)	0.44 (0.042)	50.9 ^e	77.8
Inverse probability treatment weights	−0.012 (0.009)	0.46 (0.060)	49.7	77.5
Alternate definition of protective ventilation ^f				
Unadjusted	−1.47 (0.043)	0.45 (0.045)	18.6	37.9
Adjusted	−1.76 (0.036)	0.28 (0.030)	14.7	29.6
Compliance included as covariate				
Adjusted	0.043 (0.042)	0.43 (0.041)	51.1	77.3
Minimum number of cases to be included in cohort changed to 50				
Unadjusted	0.093 (0.045)	0.69 (0.057)	52.3	80.7
Adjusted	0.0018 (0.040)	0.54 (0.046)	50.0	77.8
PEEP of greater than 0 cm H ₂ O				
Unadjusted	2.44 (0.075)	1.35 (0.14)	92.0	98.9
Adjusted	2.44 (0.074)	1.29 (0.14)	92.5	98.9
Tidal volume less than 8 mL/kg of PBW				
Unadjusted	−0.36 (0.033)	0.27 (0.026)	41.1	62.9
Adjusted	−0.56 (0.029)	0.19 (0.019)	36.4	57.2
Plateau pressure of less than 20 cm H ₂ O				
Unadjusted	0.67 (0.016)	0.046 (0.006)	66.2	73.0
Adjusted	0.83 (0.018)	0.047 (0.007)	70.0	75.6
Attending anesthesiologist as fixed effect				
Unadjusted	0.038 (0.07)	0.27 (0.037)	50.9	72.0
Adjusted	0.003 (0.040)	0.19 (0.027)	50.0	66.7
Early versus late time period				
Adjusted early (2007–2009)	−0.15 (0.073)	0.37 (0.066)	46.2	70.2
Adjusted late (2012–2014)	0.30 (0.070)	0.60 (0.082)	57.4	83.7

	Usage Rates of Protective Ventilation			
	β_0 (SE) ^a	σ_b^2 (SE) ^b	Average Provider ^c (% of Cases)	97.5 Percentile ^d
Excluding cases ending after 5 PM				
Unadjusted	0.12 (0.050)	0.61 (0.58)	53.1	19.1
Adjusted	0.005 (0.42)	0.43 (0.042)	50.1	23.8
				80.9
				76.4

Abbreviations: PBW, predicted body weight; PEEP, positive end-expiratory pressure; SE, standard error.

^a β_0 : The marginal (averaged across providers) log odds of using protective ventilation for the average patient.

^b σ_b^2 : Estimate of the variation in performance between individual providers on the logistic scale. When covariates are adjusted for, σ_b^2 would be expected to decrease if the variation is explained by the covariates.

^c“Average provider”: The probability that the average patient (defined as a mean probability score of zero) would receive protective ventilation across all individual providers; it is estimated as: $\exp(\beta_0)/(1 + \exp(\beta_0)) \times 100$.

^dRange directly determined from distribution of predicted values.

^eCalculated as the marginal probability with all covariates at their means and random effects portion of the model set to zero.

^fAlternate definition of protective ventilation: PEEP 5 cm H₂O, tidal volume 8 mL/kg PBW, plateau pressure 20 cm H₂O).