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# Adjustments of Ventilator Parameters during Operating Room-to-ICU Transition and 28-Day Mortality

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## Keywords:

patient handoff; patient transfer; respiration, artificial; respiratory mechanics; ventilator-induced lung injury.

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Lung-protective ventilation strategies may prevent ventilator-induced lung injury (VILI) in patients with and without acute respiratory distress syndrome (ARDS) and have been implemented as the standard of care in multiple healthcare settings (1–3). However, providers in the ICU have been stricter in adopting low VTs compared with the operating room (OR) (1). Evidence from randomized controlled trials supports the use of low VTs (4, 5), which is often compensated with higher respiratory rates (RRs) to maintain adequate minute ventilation (6). Animal and observational data suggest that, in addition to high VTs, high RRs may also contribute to VILI (7–9). Comprehensive concepts estimating the intensity of mechanical ventilation, such as mechanical power (MP), have been proposed as a tool to assess the combined effect of competing ventilator parameters, which may differ between patients in heterogeneous populations (7, 10–12).

The transition from the OR to the ICU represents a critical period of care (13, 14) in which differential clinical practice may lead to adjustments of ventilator settings. It is currently unclear whether these adjustments affect the intensity of mechanical ventilation, as measured by MP, and potentially translate into a higher risk of mortality.

This study aims to characterize ventilator adjustments upon transition of surgical patients from the OR to the ICU and to explore their effects on MP and 28-day mortality. Some of the results of these studies have been previously reported in the form of an abstract (15).

## **Methods**

### **Study Design**

This hospital registry study was conducted at Beth Israel Deaconess Medical Center, a tertiary healthcare network in Boston, Massachusetts. We included surgical patients who underwent general anesthesia and were subsequently ventilated in the ICU between January 2008 and June 2022 (see online supplement). The institutional review board at Beth Israel Deaconess Medical Center approved the study (protocol number 2023P000437) and waived the requirement for informed consent. This document adheres to the Strengthening the Reporting of Observational Studies in Epidemiology guidelines (16).

### **Study Population**

Adult patients undergoing elective or emergency noncardiac surgery who were intubated for the index procedure, directly transferred to an ICU, and underwent controlled mechanical ventilation for >1 hour postoperatively with available data for exposure and outcome were eligible for inclusion. We excluded severely moribund and brain-dead patients (American Society of Anesthesiologists physical status greater than IV) and patients who underwent another procedure within 28 days of the index procedure. The complete-case approach was used in the primary analysis.

### **Exposure and Outcome Measures**

The primary exposure was the change in MP (DMP) upon transition from the OR to the ICU. We defined DMP as the difference in median MP during the first 6 hours of mechanical ventilation in the ICU (MPICU) and the median MP during the last 1 hour of surgery

(MPOR). Based on that equation ( $DMP = MP_{ICU} - 2 \times MP_{OR}$ ), positive changes in MP reflect an increased intensity of ventilation after the transition to the ICU, whereas negative changes describe a lower intensity of ventilation in the ICU compared with the OR. Using highly granular intraoperative data collected as often as every 15 seconds, we calculated MP during the last 1 hour of surgery to address potential intraprocedural changes in mechanical ventilation. To ensure sufficient data points in the ICU, where data were collected at lower frequencies, we calculated the median MP during the first 6 hours of ICU ventilation (see online supplement and Figure E3 in the online supplement). Median MP was estimated from median values of VT, RR, peak inspiratory pressure (PIP), and positive end-expiratory pressure (PEEP) during each period using the following validated equation (17):

$$MP(J/min) = 0.098 \times V_T \times RR \\ \times [PIP - \frac{1}{2} \times (PIP - PEEP)]$$

PIP was used instead of plateau pressure because the latter was not routinely collected in the OR (18). For all parameters, only readings from ventilator modes indicating controlled mechanical ventilation were used. The primary outcome was all-cause mortality within 28 days of the procedure. The secondary outcome was the number of days a patient was ventilator-free and alive at Day 28 (19). Patients who died or whose mechanical ventilation was continued throughout Day 28 were considered to have no ventilator-free and alive days. See online supplement for detailed exposure and outcome definitions.

### **Confounding Model**

Potential confounding variables were defined a priori based on existing evidence and clinical plausibility. To avoid bias arising from adjusting for potential mediator variables, confounder control in the primary analysis was restricted to variables preceding the adjustment of ventilator settings in the ICU (20–22). Confounding variables included patient characteristics such as age, sex, body mass index, American Society of Anesthesiologists physical status, high risk of postoperative respiratory complications (Score for Prediction of Postoperative Respiratory Complications >7) (23), Charlson comorbidity index (24), as well as a history of congestive heart failure, obstructive sleep apnea (25), obstructive or restrictive pulmonary disease, and smoking. Procedural factors included the year of surgery (26, 27), emergency status, the surgical service, duration of surgery, baseline respiratory system compliance (12), and median FIO<sub>2</sub>. We further adjusted for the intraoperatively administered doses of vasopressors (28), opioids, intravenous fluid volume, and non-depolarizing neuromuscular blocking agents (NMBAs) (29). See online supplement for details on confounding variables and Figure E2 in the online supplement for a directed acyclic graph (30).

### **Primary and Secondary Analyses**

In the primary analysis, we investigated whether adjustments in ventilator parameters between the end of surgery and transition to the ICU, resulting in changes in MP, were associated with 28-day mortality. We further investigated the relative importance of individual ventilator parameters of the MP equation, namely VT, driving pressure, and RR (see online supplement).

In the secondary analysis, we investigated the association of changes inMP with ventilator-free and alive days at Day 28 (see online supplement).

### **Exploratory and Sensitivity Analyses**

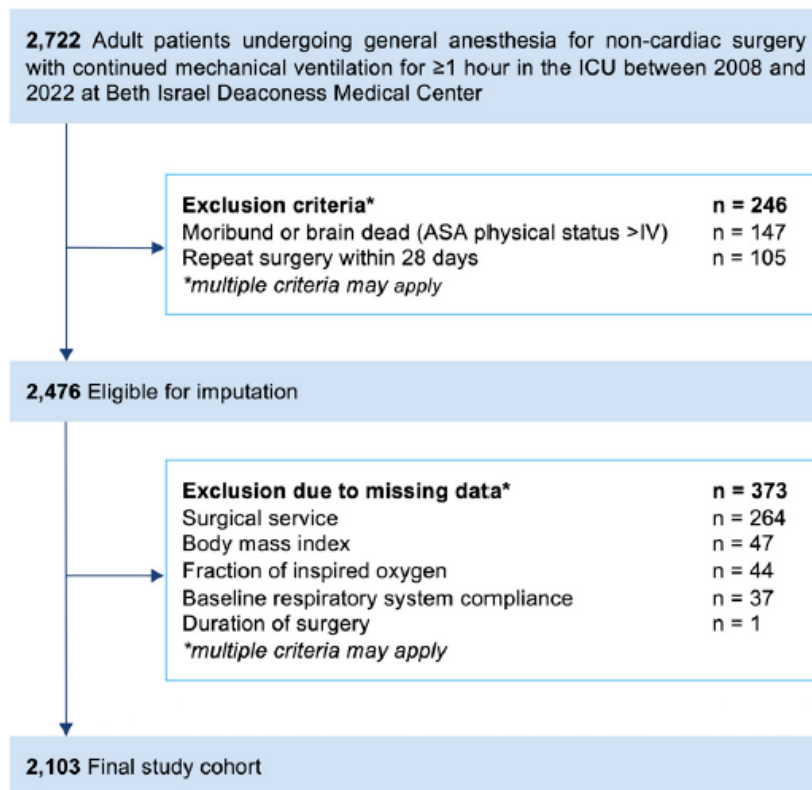
In an exploratory attempt, we tested the relative effect of the primary exposure, change of MP during the transition from the OR to the ICU, compared with the average time-weighted MP (31) during the entire exposure period (i.e., the last intraoperative and first 6 postoperative hours of ventilation; see online supplement) on 28-day mortality. Additionally, we performed a time-to-event analysis, comparing survival time at 28 days in patients with and without increasing MP.

We conducted multiple sensitivity analyses to test the robustness of our primary findings (see online supplement), including reanalysis after: 1) calculating MP using measured and imputed plateau pressures, 2) matching patients with and without increasing MP by their Acute Physiology and Chronic Health Evaluation II score (32), and exclusion of 3) open abdominal and open thoracic procedures, 4) all thoracic procedures, 5) laparoscopic and video-assisted thoracoscopic procedures, and 6) patients with respiratory efforts. We additionally adjusted for: 7) factors related to ICU care (fluids, blood components, sedation, pain management, NMBAs, and vasopressors), 8) the ventilatory ratio (33), 9) alveolar dead space, 10) arterial pH, 11) metabolic acidosis, 12) intraprocedural changes in respiratory system compliance, 13) changes in dead space-adjusted minute ventilation during the transition, 14) PaCO<sub>2</sub>, 15) FIO<sub>2</sub> in the ICU, and 16) the patient's predicted body weight (PBW) (4). Additionally, we analyzed our data: 17) in a first-case approach and 18) without excluding patients undergoing another procedure within 28 days. We further: 19) performed multiple imputation of missing data based on the assumption that they were missing at random(34) and 20) calculated the E-value (35).

### **Statistical Analyses**

Primary and secondary analyses were defined a priori. Variables demonstrating a nonnormal distribution are reported as medians with IQRs. Changes in ventilator settings and MP between the OR and ICU were assessed using the Wilcoxon signed rank or rank sum test, as appropriate. Multivariable logistic regression models were used for the primary outcome. Adjusted odds ratios (aORs) and adjusted risk differences (aRDs) with their 95% confidence intervals (CI) are reported for logistic regression models. The performance of the primary model was evaluated with regard to discrimination, calibration, and using lift charts (see online supplement). The relative importance of ventilator parameters was assessed using logistic regression and, for the relative contribution to mortality prediction, dominance analysis (see online supplement) (36). A negative binomial regression model was used for the outcome of ventilator-free and alive days (see online supplement for additional details on this model). Results are reported as incidence rate ratio and adjusted absolute difference, each with 95% CIs. A flexible parametric proportional-hazards model was used for the time-to-event analysis (37), see online supplement for additional details. Results are reported as hazard ratios with 95% CIs. Statistical significance was assumed at a two-sided P value,0.05. Analyses were performed using Stata (version 16.1MP; StataCorp LLC) and R statistical software (version 4.2.0; R Foundation for Statistical Computing).

# Results



**Figure 1.** Study flow diagram. ASA = American Society of Anesthesiologists. \*Multiple criteria may apply.

## Study Cohort and Characteristics

The final study cohort included 2,103 patients (Figure 1 and Table 1). Assessment of temporal trends in ventilation practice revealed that RRs continuously increased over the years in the OR and ICU whereas VTs and driving pressures decreased (Figure 2).

**Table 1.** Patient Characteristics and Distribution of Variables

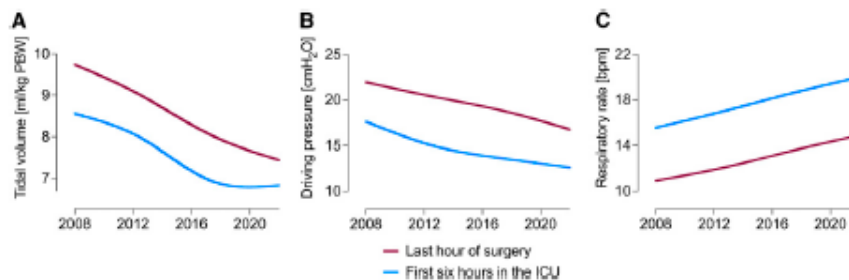
Characteristic/Variable	No Increase in Mechanical Power (n=881)	Increase in Mechanical Power (n=1,222)	Standardized Difference
Age, yr	60 (49–69)	67 (56–76)	–0.415
Female sex	358 (40.6%)	571 (46.7%)	–0.123
Body mass index, kg/m <sup>2</sup>	28.5 (24.6–34.0)	26.7 (23.2–31.3)	0.289
APACHE score*	21 (17–25)	22 (18–27)	–0.245
ASA physical status			–0.062
I	10 (1.1%)	13 (1.1%)	
II	85 (9.6%)	89 (7.3%)	
III	359 (40.7%)	506 (41.4%)	
IV	427 (48.5%)	614 (50.2%)	
Emergency status	482 (54.7%)	709 (58.0%)	–0.067
Charlson comorbidity index	4 (1–7)	3 (1–7)	–0.006
Surgical service			0.039
Colorectal	20 (2.3%)	31 (2.5%)	
Ear, nose, throat	17 (1.9%)	51 (4.2%)	
General surgery	88 (10.0%)	196 (16.0%)	
Gynecology and obstetrics	29 (3.3%)	49 (4.0%)	
Neurosurgery	110 (12.5%)	129 (10.6%)	
Orthopedic surgery	117 (13.3%)	108 (8.8%)	
Surgical oncology	20 (2.3%)	21 (1.7%)	
Thoracic surgery	73 (8.3%)	94 (7.7%)	
Transplant surgery	194 (22.0%)	124 (10.1%)	
Trauma surgery	83 (9.4%)	145 (11.9%)	
Urology	21 (2.4%)	24 (2.0%)	
Vascular surgery	77 (8.7%)	209 (17.1%)	
Other services	32 (3.6%)	41 (3.5%)	
SPORC	6 (5–8)	6 (5–8)	–0.098
Smoking	239 (27.1%)	273 (22.3%)	0.111
Congestive heart failure	193 (21.9%)	309 (25.3%)	–0.080
Obstructive sleep apnea	59 (6.7%)	71 (5.8%)	0.037
Obstructive pulmonary disease	227 (25.8%)	334 (27.3%)	0.035
Restrictive pulmonary disease	18 (2.0%)	63 (5.2%)	0.168
Duration of surgery, min	284 (162–440)	215 (133–357)	0.270
Baseline respiratory system compliance, ml/cm H <sub>2</sub> O <sup>†</sup>	28.9 (22.7–35.8)	29.2 (23.1–36.4)	–0.039
F <sub>I</sub> O <sub>2</sub> in OR, %	57.3 (52.0–72.0)	59.4 (53.0–82.5)	–0.157
Vasopressor dose in OR, mg norepinephrine equivalents	0.8 (0.2–2.0)	0.6 (0.1–1.4)	0.096
Crystalloid and colloid infusion in OR, ml	3,000 (1,700–4,775)	2,700 (1,500–4,500)	0.130
Total opioids dose in the OR, mg OME	71.0 (37.5–142.0)	62.5 (25.0–112.5)	0.150
Nondepolarizing NMBA in OR, ED <sub>95</sub>	4.5 (2.6–7.1)	3.8 (2.4–5.9)	0.213

*Definition of abbreviations:* APACHE = Acute Physiology and Chronic Health Evaluation II; ASA = American Society of Anesthesiologists; ED<sub>95</sub> = median effective dose needed to achieve a 95% reduction in maximal twitch response from baseline; F<sub>I</sub>O<sub>2</sub> = fraction of inspired oxygen; NMBA = neuromuscular blocking agent; OME = oral morphine equivalent; OR = operating room; SPORC = Score for the Prediction of Postoperative Respiratory Complications.

Data are expressed as median (interquartile range [25th–75th percentile]) or frequency (prevalence in %) with their standardized difference. The standardized difference is defined as the difference in mean between groups shown in the table divided by an estimate of the SD of that variable. Comorbidities were defined using the *International Classification of Diseases (9th/10th Revision, Clinical Modification)* diagnostic codes.

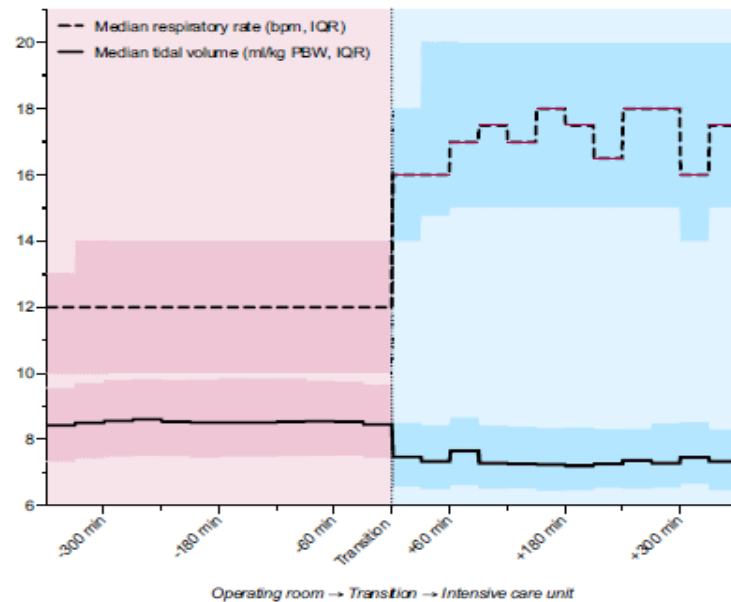
\*The APACHE score was calculated during the first 6 hours after transition to the ICU.

†Baseline respiratory system compliance was assessed during the first 10 minutes of ventilation in the operating room.

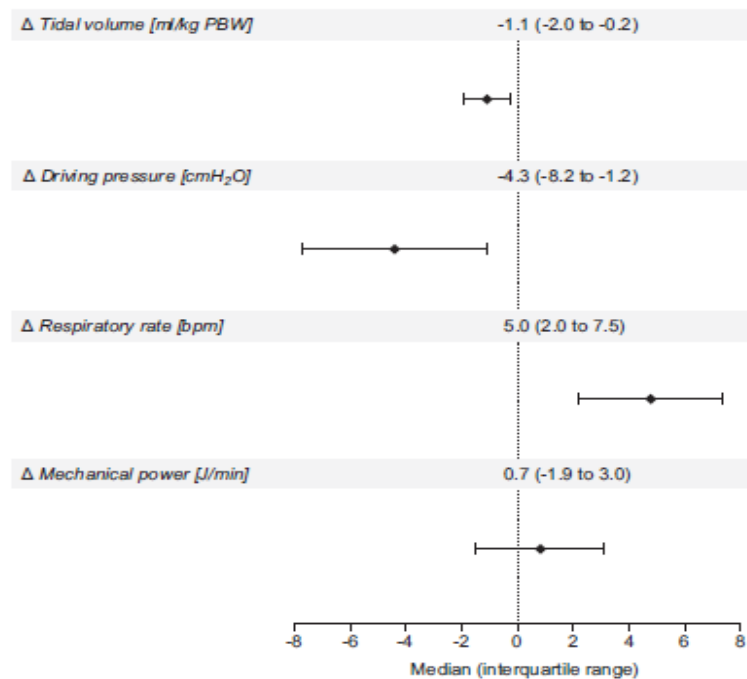


**Figure 2.** Temporal trends of mechanical ventilation in the operating room and ICU. Mechanical ventilation during the last 1 hour of surgery (maroon) compared with the first 6 hours in the ICU (blue) shows differential patterns of clinical practice, with lower V<sub>T</sub>s and driving pressures but higher respiratory rates in the ICU. V<sub>T</sub>s and driving pressures continuously decreased over a period of 14 years in both settings, whereas respiratory rates increased. Spline regression applied to median ventilator parameters was used to show gradual changes in mechanical ventilation practice over time while accounting for fluctuations and noise in the data. bpm = breaths per minute; PBW = predicted body weight.

Ventilator adjustments from the OR to the ICU occurred at the time of transition, whereas settings remained stable during the last 1 hour of surgery and the first 6 hours in the ICU (Figure 3). Upon transition, VTs were lowered (P,0.001; Figure 4 and Table E1 in the online supplement), leading to decreased peak inspiratory pressures (23.8 cmH<sub>2</sub>O [IQR,27.5 to20.3]; P,0.001) and lower driving pressures (P,0.001), whereas RRs were increased (P,0.001). These adjustments resulted in higher MP during ICU ventilation (P,0.001). PEEPs remained clinically unchanged (0 cmH<sub>2</sub>O [20.1 to 2.5]; P,0.001).



**Figure 3.** Trajectories of respiratory rate and  $V_T$  during the transition from the operating room to the ICU. Median respiratory rate (breaths/min, dashed line) and  $V_T$  (ml/kg predicted body weight, solid line) are shown with their IQR for each 30-minute increment during intraoperative (maroon) and ICU (blue) ventilation. bpm = breaths per minute; PBW = predicted body weight.

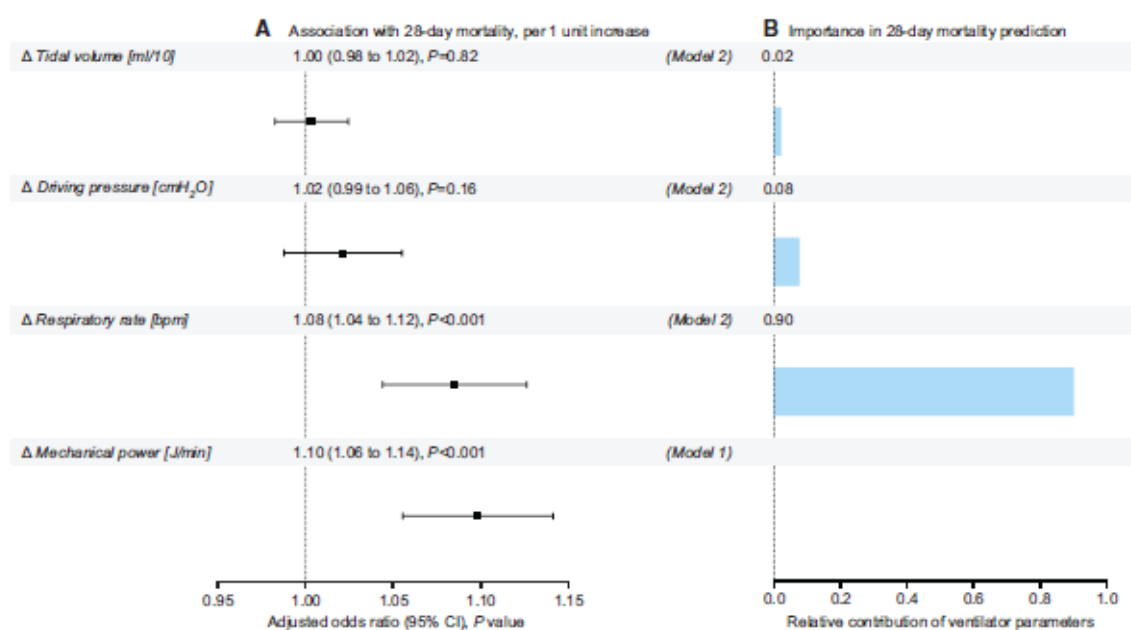


**Figure 4.** Adjustments of ventilator settings during the transition from the operating room to the ICU. Changes in ventilator parameters between the last 1 hour of surgery and first 6 hours of ventilation in the ICU. Mechanical power slightly increased from the operating room to the ICU, which was mainly driven by increased respiratory rates, whereas  $V_T$ s and driving pressures were decreased. bpm = breaths per minute; PBW = predicted body weight.



## Primary and Secondary Analyses

A total of 212 patients (10.1%) died within 28 days (Table E2 in the online supplement). Patients who died had a greater increase in MP during transition from the OR to the ICU than those who survived (1.9 J/min [IQR, 20.3 to 4.2] vs. 0.5 J/min [22.1 to 2.9];  $P=0.001$ ). Increases in MP during the transition were associated with a higher mortality risk after adjusting for confounding variables (aOR, 1.10 per 1-J/min increase; 95% CI, 1.06–1.14;  $P=0.001$ ; equivalent to an aOR of 1.59 per 5-J/min increase; 95% CI, 1.31–1.94). Among the individual components of MP, only changes in RR were significantly associated with 28-day mortality (aOR, 1.08 per 1-breath/min increase; 95% CI, 1.04–1.12;  $P=0.001$ ), while changes in VT and driving pressure were not (Figure 5A), which was corroborated by findings from the dominance analysis (Figure 5B).



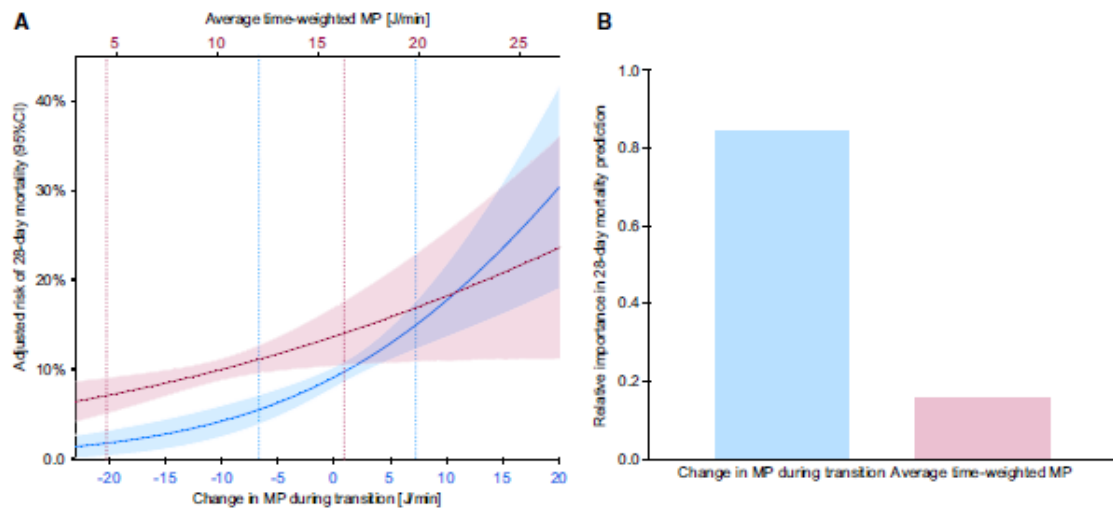
**Figure 5.** Association of mechanical power (MP) and its components with 28-day mortality and their relative importance in mortality prediction. (A) Association of ventilator adjustments with 28-day mortality. Estimates for MP were obtained from the primary model (model 1). A separate model (model 2) was used to assess the association of changes in  $V_T$ , driving pressure, and respiratory rate with 28-day mortality, including parameters as individual covariates without MP. (B) Dominance analysis was performed in model 2 (without MP). Relative importance for the components of MP was determined by their contribution to 28-day mortality prediction-error reduction, scaled to the total contribution of all ventilator parameters included in the model. bpm = breaths per minute; CI = confidence interval.

The median time a patient was ventilator-free and alive was 26 days (IQR, 23–27). Increasing MP upon transition to the ICU was associated with fewer ventilator-free and alive days (incidence rate ratio, 0.99 per 1-J/min increase; 95% CI, 0.98–0.99;  $P = 0.001$ ; adjusted absolute difference, 20.26 days per 1-J/min increase; 95% CI, 20.42 to 20.10).

## Exploratory and Sensitivity Analyses

Average time-weighted MP was independently associated with 28-day mortality (aOR, 1.08 per 1-J/min increase; 95% CI, 1.02–1.14;  $P = 0.005$ ). The aRD of 28-day mortality was 0.6% per 1-J/min increase (95% CI, 0.2–1.0;  $P = 0.005$ ) in average time-weighted MP. In comparison, changes in MP during the transition for the OR to the ICU demonstrated a 16.7% larger effect size per 1-J/min increase, corresponding to an aRD of 0.7% per 1-J/min increase (95% CI, 0.4–1.0;  $P=0.001$ ; Figure 6A). Dominance analysis corroborated these findings

(Figure 6B). An increase (vs. no increase) of MP was associated with lower survival time (hazard ratio, 1.82; 95% CI, 1.30–2.54;  $P=0.001$ ; Figure E7 in the online supplement).



**Figure 6.** Comparison of change in mechanical power (MP) during the transition from the operating room to the ICU and average time-weighted MP. (A) Adjusted risk of 28-day mortality at different levels of change in MP (blue) and average time-weighted MP (maroon). Adjusted risks are presented for the entire range of the predictors represented in the cohort. Vertical dotted lines represent the 5th and 95th percentile in the cohort for each predictor, respectively. The adjusted risk difference was 0.7% (95% confidence interval, 0.4–1.0;  $P < 0.001$ ) per 1-J/min change in MP from the operating room to the ICU, versus 0.6% (95% confidence interval, 0.2–1.0;  $P = 0.005$ ) per 1-J/min increase for average time-weighted MP, corresponding to a 16.7% larger effect size of changes in MP during the transition. (B) Dominance analysis was performed in a model including changes in MP as well as average time-weighted MP as individual covariates. The relative importance is reported for change in MP (blue) and average time-weighted MP (maroon), as determined by their contribution to 28-day mortality prediction-error reduction. CI = confidence interval.

The association of changes in MP and mortality remained robust throughout all sensitivity analyses (see online supplement).

## Discussion

In 2,103 surgical patients undergoing general anesthesia and continued postoperative ventilation in the ICU, we observed that, upon transition from the OR to the ICU, on average, VTs and driving pressures decreased, whereas RRs increased. These adjustments overall resulted in a slightly increased MP after the transition. In adjusted analysis, ventilator adjustments yielding a higher MP were associated with a higher risk of 28-day mortality. This translated into an increase in 28-day mortality from 9.2% in patients with stable MP during transition to 12.9% when MP was increased by 5 J/min (Figure 6).

This study is the first to demonstrate differences in ventilator settings during the transition between two distinct healthcare settings and provider groups. Although this observation stems from a single academic healthcare center in Boston, Massachusetts, previous studies support that ventilator patterns following lower VTs and higher RRs in the ICU, compared with slightly higher VTs and lower RRs in the OR, are representative for different hospital settings and geographical regions (1). Our findings add to the literature because as we identified differential practice patterns in ventilation within the same patients during a care transition and observed that an increase in the intensity of mechanical ventilation following a transition between healthcare settings was associated with a higher mortality risk. Our results are in agreement with previous findings showing that temporal increases of MP during surgery are associated with postoperative respiratory failure (18), as well as studies in critically ill

patients demonstrating that higher intensity of mechanical ventilation per se, as measured by MP, is associated with increased ICU mortality in patients without ARDS (38).

We observed that the average minute ventilation increased during the transition. However, analyses additionally adjusted for changes in minute ventilation from the OR to the ICU, pH, the ventilatory ratio, and PaCO<sub>2</sub> levels yielded confirmatory results. This suggests that increases in MP upon the transition may be associated with mortality independent of potentially higher demands for ventilation.

When compared with changes in VT and driving pressure, changes in RR were the most important predictor of mortality. Observational studies suggest that not only stress and strain but also the rate at which energy is delivered to the lung may exert injurious effects, even though the underlying causal mechanisms remain unclear (7, 8). Based on our data, we cannot determine with certainty what factors drove the abrupt increases in set RRs from the OR to the ICU. However, we suggest that clinicians may additionally consider RR while setting ventilator parameters if VTs and driving pressures already lie within acceptable limits, as observed in our study.

In a pooled cohort of 4,549 patients with ARDS, Costa and colleagues reported that the effect of driving pressure on mortality was four times as strong as the effect of RR(7). In that study, driving pressure and RR were calculated during the first 24 hours after randomization, whereas we assessed abrupt changes upon postoperative transition to the ICU.

In contrast to landmark ARDS studies demonstrating improved survival with low (6 ml/kg PBW) versus high (12 ml/kg PBW) VTs or lower driving pressures (4, 39), we did not observe an association of changes in these parameters with mortality. As a result of local protocols at our institution, virtually all patients received low VTs, which, on average, decreased by only 13% from the OR to the ICU. Thus, the low heterogeneity of VT changes could have affected the statistical power to show an effect. We also included only perioperative patients electively intubated for the procedure who did not have ARDS. Compared with typical ARDS cohorts, this patient collective represents a vastly different population, in which findings on the effect of low VTs are equivocal (5, 40). It has been further shown that the effect of VTs on mortality is fully mediated through driving pressure and is therefore more prominent among patients with impaired respiratory system mechanics (12, 41). We observed low dynamic driving pressures of 18.5 cmH<sub>2</sub>O in the OR and 14.0 cmH<sub>2</sub>O in the ICU (translating into even lower static driving pressures). Therefore, we speculate that the VTs did not reach a VILI threshold in our population, whereas the relationship between RR and VILI may be more linear. Further studies are now warranted to explore this hypothesis.

Xavier and colleagues demonstrated in a rat model of ARDS that abrupt versus gradual increases in RR resulted in higher levels of inflammatory biomarkers in addition to endothelial and epithelial cell damage (42). These findings support our observation that abrupt changes in MP, mainly driven by RR, resulted in a larger effect size compared with the average MP. This observation may also raise the concern of residual confounding. However, the E-values for both factors (1.43 for the point estimate and 1.31 for the CI of changes in MP vs. 1.37 and 1.16 for average time weighted MP) indicate that the risk of considerable residual confounding is low and substantial residual confounding would be needed above and beyond the comprehensive set of adjusted confounders to explain away the observed associations (35). Additionally, average time-weighted MP was compared between patients, whereas

changes of MP from the OR to the ICU were calculated within each individual patient, limiting the risk of residual confounding due to patient demographics and disease severity. Of note, most patients were ventilated for less than 24 hours postoperatively, and the average time-weighted MP was calculated during only the 7 hours included in the primary exposure definition, reflecting a lower cumulative energy than in landmark ICU studies (7, 31). Therefore, average time-weighted MP and abrupt changes may represent complementary mechanisms of injury. This is further corroborated by previous findings on the harmful effects of abrupt (vs. gradual) increases in RR, even if less cumulative MP was applied overall (42).

Observed adjustments during the critical period of transitioning from the OR to the ICU may be explained by differences in the respiratory system mechanics of the typical patients encountered by providers in the critical care and perioperative settings. While surgical patients often present with normal respiratory system mechanics, patients ventilated in the ICU are characterized by higher rates of lung injury. In these patients, low VTs have been consistently proven beneficial (4, 43). However, at normal respiratory system mechanics, lowering VTs may not reduce lung stress and strain (i.e., driving pressure) to the same extent (41, 44–46). Consequently, in these patients, the benefit of decreasing VTs may be outweighed by the injurious effects of other competing factors, also contributing to VILI. Based on our data, integrative concepts such as MP could be considered for prospective validation as tools to monitor ventilator adjustments and the resulting intensity during the transition of ventilated patients between healthcare settings.

The retrospective design of the present study presents a limitation, and there remains the risk of residual confounding because variable selection was limited to data stored in the healthcare network's electronic databases. Although evidence is growing that MP may be causal in the development of lung injury, these data can not be used to definitively demonstrate a causal pathway. By contrast, clinical practice patterns are better depicted in observational studies, and the retrospective design allows for insights into real-world ventilation practices (47). MP may also be reflective of disease severity (7) and could be used to monitor the intensity of mechanical ventilation for prognostication. For most patients, plateau pressures were not recorded during intraoperative ventilation; thus, we calculated MP during OR and ICU ventilation using the peak inspiratory pressure for adequate comparison of both periods. However, this previously published approach may result in inaccuracies, especially when changing from volume- to pressure-control modes. Therefore, we reanalyzed our data using measured and imputed plateau pressures, both with confirmatory results. In the clinical setting, effects of RR may be mediated through subsequent changes in inspiratory flow. Because data on flow were not available in our cohort, this should be explored in future investigations. We included only ventilator readings indicating controlled mechanical ventilation but cannot fully rule out artifacts due to patients' efforts. However, a sensitivity analysis excluding patients with mismatching set and observed ventilator parameters confirmed our findings. Because our findings are limited to surgical patients with a non-pulmonary cause of mechanical ventilation, they may not translate to all patients ventilated in the ICU. A strength of this study is that the primary exposure was derived from changes within patients, eliminating many typical drivers of residual confounding. Finally, the findings remained robust throughout a wide variety of sensitivity analyses, including additional adjustment for factors related to care in the ICU (fluids, blood components, sedation, pain management, NMBAs, and vasopressors) and potential motivators to increase the intensity of ventilation (e.g., metabolic acidosis and increased dead space).

In conclusion, the transition of mechanically ventilated patients from the OR to the ICU was characterized by decreased VTs and increased RRs, which may reflect differences in clinical practice across the two healthcare settings. Increases in MP during the transition from the OR to the ICU were associated with a higher 28-day mortality risk. Prospective validation of these findings is now warranted, which ultimately could facilitate real-time monitoring of ventilator adjustments to aid prognostication or clinical decision-making.

Author disclosures are available with the text of this article at [www.atsjournals.org](http://www.atsjournals.org).

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### **Author Contributions:**

Study concept and design: D.v.W., S.R., A.S., B.J., E.N.B.-K., and M.S.S. Acquisition, analysis, or interpretation of data: D.v.W., S.R., A.S., L.J.W., and M.F. Drafting of the manuscript: D.v.W., S.R., L.J.W., and B.J. Critical revision of the manuscript for important intellectual content: all authors. Statistical analysis: D.v.W., S.R., M.F., and G.C. Study supervision: D.T., B.J., E.N.B.-K., and M.S.S.

### **Data sharing:**

Requests of qualified researchers trained in human subject research and confidentiality to access additional documents and the dataset may be sent to the corresponding author.

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# Abstract

## Rationale:

Lung-protective mechanical ventilation strategies have been proven beneficial in the operating room (OR) and the ICU. However, differential practices in ventilator management persist, often resulting in adjustments of ventilator parameters when transitioning patients from the OR to the ICU.

## Objectives:

To characterize patterns of ventilator adjustments during the transition of mechanically ventilated surgical patients from the OR to the ICU and assess their impact on 28-day mortality.

## Methods:

Hospital registry study including patients undergoing general anesthesia with continued, controlled mechanical ventilation in the ICU between 2008 and 2022. Ventilator parameters were assessed 1 hour before and 6 hours after the transition.

## Measurements and Main Results:

Of 2,103 patients, 212 (10.1%) died within 28 days. Upon OR-to-ICU transition,  $V_T$  and driving pressure decreased (-1.1 ml/kg predicted body weight [IQR, -2.0 to -0.2];  $P < 0.001$ ; and -4.3 cm H<sub>2</sub>O [-8.2 to -1.2];  $P < 0.001$ ). Concomitantly, respiratory rates increased (+5.0 breaths/min [2.0 to 7.5];  $P < 0.001$ ), resulting overall in slightly higher mechanical power (MP) in the ICU (+0.7 J/min [-1.9 to 3.0];  $P < 0.001$ ). In adjusted analysis, increases in MP were associated with a higher 28-day mortality rate (adjusted odds ratio, 1.10; 95% confidence interval, 1.06-1.14;  $P < 0.001$ ; adjusted risk difference, 0.7%; 95% confidence interval, 0.4-1.0, both per 1 J/min).

## Conclusion:

During transition of mechanically ventilated patients from the OR to the ICU, ventilator adjustments resulting in higher MP were associated with a greater risk of 28-day mortality.

