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Comparison of mechanical ventilation procedure based on predicted body weight and driving pressure in critically ill patients without ARDS (study of potential lung injury caused by mechanical ventilation)

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Abstract

***Objective*: This study aimed to assess the effect of mechanical ventilation based on predicted body weight (PBW) and driving pressure (DP) as directed in patients without acute respiratory distress syndrome (ARDS).**

***Design*: Experimental, single-blind design with pretest-posttest control group design to assess the effect of using PBW and DP as a guide in regulating the amount of tidal volume and airway pressure in mechanically ventilated patients without ARDS.**

***Setting*: We conducted this study in the Intensive Care Unit (ICU) at Dr. Wahidin Sudirohusodo General Hospital, Makassar, from November 2023 to March 2024.**

***Patients and participants*: Patients with respiratory failure who were admitted to the ICU of Dr. Wahidin Sudirohusodo General Hospital, Makassar.**

***Intervention*: Patients in the PBW group were given a tidal volume setting of 8 ml/kg PBW, adjusted to the lowest positive end-expiratory pressure (PEEP) with the largest lung compliance target, while the DP group did the same thing and adjusted the tidal volume regarding the driving pressure target. The oxygen partial pressure (pO2), carbon dioxide partial pressure (pCO2), oxygen partial pressure to fractional inspired oxygen ratio (P/F ratio), mechanical power, and ventilatory ratio were assessed at the first hour and 24th hour.**

***Measurement and results*: Thirty-two patients were divided into two groups, 16 patients each, recruited from November 2023 to March 2024. There was a significant difference in the P/F ratio in the DP group compared to the PBW group after 24 hours ($p<0.001$ vs $p=0.190$). Similarly, pCO2 after 24 hours significantly differed between the DP group ($p=0.001$) and the PBW group ($p=0.658$). Regarding mechanical power, the two groups had no significant difference (10.92±2.51 vs 11.68±1.21 Joules/min, $p=0.284$). The PBW group had a wider range of mechanical power values (range 8.4 J/min) than the DP group (range 4.6 J/min), suggesting the DP group had more consistent mechanical power magnitude.**

***Conclusion*: Mechanical ventilation guided by DP can improve oxygenation and ventilation outcomes. Even though both the PBW and DP methods resulted in similar mechanical power levels, the DP-guided approach provided more stable and predictable mechanical power values. This stability can benefit patient management in the ICU, as it suggests a reduced risk of lung injury and potentially better overall outcomes for patients receiving mechanical ventilation.**

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Key words: Predicted body weight, driving pressure, without ARDS, mechanical ventilator, ventilator-induced lung injury, mechanical power, ventilatory ratio.

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Introduction

Mechanical ventilation is a critical medical intervention that provides respiratory support to patients unable to maintain adequate oxygenation or ventilation on their own. It involves the use of artificial means to assist or replace spontaneous breathing. Consequently, using positive pressure by the ventilator into the respiratory system during mechanical ventilation causes an increase in intrathoracic pressure to expand the lung to facilitate and maintain the ventilation process to keep optimum oxygen supply and release carbon dioxide from the body. During this process, there are dynamics in intrapulmonary pressure that have a potential for lung injury, and this situation can worsen the condition of mechanically ventilated patients. (1,2)

Excessive transpulmonary pressure (distending force of the lung) increases lung stress, lung stretch, and atelectrauma (cyclic atelectasis or repeated alveolar collapse and expansion), possibly contributing to lung injury. (3) To reduce morbidity and mortality in patients with respiratory failure caused by this biophysical threat, it is important to use a proper setting of mechanical ventilation (tidal volume and positive end-expiratory pressure [PEEP]). (2-4) To anticipate these consequences, several approaches to mechanical ventilation settings have been taken to minimize the potential for lung injury due to mechanical ventilation and high transpulmonary pressures.

The use of low tidal volume mechanical ventilation (6 ml/kg predicted body weight [PBW]) reduces ventilator-induced lung injury (VILI). It decreases mortality in clinical trials, per a pioneering study conducted by ARDSNet and published in 2000. (4) PEEP settings aim to create motion (kinetic energy), which overcomes the respiratory system's elastic and resistive forces. Conversely, the PEEP level represents the static component (potential energy), which reflects the baseline tension of the respiratory system (assuming the system is relaxed with no muscle activity). (5) In addition, PEEP may minimize atelectrauma due to the (forced) opening and closing of lung units (alveoli) that can be recruited during tidal ventilation. (6,7)

Driving pressure (DP), the ratio between tidal volume and lung compliance, is also considered to minimize the potential for lung injury, and driving pressure less than 14 cmH2O is associated with better outcomes. (8,9) Combining tidal volume reduction, PEEP optimization, and recruitment maneuvers can improve lung compliance and reduce driving pressure. (10) Driving pressure-guided ventilation in acute respiratory distress syndrome (ARDS) (target 12-14 cmH2O), which affects the tidal volume and breath rate, can significantly reduce the ventilatory ratio (the effectiveness of breathing) and significantly reduce mechanical power that is associated with the reduced risk of lung injury. (11) After reading a study by Simonis et al. (the PreVENT study) that used a driving pressure of 11.0 (8.7-14.0) cmH2O (in the low tidal volume ventilation group) and of 13.0 (10.0-16.0) cmH2O (in the intermediate tidal volume ventilation group), (12) a study by Schmidt et al. that used a driving pressure of 11-16 cmH2O, (13) and also a study by Lanspa et al. that used a driving pressure of 8-12 cmH2O, (14), we decided to use a driving pressure of 10 cmH2O as a standard point in our study. Similar to the previous studies on mechanical ventilation in patients without ARDS, we tried to assess the effect of mechanical ventilation based on PBW and DP-guided in patients without ARDS on oxygenation, ventilation outcomes, and potential lung injury.

Material and methods

Settings and design

This study was conducted from November 2023 to March 2024 in the Intensive Care Unit (ICU) of Dr. Wahidin Sudirohusodo General Hospital Makassar, South Sulawesi, Indonesia. The Medical Research Ethics Committee of Hasanuddin University Makassar approved all experimental protocols employed in this study (No 916/UN4.6.4.5.31/PP36/2023). This experimental study and the approach used a single-masked design, pretest-posttest control group design, where in this design, there were two groups selected systematically random (the first patient was drawn to determine the treatment group, and then, without drawing, the next patient was assigned to another group, and so on in turn until the sample size was fulfilled). A pretest was then given to determine the initial state and a posttest to assess the difference in the treatment results. This study aimed to determine the effect of using PBW and DP as a guide in regulating tidal volume and airway pressure in mechanically ventilated patients in the Intensive Care Unit. This study used the Puritan Bennett™ 840 ventilator and the Mindray ePM15 patient monitor as data collection tools.

Study group

There were two groups of patients enrolled. The first group was the PBW group, in which the patient's tidal volume was set at 8 ml/kg PBW with adjusted positive end-expiratory pressure (PEEP). The second group was the DP group, in which the patient's tidal volume was set at 8 ml/kg PBW with adjusted PEEP and then tuned based on driving pressure (10 cmH2O), where the tidal volume could be maintained between 6-10 ml/kg PBW.

Study protocol

The inclusion criteria were as follows: patients (male or female) aged 18 to 60 who met the respiratory failure criteria and patients with stable hemodynamics without inotropic or vasopressor support. Patients who were hemodynamically unstable, had increased intracranial pressure, and had a history of heart failure were excluded. Patients with worsening conditions, such as hemodynamic instability, severe acid-base imbalance, or conditions that affected the study protocols or whose families or relatives canceled participation, were dropped.

A total of 32 patients who met the inclusion criteria were included. These patients were systematically randomized into two groups (PBW and DP groups), with 16 patients in each group. All patients were given atracurium (a neuromuscular blocking agent) to allow full control of mechanical ventilation in pressure-controlled mode.

In the PBW group, the tidal volume for ventilation was set at 8 ml/kg PBW. PEEP was then adjusted to achieve optimal lung compliance, meaning the lungs could expand and contract efficiently. Lung compliance was measured using an inspiratory hold maneuver for three seconds on a ventilator. The respiratory rate was 14 times per minute, with a fraction of inspired oxygen (FiO2) at 100%.

In the DP group, the initial settings were similar to those in the PBW group. Still, with an additional adjustment, i.e., the tidal volume was further fine-tuned to maintain a driving pressure of around 10 cmH2O by adjusting inspiratory pressure (Pinsp). Driving pressure is a measure that helps ensure the lungs are not overinflated and can be a crucial factor in preventing lung injury.

Blood gas analysis was performed to measure key indicators of lung function, such as partial pressure of oxygen (pO2), partial pressure of carbon dioxide (pCO2), and the oxygen partial pressure to fractional inspired oxygen ratio (P/F ratio), which is the ratio of arterial oxygen partial pressure to fractional inspired oxygen. These measurements were taken at the first hour of ventilation and again after 24 hours to assess the effectiveness of ventilation strategies. We also measured mechanical power, the energy delivered to the lungs per minute during mechanical ventilation in both groups. All setting data used, as well as blood gas analysis results, were documented.

Data analysis

The data obtained were processed, and the results were displayed in narratives, tables, or graphs, as mean and standard deviation, frequencies, and percentages, using IBM® SPSS® Statistics version 25 for Windows. Variables were tested using a paired t-test for paired data and an independent t-test for unpaired data with $\alpha=5\%$.

Results

Table 1 shows that in the PBW group, the gender distribution was seven males (44%) and nine females (56%), while in the DP group, there were eight males and eight females (50%) as well. The average age of the patients was 43.31 years in the PBW group and 48.06 years in the DP group. The average height in each group was 159.94 cm and 165.13 cm, respectively. PBW based on height was 54.31 kg and 59.31 kg, respectively. The variety of cases used as research subjects was the type of case based on the patient's admission to the ICU. In the PBW group, the majority of cases were orthopedic (31.3%), followed by oncology (25%), obstetrics and gynecology (18.8%), digestive (12.5%), and urology (12.5%). In the DP group, the majority of cases were orthopedic (37.5%), followed by digestive (25%), and oncology (18.8%), while obstetrics-gynecology, endocrine-metabolic, and urology cases were each 6.3%.

Table 2 shows the response parameters of mechanical ventilation in the PBW and DP groups. All data with $p<0.05$ were considered significant. The adjusted breath rate to target pCO2 in the 35-45 mmHg range in both groups insignificantly differed (14.31 ± 1.70 breaths/min vs 14.06 ± 1.34 breaths/min with $p>0.05$). The tidal volume resulting from ventilator settings in both groups showed a significant difference ($p<0.05$) of 436.25 ± 68.16 ml in the PBW group vs 493.81 ± 51.15 ml in the DP group. Similarly, the amount of tidal volume in ml/kg was found to be 8.02 ± 0.25 ml/kg vs 8.63 ± 0.26 ml/kg with $p<0.05$. The minute volume, closely related to CO2 regulation in the body, also showed a significant difference ($p<0.05$) between the two groups (6.23 ± 1.25 l/min vs 7.26 ± 0.85 l/min).

From the perspective of interacting pressures during mechanical ventilation, **Table 2** shows no significant difference in PEEP with 5.94 ± 0.93 cmH2O vs 5.44 ± 0.51 cmH2O ($p>0.05$). Pinsp values in each group differed significantly (13.50 ± 3.35 cmH2O vs 11.19 ± 1.05 cmH2O with $p<0.05$). The peak pressure (Ppeak) in the inspiratory phase in both groups was found to have no significant difference (17.63 ± 2.03 cmH2O vs 16.69 ± 0.9 cmH2O, $p>0.05$). Plateau pressure (Pplat) was also found to have no significant difference of 14.69 ± 2.36 cmH2O vs 15.31 ± 0.70 cmH2O ($p>0.05$), while driving pressure showed no significant difference of 8.81±2.37 cmH2O vs 10 cmH2O ($p>0.05$). The driving pressure in the DP group did not have a mean and standard deviation because the driving pressure was set at 10 cmH2O. Lung compliance (Cstat), measured by performing the inspiratory hold maneuver for three seconds, showed no difference between the two groups (55.50±9.84 cmH2O vs 56.44±6.74 cmH2O, $p>0.05$).

Similarly, with mechanical power, no difference was found between the two groups (10.92±2.51 J/min vs 11.68±1.21 J/min, $p>0.05$). Although no significant difference was found, **Figure 1** shows that the PBW group obtained a larger range of mechanical power values (range 8.4 J/min) than the DP group, which seemed to provide a more consistent amount of mechanical power (range 4.6 J/min).

The blood gas analysis parameters in **Table 3** were taken to assess the effect of mechanical ventilation settings based on PBW and DP taken at the first hour and the 24th hour after settings, then compared statistically. The results show no significant difference in changes in pH, pCO2, P/F ratio, and the ventilatory ratio at the first hour and 24th hour ($p>0.05$).

In the observation of the effect of mechanical ventilation based on PBW compared to DP on mean arterial pressure (MAP), there was no significant difference between the two groups: 84.88±14.45 mmHg vs 84.44±14.36 mmHg, respectively ($p>0.05$).

Table 4 shows the changes in variables from the first to the 24th hour. The changes in pH, pCO2, P/F ratio, and ventilatory ratio in the PBW group did not demonstrate any significant differences ($p>0.05$). On the other hand, in the DP group, the changes in pH, pCO2, P/F ratio, and ventilatory ratio showed significant changes ($p<0.05$). This was possible due to changes in tidal volume, minute volume, and Pinsp, which also experienced significant changes, as shown in **Table 1**.

Discussion

From our results, there was no effect on the P/F ratio by setting mechanical ventilation based on PBW for 24 hours, while in the DP group, there was a significant change ($p=0.190$ vs $p<0.001$) despite no difference in the use of FiO2 ($p=1.00$) and PEEP ($p=0.069$) obtained in both groups. This result indicates a more optimal improvement in oxygenation ratio using the driving pressure approach as a guide. A study using the same method in ARDS cases by Haudebourg et al. showed that mechanical ventilation with driving pressure guidance significantly improved the P/F ratio. (11) The findings of another study by Schmidt et al. related to the effect of driving pressure and hospital mortality in patients without ARDS found no difference in the P/F ratio in patients who survived and those who did not survive. (13) This shows the need for further research on the role of driving pressure.

The regulation of pCO2 levels in the body is closely related to minute volume; the greater the ventilation volume, the more pCO2 is released. (15) Mechanical ventilation's role in maintaining pCO2 balance in the body is crucial since proper regulation can help avoid adverse effects of pCO2, such as acidosis.

In terms of minute volume, the increased tidal volume values in the DP group caused a significant increase in minute volume ($p<0.05$), thus affecting pCO2 regulation in the body. In line with this, changes in pCO2 in 24 hours in the DP group also showed significant results ($p=0.001$) compared to the PBW group, which did not experience significant changes in tidal volume and minute volume. From the findings of this study, it can be concluded that using driving pressure as a guide in mechanical ventilation can have a better effect on pCO2. In line with the data above, Tiruvoipati et al.'s literature review said that increasing minute volume can help overcome hypercapnia. (16) However, Serpa Neto et al. also said that increasing the minute volume was not without risk because increasing the minute volume would also increase mechanical power, potentially increasing mortality. (17)

Mechanical power has a critical role in the management of mechanical ventilation. Monitoring mechanical power can predict the potential incidence of ventilator-induced lung injury (VILI). A recent analysis revealed the association between mechanical power and mortality, including in ARDS and non-ARDS patients. (18,19) The mechanical power of pressure-controlled mechanical ventilation can be calculated using the formula: mechanical power = 0.098 × respiratory rate × tidal volume × (PEEP + pressure above PEEP). (18,20)

In our study, the mechanical power in the PBW and DP groups was not significantly different ($p=0.284$). Still, the interesting thing is that there was a variation in the amount of mechanical power in the PBW group, giving a broader range of values than the DP group (8.4 J/min vs 4.6 J/min). This suggests that the amount of mechanical power in the DP group tends to be more consistent than in the PBW group, so the effect of mechanical power on the lungs in driving pressure-guided mechanical ventilation is more predictable and stable.

The significant change in the ventilatory ratio in the DP group in this study was influenced by the significant change in tidal volume in the DP group. This

shows the efficiency of ventilation in patients in the DP group. Maintaining tidal volume and driving pressure to produce optimal mechanical power and monitoring ventilatory ratio can improve ICU patient care quality. Sinha et al. found the ventilatory ratio value in non-survivors of ventilated patients was higher than in survivors (1.55 vs 1.32, $p<0.01$). Besides, the ventilatory ratio is also related parallel to pulmonary dead space, so they recommend the use of the ventilatory ratio as an evaluation form of ventilation efficiency in patients receiving mechanical ventilation. (21,22) Parada-Gereda et al. have shown that ventilatory ratio, plateau pressure, and driving pressure were risk factors for mortality. (23) Minute ventilation / (body weight × $PaCO_2$ × 37.5) is a relatively simple ventilatory ratio formula at the bedside. (21)
About MAP, there was no significant effect on mean arterial blood pressure (p=0.932) due to the increase in minute volume and tidal volume. This was made possible by the increase in tidal volume, which was still within 8 ml/kg. As a result of this condition, the heart-lung interaction is not significantly affected. The amount of tidal volume produced in this study was still in the category of lung protective ventilation, which sets a tidal volume of 6-8 ml/kg. (24-26) Corp et al.'s study found that a tidal volume of more or equal to 10 ml/kg significantly increases the right heart's performance due to increased lung volume, which causes an increase in pulmonary vascular resistance. (27,28)
The research we conducted still had limitations. First, the small sample size would influence the study results, so using a larger sample is expected to produce more objective results. Second, the body mass index was not calculated, so it could not reflect the influence and results of mechanical ventilation settings. Third, there was no anticipation of chest wall compliance influencing driving pressure.

Conclusion
The study concluded that using driving pressure to guide mechanical ventilation can improve oxygenation and ventilation outcomes (better P/F ratio, pCO_2, and ventilatory ratio) in patients without ARDS. Even though both the PBW and DP methods resulted in similar mechanical power levels, the DP-guided approach provided more stable and predictable mechanical power values. This stability can benefit patient management in the ICU, as it suggests a reduced risk of lung injury and potentially better overall outcomes for patients receiving mechanical ventilation.

Declaration of competing interest
The authors declare no conflicts of interest in preparing this manuscript. This research received no specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Table 1. Characteristics of patients who underwent predicted body weight- and driving pressure-guided ventilation

Variable	PBW group	DP group
Gender, n (%) - Male - Female	 7 (44%) 9 (56%)	 8 (50%) 8 (50%)
Age (year), mean±SD	43.31±13.812	48.06±7.523
Height (cm), mean±SD	159.94±7.057	165.13±4.897
PBW (kg), mean±SD	54.31±8.22	59.31±6.279
ICU cases, n (%) - Obstetrics-gynecology - Orthopedics - Oncology - Digestive - Endocrine-metabolic - Urology	 3 (18.8%) 5 (31.3%) 4 (25.0%) 2 (12.5%) 0 (0.0%) 2 (12.5%)	 1 (6.3%) 6 (37.5%) 3 (18.8%) 4 (25%) 1 (6.3%) 1 (6.3%)

Legend: SD=standard deviation; PBW=predicted body weight; ICU=intensive care unit; DP=driving pressure.

Table 2. Mechanical ventilation response parameters

Variable	PBW group	DP group	p
Respiratory rate (breaths/min), mean±SD	14.31±1.70	14.06±1.34	0.648
Tidal volume (ml), mean±SD	436.25±68.16	493.81±51.15	0.011
Tidal volume (ml/kg), mean±SD	8.02±0.25	8.63±0.26	<0.001
Minute volume (l/min), mean±SD	6.23±1.25	7.26±0.85	0.011
FiO2 (%)	100	100	1.00
PEEP (cmH2O), mean±SD	5.94±0.93	5.44±0.51	0.069
Pinsp (cmH2O), mean±SD	13.50±3.35	11.19±1.05	0.013
Ppeak (cmH2O), mean±SD	17.63±2.03	16.69±0.9	0.100
Pplat (cmH2O), mean±SD	14.69±2.36	15.31±0.70	0.318
Driving pressure (cmH2O), mean±SD	8.81±2.37	10	0.318
Cstat (ml/cmH2O), mean±SD	55.50±9.84	56.44±6.74	0.755
Mechanical power (J/min), mean±SD	10.92±2.51	11.68±1.21	0.284

Legend: SD=standard deviation; FiO2=fraction of inspired oxygen; PEEP=positive end-expiratory pressure; Pinsp=inspiratory pressure; Ppeak=peak inspiratory pressure; Pplat=plateau pressure; Cstat=static lung compliance; PBW=predicted body weight; DP=driving pressure.
$p<0.05$ considered significant.

Table 3. Blood gas analysis, ventilatory ratio, and hemodynamic parameters at 1st hour and 24th hour of modified mechanical ventilation settings

Variable	PBW group, mean±SD	DP group, mean±SD	p
1st hour pH	7.39±0.08	7.39±0.04	0.827
24th hour pH	7.41±0.05	7.42±0.03	0.893
1st hour pCO2 (mmHg)	34.83±6.39	38.06±2.70	0.720
24th hour pCO2 (mmHg)	35.81±4.49	36.76±2.31	0.457
1st hour P/F ratio	448.81±112.01	442.44±54.61	0.839
24th hour P/F ratio	471.81±90.78	467.25±53.61	0.864
1st hour VR	1.08±0.33	1.24±0.14	0.075
24th hour VR	1.12±0.22	1.20±0.13	0.206
MAP (mmHg)	84.88±14.45	84.44±14.36	0.932

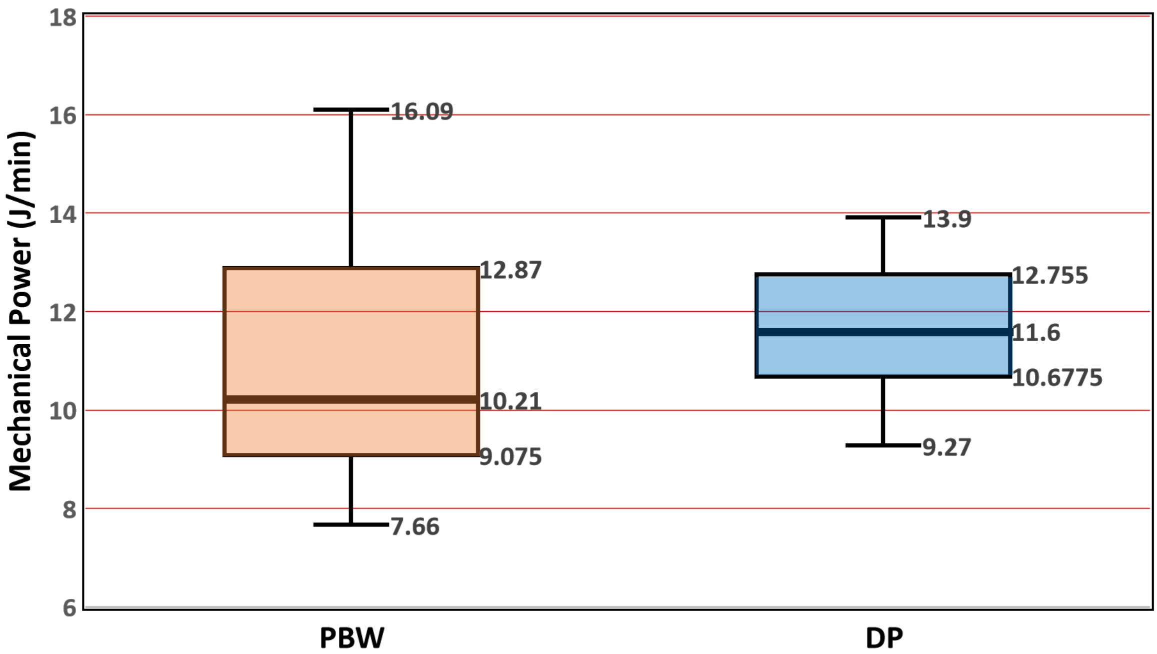
Legend: pCO2=partial pressure of carbon dioxide; P/F ratio=oxygen partial pressure to fractional inspired oxygen ratio; VR=ventilatory ratio; MAP=mean arterial pressure; PBW=predicted body weight; SD=standard deviation; DP=driving pressure.
$p<0.05$ considered significant.

Table 4. Change parameters of blood gas analysis and ventilatory ratio from the 24th hour to the 1st hour

Variables	Mean±SD	p
pH of 24th hour to 1st hour		
- PBW	0.03±0.08	0.235
- DP	0.02±0.04	0.029
pCO2 of 24th hour to 1st hour		
- PBW	0.99±8.76	0.658
- DP	-1.30±1.31	0.001
P/F ratio of 24th hour to 1st hour		
- PBW	23.00±67.03	0.190
- DP	24.81±17.69	<0.001
VR of 24th hour to 1st hour		
- PBW	0.02±0.20	0.737
- DP	-0.04±0.04	0.001

Legend: PBW=predicted body weight; DP=driving pressure; pCO2=partial pressure of carbon dioxide; P/F ratio=oxygen partial pressure to fractional inspired oxygen ratio; VR=ventilatory ratio; SD=standard deviation.
$p<0.05$ considered significant.

Figure 1. Change in mechanical power between PBW-guided ventilation and DP-guided ventilation



Legend: PBW=predicted body weight; DP=driving pressure.
The box plots represent the mechanical power (thick horizontal line: median; base and top of the box represent 25th and 75th percentiles).

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