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Weight and Abdominal Girth Predict Tidal Volume Requirement During Mechanical Ventilation for General Anaesthesia: A Cross-sectional Study

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Weight and abdominal girth predict tidal volume requirement during mechanical ventilation for general anaesthesia: A cross-sectional study

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Abstract

Background: Evidence that tidal volume (TV) is related to age, height, weight, chest circumference, and abdominal girth exists. However, it is unclear which of these has the strongest association with TV. This study aimed to investigate the main factors associated with TV and determine a method for accurately predicting TV requirement during mechanical ventilation.

Methods: From December 2019 to January 2021, we enrolled 133 patients who were scheduled for surgery. Their age, height, weight, abdominal girth, and chest circumference were recorded. Intraoperatively, at 30 minutes after mechanical ventilation during general anaesthesia, the TV was increased or decreased by 25 ml if the partial pressure of carbon dioxide ($PaCO_2$) was > 45 mmHg or < 35 mmHg, respectively. This was continued until we observed two consecutive $PaCO_2$ values between 35 and 45 mmHg. The TV setting was recorded at this point. Linear regression and multiple regression analyses were performed.

Results: The data of 100 patients were analysed. Linear regression analysis showed significant univariate correlations between age, weight, height, abdominal girth, chest circumference, and TV requirement. (all $P \leq 0.049$). Multiple linear regression analysis showed that weight and abdominal girth were key determinants of TV requirement (both $P < 0.001$). The adjusted R^2 for the regression equation was 0.813. The regression equation for accurately predicting TV requirement was $Y = 312 + 5.717X_1 - 2.798X_2$ (Y, TV requirement; X_1, weight; and X_2, abdominal girth).

Conclusion: TV requirement during mechanical ventilation for general anaesthesia can accurately be set based on weight and abdominal girth.

Keywords: Tidal volume, Mechanical ventilation, Weight, Abdominal girth

Background

Mechanical ventilation is a life-support system used to maintain adequate lung function and ensure appropriate delivery of oxygen and elimination of carbon dioxide in patients undergoing general anaesthesia[1,2]; however, it may cause lung damage. Tidal volume (TV) is the most basic parameter of mechanical ventilation. If it is set too low, injury may occur through multiple mechanisms, including intracranial hypertension due to respiratory acidosis, repeated opening and closing of bronchi and alveoli, surfactant dysfunction, and regional hypoxia[3,4]. High TV helps reduce alveolar collapse[5]. However, if it is set too high, it can reduce the arterial partial pressure of carbon dioxide ($PaCO_2$), cause respiratory alkalosis and overexpansion of the alveoli, and trigger inflammatory reactions[6,7]. High TV, even for short periods of ventilation (e.g., during general anaesthesia), may be deleterious for patients with healthy lungs[8,9]. Therefore, every anaesthesiologist should aim to set a relatively accurate TV at the beginning of mechanical ventilation. Setting the TV too high or too low should be avoided.

TV has been reported to be related to age[10], height[11], weight[12], chest circumference[13,14], and abdominal girth[15]. However, it is unclear which of these has the strongest association with TV. This study aimed to investigate the main factors associated with TV and determine a method for accurately predicting TV requirement during mechanical ventilation.

Methods

From December 2019 to January 2021, 133 patients (age, 20–77 years; weight, 39–112 kg; height, 145–190 cm) were enrolled in this study. This study was approved by the Ethics Committee of the Second Affiliated Hospital of Jiaxing University in December 2019 (JXEY-2019JX084), and written informed consent was obtained from all participants. This study confirm that all methods were carried out in accordance with relevant guidelines and regulations. All patients with American Society of Anesthesiologists physical status I or II who were scheduled for orthopaedic, hepatobiliary, gynaecologic, urologic, gastrointestinal, or general surgery were included. Patients with contraindications for surgery; urgent need of surgery; suspected acute respiratory distress syndrome; history of severe restrictive lung disease, severe chronic obstructive pulmonary disease, severe or uncontrolled bronchial asthma, pulmonary infection, bronchiectasis, or pulmonary metastases; use of positive pressure ventilation before surgery (e.g., continuous positive airway pressure for obstructive sleep apnoea syndrome); thoracic deformities and

intrathoracic diseases (such as mediastinal or chest tumour); cardiovascular or neurological disease; abnormal liver or renal function; laparoscopic surgical approach; surgeries requiring one-lung isolation; and those who were pregnant were excluded.

All patients fasted for 8 hours before surgery. On being shifted to the operating room, the patients were placed in supine position, intravenous access was established, and Ringer's lactate (10 ml/kg) was preloaded. The patients' heart rate, non-invasive blood pressure, peripheral oxygen saturation, train-of-four, and bispectral index were monitored using an automated system. Abdominal girth was measured at the level of the umbilicus, and chest circumference was measured at the level of the xiphoid process at the end of expiration. The patients' age, height, weight, abdominal girth, and chest circumference were recorded. After administration of a local anaesthetic, an arterial cannula was placed in either radial artery for invasive arterial blood pressure monitoring. Anaesthesia was induced with intravenous administration of midazolam (0.05 mg/kg), etomidate (0.2 mg/kg), sufentanil (0.6 μg/kg), and cisatracurium (0.15 mg/kg). The patients underwent endotracheal intubation (internal diameter: 7.5 mm) for mechanical ventilation. All patients were ventilated at a TV of 8 ml/kg without positive end-expiratory pressure, at a respiratory rate of 12 breaths/min, and with an inspiratory to expiratory ratio of 1:2. Anaesthesia was maintained with sevoflurane (1.0–2.0 vol%) in a 50% oxygen/air mixture at a flow rate of 2 L/min and by adjusting the intravenous infusion of propofol (4–8 $mg.Kg^{-1}.h^{-1}$) and remifentanil (0.1–0.2 $\mu g.Kg^{-1}.min^{-1}$). The bispectral index was maintained at 40–55. Cisatracurium was

adjusted based on train-of-four values. When the mean arterial pressure was lower than 55 mmHg or decreased to less than 30% of the baseline value in patients with a history of hypertension, phenylephrine was administered, while 0.5 mg atropine was administered if the heart rate fell below 50 bpm; this was repeated if necessary. At 30 minutes after mechanical ventilation, 2 ml of arterial blood was collected for blood gas analysis. TV was increased or decreased by 25 ml when the $PaCO_2$ was > 45 mmHg or < 35 mmHg, respectively. Arterial blood gas analysis was performed again after 30 minutes, and TV was adjusted by 25 ml according to the $PaCO_2$. This was continued until we observed two consecutive $PaCO_2$ values between 35 and 45 mmHg. The TV setting was recorded at this point. Patients who did not have a $PaCO_2$ between 35 and 45 mmHg until the end of surgery were excluded.

Statistical analysis

The patients' age, weight, height, abdominal girth, and chest circumference were used to predict the optimal TV requirement. The anticipated effect size was 0.15, desired statistical power level was 0.8, minimum required sample size was 91, and alpha was 0.05. Data were analysed using SPSS (SPSS Inc., Chicago, IL, USA), version 19.0. Correlations of TV requirement with age, weight, height, abdominal girth, and chest circumference were determined using linear regression analysis. Multiple regression analysis was performed to test the combined contributions of age, weight, height, abdominal girth, and chest circumference to TV requirement. Stepwise

selection was performed during multiple regression analysis, and predictors were removed from the analysis if they were not significantly correlated with the dependent variable. R^2 was the coefficient of determination. $P < 0.05$ was considered statistically significant.

Results

A total of 133 patients who underwent general anaesthesia were included in this study, 33 of whom were excluded because of failure to achieve $PaCO_2$ in the range of 35-45 mmHg. The data of the remaining 100 patients were analysed. The patients' characteristics are summarised in Table 1.

Linear regression analysis showed significant univariate correlations between age, weight, height, abdominal girth, chest circumference, and TV requirement (all $P \leq 0.049$, Table 2).

Multiple linear regression analysis showed that weight and abdominal girth were key determinants of TV requirement (both $P < 0.001$), while age, height, and chest circumference could be omitted without changing the results (all $P \geq 0.146$, Table 3). The adjusted R^2 for the regression equation was 0.813. The regression equation for TV requirement based on weight and abdominal girth was $Y = 312 + 5.717X_1 - 2.798X_2$ (Y, TV requirement; X_1, weight; and X_2, abdominal girth).

Table 1: Patient characteristics

ASA physical status, (I/II)	45/55
Sex, (male/female)	53/47
Age, y (mean ± SD)	56.1 ± 13.2
Height, cm (mean ± SD)	163.5 ± 9.0
Weight, kg (mean ± SD)	66.9 ± 14.7
BMI, kg/m^2 (mean ± SD)	25.0 ± 4.6
Abdominal girth, cm (mean ± SD)	83.8 ± 12.0
Chest circumference, cm (mean ± SD)	88.5 ± 9.1
Tidal volume setting, ml (mean ± SD)	459.8 ± 63.0
Actual tidal volume, ml (mean ± SD)	446.4 ± 66.7
$PaCO_2$, mmHg (mean ± SD)	39.3 ± 2.1
P_{peak}, cmH_2O (mean ± SD)	16.4 ± 3.0
HB, g/L (mean ± SD)	113.8 ± 19.0
SBP, mmHg (mean ± SD)	119.9 ± 17.1
DBP, mmHg (mean ± SD)	64.4 ± 11.1
HR, bpm (mean ± SD)	67.7 ± 10.7

Duration of surgery, min (mean ± SD)	162.1 ± 66.2
Operation position (supine / prone / left / right / other)	38/33/16/10/3
Department (orthopaedics / gynaecology / urology / general surgery)	85/3/1/11

Data are represented as numbers or mean ± SD. ASA: American Society of Anesthesiologists, BMI: body mass index, $PaCO_2$: partial pressure of carbon dioxide, P_{peak}: peak pressure, HB: haemoglobin, SBP: systolic blood pressure, DBP: diastolic blood pressure, HR: heart rate.

Table 2: Relationship between patient characteristics and TV requirement during general anaesthesia

Patient characteristics	TV requirement	
	r	*P*
Age	-0.198	0.049
Height	0.664	< 0.001
Weight	0.865	< 0.001
Abdominal girth	0.639	< 0.001

Chest circumference	0.750	< 0.001

r: correlation coefficient, TV: tidal volume.

Table 3: Multiple linear regression analysis of patient characteristics and TV requirement during general anaesthesia

Patient characteristics	TV requirement		95% CI	
	b	*P*	Lower limit	Upper limit
Age	0.028	0.552	–	–
Height	0.101	0.146	–	–
Weight	5.717	< 0.001	4.932	6.502
Abdominal girth	-2.798	< 0.001	-3.759	-1.837
Chest circumference	0.034	0.811	–	–

b: regression coefficient, CI: confidence interval, TV: tidal volume.

Discussion

Every year, hundreds of millions of patients undergo mechanical ventilation for general anaesthesia during major surgical procedures. TV is the most basic parameter of mechanical ventilation. However, it may induce lung injury if it is set too high or

too low [6,7,16-18].

In this study, we investigated the combined effect of patient characteristics on TV requirement during general anaesthesia. We studied five patient characteristics (age, height, weight, abdominal girth, and chest circumference) that were selected based on previous research [10-15]. The results show that four of these characteristics (height, weight, abdominal girth, and chest circumference) are related to TV requirement; weight was the most strongly correlated variable. Previously, TV during mechanical ventilation was set based on the patient's actual body weight, which was believed to reflect metabolic need. However, it was later found that this could lead to excessive TV in obese patients or inadequate TV in underweight patients. Therefore, a more appropriate way to set TV was sought, and various methods for calculating TV requirement using predicted body weight (PBW) were tested. Brochard et al. calculated PBW as actual body weight - estimated weight gain due to water and salt retention [19]. Brower et al. calculated PBW as $50.0 + 0.905 \times$ ([height in cm] - 152.4) for men and $45.5 + 0.905 \times$ ([height in cm] - 152.4) for women [20,21]. However, Martin et al. reported limitations in various PBW calculation methods [22]. Therefore, setting TV based on PBW was not very accurate, as it could result in a TV that was too large or too small [12].

Here, multiple linear regression analysis showed that age, height, and chest circumference had low predictive value for TV requirement during mechanical ventilation for general anaesthesia. We performed multiple linear regression analysis

to investigate the combined contribution of five patient variables to TV requirement during mechanical ventilation for general anaesthesia. Subsequently, a regression equation for TV requirement based on weight and abdominal girth was obtained: $Y = 312 + 5.717X_1 - 2.798X_2$ (Y, TV requirement; X_1, weight; and X_2, abdominal girth). The R^2 was 0.813, indicating that this equation could accurately predict TV requirement. From this equation, we can see that the main factors affecting TV requirement are weight and abdominal girth. The heavier the patient, the greater the required TV. In two patients with the same weight, the required TV was smaller in the patient with a larger abdominal girth. Abdominal adiposity has been negatively associated with pulmonary function [15,23]. This was consistent with our findings. This may be due to patients with large abdominal circumferences having high proportions of adipose tissue, especially visceral adipose tissue, while those with small abdominal circumference have more muscle tissue, even at the same weight. Adipose tissue metabolizes less oxygen and produces less carbon dioxide than muscle tissue. Rossi et al. [24] assessed body composition using cross-sectional computed tomography imaging. They found negative correlations between adipose tissue and pulmonary function. Further, high fat mass has negative effects on pulmonary function [25]. In particular, central fat accumulation, measured using waist circumference, waist-to-hip ratio, or sagittal abdominal diameter, was inversely associated with pulmonary function [26].

This study has some limitations. Firstly, the sample size of this study is small,

and patients with BMI less than 16 or greater than 37 were not included. Secondly, the age range of the patients in this study is 20–77 years old. Whether the equation is applicable to patients under the age of 20 and over the age of 77 needs further study.

Conclusions

Weight and abdominal girth were strongly correlated with TV requirement during mechanical ventilation for general anaesthesia. The regression equation for accurately predicting TV requirement was $Y = 312 + 5.717X_1 - 2.798X_2$ (Y, TV requirement; X_1, weight; and X_2, abdominal girth).

List of abbreviations

$PaCO_2$, partial pressure of carbon dioxide; TV, Tidal volume; PBW, predicted body weight.

Declarations

This study confirm that all methods were carried out in accordance with relevant guidelines and regulations.

Ethics approval and consent to participate

This study was approved by the Ethics Committee of the Second Affiliated Hospital of Jiaxing University in December 2019 (JXEY-2019JX084). Written informed consent was obtained from the participants.

Consent for publication

Not applicable

Availability of data and materials

The datasets supporting the conclusions of this article can be obtained by emailing 13356004720@189.cn

Competing interests

The authors declare that they have no competing interests.

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Authors' contributions

YS helped to conduct the study and write the manuscript. YC helped to conduct the study. HZ helped to analyse the data. QL helped to design the study and write the manuscript. All authors read and approved the final manuscript.

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