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Research Article

Accurate Tidal Volume for Patients under Mechanical Ventilation: A Cross-sectional Descriptive Study

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ABSTRACT

Background: In order to prevent lung injury among patients under mechanical ventilation, tidal volume should be determined based on predicted body weight. The aim of the study was to determine the accuracy of tidal volume determination for patients under mechanical ventilation and to assess nurses' knowledge about accurate tidal volume determination.

Methods: This was a cross-sectional descriptive study. This study was conducted on 250 patients under mechanical ventilation and 75 nurses who provided care to the patients. Patients' height was estimated based on their ulna length and then, their predicted body weight and tidal volume were estimated. Nurses' knowledge about tidal volume determination was also assessed.

Results: The mean of delivered tidal volume was 9.1±1.73 mL/kg of predicted body weight. Tidal volume for 172 patients (68.8%) had been set at more than 8 mL/kg of predicted body weight. Forty nine nurses (65.3%) noted that there was no guideline in their wards for height and weight measurement. They determined patients' weight and height through either visual estimation (21 nurses; 28.0%) or asking from their colleagues, patients, or patients' family members (48 nurses; 64.0%).

Conclusion: Nurses have limited knowledge about accurate tidal volume determination and hence, deliver high tidal volume to patients under mechanical ventilation which puts them at risk for ventilator-associated lung injury. Urgent interventions such as lung-protective strategies, staff training, and careful managerial supervision are needed to prevent ventilator-associated lung injury and improve patient safety.

Mechanical ventilation (MV) is a lifesaving measure for patients with critical conditions. It facilitates gas exchange in the lungs and promotes the development of modern intensive care units. Each year, many patients need to undergo MV due to their critical conditions and the number of patients who need MV is progressively increasing [1-3].

Despite the lifesaving effects of MV, it can cause serious complications in the lungs and aggravate pulmonary problems [4-5]. MV-associated complications include barotrauma, alveolar overdistension or volutrauma, barotrauma, atelectrauma, and oxygen toxicity. These complications are called ventilator-associated lung injury (VALI) or ventilator-induced lung injury (VILI) [1,6-7].

High tidal volume (Vt) is a key factor contributing to VALI. By definition, Vt is the volume of air which enters into the lung during inspiration or the volume of air which exits from the lung during expiration. In 1963, a Vt of more than 10 milliliters per kilogram (mL/kg) of predicted body weight (PBW) was recommended to prevent acidosis and atelectasis and to improve oxygenation. However, later studies showed that such

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high Vt was associated with VALI and increased mortality rate [8]. High Vt causes lung overdistension, alveolar microfractures, and thereby, release of inflammatory mediators, aggravation of lung injury, and development of multiple organ dysfunction [9-10]. Contrarily, low Vt reduces lung injury and mortality rate [1,11-13].

Given the negative effects of high Vt, a key component of effective and safe MV is the accurate determination of Vt at safe values. Two key points should be taken into account in Vt determination. First, Vt should be determined based on patients' PBW which is calculated using the gender-specific PBW calculation formulas [8,14] as shown below:

Male PBW= 50+ [0.91 (Height– 152.4)]

Female PBW = 45+ [0.91 (Height– 152.4)]

Second, Vt should be set at 6–8 ml/kg PBW according to the intended patient's conditions. [15-16] Some studies even recommended a Vt of 6 ml/kg PBW [17], particularly at the beginning of MV [4].

Despite the potential effectiveness of low Vt in preventing VALI [15-16], some studies reported that low Vt is not used for most patients [10,18-19]. Moreover, Vt is not determined based on patients' PBW. For instance, a study in Britain showed that Vt was determined based on PBW only in one third of cases and healthcare providers tended to determine Vt based more on visual estimations than exact calculations [14]. Some other studies also showed that nurses had limited knowledge and some levels of uncertainty about ventilator setting and VALI [20-21].

In addition, there is limited information regarding nurses' knowledge about Vt determination based on PBW. The present study was conducted to narrow these gaps. The aim of the study was to determine the accuracy of Vt determination for patients under MV and to assess nurses' knowledge about accurate Vt determination.

Methods

This cross-sectional descriptive study was conducted in April–May 2018. The accuracy of Vt determination for patients under MV was assessed during 1.5 months. Simultaneously, nurses' knowledge about Vt determination was assessed.

Participants and Setting

Study setting was a teaching referral subspecialty hospital in Tehran, Iran, with 800 active beds. The hospital had general medical-surgical wards, a cardiac surgery intensive care unit (ICU), a neurological ICU, a medical ICU, and a surgical ICU. Because of the low number of intensive care beds in the study setting, some patients with critical conditions underwent endotracheal intubation and MV in general hospital wards and were put in ICU waiting list. There was no respiratory technician in the study setting and ventilator setting was controlled solely by physicians and nurses.

Patients under mechanical ventilation and critical care nurses in the hospital constituted the study population. MV mode for all patients in the study setting was determined and set by physicians and nurses according to ward policies. Daily visits were performed by physicians to control ventilator setting.

Study sample consisted of 75 nurses and 250 patients under MV. Inclusion criteria for patients were an age of more than eighteen, MV with a volume-controlled mode, and no injury in the hand or the forearm. They were recruited to the study from ICUs, emergency department, and general hospital wards and were excluded if they died during the first 24 hours of MV. Inclusion criteria for nurses were bachelor's degree or higher in nursing and involvement in care delivery to patients with MV.

All 250 patients who were hospitalized in the study setting during the 1.5-month course of the study were recruited through the census method. In other words, data on the ventilator setting of all patients who underwent mechanical ventilation using volume-controlled mode during the course of the study were collected and documented. Moreover, ulna length was measured and PBW was calculated.

Sampling among nurses was conducted in two steps. Initially, all forty head nurses, charge nurses, and supervisors of the hospital were recruited through the census method and were asked to complete a Vt-related knowledge questionnaire. This group of senior nurses and nurse managers was selected due to their direct involvement in the supervision of hospital wards, other nurses' practice, and Vt determination. In the second step, 35 hospital nurses were recruited to the study through quota sampling. For quota sampling, at least two eligible nurses were selected from each ward/unit of the study setting through convenience sampling.

Sample size for this group of nurses was calculated to be 35 based on a d of 0.05, a type I error of 0.05, and a variance of 1.5. In total, 350 nurses were working in the study setting, including eighty nurses in surgical wards, eighty in medical wards, seventy in medical-surgical wards, eighty in ICUs, and forty in emergency department. Based on the total number of nurses in these wards, eight nurses were selected from surgical wards, eight from medical wards, seven from medical-surgical wards, eight from critical care units, and four from emergency department.

Data collection tools and method

A demographic questionnaire and a ventilator setting data sheet were used to collect patient-related data. The items of the demographic questionnaire were on age, gender, height, weight, ulna length, and number of MV days. The ventilator setting data sheet included items on ventilation mode, respiratory rate (RR), fraction of inspired oxygen (FiO2), Vt, trigger, inspiratory flow rate, positive end-expiratory pressure (PEEP), and pressure support (PS).

Nurses' data were collected using a demographic questionnaire and a Vt-related knowledge questionnaire. The items of the demographic questionnaire were on age, gender, affiliated hospital ward, and work experience. The Vt-related knowledge questionnaire included two questions on determining PBW, one question on weight-based Vt, and one question on the availability of any guideline for calculating Vt.

The content validity of all instruments was approved by ten nursing faculty members. For reliability assessment, the ventilator setting and the ulna length of ten patients were measured by two of the authors. The inter-rater correlation coefficient was 1. The reliability of the nurses' Vt-related knowledge questionnaire was evaluated through the test-retest questionnaire which yielded a test-retest correlation coefficient of 0.8.

Data on patients' demographic characteristics were collected from their medical records. Data on baseline MV parameters including baseline MV mode, Vt, PEEP, FiO2, trigger, and PS were collected from ventilator monitor and from patients' medical records.

Patients under MV are positioned in the supine position and hence, accurate height measurement is impossible. Thereby, height in the present study was determined based on ulna length. Ulna length provides a reliable estimate of body height [22]. Ulna length was measured using a tape measure and then, body height was determined using the table for ulna length conversion to body height [22]. Estimated height was used to determine PBW using the gender-specific PBW calculation formulas. Participating nurses completed the demographic questionnaire and the Vt-related knowledge questionnaire through the self-report method.

Data analysis

Data were analyzed using the SPSS software. Data description was done using the measures of descriptive statistics, including absolute frequency, relative frequency, mean, and standard deviation.

Ethical and research approvals

This study was approved by the Ethics Committee of School of Nursing and Midwifery & Rehabilitation - Tehran University of Medical Sciences, Tehran, Iran (code: IR.TUMS.FNM.REC.1398.026). The aim of the study was explained to nurses' participants and their consent for participation was obtained.

Results

In total, 209 patients from ICUs and 41 patients from medical-surgical wards and emergency department participated in this study. The mean of patients' age was 53.22±18.26. The height of only 158 patients (63.2%) had been documented in their medical records. Based on ulna length, the mean of patients' height was 163.68±16.01 centimeters and the mean of their PBW was 59.37±8.81 kg.

MV mode for 240 patients (96%) was synchronized intermittent mandatory ventilation (SIMV) and the mean of Vt was 529.84±69.11 in the range of 380–800 mL. The division of mean Vt by mean PBW revealed that Vt had been set at 9.1±1.73 in the range of 5.2–15.2 ml/kg PBW. The mean of Vt was more than 8 ml/kg PBW for 172 patients (68.8%). Table 1 shows patients' characteristics and their ventilator setting.

Table 1- Patients' characteristics and their ventilator setting

Characteristics			Mean±SD or N (%)
Age (Year)			53.22±18.26
Gender	Female		113 (45.2)
	Male		137 (54.8)
Height documentation in medical records	Yes		158 (63.2)
	No		92 (36.8)
Height based on ulna length			163.68±16.01
Height documented in medical records			160.83±15.92
PBW based on height (based on ulna length) and gender			59.37±8.81
Ward	Medical-surgicalwards and emergency department		41 (16.4)
	ICU		209 (83.6)
Days of MV			5.61±8.64
Ventilator setting	Vt		529.84±69.11/380–800†
	Fio2		53.6±8.9/30-90†
	Flow		57.59±13.99
	Trigger		4.33±3.77
	PS		12.65±2.86
	PEEP		4.76±1.17
	RR	10-12	215 (86)
		14-16	35 (14)
	Mode	SIMV/SIMV(Dual)	240 (96)
		Others	10 (4)
Vt (mL/kg of PBW)			9.1±1.73/5.2–15.2†
Vt (mL/kg of PBW)		Less than 8	78 (31.2)
		More than 8	172 (68.8)

† value are mean±SD/Min-Max)

The mean of nurses' age was 34.01±8.56. Twenty four nurses (32%) were from ICUs and 51 (68%) were from medical-surgical wards and emergency department. Nurses reported that on average, 5.45 patients per month were hospitalized in medical-surgical wards and emergency department for undergoing MV. Around 58.7% of nurses had not participated in continuous education programs on critical care and 46.7% of them reported that they had no opportunity for developing their MV-related knowledge and skills through participating these programs (Table 2).

Table 2-Nurses' characteristics

Characteristics		**Mean±SD or N (%)**
Age (Year)		34.01±8.56
Total work experience (Year)		11.23 ±8.31
ICU work experiences of ICUs nurses (Year)		6.60 ±6.67/1.2-25†
Number of nurses in medical-surgical wards and emergency department who had experience working in ICUs		27(52.94)
ICU work experiences of nurses in medical-surgical wards and emergency department ward who had experience working in ICUs (Year)		2.77±2.57/1-10†
Number of patients receiving MV in medical-surgical wards and emergency department each month		5.45 (2.39)
Gender	Female	64 (85.3)
	Male	11 (14.7)
Affiliated ward	Medical-surgicalwards and emergency department	51 (68)
	ICUs	24 (32)

† value are mean±SD/Min-Max)

Forty nine nurses (65.3%) noted that they had no guideline in their wards for determining patients' height and weight and hence, 21 of them (28%) relied on visual estimation for height and weight determination and 48 of them (64%) asked patients' height and weight from their colleagues, patients, or patients' family members. Sixty one nurses (81.33%) noted that they determined Vt based on patients' weight, eight nurses (10.7%) noted that they determined it based on patients' weight, height, gender, and body size, and only six of them (8%) noted that they determined it based on patients' gender and height. Moreover, 33 nurses (44%) reported that they set Vt at 8–10 ml/kg PBW, nineteen (25.3%) reported that they set Vt at 300–600 mL based on patients' body size, and only seventeen (22.7%) reported that they set Vt at 6–8 ml/kg PBW (Table 3).

Table 3- Nurses' knowledge about accurate tidal volume determination

Nurses knowledge about accurate tidal volume determination		**N (%)**
Availability of any guideline for height or weight determination	Yes	26 (34.7)
	No	49 (65.3)
Methods for measuring height, weight, and body size	Visual estimation	21 (28.0)
	Asking from their colleagues, patients, or patients' family members	48 (64.0)
	No answer	6 (8.0)
Parameters used for Vt determination	Weight	61 (81.33)
	Height and gender	6 (8)
	Weight, height, gender, and body size	8 (10.7)
Method for Vt determination	8–10 mL/kg of ABW	33 (44)
	6–8 mL/kg of PBW	17 (22.7)
	Giving data on height and gender to ventilator and setting Vt	6 (8)
	300–600 Ml based on visual estimation of body size	19 (25.3)

Discussion

This study aimed to determine the accuracy of Vt determination for patients under mechanical ventilation and to assess nurses' knowledge about accurate Vt determination. Findings showed that the mean of Vt delivered to participating patients was 9.1±1.73 ml/kg PBW. Moreover, findings showed that participating nurses had limited knowledge about accurate Vt determination and determined patients' weight based on visual estimation or by asking from colleagues, patients, and family members.

The findings of the present study showed that Vt was set for participating patients at values more than 8 ml/kg PBW. Such high Vt can cause complications such as lung injury [4], inflammation, alveolar overdistension, and increased mortality rate [9,10,23]. Contrarily, evidence shows that except for patients with acute respiratory distress syndrome (ARDS), low Vt can improve clinical outcomes and prevent ARDS among other patients under MV. Therefore, it recommended a baseline Vt of 6–8 ml/kg PBW [4]. The use of lung-protective ventilation with low Vt has progressively increased in recent years particularly in developed countries, resulting in significant reduction in VALI [24]. A study on fifty patients in Netherlands showed that the use of feedback and education helped significantly reduce Vt from 9.8±2.0 to 8.1±1.7 ml/kg PBW [25]. A retrospective study also showed that three years after staff training and using written guidelines for accurate Vt determination, the mean of Vt for patients under MV was 7.4±1.3 ml/kg PBW [3]. Moreover, a multicenter study in sixteen general ICUs in UK showed that the mean of Vt was 7.2±1.4 mL/kg of PBW [26]. A study on 1905 patients in six ICUs in the United States also indicated that while 40% of patients received Vt higher than 8 ml/kg PBW, the mean of Vt was 6.8 ml/kg PBW [16]. Another study on 2185 patients hospitalized in 2007–2014 in emergency departments in the United States showed that the mean of Vt was 9±1.4 ml/kg PBW and only 23% of patients received low Vt; however, care quality improvement interventions significantly reduced Vt to 7.2±0.9 [27]. These findings denote the great focus on improving patient safety, using low Vt, and preventing VALI in developed countries.

We also found that our participating nurses had limited knowledge both about using low Vt and determining Vt based on PBW. They determined Vt mostly based on actual body weight (ABW) rather than PBW. Moreover, they determined patients' weight based on their visual estimation or through asking from others. Some other studies also reported Vt determination based on patients' ABW [28]. A study in UK also reported that intensive care staff had limited knowledge about determining Vt based on PBW and hence, determined it based on ABW [29]. Other studies also reported the determination of Vt based on the visual estimation of patients' weight and height, resulting in inaccurate PBW determination and increased risk for VALI [14,30-31].

Nurses' limited knowledge about accurate Vt determination in the present study can endanger patient safety in two ways. First, nurses with limited knowledge about PBW and lung-protective strategies may set Vt at high values and thereby, cause VALI. Second, their limited knowledge about accurate Vt determination can prevent them from providing accurate information to physicians about the inaccuracy of their Vt determination. Accordingly, accurate Vt determination can be considered as a missed nursing care which can significantly affect the safety of patient under MV. Missed nursing care is defined as any necessary standard nursing care which has been omitted or delayed. Its prevalence in acute care settings around the world is 55%–98%. Missed nursing care exists in different areas of nursing practice, including care documentation, support, physical care, and coordination and can result in negative consequences for patients [32-34].

This study concludes that nurses have limited knowledge about accurate Vt determination and hence, deliver high Vt to patients under MV which can endanger patient safety and result in VALI. These findings highlight the necessity of providing nurses with in-service education about accurate Vt determination based on PBW. Lung-protective strategies, staff training, and careful managerial supervision are needed to prevent VALI and improve patient safety.

Conclusion

Given the inaccurate determination of Vt and nurses' limited knowledge about accurate Vt determination in the present study, urgent interventions are needed to manage these problems and improve patient safety. Such interventions may include educational programs for promoting nurses' and physicians' Vt-related knowledge, development and use of clear clinical guidelines for accurate Vt determination, provision of constructive feedback to nurses by nurse managers, and using care quality improvement protocols.

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