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TECHNICAL NOTE

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A novel method of continuous measurement of head of bed elevation in ventilated patients

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Abstract *Objective:* We developed a novel pressure transducer-based method of continuous measurement of head of bed elevation. Following validation of the method we hypothesized that head of bed angles would be at or above 30 ° among mechanically ventilated patients throughout the day due to a hospital-wide initiative on ventilator-associated pneumonia prevention and standardized electronic order entry system to keep head of bed at an angle of 30 ° or greater. *Design and setting:* Prospective observational study in university hospital intensive care units. *Patients and participants:* Twenty-nine consecutive mechanically ventilated patients with no contraindications for semirecumbency. *Measurements and results:* We acquired 113 pairs of measurements on unused beds for validation of the method at angles between 3 ° and 70 °. Correlation between transducer and protractor was fitted into a linear regression model ($R^2 = 0.98$) with minimal variation of data along the line of equality. Bland–Altman analysis showed a mean difference of 1.6 ° ± 1.6 °. Ninety-six percent of differences were within 2 SD from the mean. This method was then used among 29 intubated patients to collect head of bed data over a 24-h period for 3 consecutive days. Contrary to our hypothesis, all patients had head of bed angles less than 30 °. *Conclusions:* Our results suggest that this method could be used with high reliability and patients in our institution were not kept even at 30 °. The results are in accord with those of a recent study which found that continued maintenance of previously suggested head of bed angles was difficult to attain clinically. This may lead us to reevaluate methods studying the impact of head of bed elevation in VAP prevention.

Keywords Head of bed elevation · Ventilator-associated pneumonia · Pulmonary aspiration · Prevention · Guidelines · Continuous measurement

Introduction

The rate of nosocomial infections among critically ill patients may be as high as 60% among those who remain in the intensive care unit (ICU) for more than 5 days [1]. ICU-related infections are the major cause of increased morbidity, and health-care costs, with an associated mortality rate approaching 30% [2, 3]. Pneumonia is the most common ICU infection, with an incidence of 10–65% [1]. Ventilator-associated pneumonia (VAP) is a leading cause of morbidity and mortality among ventilated patients. Patients with VAP remain in the ICU 4.3 days (1.5–7.0) longer than patients without VAP and have an attributable mortality risk of up to 50% [4–8]. Mortality risk has been associated with several factors, including supine position [8–10]. Studies have demonstrated that having the head of bed (HOB) elevated to 45 ° decreases the incidence of gastroesophageal reflux and VAP in mechanically ventilated patients [11, 12]. These have been supported by studies using the instillation of radiotracers into the stomach, demonstrating higher radioactive counts in oropharyngeal and endobronchial secretions in supine position than in semirecumbency. Time spent in supine position was also a risk factor for aspiration of gastric contents [13–15].

Attempts to establish a relationship between patient position and outcomes have largely relied on intermittent measurements and suggest that 45 ° of HOB elevation would prevent VAP [12, 16, 17]. However, a recent study using continuous HOB monitoring which assigned patients to 45 ° of HOB elevation showed that keeping patients at 45 ° was not feasible [18]. This study questioned the applicability of 45 ° in VAP prevention. We present a continuous HOB measurement method and assess its feasibility. Following validation of the method, we used the method to collect data on patients with the hypothesis that they would be placed at or above 30 ° due to institutional initiatives on VAP prevention.

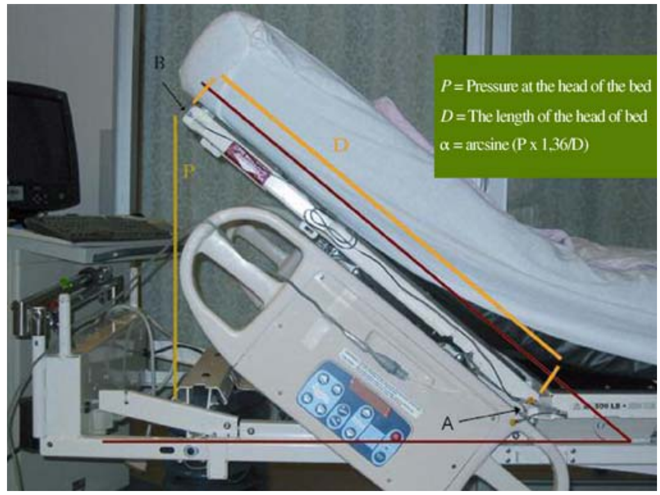

Fig. 1 Schematic and pictorial description of the HOB angle measurement set-up. *A* Axis of the bed frame; *B* top of the head of bed; *P* height relative to point *A*; *D* length of the head part of the bed frame. Pressure tube was filled with methylene blue to make it more visible on the picture

Methods

The study was approved by the institutional review board at Beth Israel Deaconess Medical Center.

Description of HOB measurement method

We developed a transducer-based method for measuring HOB angle. Our method is a simplified revision of a previous approach [17]. We attached the tubing of a single transducer as a pressure sensor (point B; Transpac, Lake Forrest, Ill., USA) to the head piece (Stryker EPIC II, Kalamazoo, Mich., USA; and KCI KinAir Pulse MedSurge, San Antonio, Tex., USA) and the pressure transducer at the pivotal middle portion (point A) of the bed frames. The system was calibrated to 0 cmH_2O (Fig. 1). The pressure created by the fluid column between points A and B represents the elevation in HOB relative to the horizon. The pressure transducer was connected to the bedside monitor (Hewlett-Packard). The displayed pressure data were transferred to a computerized data collection system (CareVue 9000, Bothell, Wash., USA) and then transcribed by the research team. We used the following formula to convert pressure data into elevation angles, $\alpha = \text{arcsine}(P \times 1.36/D)$, where P is the vertical fluid column pressure in mmHg, 1.36 is the conversion factor from mmHg to cmH_2O, and D is the length of HOB. The pressure data were converted using Microsoft Excel (Seattle, Wash., USA). We validated our method using a protractor.

Patient data

Data were collected in two ICUs over a 3-month period. We enrolled beds occupied by mechanically ventilated patients who did not have specific indications for remaining supine (e.g., hypovolemic shock), contraindications for semirecumbency (e.g., trauma of lumbar spine), or the need to remain at a specific angle (e.g., increased intracranial pressure).

Statistics

Results are expressed as mean ± standard deviation (SD). A linear regression equation and R^2 value were calculated for directly measured ("protractor") and transducer-based calculated ("transducer") angles. Comparison of the two data pools was performed using Bland–Altman technique for paired measurements. We calculated the average of differences between two methods (estimated bias). To measure the extent of disagreement between methods we took the range of 2 SD above and below the mean difference in observations. Subsequently, transducer data collected from patients were compared to 30 ° at each time point to study our hypothesis. We used 30 ° as a target because it is the minimal HOB elevation adopted by our institution for the past 6 months to reduce VAP [19]. Our institution implemented HOB elevation through education of ICU personnel as well as standardized electronic order entry system. A difference of more than 2 SD between measured mean value and 30 ° was considered statistically significant.

Results

To validate our method, 113 pairs of measurements were obtained on two unused beds at angles ranging from 3 ° to 70 °. The correlation between transduced measurements and protractor is presented in a linear regression model with minimal variation in data points along the line of equality (Fig. 2). Bland–Altman analysis showed that mean difference was 1.6 °, indicating a minimal systemic bias between the two methods. The SD of the differences was also 1.6 °, which is small compared to observed angles (up to 70 °). As shown in Fig. 3, 96% of differences were within 2 SD from the mean. To test our hypothesis that patients were kept at or above 30 ° over a given 24-h period in our institution we collected HOB data from 29 ICU patients (Fig. 4). Data were stored manually every 2–3 h. Observation time for HOB elevation was 76.3 ± 10.4 h/patient, and we collapsed the 76-h data into a 24-h time scale with approx. three data points per hour per patient. These results show that for the majority of assessments in a 24-h period, HOB elevation was significantly lower than 30 ° ($p < 0.05$). The measured HOB approached institutionally targeted 30 ° only at 7 a. m. ($p > 0.05$).

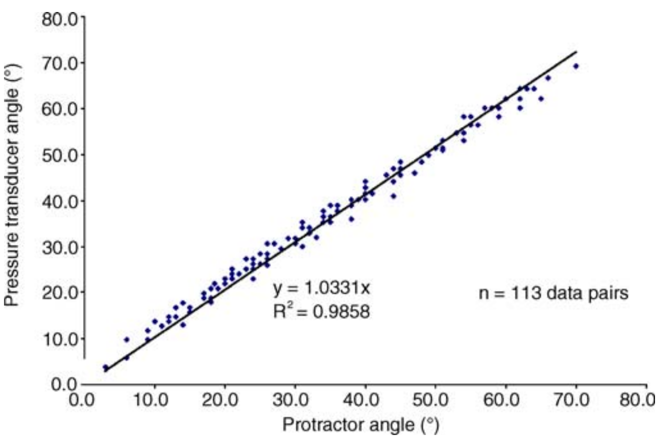

Fig. 2 Correlation and linear regression of measured HOB angles to angles measured by using a protractor ($n = 113$, $R^2 = 0.9858$)

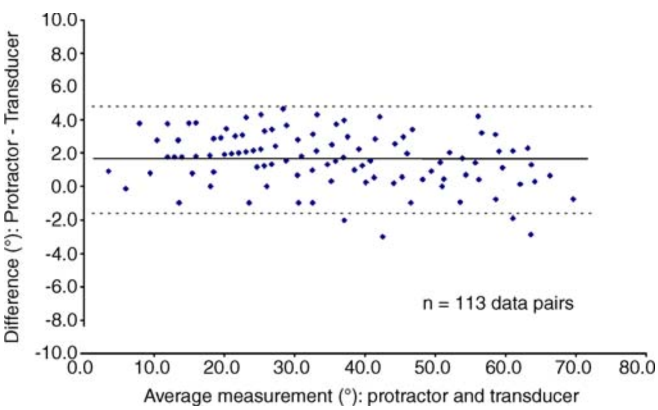

Fig. 3 Bland–Altman graph. Transducer to protractor difference vs. the mean of two values. *Solid line* Bias; *dashed lines* ±2 SD

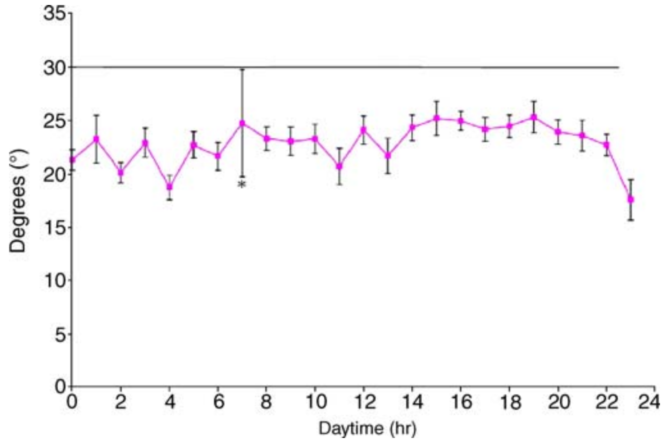

Fig. 4 Continuous HOB data obtained from 29 patients/96 patient days. Except data collected at 7 a. m. all other data differed significantly from 30 °

Discussion

Pathogenesis of VAP includes two important processes: bacterial colonization of respiratory-digestive tract and microaspiration into lower airway. Patient positioning is a key component of nursing care and has the potential to impact morbidity and mortality by preventing VAP [12]. HOB angle and time spent in supine position are risk factors for VAP [8, 12, 13, 18, 20, 21].

We present a cost-effective and clinically applicable method to measure HOB angles continuously using a single standard pressure transducer. The clinically insignificant bias of our method merely serves as a proof-of-concept of its accuracy. Following validation of the method, we observed HOB elevation in a group of patients. Almost the entire observational period our patients were at HOB elevations less than 30 ° despite a hospital-wide initiative on VAP prevention. The only time point when patients were close to 30 ° was 7 a. m., when nursing shift changed.

Information related to positioning of critically ill patients over time could provide important data for developing interventions that may improve outcome. In addition to a single HOB measurement, time spent in supine has more importance, as proven by the time-dependency of the accumulation of ^{99m}technetium in bronchoalveolar lavage following intragastric instillation [13, 20]. We believe that data related to backrest elevation centers around the ability to collect data continuously. However, few studies have described positioning effects of critically ill intubated patients over time. A variety of procedures have been used to obtain continuous data, for example, observers documenting patient positioning on a regular basis either by estimating angle or using a measuring device such as protractor or inclinometer. Electronic devices have also been used for this purpose [17, 18, 22]. Beyond inconsistencies and expense, research methods on patient positioning have provided only a brief moment's view of the patient's course.

We are excited to see the recent publication by van Nieuwenhoven et al. [18], as it will stimulate further discussions on the impact of HOB elevation in VAP prevention. It is interesting and striking that they could not replicate the findings of Drakulovic et al. [12] by keeping HOB at 45 °, because it was not attainable in their study population despite the presence of dedicated investigators. One of the major differences between the studies by Drakulovic et al. and van Nieuwenhoven et al. is the time frame in which HOB was measured: the former measured angles only once a day while the latter measured it continuously. Even if the endpoints were not VAP, Helman et al. [16] showed an increase in the HOB towards 45 ° from 3% up to 29% with standard orders and educational program using intermittent sampling of HOB angles.

We believe that the major point which differentiates the studies by Drakulovic et al. [12] and Helman et al. [16] from that by van Nieuwenhoven et al. [18] is the data sampling frequency. A simple random or scheduled sampling of a variable may be less efficient than a continuous method due to sample heterogeneity. We suggest using continuous monitoring of HOB for clinical research as well as patient care. Orozco-Levi et al. [20] also suggested time-dependency of microaspirations in semirecumbency using radioactive tracers supporting our emphasis on continuous monitoring. The purpose of this communication is merely proof-of-concept and to present observational data from intubated patients. The measured HOB in our institution was significantly lower than 30 ° target throughout the whole day despite education and electronic ordering system [16]. We hope that our method will replace more costly devices such as inclinometers and may decrease the time spent by research personnel.

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