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Original Article / *Özgün Makale*

Heat and moisture exchanger used in a cardiothoracic surgery intensive care unit: Airway resistance and changing interval

Kardiyotorasik cerrahi yoğun bakım ünitesinde kullanılan ısı ve nem değiştirici: Hava yolu direnci ve değişim aralığı

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ABSTRACT

Background: This study aims to investigate the efficacy and safety of heat and moisture exchanger on airway resistance in a cardiothoracic surgery intensive care unit.

Methods: A total of 31 patients (18 males, 13 females; mean age 51.5 years; range, 39 to 61 years) who were treated with long-term mechanical ventilation due to low cardiac output syndrome after cardiopulmonary bypass and cardiac surgery were retrospectively analyzed between December 2014 and December 2018. In addition, an *in vitro* lung model and different doses of hydroxyethyl starch in the heat and moisture exchangers to mimic the airway secretions were used and the proper interval to change heat and moisture exchangers was evaluated.

Results: In the *in vitro* lung model, the mean airway resistance was 19.4±0.2 cmH_2O/L/sec in the 5 mL group (p=0.060), 20.3±1.0 cmH_2O/L/sec in the 10 mL group (p=0.065), and 30.2±1.7 cmH_2O/L/sec in the 15 mL group (p<0.001). The airway resistance of heat and moisture exchangers, and total hospital stay and ventilation duration significantly increased in the seven-day group compared to the one-day and three-day groups. The positive culture of bacteria was also significantly higher in the seven-day group.

Conclusion: Our study results suggest that heat and moisture exchangers can be safely used for an efficient and timely removal of airway secretions. Volume of approximately 15 mL of liquid in the airflow can dramatically increase the airway resistance. The three-day interval of changing heat and moisture exchangers is ideal in a cardiothoracic surgery intensive care unit where patients have more airway secretions than patients in the general intensive care unit.

Keywords: Airway resistance, intensive care unit, mechanical ventilation, thoracic surgery.

ÖZ

Amaç: Bu çalışmada kardiyotorasik cerrahi yoğun bakım ünitesinde ısı ve nem değiştiricinin hava yolu direnci üzerindeki etkinliği ve güvenliliği araştırıldı.

Çalışma planı: Aralık 2014 - Aralık 2018 tarihleri arasında kardiyopulmoner baypas ve kalp cerrahisi sonrasında düşük kalp debisi sendromuna bağlı uzun süreli mekanik ventilasyon ile tedavi edilen toplam 31 hasta (18 erkek, 13 kadın; ort. yaş 51.5 yıl; dağılım, 39-61 yıl) retrospektif olarak incelendi. Ayrıca hava yolu sekresyonlarını simüle etmek için *in vitro* akciğer modeli ve ısı ve nem değiştiricilerde farklı hidroksietil nişasta dozları kullanıldı ve ısı ve nem değiştiricilerin doğru değişim aralığı değerlendirildi.

Bulgular: *İn vitro* akciğer modelinde, ortalama hava yolu direnci 5 mL grubunda 19.4±0.2 cmH_2O/L/saniye (p=0.060), 10 mL grubunda 20.3±1.0 cmH_2O/L/saniye (p=0.065) ve 15 mL grubunda 30.2±1.7 cmH_2O/L/saniye (p<0.001) idi. Isı ve nem değiştiricilerin hava yolu direnci ve toplam hastanede kalış ve ventilasyon süreleri, bir ve üç günlük gruplara kıyasla, yedi günlük grupta anlamlı düzeyde arttı. Pozitif bakteri kültürü de, yedi günlük grupta anlamlı düzeyde daha yüksekti.

Sonuç: Çalışma sonuçlarımız, hava yolu sekresyonlarının etkili ve zamanında atılması için ısı ve nem değiştiricilerin güvenli olarak kullanılabileceğini göstermektedir. Hava akımında yaklaşık 15 mL'lik bir sıvı hacmi, hava yolu direncini önemli düzeyde artırabilir. Genel yoğun bakım ünitesinde yatan hastalara kıyasla, daha fazla hava yolu sekresyonu olan hastaların olduğu kardiyotorasik cerrahi yoğun bakım ünitesinde ısı ve nem değiştiricilerin üç gün arayla değiştirilmesi idealdir.

Anahtar sözcükler: Hava yolu direnci, yoğun bakım ünitesi, mekanik ventilasyon, toraks cerrahisi.

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Operative and postoperative mortality after cardiac surgery with cardiopulmonary bypass (CPB) have decreased in recent years.[1-5] However, many patients need long-term mechanical ventilation after cardiac surgery, due to complications such as low cardiac output syndrome postoperatively.[6-9] The use of heat and moisture exchanger (HME) has been increasingly used in the intensive care unit (ICU) for patients requiring long-term mechanical ventilation, owing to their low cost, simplicity of use, avoidance of an energy source, and microbiological filtration for some HMEs.[10] Some patients need long-term ventilation after cardiac surgery, usually applied with HMEs.

The HMEs increase airway resistance in patients who need long-term mechanical ventilation.[11] A number of studies have investigated whether HMEs can increase airway resistance in patients after CPB. Manufacturers recommend replacing disposable HMEs every 24 h;[12] however, Ricard et al.[13] showed that some HMEs could be changed once a week without any adverse effects for patients in general ICU. The proper intervals of changing HMEs in a cardiothoracic surgery ICU has not been well understood, yet.

In the present study, we aimed to investigate the efficacy and safety of HMEs in patients who underwent cardiac surgery and with a poor cardiac output, in the cardiothoracic surgery ICU. The first part of the study used an *in vitro* lung model fitted with an HME to mimic the effect of different amounts of airway secretions on airway resistance. The second part of the study retrospectively analyzed the efficacy and safety of changing HMEs at different intervals.

PATIENTS AND METHODS

Assessment of airway resistance on in an *in vitro* lung model

The lung model used in this study consisted of an intubated teaching mannequin with an endotracheal tube of 7.0-mm inner diameter. It had bronchi directly attached to a collecting filter (Respirgard II; Vital Signs Inc., NJ, USA) and a test lung to provide testing without active exhalation (Figure 1). The HME (PORTEX®, Smiths Medical International Ltd., Kennington, Ashford, UK) was placed in the middle of the endotracheal tube and the Y-piece of the circuit (Adult Breathing Circuit; Covidien LLC, Huizhou, Guangdong, China). The Y-piece of the circuit was connected to the ventilator (Nellcor Puritan Bennett™ 840; Medtronic, CO, USA).

The lung model was ventilated using the ventilator. The ventilator settings were as follows: tidal volume (VT), 450 mL; respiratory rate, 13 bpm; positive end-expiratory pressure (PEEP), 5 cmH_2O; and inspiratory time (IT), 2 s. A disposable HME and

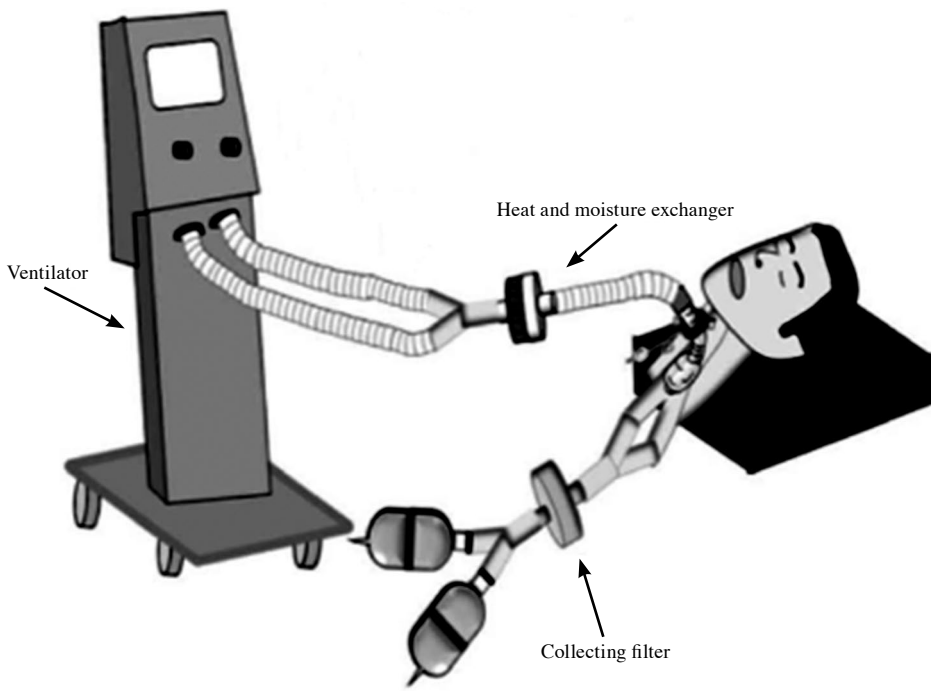

Figure 1. The experimental model of this study.

an ordinary disposable ventilator circuit were used. The ventilator circuit and lung model were checked before the experiment to ensure connection integrity and proper functionality. The HME was placed vertically above the tracheal tube (using a flex tube) to reduce the risk of partial obstruction due to refluxed secretions from the tracheal tube. The position of each HME was regularly checked. The HME was replaced before each measurement. The peak airway pressure (P_{peak}) and platform pressure (P_{plat}) were monitored on the ventilator side of the HME during mechanical ventilation.[14]

The airway resistance was estimated based on the following equation:

Airway resistance=(P_{peak} - P_{plat})/V

The V was simulated based on the equation

V=VT/IT

during inspiration, and

Airway resistance=(P_{peak} - P_{plat})/(VT/IT)

V, inspiratory flow

The HMEs were connected to a nebulizer (Micro Mist® nebulizer #1884, Hudson RCI, CA, USA) that aerosolized settled dose of hydroxyethyl starch (HES) into the HME.[15,16] The amount of HES aerosolization was empirically determined to obtain a wet weight similar to the airway secretions that obtained by the patients after use. This weight information was derived from samples of each of the studied HMEs used in different patients after use.[11,17]

The HMEs were added 0 mL, 5 mL, 10 mL, and 15 mL of HES using a nebulizer. Four test groups (0 mL, 5 mL, 10 mL, and 15 mL) were formed, depending on the different doses of HES in HMEs, and one cohort without HME was used as control. The HMEs were connected in the ventilation circuit and the P_{peak} and P_{plat} were monitored. The airway resistance can be estimated based on the monitored P_{peak}, P_{plat}, VT, and IT.[14]

Retrospectively analysis of HME's efficacy and safety

Thirty-seven patients were retrospectively analyzed in the department of cardiothoracic surgery ICU between December 2014 and December 2018 at the First Affiliated Hospital of Chongqing Medical University. The patients were treated with long-term mechanical ventilation due to low cardiac output syndrome after CPB and cardiac surgery. Four patients with pulmonary infections and two with other lung diseases, such as chronic obstructive pulmonary disease (COPD), which affected the duration of the mechanical ventilation and hospital stay, were excluded. A total of 31 patients (18 males, 13 females; mean age 51.5 years; range, 39 to 61 years) were enrolled. A written informed consent was obtained from each patient. The study protocol was approved by the Ethics Committee of the First Affiliated Hospital of Chongqing Medical University (2014-033). The study was conducted in accordance with the principles of the Declaration of Helsinki.

The patients were divided into three groups according to the interval of replacing HMEs. The HMEs for the first group were replaced daily, the second group every three days, and the third group every seven days. Humidity, bacterial culture of airway secretions, and airway resistance of HMEs were monitored. The total hospital stay and ventilation duration of each patient were also compared. The ventilator (Nellcor Puritan Bennett™ 840; Medtronic, CO, USA), ventilator circuit (Adult Breathing Circuit; Covidien LLC, Huizhou, Guangdong, China), and HME (PORTEX®, Smiths Medical International Ltd, Ashford, Kent, UK) were placed the same group as the *in vitro* lung model. The total follow-up time was seven days for each patient.

The number of tracheal suctioning and tracheal instillations was recorded daily. The P_{peak} was monitored every 6 h and recorded as X±S. Absolute humidity (AH) and relative humidity (RH) were also measured. Absolute humidity at saturation (AHs) was used as a measurement of airway humidity, and it was the maximum amount of water vapor which could be contained in air at a given temperature. The RH was the ratio of AH-to-AHs, expressed in percentage. These parameters can be measured by psychrometry, a technique widely used in clinical studies to evaluate the performance of HME. The RH was calculated using a reference nomogram. The AH was calculated using the equation: AHs=16.451563-0.731T + 0.03987T2 mg H_2O/L. T (°C) is the temperature measured by a probe. The AH was derived using the formula: AH = (AHs × RH)/100 (in mg H_2O/L).[18] The room temperature was kept constant at 24.0 to 26.0°C.

The airway resistance of HMEs was measured daily and averaged according to the International Organization for Standardization (ISO)/Technical Committee (TC) 249 guidelines.[19] The airway resistance of HMEs in the one-day, three-day, and seven-day groups, when HMEs were replaced, was compared. Briefly, the airway resistance was calculated from the pressure drop on either side of the HME,

Table 1. Airway resistance *in vitro* lung model

	Without HME	With HME adding 0.9% saline			
		0 mL	5 mL	10 mL	15 mL
Airway resistance (cmH_2O/L/sec)	17.3±1.0	18.8±0.3	19.4±0.2	20.3±1.0	30.2±1.7
P value		0.066*	0.060†	0.065†	<0.001† <0.001‡

HME: Heat and moisture exchanger; * Represents compared with control; † Represents compared with 0 mL group; ‡ Represents compared with 10 mL group.

when a constant 60-L/min flow was applied through the HME.[13]

To evaluate bacterial filterability of the HME, secretions drawn from the airway were sent for sputum culture, when HMEs were replaced during the study period.

Statistical analysis

Statistical analysis was performed using the IBM SPSS version 21.0 statistical software (IBM Corp., Armonk, NY, USA). Descriptive data were expressed in mean ± standard deviation (SD), median (min-max) or number and frequency. Differences among the groups were analyzed using the chi-square (χ^2) test. A *p* value of <0.05 was considered statistically significant.

RESULTS

Assessment of airway resistance on an *in vitro* lung model

Different amounts of airway secretions in the HMEs were mimicked using HES. Airway resistance was compared to the resistance in long-term mechanical ventilated patients. The P_{peak} and P_{plat} were recorded during mechanical ventilation, and airway resistance estimated based on the P_{peak} and P_{plat} (Table 1). The mean airway resistance in the cohort without HME was 17.3±1.0 cmH_2O/L/sec, 83±0.3 cmH_2O/L/sec (p=0.066) in the 0 mL HES group, 0 mL HES in HMEs group was 18.8±0.3 cmH_2O/L/sec (p=0.066), 19.4±0.2 cmH_2O/L/sec in the 5 mL HES group (p=0.060, compared to 0 mL HES group), 30±1.0 cmH_2O/L/sec in the 10 mL HES group

Table 2. Demographic and clinical characteristics of patients

Features	1-Day group	3-Day group	7-Day group	
	n	n	n	*p*
Sex				0.132
Male	5	6	7	
Female	5	5	3	
Age (year)				0.279
≤50	4	7	7	
>50	6	4	3	
Smoking state				0.643
Smoking	4	6	5	
Non-smoking	6	5	5	
White blood cell count				0.170
Normal	9	6	5	
Abnormal	1	5	5	
APACHE II score				0.417
<13	4	4	6	
≥13	6	7	4	
PaO_2/FiO_2				0.101
<220	4	5	5	
≥220	6	6	5	

APACHE: Acute physiology and chronic health evaluation.

Table 3. Clinical assessment of humidifying efficacy

	1-Day group	3-Day group	7-Day group		
	Mean±SD	Mean±SD	Mean±SD	*p*	*p*
Tidal volume (mL)	480±11	482±35	469±62	0.877*	0.586†
Respiratory rate (breaths per minute)	13.5±0.7	13.6±0.8	14.0±1.1	0.687*	0.229†
Mean peak airway pressure (cmH_2O)	17.9±0.7	17.9±0.7	18.7±1.2	0.977*	0.082†
No of tracheal suctionings (per day)	9.0±1.2	9.1±0.9	9.8±1.2	0.845*	0.151†
No of tracheal instillations (per day)	0.1±0.3	0.1±0.3	0.3±0.5	0.947*	0.288†

SD: Standard deviation; * Represents 3-day group compared with 1-day group; † Represents 7-day group compared with 1-day group.

(p=0.065, compared to 0 mL HES group), and 30.2±1.7 cmH_2O/L/sec in the 15 mL HES group (p<0.001, compared to 0 mL HES group). The 15 mL HES group increased significantly compared to the 10 mL HES group (p<0.001, compared to 10 mL HES group), indicating that about 15 mL HES aerosolized in the HME could increase airway resistance for the *in vitro* lung model.

Retrospectively analysis of HME's efficacy and safety

This study retrospectively studied 31 post-cardiac surgery patients having low cardiac output and mechanically ventilated for more than seven days. This was to evaluate the efficacy and safety of HME. Patients with pulmonary infections or other lung diseases were excluded. Only synchronized intermittent mandatory ventilation was used for mechanical ventilation. Sex, age, smoking state, white blood cell count, Acute Physiology and Chronic Health Evaluation II (APACHE II) score, or partial pressure of oxygen (PaO_2)/fraction of inspired oxygen (FiO_2) were not significantly different in the use of HMEs (Table 2).

The parameters used to evaluate the efficacy and safety of HMEs are shown in Table 3. The number of tracheal inhalations, tracheal infusion volume, and the mean P_{peak} were not significantly different among the one-day, three-day, and seven-day use of HMEs (p>0.05).

The AH and RH measured in the three-day and seven-day use of HMEs was not significantly different compared to changing HMEs daily throughout the study period (Table 4, p>0.05). Endotracheal tube obstruction never occurred during seven days of mechanical ventilation.

The airway resistance of HMEs was compared in one-day, three-day, and seven-day groups. The results indicate that airway resistance increased significantly in the seven-day group compared to the one-day group (p=0.002) and three-day groups (p=0.015, Table 5). There were no significant differences in the airway resistance of HMEs between the one-day and three-day groups (p=0.163). In addition, there was no significant difference in the ventilation duration and total hospital stay between the patients in the one-day and three-day groups (p>0.05). However, the total hospital stay was significantly longer in patients in whom the HMEs changed at a seven-day interval compared to the one-day interval group (p=0.030). The ventilation duration was significantly longer in patients in whom the HMEs changed at a seven-day interval compared to the one-day interval group (p=0.006). The total hospital stay and ventilation duration were longer in patients in the seven-day group compared to the three-day group (p=0.041 and p=0.021 respectively).

The secretions were drawn from the airway and sent for bacterial culture. There were two positive cases of bacterial culture in one-day and three-day use

Table 4. Humidity parameters

	1-Day group	3-Day group	7-Day group		
	Mean±SD	Mean±SD	Mean±SD	*p*	*p*
Absolute humidity (cmH_2O/L)	30.8±0.5	30.7±0.4	30.7±0.6	0.768*	0.758†
Relative humidity (%)	99.1±0.5	99.1±0.5	99.2±0.3	0.881*	0.682†

SD: Standard deviation; * Represents 3-day group compared to 1-day group; † Represents 7-day group compared to 1-day group.

Table 5. Clinical assessment of airway resistance

	1-Day group	3-Day group	7-Day group			
	Mean±SD	Mean±SD	Mean±SD	*p*	*p*	*p*
HME resistance (cmH_2O/L/sec)	3.2±0.1	3.2±0.1	3.5±0.2	0.163*	0.002†	0.015‡
Ventilation duration (day)	9.5±2.0	10.0±2.5	13.1±3.1	0.621*	0.006†	0.021‡
Hospital stay (day)	28.6±2.2	28.±2.5	31.1±2.5	0.902*	0.030†	0.041‡

SD: Standard deviation; HME: Heat and moisture exchanger; * Represents 3-day group compared with 1-day group; † Represents 7-day group compared with 1-day group; ‡ Represents 7-day group compared with 3-day group.

of HMEs, and four positive cases in seven-day use of HMEs. The results showed that the seven-day group had a higher positive culture rate than the other groups ($p<0.05$).

DISCUSSION

Cardiothoracic surgery involves a long operation time and large trauma. Open chest surgery leads to large amounts of hard-to-clear sputum.[20-22] Post-cardiothoracic surgery ICU patients are considerably different from general patients with long-term mechanical ventilation on airway resistance.[20,21,23] The HMEs are commonly used in patients who need long-term ventilation after cardiothoracic surgery, although there is still a need to study their effects on the airway resistance. The time interval of changing HMEs for cardiothoracic surgery patients remains unknown. Therefore, it is important to examine how to properly use HME in the cardiothoracic ICU setting.

The primary objective of this study was to evaluate airway resistance using the *in vitro* lung model in a ventilator fitted with an HME and to determine the quantity of secretions which would increase the airway resistance. The use of HMEs needs to prevent the sudden increase of airway resistance in patients on mechanical ventilation. The secondary objective was to compare the different intervals of changing HMEs (one-day, three-day, and seven-day intervals) by monitoring the humidity parameters, airway resistance, bacterial culture of the secretions, and duration of hospital stay and ventilation.

Airway resistance was higher in patients with airflow obstruction; however, Ikeda et al.[24] did not explore how much airflow obstruction led to a significant increase in the airway resistance. There are ISO standards for aerosolizing saline into the HME to evaluate the airway resistance, although the saline's density and weight are different from the airway secretions of patients. In this study, we used HES to mimic actual airway secretions, and the density HES was similar to the airway sputum from the patients. Therefore, this study produced closer results to the real-life setting. Our results suggest that about 15 mL of liquid in the airflow can dramatically increase airway resistance. Patients tend to have more airway secretions in a cardiothoracic surgery ICU setting,[21] and the use of HME would increase the airway resistance.[14] Therefore, timely removal of airway secretions would be prudent during using HMEs.

Manufacturers recommend replacing disposable HMEs every 24 h, although objective data do not support this.[12] The weekly change of HMEs was found to be effective and safe in general ICU through analysis of clinical parameters, humidity parameters, HMEs resistance of airflow, and bacterial colonization.[13] The proper interval of changing HMEs has not been well established in a cardiothoracic surgery ICU, due to the increased secretions after cardiothoracic surgery.

In our study, 31 patients on long-term mechanical ventilation were retrospectively analyzed due to low cardiac output syndrome after cardiac surgery (i.e., patients did not have signs of pulmonary infection or other lung diseases which may affect the airway resistance). These patients were divided into three groups based on the intervals of changing HMEs (one-day, three-day, and seven-day). Humidity, airway resistance of HMEs, secretion bacterial culture, total hospital stay, and ventilation duration were recorded. The results suggested that changing HMEs in a three-day interval did not show increased humidity, airway resistance, bacterial culture of secretions, total hospital stay, and ventilation duration of HMEs compared to daily changes. There was significantly increased airway resistance, bacterial culture, total hospital stay, and ventilation duration for HMEs changed at a seven-day interval, compared to daily change. This may due to the trends of patients to have longer surgical time, more trauma, and more

airway secretions after cardiothoracic surgery than the general patients.[25] Jayakumar et al.[26] reported that cardiothoracic surgery had the most postoperative pain among surgeries. These factors can contribute to high airway secretions in patients after open chest surgery;[21] the changes in post-cardiothoracic surgery ICU patients with HMEs are different from general ICU patients. The three-day interval change of HMEs is ideal for patients with long-term mechanical ventilation undergoing cardiovascular surgery with CPB.

Airway secretions and sputum, which block the HMEs, may cause a sudden increase in airway resistance and eventually death.[27] Physicians and nurses in the ICU must inspect, if there are stains in the HMEs. The HMEs must be changed immediately, if stain occurs at any time.

This study has several limitations. First, the study represents one type of HME. Each type, design, and brand of HME is different for the amount of moisture collected;[25] therefore it is necessary to test a variety of HMEs to understand their effects on the airway resistance. Second, this study used HES instead of real airway secretions. Thus, the results may not exactly the same as the clinical situation, although the HES weight was the same as the airway secretions weight that obtained by the patients after use. Finally, further studies including larger samples are needed to confirm these findings.

In conclusion, our study results show that the safe use of heat and moisture exchangers facilitates efficient removal of airway secretions; only about 15 mL of liquid in the airflow can dramatically increase the airway resistance. It is not necessary to change heat and moisture exchangers daily. However, heat and moisture exchangers are needed to be replaced more than once a week in a cardiothoracic surgery intensive care unit and a three-day interval is ideal for patients on long-term mechanical ventilation. Patients who undergo cardiovascular surgery have more airway resistance than general intensive care unit patients. Changing heat and moisture exchanger at a three-day interval is safer than changed once a week and cheaper than daily.

Declaration of conflicting interests

The authors declared no conflicts of interest with respect to the authorship and/or publication of this article.

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REFERENCES

1. Aya HD, Cecconi M, Hamilton M, Rhodes A. Goal-directed therapy in cardiac surgery: a systematic review and meta-analysis. Br J Anaesth 2013;110:510-7.
2. Rhodes A, Moreno RP, Metnitz B, Hochrieser H, Bauer P, Metnitz P. Epidemiology and outcome following post-surgical admission to critical care. Intensive Care Med 2011;37:1466-72.
3. Pivatto Júnior F, Kalil RA, Costa AR, Pereira EM, Santos EZ, Valle FH, et al. Morbimortality in octogenarian patients submitted to coronary artery bypass graft surgery. Arq Bras Cardiol 2010;95:41-6.
4. Gökalp O, İner H, Beşir Y, Gökalp G, Yılık L, Gürbüz A. Using of Extracorporeal Membrane Oxygenation in postcardiotomy heart failure. Turk Gogus Kalp Dama 2018;26:165-6.
5. Oruç M, Ülkü R. Evaluation of factors affecting prognosis in penetrating thoracic injuries. Turk Gogus Kalp Dama 2018;26:598-605.
6. Tanigami H, Yahagi N, Kumon K, Watanabe Y, Haruna M, Matsui J, et al. Long-term sedation with isoflurane in postoperative intensive care in cardiac surgery. Artif Organs 1997;21:21-3.
7. Hummel J, Rücker G, Stiller B. Prophylactic levosimendan for the prevention of low cardiac output syndrome and mortality in paediatric patients undergoing surgery for congenital heart disease. Cochrane Database Syst Rev 2017;8:CD011312.
8. Zarbock A, Mueller E, Netzer S, Gabriel A, Feindt P, Kindgen-Milles D. Prophylactic nasal continuous positive airway pressure following cardiac surgery protects from postoperative pulmonary complications: a prospective, randomized, controlled trial in 500 patients. Chest 2009;135:1252-9.
9. De Wet CJ, McConnell K, Jacobsohn E. Progress in postoperative ICU management. Thorac Surg Clin 2005;15:159-80.
10. Martin C, Perrin G, Gevaudan MJ, Saux P, Gouin F. Heat and moisture exchangers and vaporizing humidifiers in the intensive care unit. Chest 1990;97:144-9.
11. Lucato JJ, Tucci MR, Schettino GP, Adams AB, Fu C, Forti G Jr, et al. Evaluation of resistance in 8 different heat-and-moisture exchangers: effects of saturation and flow rate/profile. Respir Care 2005;50:636-43.
12. Kola A, Eckmanns T, Gastmeier P. Efficacy of heat and moisture exchangers in preventing ventilator-associated pneumonia: meta-analysis of randomized controlled trials. Intensive Care Med 2005;31:5-11.
13. Ricard JD, Le Mière E, Markowicz P, Lasry S, Saumon G, Djedaïni K, et al. Efficiency and safety of mechanical ventilation with a heat and moisture exchanger changed only once a week. Am J Respir Crit Care Med 2000;161:104-9.
14. Uchiyama A, Yoshida T, Yamanaka H, Fujino Y. Estimation of tracheal pressure and imposed expiratory work of breathing by the endotracheal tube, heat and moisture exchanger, and ventilator during mechanical ventilation. Respir Care 2013;58:1157-69.

15. van Galen G, Hallowell G. Hydroxyethyl starches in equine medicine. J Vet Emerg Crit Care (San Antonio) 2019;29:349-59.
16. Ntoumenopoulos G, Berry MP, Camporota L, Lam L. Indicators of Airway Secretion Weight in Mechanically Ventilated Subjects. Respir Care 2019;64:1377-86.
17. Ahmed SM, Mahajan J, Nadeem A. Comparison of two different types of heat and moisture exchangers in ventilated patients. J Emerg Trauma Shock 2009;2:164-9.
18. Baskerville EB, Cobey S. Does influenza drive absolute humidity? Proc Natl Acad Sci U S A 2017;114:E2270-E1.
19. Liu YQ, Wang YX, Shi NN, Han XJ, Lu AP. Current situation of International Organization for Standardization/Technical Committee 249 international standards of traditional Chinese medicine. Chin J Integr Med 2017;23:376-80.
20. Hu XL, Xu ST, Wang XC, Hou DN, Chen CC, Song YL, et al. Prevalence of and risk factors for presenting initial respiratory symptoms in patients undergoing surgery for lung cancer. J Cancer 2018;9:3515-21.
21. Wang Y, Li H, Zou H, Li Y. Analysis of Complaints from Patients During Mechanical Ventilation After Cardiac Surgery: A Retrospective Study. J Cardiothorac Vasc Anesth 2015;29:990-4.
22. Kartal E, Balaban ME. Machine learning techniques in cardiac risk assessment. Turk Gogus Kalp Dama 2018;26:394-401.
23. Huang H, Yao T, Wang W, Zhu D, Zhang W, Chen H, et al. Continuous ultrafiltration attenuates the pulmonary injury that follows open heart surgery with cardiopulmonary bypass. Ann Thorac Surg 2003;76:136-40.
24. Ikeda T, Uchida K, Yamauchi Y, Nagase T, Oba K, Yamada Y. Relationship between pre-anesthetic and intra-anesthetic airway resistance in patients undergoing general anesthesia: A prospective observational study. PLoS One 2017;12:e0172421.
25. Ari A, Dang T, Al Enazi FH, Alqahtani MM, Alkhathami A, Qoutah R, et al. Effect of Heat Moisture Exchanger on Aerosol Drug Delivery and Airway Resistance in Simulated Ventilator-Dependent Adults Using Jet and Mesh Nebulizers. J Aerosol Med Pulm Drug Deliv 2018;31:42-8.
26. Jayakumar S, Borrelli M, Milan Z, Kunst G, Whitaker D. Optimising pain management protocols following cardiac surgery: A protocol for a national quality improvement study. Int J Surg Protoc 2019;14:1-8.
27. Chuang ML, Chou YL, Lee CY, Huang SF. Instantaneous responses to high-frequency chest wall oscillation in patients with acute pneumonic respiratory failure receiving mechanical ventilation: A randomized controlled study. Medicine (Baltimore) 2017;96:e5912.