Journal of Clinical Monitoring and Computing (2021) 35:463–468
https://doi.org/10.1007/s10877-020-00499-7

ORIGINAL RESEARCH

# A mobile terminal application program was used for endotracheal tube cuff pressure measurement

**Wei-Zhong Wang[1] · Yao-Ying Zhou[1] · Zhi-Juan Wang[2] · Mei-Li Zhu[2] · Xiao-Yan Yao[1] · Jian-Di Yu[1] · Yan-Hong Lin[1] · Fei-Yun Yu[1] · Chun-Yan Wu[1] · Hui-Hui Zhang[1] · Dan Lou[1] · Yue-Hong Hu[1]**

Received: 30 June 2019 / Accepted: 12 March 2020 / Published online: 18 March 2020


## Abstract

We studied the application of a mobile terminal application program in endotracheal tube (ETT) cuff pressure measurement to improve the implementation rate of scientific ETT cuff pressure measurement and to ensure that the pressure falls within the recommended range. A pre-post controlled study lasting for 18 months was undertaken in a 40-bed general intensive care unit (GICU). This included a 6-month baseline period (baseline group) and a 6-month intervention period (intervention group). The mobile terminal application program was applied to monitor the cuff pressure of endotracheal intubation as an intervention measure during the intervention period. ETT pressure was the main outcome measure, while gender, age, causes for ICU admission, sedation score, duration of prior intubation, size of ETT, and number of VAP patients were secondary outcomes. ETT cuff pressure was monitored 742 times in both the baseline group and the intervention group. A total of 56.9% of the cuff pressure measurements in the baseline group were within the recommended range, while 78.4% of measurements in the intervention group were within the recommended range, reflecting a statistically significant difference ($P < 0.05$). The application of the mobile terminal application program used for ETT cuff pressure measurement could improve the percentage of ETT cuff pressure measurements falling within the recommended range.

**Keywords** Mobile terminal application program · Cuff pressure · Endotracheal tube

## Abbreviations

| | |
|---|---|
| ETT | Execution of endotracheal tube |
| GICU | General intensive care unit |
| VAP | Ventilator-associated pneumonia |

## 1 Introduction

To prevent tracheal injury and leakage, cuff pressure should be maintained between 25 and 30 cm $H_2O$ [1]. High pressures against the trachea may impede mucosal blood flow, resulting in mucosal ischaemia, necrosis [2], and tracheoesophageal fistula [3]. Low pressures could increase the risk of leakage and pulmonary aspiration. Rello [4] showed that cuff pressure below 20 cm $H_2O$ was an independent risk factor for VAP (RR = 4.23). Currently, the incidence of VAP in patients with mechanical ventilation is as high as 6–52% [5–7], which lead to the following serious consequences: VAP was associated with a 6.4-day extension of the duration of prior intubation [8], a 12.5-day extension of ICU stay [8], an average increase of $40,000 in hospital costs [5], and a 13% increase in attributable mortality [9].

However, the pilot balloon palpation (or 'finger-pressure') method is still widely used to assess endotracheal tube cuff inflation, which will lead to abnormal ETT cuff pressure [10–12]. Nseir et al. measured cuff pressure every 8 h and found that cuff pressure was maintained within the recommended range in only 18% of patients [13]. Only a few large

✉ Wei-Zhong Wang
906134210@qq.com

Yao-Ying Zhou
1275965033@qq.com

Zhi-Juan Wang
296942649@qq.com

Mei-Li Zhu
1523467675@qq.com

Xiao-Yan Yao
835423599@qq.com

[1] Department of General Intensive Care Unit, Shaoxing People's Hospital, Zhongxing North Road, Shaoxing 312000, Zhejiang, China

[2] Nursing Department, Shaoxing People's Hospital, Shaoxing, Zhejiang, China

general hospitals in China have established a department of respiratory therapy [14], and the ETT cuff pressure is managed by the nurse. Xiang et al. found that only 34.8% of nurses in a class III grade I hospital in Beijing used a manometer to assess cuff pressure scientifically [15]. Fu et al. measured cuff pressure 812 times in 53 patients and found that 46.3% of pressure was not within the normal range [16]. Therefore, it is necessary to improve the normative measurement of the ETT cuff pressure. We studied the application of a mobile terminal application program in the execution of ETT cuff pressure measurement, which could ensure that only the manometer is allowed to assess cuff pressure, with the pressure measured at least three times a day, and provide convenient feedback to improve the execution of the normative measurement of the ETT cuff pressure.

## 2 Methods

### 2.1 Study design and setting

This prospective, experimental, before-after study that lasted for 18 months was undertaken in a 40-bed GICU of a class III grade I hospital in Zhejiang Province. Training on cuff pressure measurement was provided according to the recommended method [1, 17] in July 2017 and followed by a 2-month wash-out period. The baseline period (baseline group) was from October 2017 to March 2018. Training on cuff pressure measurement methods applied by mobile terminal application program was provided in April 2018 and followed a 2-month wash-out period. The intervention period (intervention group) was from July 2018 to December 2018. Cuff pressure was monitored and compared between baseline and intervention periods. All patients aged over 18 years who were receiving Mechanical Ventilation (MV) for 3–14 days with the endotracheal tube (COVIDIEN, size of ETT: 7.0–8.0) were included in the study. We excluded patients receiving MV via a tracheostomy.

### 2.2 Interventions

We applied the mobile terminal application program to ETT cuff pressure measurement as an intervention to improve the execution of the normative measurement of the ETT cuff pressure. This intervention ensured that only the manometer was allowed to assess cuff pressure, with the pressure measured at least three times a day.

#### 2.2.1 The steps of ETT cuff pressure measurement

The researchers performed the following steps to measure cuff pressure in participants: (a) took the mobile terminal to the bedside of the patient, scanned the two-dimensional code of the patient's wrist band, and entered the interface for recording nursing operations of the current patient; (b) used the mobile terminal to scan the two-dimensional code on manometer and entered the interface for recording cuff pressure; (c) measured cuff pressure with the manometer; and (d) recorded the pressure before and after measurement on the interface of the mobile terminal. Note: when the cuff pressure was not measured and over 8 h had passed, the mobile terminal would display a message to remind the nurse to measure the pressure (Fig. 1).

#### 2.2.2 The mobile terminal application program has the function of ETT cuff pressure measurement feedback

The head nurse could glance at the cuff pressure measurement of each patient on the computer, including the frequency of cuff pressure measurement and the pressure value before and after each measurement. In cases of failure to check the cuff pressure in accordance with the training method, the head nurse needed to determine the reason for this occurrence and try to resolve the issue.

### 2.3 ETT cuff pressure measurement

Compared with intermittent measurement, a continuous ETT cuff pressure control system could better maintain the cuff pressure within the recommended range [18, 19]. However, we lack a continuous ETT cuff pressure control system, so we used the manometer to measure cuff pressure every 8 h and maintained the pressure at 30 cm $H_2O$ (the upper limit of the recommended range) for each cuff pressure measurement.

The four nursing team leaders measured and recorded the cuff pressure once more at 14:00–16:00 every day during the baseline period and intervention period, and maintained cuff pressure at 30 cm $H_2O$ after measurement. The nursing team leaders who were responsible for measuring the cuff pressure were blinded, as they were unaware of the study conditions.

Bolzan et al. [20] showed that the cuff pressure drops by approximately 2 cm $H_2O$ (consistent with our monitoring results) when the manometer is connected to and disconnected from the cuff pressure valve during pressure checks. We also considered the loss of cuff pressure when the manometer was connected to and disconnected from the cuff pressure valve in our study.

The manometer was a VBM (54-05-000) cuff pressure gauge that was made in Germany.

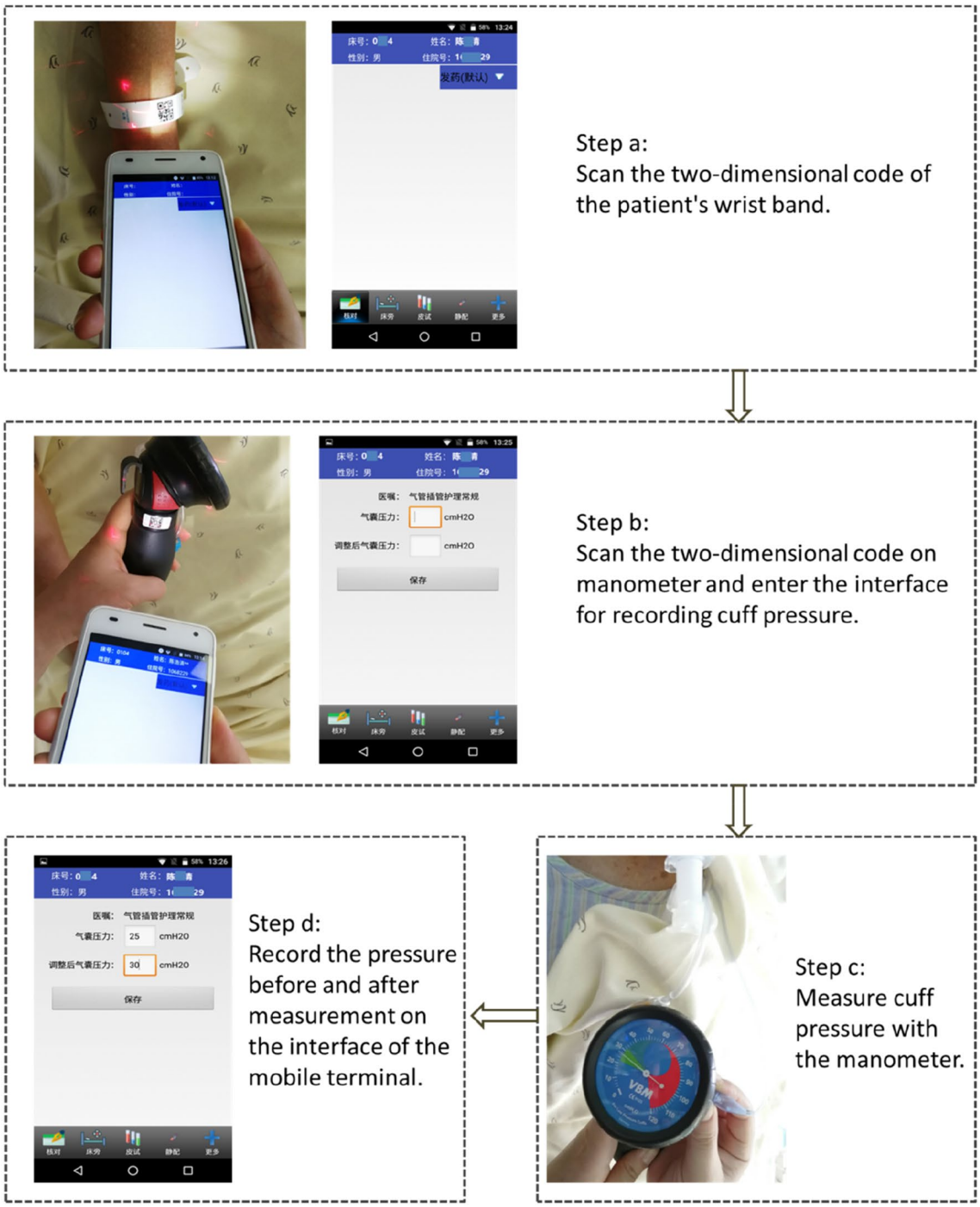


**Fig. 1** The steps of ETT cuff pressure measurement

## 2.4 Clinical criteria for VAP

Clinical criteria for VAP include a new or persistent infiltration or progressive radiographic infiltrate in patients with mechanical ventilation for more than 48 h [21, 22], plus 2 or more of the following: (1) temperature > 38 °C; (2) purulent tracheal secretions; and (3) blood leukocyte count $> 10 \times 10^9$/L or $< 4 \times 10^9$/L [23].

### 2.5 Variables recorded

There were other factors contributing to abnormal cuff pressure, in addition to the method of cuff pressure measurement. Nseir et al. [13] found that the risk factors for underinflation of the endotracheal cuff, including the absence of sedation and the duration of prior intubation by multivariate analysis, and no risk factors for the overinflation of the endotracheal cuff could be identified by univariate analysis. Therefore, we collected Richmond Agitation-Sedation Scale (RASS) scores [24] and information on the duration of prior intubation in addition to the cuff pressure of the baseline and intervention groups. Other data included gender, age, causes for ICU admission, size of ETT, and number of VAP patients.

### 2.6 Sample size calculations

According to our pre-experiment, 55.2% of the cuff pressure was maintained within the recommended range in our GICU. It was assumed that the percentage of cuff pressure within the recommended range was increased by 10% after the intervention of the mobile terminal application program, which was considered to be effective. Under the conditions of a 1:1 parallel design, a unilateral test, $\alpha = 0.01$, and power = 90%, the sample size during the study phase was at least 618, as calculated by Pass 11. Because of operating errors or unpredictable factors, the sample size was expanded by 20%, and the final sample size at each study phase was 742.

### 2.7 Statistical analysis

Statistical analyses were performed using SPSS 16.0. Measurement data showing normal distributions were expressed as the mean ± standard deviation, and comparisons before and after interventions were performed using the *t* test. Classification data were expressed as a percentage of the positive samples/total samples in one study period (%) and compared using the $\chi 2$ test. All tests were 2-tailed. $P < 0$ 0.05 was considered statistically significant.

## 3 Results

A total of 73 patients with mechanical ventilation support were monitored in the baseline group, and 102 patients were monitored in the intervention group. ETT cuff pressure was monitored 742 times in both the baseline group and the intervention group.

There was no statistical significance ($P > 0.05$) between the baseline group and the intervention group in terms of gender, age, basic disease, RASS score, duration of prior intubation and size of ETT ($P > 0.05$), and the detailed data are shown in Table 1.

A total of 56.9% of cuff pressure measurements in the baseline group were within the recommended range, while 78.4% of measurements in the intervention group were within the recommended range, reflecting a statistically significant difference ($P < 0.05$).

The incidence of VAP was 13.7% in the baseline group and 11.9% in the intervention group. There was no significant difference between the two groups ($P > 0.05$), and the detailed data are shown in Table 1.

## 4 Discussion

Maintaining cuff pressure in the recommended range can reduce related complications [1–9]. However, it is common to use unscientific methods to assess cuff pressure in clinical practice [10–12, 15], and pressure cannot be maintained within the recommended range [13, 16]. In addition to the lack of training in cuff pressure measurement, these issues may be related to the following conditions. First, nurses may not use a manometer: The ratio of nurses to the number of beds as low as 1.91, which increases the nursing workload in the GICU of class III grade I hospitals in East China [25], and thus, nurses would use the pilot balloon palpation method to assess pressure because it saves more time. However, the pilot balloon palpation method is less reliable in assessing pressure [10, 26]. Second, the head nurse could not obtain feedback information that the nurse measured cuff pressure using a method that was not recommended.

The percentage of cuff pressure measurements falling within the recommended range increased from 56.9 to 78.4% in our study. The main principles are as follows: (1) The use of the manometer must be ensured: after the intervention, the cuff pressure measurement required the mobile terminal to scan the two-dimensional code of the patient's wrist band and the two-dimensional code of the manometer, so the manometer must be used for the cuff pressure measurement; (2) The frequency of cuff pressure measurement was properly implemented: when the cuff pressure was not measured and over 8 h had passed, the mobile terminal would display a message to remind the nurse to measure the pressure; and (3) A convenient feedback channel must be provided: Step d required that the pressure values before and after measurement be recorded in the mobile terminal. The head nurse could glance at the cuff pressure measurement of each patient on the computer, including the frequency of cuff pressure measurement and the pressure values before and after measurement, which were used to supervise nurses and urge them to check cuff pressure using the recommended method.

**Table 1** Comparison of statistical results between the baseline group and the intervention group

| | Baseline group | Intervention group | *P* |
|---|---|---|---|
| Gender, n (%) | | | 0.747 |
| Male | 39 (53.4%) | 57 (55.9%) | |
| Female | 34 (46.6%) | 45 (44.1%) | |
| Age, mean ± SD | 65.52 ± 13.21 | 67.37 ± 12.83 | 0.596 |
| Causes for ICU admission, n (%) | | | 0.953 |
| Lung disease | 33 (45.2%) | 41 (40.2%) | |
| Heart failure | 8 (11.0%) | 12 (11.4%) | |
| Cerebrovascular accident | 11 (15.1%) | 16 (15.4%) | |
| Surgery | 9 (12.3%) | 12 (12.0%) | |
| Others | 12 (16.4%) | 21 (18.9%) | |
| RASS score, n (%) | | | 0.689 |
| +4 ~ +2 | 41 (5.5%) | 44 (5.7%) | |
| +1 ~ −2 | 577 (77.8%) | 563 (76.8%) | |
| −3 ~ −5 | 124 (16.7%) | 135 (17.5%) | |
| Duration of prior intubation, n (%) | | | 0.425 |
| 3–6 days | 237 (31.9%) | 228 (30.7%) | |
| 7–10 days | 342 (46.1%) | 366 (49.3%) | |
| 11–14 days | 163 (22.0%) | 148 (19.9%) | |
| Size of ETT, n (%) | | | 0.883 |
| 7 | 18 (24.7%) | 26 (25.1%) | |
| 7.5 | 23 (31.5%) | 35 (34.3%) | |
| 8 | 32 (43.8%) | 41 (40.2%) | |
| Cuff pressure, n (%) | | | < 0.01 |
| < 25 cm $H_2O$ | 287 (41.4%) | 151 (20.4%) | |
| 25–30 cm $H_2O$ | 422 (56.9%) | 582 (78.4%) | |
| > 30 cm $H_2O$ | 13 (1.8%) | 9 (1.2%) | |
| Number of VAP patients, n (%) | | | 0.543 |
| VAP | 10 (13.7%) | 11 (11.9%) | |
| No VAP | 63 (86.3%) | 92 (88.1%) | |

The maintenance of ETT cuff pressures within the recommended range could reduce the risk of the aspiration of subglottic secretions past the cuff and reduce the incidence of VAP. After the intervention, the incidence of VAP decreased, but there was no statistical significance ($P > 0.05$) between the baseline group and the intervention group. The main reason may be that the sample size of the study was not large enough (73 cases in the baseline group and 102 cases in the intervention group). If the sample size is increased, the incidence of VAP may be statistically significant. And VAP can be reduced by some measures, such as novel multimodal hand hygiene system [27], endotracheal tube with polyurethane cuff and subglottic secretion drainage [28], semirecumbent position (45-degree) [29], and duodenal versus gastric feeding [30]. However, the intervention measures in this study did not include these factors.

There were still some shortcomings in this study: we could not collect and analyse all the factors that might affect the cuff pressure. Further research is needed to determine whether the use of a mobile terminal application program for ETT cuff pressure measurement can significantly reduce the incidence of VAP.

## 5 Conclusion

The application of the mobile terminal application program used for ETT cuff pressure measurement could improve the percentage of ETT cuff pressure measurements that fall within the recommended range.

## Compliance with ethical standards

**Conflict of interest** All authors declare that they have no conflict of interest.

**Ethical approval** All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Dec-

laration of Helsinki and its later amendments or comparable ethical standards.

## References


1. Bassi GL, Ferrer M, Marti JD, et al. Ventilator-associated pneumonia. Semin Respir Crit Care Med. 2014;35(4):469–81.
2. Touat L, Fournier C, Ramon P, et al. Intubation-related tracheal ischemic lesions: incidence, risk factors, and outcome. Intensiv Care Med. 2013;39(4):575–82.
3. Hameed AA, Mohamed H, AI-Mansoori M. Acquired tracheoesophageal fistula due to high intracuff pressure. Ann Thorac Med. 2008;3(1):23–5.
4. Rello J, Soñora R, Jubert P, et al. Pneumonia in intubated patients: role of respiratory airway care. Am J Respir Crit Care Med. 1996;154(01):111–5.
5. Joseph NM, Sistla S, Dutta TK, et al. Ventilator-associated pneumonia: a review. Eur J Intern Med. 2010;21(5):360–8.
6. Xie DS, Xiong W, Lai RP, et al. Ventilator-associated pneumonia in intensive care units in Hubei Province, China: a multicentre prospective cohort survey. J Hosp Infect. 2011;78(4):284–8.
7. Zhang JY, He QQ, Zhou B, et al. Risk factors for ventilator-associated pneumonia in ICU patients. Chin J Nosocomiol. 2015;25(15):3467–9.
8. Restrepo MI, Anzueto A, Arroliga AC, et al. Economic burden of ventilator associated pneumonia based on total resource utilization. Infect Control Hosp Epidemiol. 2010;31(5):509–15.
9. Melsen WG, Rovers MM, Groenwold RH, et al. Attributable mortality of ventilator-associated pneumonia: a meta-analysis of individual patient data from randomised prevention studies. Lancet Infect Dis. 2013;13(8):665–71.
10. Liu J, Zhang X, Gong W, et al. Correlations between controlled endotracheal tube cuff pressure and postprocedural complications: a multicenter study. Anesth Analg. 2010;111(5):1133–7.
11. Hoffman RJ, Parwani V, Hahn IH. Experienced emergency medicine physicians cannot safely inflate or estimate endotracheal tube cuff pressure using standard techniques. Am J Emerg Med. 2006;24(2):139–43.
12. Soni R, Mehta K, Mehta T, et al. Influence of ventilator-associated pneumonia on length of stay for hospitalized patient requiring mechanical ventilation: a nationwide analysis. Chest. 2014;146(4_MeetingAbstracts):206A.
13. Nseir S, Brisson H, Marquette CH, et al. Variations in endotracheal cuff pressure in intubated critically ill patients: prevalence and risk factors. Eur J Anaesthesiol. 2009;26(3):229–34.
14. Li J, Zhan QY, Liang ZA, et al. A questionnaire survey on the current practices of respiratory care in intensive care unit in 30 provinces. Zhongguo Wei Zhong Bing Ji Jiu Yi Xue. 2009;21(4):211–4.
15. Xiang YJ, Sai DH. Investigation and analysis on nurses' recognition on the related knowledge of cuffed balloons administration for patients with endotracheal tube. Chin J Mod Nurs. 2010;16(21):2512–5.
16. Fu Y, Xi XM. Analysis on risk factors of endotracheal cuff under inflation in mechanically ventilated patients. Zhonghua Wei Zhong Bing Ji Jiu Yi Xue. 2014;26(12):870–4.
17. Jaillette E, Zerimech F, De Jonckheere J, et al. Efficiency of a pneumatic device in controlling cuff pressure of polyurethane-cuffed tracheal tubes: a randomized controlled study. BMC Anesthesiol. 2013;13(1):50.
18. Lorente L, Lecuona M, Jiménez A, et al. Continuous endotracheal tube cuff pressure control system protects against ventilator-associated pneumonia. Crit Care. 2014;18(2):R77.
19. Patel V, Hodges EJ, Mariyaselvam MZ, et al. Unintentional endotracheal tube cuff deflation during routine checks: a simulation study. Nurs Crit Care. 2019;24(2):83–8.
20. Bolzan DW, Guizilini S, Faresin SM, et al. Endotracheal tube cuff pressure assessment maneuver induces drop of expired tidal volume in the postoperative of coronary artery bypass grafting. J Cardiothorac Surg. 2012;7:53.
21. Koenig SM, Truwit JD. Ventilator-associated pneumonia: diagnosis, treatment, and prevention. Clin Microbiol Rev. 2006;19(4):637–57.
22. Wunderink RG, Woldenberg LS, Zeiss J, et al. The radiologic diagnosis of autopsy-proven ventilator-associated pneumonia. Chest. 1992;101(2):458–63.
23. Kalil AC, Metersky ML, Klompas M, et al. Executive summary: management of adults with hospital-acquired and ventilator-associated pneumonia: 2016 clinical practice guidelines by the infectious diseases society of America and the American thoracic society. Clin Infect Dis. 2016;63(5):575–82.
24. Sessler CN, Gosnell MS, Grap MJ, et al. The Richmond agitation-sedation scale: validity and reliability in adult intensive care unit patients. Am J Respir Crit Care Med. 2002;166(10):1338–444.
25. Wang CT, Chen M, Yu KJ, et al. Current status of critical care medicine in Eastern China. Chin J Crit Care Intensiv Care Med. 2016;2(1):43–9.
26. Pisano A, Verniero L, Galdieri N, et al. Assessing the correct inflation of the endotracheal tube cuff: a larger pilot balloon increases the sensitivity of the 'finger-pressure' technique, but it remains poorly reliable in clinical practice. J Clin Monit Comput. 2019;33(2):301–5.
27. Koff MD, Corwin HL, Beach ML, et al. Reduction in ventilator associated pneumonia in a mixed intensive care unit after initiation of a novel hand hygiene program. J Crit Care. 2011;26:489–95.
28. Lorente L, Lecuona M, Jiménez A, et al. Influence of an endotracheal tube with polyurethane cuff and subglottic secretion drainage on pneumonia. Am J Respir Crit Care Med. 2007;176:1079–83.
29. Alexiou VG, Lerodiakonou V, Dimopoulos G, et al. Impact of patient position on the incidence of ventilator-associated pneumonia: a meta-analysis of randomized controlled trials. J Crit Care. 2009;24:515–22.
30. Hsu CW, Sun SF, Lin SL, et al. Duodenal versus gastric feeding in medical intensive care unit patients: a prospective, randomized, clinical study. Crit Care Med. 2009;37:1866–72.