Clinical paper

How much experience do rescuers require to achieve successful tracheal intubation during cardiopulmonary resuscitation?**


**Department of Emergency Medicine, School of Medicine, Konkuk University, Konkuk University Medical Center, Seoul, Republic of Korea

*Department of Biology, University of Iowa, Iowa City, IA, USA

**Department of Emergency Medicine, Soonchunhyang University Bucheon Hospital, Bucheon, Republic of Korea

A R T I C L E   I N F O

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A B S T R A C T

Aim: The cardiopulmonary resuscitation (CPR) guidelines recommend that endotracheal intubation (ETI) should be performed only by highly skilled rescuers. However, the definition of ‘highly skilled’ is unclear. This study evaluated how much experience with ETI is required for rescuers to perform successful ETI quickly without complications including serious chest compression interruption (interruption time < 10 s) or oesophageal intubation during CPR.

Methods: This was a clinical observation study using review of CPR video clips in an urban emergency department (ED) over 2 years. Accumulated ETI experience and performance of ETI were analysed. Main outcomes were 1) ‘qualified ETI: successful ETI within 60 s without complications and 2) ‘highly qualified ETI: successful ETI within 30 s without complications.

Results: We analysed 110 ETIs using direct laryngoscopy during CPR. The success rate improved and the time to successful ETI decreased with increasing experience; however, the total interruption time of chest compression did not decrease. A 90% success rate for qualified ETI required 137 experiences of ETIs (1218 days of training). A 90% success rate for highly qualified ETI required at least 243 experiences of ETIs (1973 days of training).

Conclusions: Accumulated experience can improve the ETI success rate and time to successful ETI during CPR. Because ETI must be performed quickly without serious interruption of chest compression during CPR, becoming proficient at ETI requires more experience than that required for non-arrest patients. In our analysis, more than 240 experiences were required to achieve a 90% success rate of highly qualified ETI.

Introduction

Endotracheal intubation (ETI) has been performed as a primary procedure of airway securing during cardiopulmonary resuscitation (CPR) for several decades [1,2]. However, ETI attempts during CPR often cause serious problems because of unrecognized oesophageal intubation or prolonged interruption of chest compression [3–5]. Therefore, the CPR guidelines recommended the ETI should be performed until an expert practitioner is available during CPR [1,2]. However, these guidelines do not indicate the obvious level of physicians expertise needed for rescuer to perform ETI successfully.

Many studies have reported that intubators with more cumulated ETI experience have a higher ETI success rate and good clinical outcomes compared with less experienced intubators [6–9]. Other study has suggested a minimal number of ETI experiences required to achieve a high ETI success rate [7,8,10,11]. However, previous studies have mainly included patients who did not experience cardiac arrest and have focused only on whether ETI was successful upon the first attempt and the number of ETI attempts needed for success. Previous studies have not reported on interruption of chest compression or the time to successful ETI at all.

No reliable study has reported on how much experience, especially during the training of physicians, is required to acquire the skill needed to perform ETI during CPR. The primary aim of this study was to determine the experience level needed for an intubator to become highly skilled at ETI, which can be defined as the ability to perform a fast and...
safe process without serious chest compression interruption or unrecognized oesophageal intubation during CPR.

Methods

This clinical observation study was performed retrospectively using prospectively collected CPR data over 2 years at an urban emergency department (ED) of a tertiary university hospital. The study was performed after approval from the Institutional Review Board for Human Research at our institution (approval number is KUH1260009).

The hospital is located in the mid-eastern part of Seoul, South Korea, and over 50,000 patients visit the ED annually. Our ED has a 4-year resident training curriculum, which accepts 3–5 first-grade residents annually. The first-year ED residents began working in March of their first training year. First-year ED residents worked about 60–80 h a week in the ED, and this included training and teaching time. Second- to fourth-year residents worked about 40–60 h a week in the ED, and had 2-month placements in other departments each year. During the first 3 months of their training, first-year residents participated in monthly airway education sessions comprising basic, advanced and difficult airway management. All training sessions included a comprehensive lecture and multiple trials of ETI using a manikin and cadavers. To acquire the necessary ETI skills during ED residency, we allowed first-year residents to perform ETI under the supervision of ED faculty or senior residents. All residents performed ETI intermittently when on duty, and they performed about 40–60 ETIs annually.

About 120–130 CPRs are performed in the ED for out-of-hospital or in-hospital cardiac arrest patients every year. ED residents are mainly responsible for providing advanced cardiovascular life support (ACLS) along with ED faculties and experienced nurses. In the ACLS teams, ETI attempts are performed mainly by ED residents who complete a well-organized ETI training course and had experiences of real world ETIs for various emergency patients. ETI attempts during CPR are randomly assigned to the resident or staff on duty who is competent to perform the ETI immediately.

A closed-circuit television system (MagicRadar™ Cs16 System; Safelong Co., Ltd, Shenzhen, China) in our ED automatically records all performances of physicians and nurses when delivering ACLS to arrest patients. When an ETI is attempted, all electrical rhythm sheets are obtained from a monitor/defibrillator device and collected for evaluation of the duration of interrupted chest compressions. To analyse the accumulated number of ETIs per resident enrolled in this study, all previous data for ETIs were collected from the intubation registry forms between 2008 and 2013. High cognitive load or emotional and psychological stress experienced by the intubators at night or weekend may be related to a lower level of concentration when trying to perform ETI during CPR. We also evaluated time factors for CPR events (night or day/evening, weekend or weekday). Night was defined as the hours 23:00 to 6:59 the next morning, and the weekend was defined as 23:00 on Friday to 6:59 on Monday morning [12].

The inclusion criteria for the study were all ETIs performed by ED residents using a conventional direct laryngoscope for adult cardiac arrest patients. We excluded ETIs involving 1) use of other adjunctive devices such as supra-glottic airway or indirect laryngoscope, 2) ETIs for traumatic cardiac arrest patients who needed cervical immobilization during ETI, and 3) attempts by residents of another major or faculty. Video data were reviewed after consent was provided from all enrolled ACLS team members and all patients or the bereaved family. Two separate researchers judged the success of ETIs and measured the time variables using a stopwatch independently by reviewing the CPR video clips and electrical rhythm sheets. In cases of serious differences in the review data, the main researcher repeated the review until the two analysed values matched.

The outcomes of the study included 1) successful ETI on the first attempt; 2) time to successful ETI, which was defined as the total duration from initiation of the advance of the blade into the patient’s mouth to successful delivery of the first ventilation using the bag; and 3) the total duration of interrupted chest compressions during the first ETI attempt. Adverse events associated with ETI performance were also evaluated and included oesophageal intubation, endobronchial intubation (defined as repositioning of the inserted tube after lung auscultation during CPR or checking the chest radiography after recovery of spontaneous circulation) and combined occurrence of serious interruption of chest compression (defined as consecutive interruption of chest compression > 10 s) [13,14].

The cases included in the study were categorized into the following five quintiles of accumulated ETI experience of intubators: Q1 (lowest experience, 0–20% of the study subjects), Q2 (lower experience, 21–40% of the study subjects), Q3 (medium experience, 41–60% of the study subjects), Q4 (high experience, 61–80% of the study subjects), and Q5 (highest experience, 81–100% of the study subjects). To provide a more detailed definition of a successful ETI during CPR (which should be performed rapidly without adverse events) and by referencing the CPR guidelines and other previous opinions, we defined a ‘qualified ETI’ as a successful ETI performed within 60 s without serious interruption of chest compression or oesophageal intubation and ‘highly qualified ETI’ as a successful ETI performed within 30 s without serious interruption of chest compression or oesophageal intubation [1,2,8].

For statistical analysis, we used a chi-square test or Mann–Whitney rank-sum test to compare the outcomes between groups. Kaplan–Meier analysis was used to analyse the cumulative rate associated with the time variables. The generalized Wilcoxon test was used to compare the cumulative success rates between groups. Simple linear regression analysis was performed to evaluate relationships between two consecutively measurable variables. Two-sided p-values < 0.05 were considered to be significant. Data were analysed using IBM SPSS Statistics (version 21.0; SPSS, Inc., Armonk, NY).

Results

During the 2-year study period from April 2011 to March 2013, a total of 255 CPRs were performed for out-of-hospital or in-hospital adult (aged > 18 years) cardiac arrest patients. A total of 162 cases were excluded for the following reasons: video recording problems (12 cases), disturbance of the video review (8 cases), a “Do Not Attempt CPR” order before the ETI (10 cases), previously placed advanced airways before ED arrival (27 cases), ETI performed using video laryngoscopy (83 cases), ETI by faculty or other major (three cases), and traumatic cardiac arrest patients who need cervical immobilization (19 cases). Finally, total 110 trials of ETI for 93 adult CPR patients were enrolled in this study. Eleven ED residents who were regular users of direct laryngoscopy participated in the study.

The 110 cases were categorized into the five quintiles Q1–Q5, each of which comprised 22 cases, according to the accumulated ETIs. Table 1 and Fig. 1 shows the overall data for ETIs and a comparison of the ETI performance between quintile groups Q1 to Q5. The overall success rate of the first attempt at ETI was 68.2%, and it tended to increase with the accumulated experience of ETIs. A total of 11 oesophageal intubations were reported, and there were no unrecognized oesophageal intubations. The incidence of endobronchial intubation did not differ between quintile groups Q1–Q5. For affecting the chest compression quality during CPR, there is no statistical difference in the number of serious interruption of chest compression and total time of chest compression interruption between groups (Table 1 and Fig. 2). The numbers of participants who performed qualified ETIs and highly qualified ETIs were significantly higher in the higher quintile groups (Table 1).

We used linear regression analysis to estimate how many experiences are required to achieve a qualified ETI or highly qualified ETI. We derived formulas for estimating the relationship between the median number of ETI experiences and the rates of qualified and highly qualified ETI, using linear regression analysis and the existing data. The
formulas were: 1) Probability of qualified successful ETI (%) = 0.504 × number of ETI experiences + 10.752 (p = 0.051); 2) Probability of highly qualified successful ETI (%) = 0.432 × number of ETI experiences − 14.914 (p = 0.006). The estimated probability of an 80% qualified ETI success rate required 137 ETI experiences and that of a 90% qualified ETI success rate required 157 experiences. The estimated probability of an 80% highly qualified successful ETI rate required 220 ETI experiences and that of a 90% highly qualified success rate required 243 ETI experiences (Fig. 3).

We also estimated the success rates for qualified ETIs and highly qualified ETIs according to the days of ED training in general. The formulas are as follows: 1) probability of qualified successful ETI (%) = 0.057 × days of ED training in general + 20.576 (P = 0.046), and 2) probability of highly qualified successful ETI (%) = 0.049 × days of ED training in general − 6.684 (P = 0.002). The estimated probability of an 80% qualified ETI success rate required 1042 days (2.8 years) of training, and a 90% success rate required 1218 days (3.3 years) of training. An estimated probability of a 80% highly qualified successful ETI rate required 1793 days (4.9 years) of training, and 90% success rate required 1973 days (5.4 years) of training (Fig. 4).

Discussion

Traditionally, most physicians view ETI as the first choice for airway management of critically ill patients [15]. However, the overriding the establishment of ETI remains a controversial issue in the treatment of cardiac arrest patient [1]. Inherently, ETI for arrest patients has overwhelming advantages over bag-mask device (BMD) such as the ability to supply more effective ventilation, protection against lung aspiration, avoidance of gastric regurgitation and no need to pause compressions during ventilation [16]. However, previous studies that compared the outcomes of out-of-hospital cardiac arrest between the ETI and BMD did not show superiority of ETI over BMD, and some have shown worse outcomes for ETI use [17–22]. The superiority of BMD over ETI may be explained by the wide gap in difficulty between the two devices; the ability to use the airway-ventilation BMD can be quickly acquired.

Table 1
Baseline data of subjects and comparison of data between quintile groups.

<table>
<thead>
<tr>
<th>Overall (n = 110)</th>
<th>Lowest Q1 (n = 22)</th>
<th>Lower Q2 (n = 22)</th>
<th>Med Q3 (n = 22)</th>
<th>High Q4 (n = 22)</th>
<th>Highest Q5 (n = 22)</th>
<th>p-value</th>
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<tr>
<td>Baseline</td>
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<td>No. of ETI experiences, median (IQR)</td>
<td>68 (38.95)</td>
<td>26 (22.28)</td>
<td>36 (31.40)</td>
<td>55 (49.61)</td>
<td>81 (74.90)</td>
<td>103 (101,123)</td>
</tr>
<tr>
<td>Days of ED training in general, median (IQR)</td>
<td>338 (138.589)</td>
<td>79 (43.199)</td>
<td>164 (133,239)</td>
<td>285 (252,424)</td>
<td>491 (407,636)</td>
<td>775 (665,925)</td>
</tr>
<tr>
<td>ETI at night, n (%)</td>
<td>13 (11.8)</td>
<td>2 (8.7)</td>
<td>3 (12.5)</td>
<td>1 (5.3)</td>
<td>4 (18.2)</td>
<td>3 (13.6)</td>
</tr>
<tr>
<td>ETI at weekend, n (%)</td>
<td>37 (33.6)</td>
<td>12 (52.2)</td>
<td>6 (25.0)</td>
<td>3 (15.8)</td>
<td>7 (31.8)</td>
<td>9 (40.9)</td>
</tr>
<tr>
<td>ETI performance</td>
<td></td>
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<td>1st attempt success, n (%)</td>
<td>75 (68.2)</td>
<td>8 (36.4)</td>
<td>15 (68.2)</td>
<td>15 (68.2)</td>
<td>19 (86.4)</td>
<td>18 (81.8)</td>
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<tr>
<td>Time to successful ETI (sec), mean (SD)</td>
<td>63.1 (3.2)</td>
<td>81.5 (7.8)</td>
<td>62.2 (5.0)</td>
<td>65.0 (7.1)</td>
<td>56.2 (6.2)</td>
<td>48.8 (5.0)</td>
</tr>
<tr>
<td>Oesophageal intubation, n (%)</td>
<td>11 (10.0)</td>
<td>3 (13.6)</td>
<td>3 (13.6)</td>
<td>3 (13.6)</td>
<td>1 (4.5)</td>
<td>1 (4.5)</td>
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<tr>
<td>Endo-bronchial intubation, n (%)</td>
<td>2/75 (2.7)</td>
<td>1/9 (11.1)</td>
<td>0/15 (0.0)</td>
<td>0/15 (0.0)</td>
<td>0/19 (0.0)</td>
<td>1/18 (5.3)</td>
</tr>
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<td>Occurrence of serious interruption of chest compression, n (%)</td>
<td>25 (22.7)</td>
<td>3 (13.6%)</td>
<td>3 (13.6)</td>
<td>8 (36.4)</td>
<td>5 (22.7)</td>
<td>6 (27.3)</td>
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<td>Total interruption time of chest Compressions (sec), mean (SD)</td>
<td>8.6 (1.2)</td>
<td>8.2 (2.1)</td>
<td>5.0 (1.0)</td>
<td>8.5 (1.7)</td>
<td>7.9 (2.4)</td>
<td>10.3 (3.1)</td>
</tr>
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<td>Qualified successful ETI, n (%)</td>
<td>44 (40.0)</td>
<td>3 (13.6)</td>
<td>9 (40.9)</td>
<td>9 (40.9)</td>
<td>10 (45.5)</td>
<td>14 (63.6)</td>
</tr>
<tr>
<td>High-qualified successful ETI, n (%)</td>
<td>12 (10.9)</td>
<td>0 (0)</td>
<td>0 (0)</td>
<td>1 (4.5)</td>
<td>4 (18.2)</td>
<td>7 (31.8)</td>
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ETI; Endotracheal intubation, IQR; Interquartile ranges (25%,75%), SD; Standard Deviation.

Fig. 1. Comparison of the time to complete endotracheal intubation in the five quintile groups, assessed using Kaplan–Meier analysis.

Fig. 2. Comparison of the total number of chest compression interruptions in the five quintile groups, assessed using Kaplan–Meier analysis.
Otherwise acquisition of the highly qualified ETI skill demands more complex training and a high volume of clinical experiences [16]. Some paramedics or physicians who are responsible for ETI performance in out-of-hospital or in-hospital CPR may not have sufficient ETI skills, which may cause frequent failure at first attempt or delay of ETI, unrecognized oesophageal intubations and serious interruption of chest compressions that can adversely affect the outcomes of CPR. Several observational studies in hospital setting have reported over 90% overall success rates regardless of the attempted numbers. However, if the success rate is confined to success only on the first attempt, the success rate is lower. The study by Wang et al reported 61.7% of success rates on the first attempt [18], and reported first attempted success rates in multicentre studies in Japan were 40–83% [23]. In our cohort, only about 70% of ETIs succeeded on the first attempt only. For time for successful ETI, in this study even highly experienced residents needed about 50 s to perform an ETI successfully. Considering that most successful ETIs seldom require more than 20–30 s in the hospital setting, especially in the operating room, the observed in our study seems to be long. Different from the treatment of non-arrest patients, in patients requiring CPR, shaking the body by continuously delivering chest compressions may obstruct the rescuer’s view of the glottis or may disturb the insertion of the tube into the trachea. Unpredictable events, including checking the rhythm, defibrillation, presence of vomitus or blood in the airway and airway suctioning can also occur, and these may delay completion of ETI.

Unfortunately, there were few data for the time needed to complete ETI during CPR because of difficulties in assessing the time variables in the CPR setting. One clinical study reported that the time to the first attempt at ETI is 1.4 min in the in-hospital CPR setting [24] except our cohort. Insufficient ETI skills may cause unrecognized oesophageal intubations during CPR. The documented incidence of unrecognized oesophageal intubations ranges widely from 0.5% to 17% [3,4,25–28]. The incidence of unrecognized oesophageal intubations by expert physicians is extremely low. One study reported only 0.5% of unrecognized oesophageal intubations among ETIs by emergency physicians [28]. But other pre-hospital settings, which may involve less experienced paramedics, have reported higher incidence rates of unrecognized oesophageal intubation such as 2.4%, 6%, 9% and 17%. In our study, the incidence of oesophageal intubation reported was 10.0%. Our cohort included lesser experienced residents in training, who may have a higher rate of oesophageal intubation (which can reach 13.6%). However, there was no serious unrecognized oesophageal intubation because ED staff or senior residents checked immediately whether the intubations were successful using end-tidal CO₂ monitoring or direct viewing of the glottis.

About 25% of all interruptions of chest compression are related to the performance of ETI [5]. An observational study reported that the ETI failure rate can be as high as 50% when ETIs are performed in the pre-hospital setting, where staff experience a lower volume of ETIs.
Therefore, to minimize the risk of hypoxia or chest compression interruption during the procedure, ETI should be performed only by expert rescuers with high ETI success rates [1,2]. The key question is how much experience is needed to achieve successful ETI quickly with minimal interruption of chest compression during CPR.

Various institutional factors, such as preferences for procedures, capacity of the learning system, and number of ETIs performed over time, can affect the learning curve [31–34]. In particular, accumulated experience of ETI in real-world situations is thought to be the most important factor for achieving proficiency in ETI [16]. ETI training programs and treatment guidelines note that experience performing a certain number of ETIs is essential to determining the optimal rate of successful ETI. Studies have tried to determine the cumulative number of ETIs needed to acquire proficiency with this technique. These studies have focused mainly on evaluating the number of ETIs to achieve a high success rate of 80–90% [6–8,10,11]. In the operating room setting, 20–57 ETI experience has been reported to be required to achieve a 90% success rate [6–8]. In the pre-hospital setting, it has been suggested that paramedic students may require 15–25 or more live ETI experiences across clinical settings in all areas to achieve a 90% success rate [35]. Konard et al. suggested that a mean 57 ETI attempts is required to achieve a success rate of 90% [7]. The statistical modelling by Julian et al. indicated that a 90% probability of a “good intubation” required 47 attempts [8]. A range of 30–60 ETIs was supposed to be the minimum necessary to achieve a 90% success rate in ETI.

Application of these results to CPR situations seems to be problematic because specific factors that can adversely affect the outcomes of arrest patients are not considered at all. Even when an intubator completes an ETI on the first attempt, a successful ETI may not lead to better outcomes if some problematic events occur during the ETI process. A prolonged time until successful ETI can worsen the patient’s hypoxia. Prolonged interruption of chest compression can interfere with the ability to deliver high-quality CPR and may lead to adverse outcomes in arrest patients. Previous studies of the learning curve of ETI have not included these elements, and more accurate definitions should be established to determine the expertise level required for successful ETI during CPR. Unfortunately, current guidelines do not define the level of required expertise of intubators responsible for performing ETI in arrest patients.

In this study, we newly designed two outcomes of successful ETI in CPR situations: ‘qualified success’ and ‘highly qualified success’. The ETI success rates of qualified and highly qualified ETI tended to increase with the number of ETI experiences. In our estimating model using linear regression formula, more ETI experience was required for 80% or 90% success rates during CPR compared with the numbers reported in other studies, which found that 30–60 ETIs was sufficient to achieve 80–90% ETI success rates. For successful qualified ETIs (success within 60 s), 80% and 90% success rates required 137 and 157 experiences with ETI, respectively. For successful highly qualified ETIs (success within 30 s), 80% and 90% success rates required 220 and 243 experiences with ETI, 4–8 times more experiences than the numbers in previous studies which enrolled non-arrest patients. In our hospital setting, about 3 years of training would be required to achieve an 80% success rate and 4 or more years to achieve a 90% success for qualified ETI. The respective years for 80% or 90% success rate for highly qualified ETI would be about 5 or 5.4 years of training, respectively. For rescuers who responsible to manage the airway of arrest patients becoming proficient at ETI requires numerous days of training period than that required for non-arrest patients.

The number of ETI experiences found to be necessary for performing ETI successfully in our study may be unrealistic for many clinicians or paramedics in the real world, except for anaesthetists or some emergency doctors who have more frequent ETI experiences. ETI is accepted as a method for elemental airway management, but numerous studies have shown no superiority, and some inferiority, of ETI in terms of outcome compared with other methods of airway management such as the use of supraglottic airway devices or use of a BMD despite the overwhelming benefits [17,18,20,22]. ETI during CPR may be more technically difficult than it appears, and some institutions with lower volumes of ETI experiences might consider abandoning the use of ETI and choosing a method involving supra-glottic airway devices or BMD, which are easier airway-management methods than ETI. However, ETI is still the best option for airway management of arrest patients. Another option is to waive using direct laryngoscopy for ETI and instead using another device for ETI, such as video-laryngoscopy primarily which can be a good candidate. More evidence from well-designed comparative studies is needed in future.

There are some limitations to this study. First, our data may not be generalizable to all institutions because this study was conducted at a single hospital comprising a small sample of participants. The number of ETIs required to become proficient, the number of CPR performed and policies about primary airway management can differ for out-of-hospital vs. in-hospital arrest. To understand this problem more completely, multi-centre studies with large sample sizes are needed. Second, in 2010, our ED was equipped with video-laryngoscopy as an adjuvant airway tool and has included the use of video-laryngoscopy into resident airway training system since then. During a 2-year study period, some residents preferred to use the video-laryngoscopy as a primary airway tool during CPR and we could not control this choice. Therefore, nearly 50% of cases of ETI using video-laryngoscopy were dropped from this cohort, which resulted in fewer cases than we expected being enrolled in this study. Third, the degree of difficulties performing ETI, such as the Mallampati grade, neck mobility, mouth opening and thyromental distance or grade of view, such as the Cormack and Lehane view, may have affected the outcomes of this study. Unfortunately, these data could not be obtained because some intubators could not evaluate the difficulty level of ETI or recall the corrected glottis view under the chaotic environment of CPR situations.

Conclusions

Accumulated experience can improve the ETI success rate and time to successful ETI during CPR. Because ETI must be performed quickly without serious interruption of chest compression during CPR, becoming proficient at ETI requires more experience than that required for non-arrest patients. In our analysis, more than 240 experiences (5.4 years of training in general) were required to achieve a 90% success rate of highly qualified ETI.

Conflict of interest statement

All authors have no conflicts of interest to declare.

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Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.resuscitation.2018.08.032.

References


