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Clinical paper

Tracheal intubation during pediatric cardiopulmonary resuscitation: A videography-based assessment in an emergency department resuscitation room☆

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ABSTRACT

Objectives: To describe procedural characteristics of tracheal intubation (TI) during cardiopulmonary resuscitation (CPR) in a pediatric emergency department, and to characterize interruptions in CPR associated with TI performance.
Methods: Retrospective single center case series. Resuscitations in a pediatric ED are videorecorded for quality improvement. Children who underwent TI while receiving chest compressions were eligible for inclusion. Intubations done by methods other than direct laryngoscopy were excluded. Background data included patient age and training background of intubator. Data on intubation attempts (success, laryngoscopy time) and chest compressions (interruptions, duration of pauses) were collected.
Results: Between December 2012 and February 2014, 32 patients had 59 TI attempts performed during CPR. Overall first attempt success at TI was 15/32 (47%); a median of 2 attempts were made per patient (range 1 to 4). Median laryngoscopy time was 47 s (range 8–115 s). 32/59 (54%) TI attempts had an associated interruption in CPR; the median interruption duration was 25 s (range 3–64 s). TI attempts without interruption in CPR were successful in 20/32 (63%) compared to 11/27 (41%) when CPR was paused ($p = 0.09$). Laryngoscopy time was not significantly different between TI attempts with (47 ± 21 s) and without (47 ± 26 s; $p = 0.2$) interruptions in compressions. 25/32 (78%) of pauses exceeded 10 s in duration.
Conclusions: TI during pediatric CPR results in significant interruptions in chest compressions. Procedural outcomes were not significantly different between attempts with and without compressions paused. In children receiving CPR, TI should be performed without pausing chest compressions.

Background

Cardiac arrest in the pediatric patient is frequently the result of respiratory insufficiency, with hypoxia and/or hypercarbia culminating in cessation of effective pulsatile blood flow. Population based studies have demonstrated that pediatric patients suffering out-of-hospital cardiac arrest due to non-cardiac causes have more favorable outcomes when ventilations and compressions are performed, as opposed to chest compressions alone.[1] Published guidelines on pediatric cardiopulmonary resuscitation continue to recommend positive pressure ventilation along with chest compressions for the child in cardiac arrest.[2]

Pediatric resuscitation guidelines recognize that an advanced airway in the form of an endotracheal tube is the optimal method of providing positive pressure ventilation. However, performing tracheal intubation (TI) in children can be challenging. Studies have uniformly shown a poorer success rate at emergency TI among pediatric patients than among adult patients in multiple clinical settings.[3] Advanced airway placement during CPR is fraught with technical challenges (e.g. blood or secretions in pharynx), the need for rapid completion of the procedure (minimizing interruptions in compressions), and the experiential challenges of a rare event at the provider level. Adult and pediatric prehospital cardiac arrest data has shown that tracheal intubation is not associated with improved

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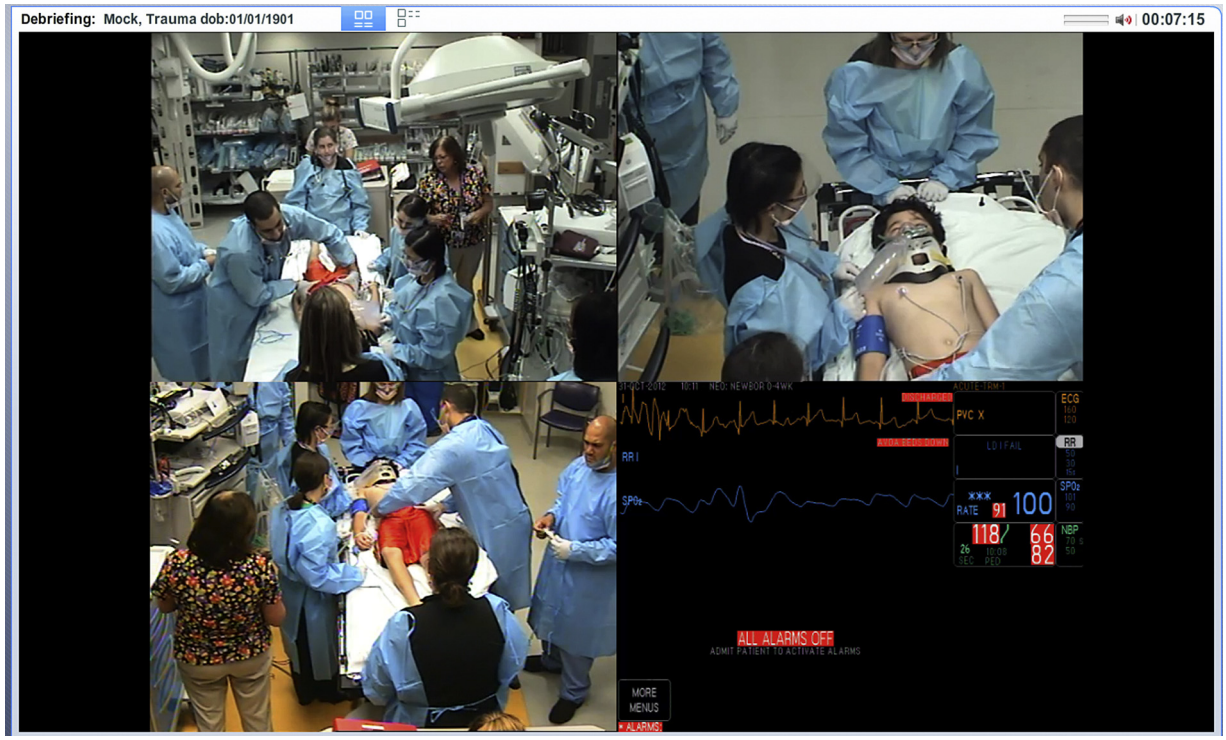

Fig. 1. Video recording system configuration (simulated patient).

survival.[4–6] Clinical studies documenting the impact of intubation on pediatric CPR performance are lacking in currently published literature.

We report data from a novel quality assurance and improvement program in a tertiary pediatric emergency department (ED) where resuscitative care is video-recorded. We sought to describe TI practice in pediatric patients receiving chest compressions. We hypothesized that TI attempts would constitute a significant source of interruptions in chest compressions, and that significant differences in success rates and duration of attempts would exist between attempts made with and without interruptions in chest compressions.

Methods

This was an observational study done in the emergency department of a single tertiary pediatric center between December 2012 and February 2015. Resuscitative care in the ED is video recorded as a part of a peer-reviewed, intradivisional continuous quality assurance program, created by a multidivisional task force including legal, risk management, and patient safety divisions. Patient/parent consent is obtained at the time of consent for treatment. Video-recording is done using three synchronized camera views (Fig. 1) plus a view of the monitor waveforms (LiveCapture, BLine Medical, Washington, DC). Videos are reviewed and deidentified data is collected on common resuscitative procedures, including CPR and TI. Following bimonthly video review sessions and data collection, videos are deleted after 30 days and are not retained as a part of the permanent patient medical record. Because the data was collected as part of an existing quality assurance program, the study was exempted from oversight by the Institutional Review Board of the Children's Hospital of Philadelphia.

Patients were eligible for inclusion if they had at least one attempt at TI while receiving chest compressions in the ED resuscitation bay under video-recorded conditions. Patients who underwent TI either before or after a period of chest compressions were excluded. Patients whose intubation and/or chest compressions were incompletely recorded on video were excluded. Patients were also excluded if they were intubated using a method other than direct laryngoscopy (e.g. videolaryngoscopy, fiberoptic bronchoscopy, surgical).

All data was collected by retrospective review of video recordings by members of the investigative team. Patients were categorized by age as either newborns (age 0–28 days), infants (age 28 days to one year), children (age 1 year to 7 years), and adolescent/adult (age > 8 years). Physicians attempting TI were categorized by level of training (resident, fellow, attending).

Chest compressions were considered 'interrupted' if a single provider stopped compressions for any reason, including to change compressors. Interruptions in compressions were measured in duration (seconds) and were secondarily dichotomized into greater than or less than 10 s; a minimum duration of 1 s was given to transient interruptions (e.g. a change in compressor that was rapidly accomplished). TI attempts were classified dichotomously as occurring with a pause in compressions (as defined above) or with compressions uninterrupted. Chest compression fraction was defined as the amount of time from the start of CPR to the conclusion of the event (ROSC or death) during which compressions were in progress, expressed as a percentage of the total arrest time.

A successful TI attempt was one where an endotracheal tube was successfully placed in the trachea prior to removal of the laryngoscope, as evidenced by exhaled carbon dioxide detection, either by colorimetric device or by waveform capnography (both of which are apparent from video review). Given that the patients being enrolled were in cardiac arrest, we anticipated that exhaled carbon dioxide detection might exhibit imperfect specificity (i.e. a successfully intubated patient might not yield detectable exhaled carbon dioxide); it was agreed a priori by the investigative team that such cases would be reviewed for secondary signs of successful tube placement such as chest wall motion with positive pressure. Time of laryngoscopy was defined as the time from insertion of a laryngoscope blade into the patient's mouth to the time when the blade was removed for any reason, whether a tube was inserted or not.

Table 1
Patient characteristics ($n = 32$).

Age category	
• Newborn	2
• Infant	15
• 1–8 yo	7
• >8 yo	8
Arrest location	
• OHCA	29
• IHCA	3
Illness category	23
• Medical	9
• Trauma	
C spine immobilization	2
ROSC	5
Survival to admission	5
Survival to discharge	OHCA: 0/29 IHCA: 2/3

All variables and outcomes were summarized descriptively. Unadjusted univariate analysis was performed between TI attempts with and without pauses in compressions using chi square analysis for successful TI and nonparametric analysis (Wilcoxon rank sum) for duration of attempt. All statistical analysis was performed using STATA Version 12 (STATA Corporation, College Station, TX).

Results

32 patients underwent 59 TI attempts during CPR events during the study period. Clinical characteristics, including Utstein outcomes from cardiac arrest, and procedural characteristics are summarized in Table 1. Overall first attempt success at TI was 15/32 (47%). TI was successful in 30/32 patients; two patients had their resuscitation terminated without successful placement of an advanced airway. TI attempt success stratified by provider group and patient age category are shown in Table 2. TI success was 11/27 (41%) during attempts with no interruptions in chest compressions and 20/32 (63%) during attempts with compressions interrupted ($p = 0.09$). Details for all TI attempts on all patients are summarized in Fig. 2.

Median laryngoscopy time for all attempts was 47 s (IQR 29–57 s). Laryngoscopy time stratified by provider group, patient age category, and success are shown in Fig. 3. Median laryngoscopy time was 47 s (IQR 34–53 s) during attempts with interruptions in chest compressions and 48 s (IQR 22–69 s) during attempts with no interruption in compressions ($p = 0.2$). There were no significant differences in laryngoscopy time when stratified by patient age,

Table 2
Tracheal intubation outcomes by patient age and intubator category ($n = 59$ attempts).

Category	Successful attempts/total attempts (%)
Patient age*	
• Newborn	1/2 (50)
• Infant	14/37 (38)
• 1–8 years	8/9 (90)
• >8 years	8/11 (73)
Intubator category**	
• Resident (EM PGY-3 or greater)	5/7 (71)
• Fellow (PEM or PCCM)	17/32 (53)
• Attending (PEM or PCCM)	9/20 (45)

* 2-sided Fisher's exact: $p = 0.009$.
** 2-sided Fisher's exact: $p = 0.38$.

Duration of interruptions in chest compressions associated with TI attempts are displayed graphically in Fig. 4a (in 5-s increments). 25/32 (78%) interruptions in chest compressions for TI attempts exceeded 10 s in duration. Duration of chest compression interruptions stratified by patient age, provider group, and success are shown in Fig. 4b. Median chest compression fraction for all 32 patient events was 90% (range 84–99%). There was no significant difference in chest compression fraction among patients who had chest compressions interrupted for TI attempts (median 90%, range 84–96%) compared with patients who had no interruptions during TI attempts (median 90%, range 86–99%; $p = 0.3$).

Discussion

To our knowledge, this is the first published study where the duration of CPR interruption during TI attempts in actual pediatric patients was directly measured and reported. In our study we showed that, among children receiving CPR in a pediatric ED, attempts at TI were frequently associated with interruptions in chest compressions. The majority of interruptions in CPR during TI attempts exceeded the recommended the maximal 10 s pause in chest compressions. We also showed that the proportion of successful TI attempts was greater when chest compressions were interrupted than when compressions were continuous; however, this difference did not achieve statistical significance.

A recent consensus statement from the American Heart Association on CPR quality examined intubation during CPR in the context of maximizing chest compression fraction, stating "the optimal time for insertion of an advanced airway during management of cardiac arrest has not been established".[7] The recommended approach to TI in the arrested patient includes attempting TI with

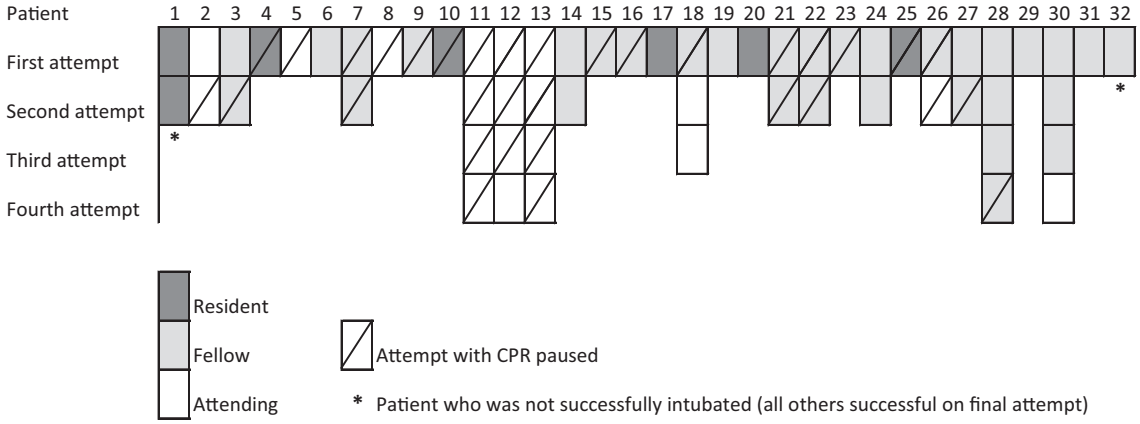

Fig. 2. Tracheal intubation attempt data.

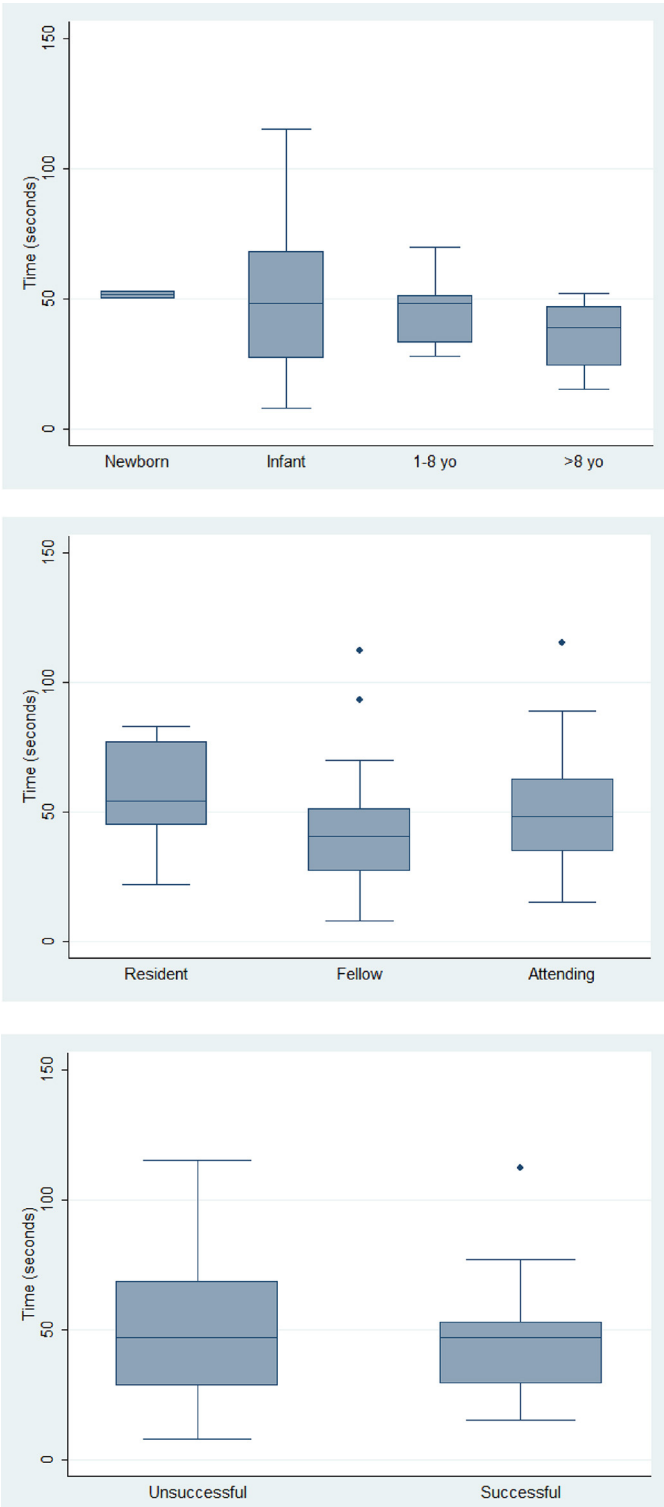

Fig. 3. Laryngoscopy time by patient age category, intubator category, and procedure outcome.

chest compressions in progress, and keeping pauses as short as possible, ideally less than 10 s. Our data demonstrates that large majority of pauses in chest compressions during TI in children exceeded this recommended duration. Our data suggest that interruptions in chest compressions for TI, when they occur, have significant potential to impact chest compression fraction during a CPR event. Despite this, all recorded events were at or above the recommended goal of 80% for compression fraction, and patients with TI-associated interruptions in chest compressions did not have a significant decrease in compression fraction.

Studies examining the impact of TI on outcomes from cardiac arrest in children have predominantly examined prehospital intubation during out-of-hospital cardiac arrest. Published case series of pediatric out of hospital cardiac arrest (OHCA) patients have yielded inconsistent results in terms of the impact of intubation on the incidence of ROSC and survival to admission.[5,8] Gausche-Hill et al. reported on a controlled trial comparing bag-valve mask ventilation to tracheal intubation for out-of-hospital respiratory failure in children and found no difference in survival; a subgroup analysis within this trial was done examining children with OHCA and the findings remained negative.[4] In a report from the Cardiac Arrest Registry to Enhance Survival (CARES) registry, McMullan et al. reported on the impact of tracheal intubation compared with supraglottic devices and with no advanced airway management. In that study, adult OHCA patients had greater odds of survival when no advanced airway management was attempted.[6] In these studies, it can be inferred that tracheal intubation may lead to interruptions in chest compressions in the arrested child or adult, and that these interruptions may influence clinical outcomes; none of these studies, however, was able to accurately report the duration of interruptions in chest compressions associated with intubation attempts, or whether compression fraction was different among groups with differing airway management strategies. Conversely, our study methodology can accurately quantify how long compressions were stopped during laryngoscopy; however, in a cohort of patients with very poor outcomes, we are not able to report any influence on survival.

The median laryngoscopy time for children in cardiac arrest in this cohort was 47 s. Few published studies have clearly delineated the duration of attempts at laryngoscopy during emergency airway management in children, with the majority of data coming from neonatology through the use of video review.[9] Rinderknecht et al. recently reported data from a tertiary pediatric ED which uses videorecording during resuscitations.[10] They described a median laryngoscopy duration of 35 s in children undergoing rapid sequence induction and intubation (i.e. not in cardiac arrest). It is noteworthy that, in our cohort of children with cardiac arrest, the median laryngoscopy time was more than 10 s longer than in the Rinderknecht study cohort, with no significant difference in the distribution of laryngoscopy time between TI attempts with and without pauses in CPR.

Reasons for longer TI attempts in the arrested pediatric patient are not clear. Regardless of the reason, this finding may have significant implications with respect to the potential impact of advanced airway management in the pediatric cardiac arrest patient. Our data demonstrated that duration of laryngoscopy during CPR, even by experienced providers, almost always exceeds 10 s. This may suggest the need to anticipate that TI in the child with cardiac arrest, even when done by experienced operators, will take a long enough period of time that any associated pause in chest compressions to facilitate intubation will likely be prolonged.

Data from the simulation literature has supported the feasibility of performing TI in pediatric patients with uninterrupted chest compressions. Marques et al. reported on a simulation-based study of pediatric residents performing TI on mannequins with ongoing uninterrupted chest compressions, finding that the majority of subjects could successfully intubate the mannequins in under 45 s.[11] In a subsequent study, Rodriguez-Nunez et al. reported on similar subjects randomized to attempt TI on a pediatric mannequin with uninterrupted chest compressions using either direct laryngoscopy or videolarygnoscopy; in that study the majority of subjects could successfully intubate and videolaryngoscopy did not result in improved success or shortened procedure times.[12] While

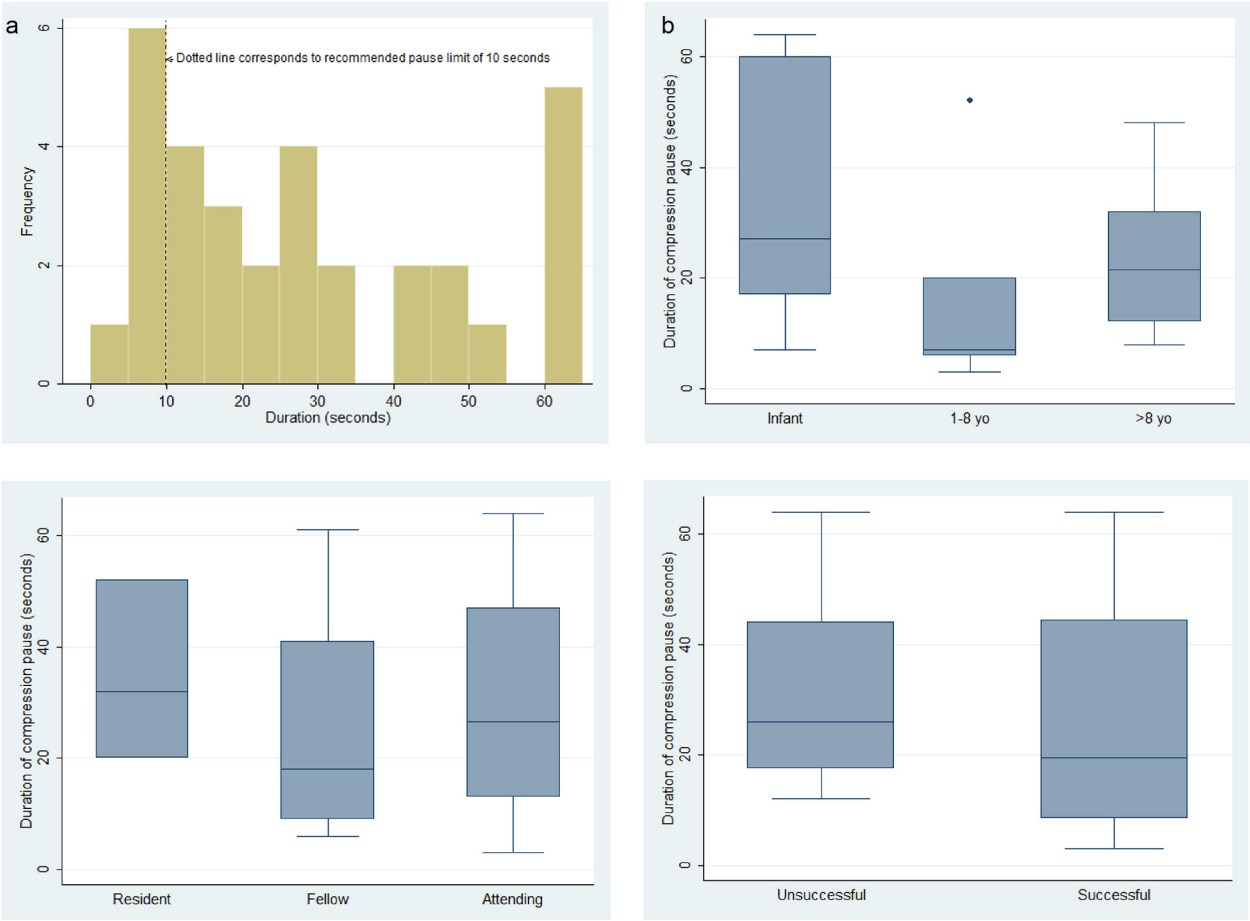

Fig. 4. (a) Duration of chest compression interruptions for TI attempts. (b) Duration of chest compression interruptions by patient age, intubator category, and procedural outcome.

it is difficult to correlate the success rates and laryngoscopy times in a real patient setting as opposed to a controlled simulation setting, we believe our data support the approach put forth in these simulation studies of intubation without interrupting chest compressions in real patients as well.

The present study adds to the growing body of literature demonstrating the utility of video to obtain discrete, unbiased data on clinical performance during resuscitation. Videorecording during trauma management and resuscitation of newborns in the delivery room is well represented in published literature, and has been shown to be an effective means of evaluating clinical and behavioral performance.[13–16] Some preliminary studies in adults have examined the use of videorecording to measure clinical performance during cardiac arrest in the emergency department (ED).[17,18] Our group recently reported the first descriptive analysis of CPR performance in children measured by videorecording.[19] Kerrey et al. recently reported on children undergoing TI in a pediatric ED, finding that the use of videorecording permitted more accurate determination of technical aspect and procedural outcomes than medical record review; in contrast to the present study, patients in cardiac arrest were excluded from their analysis.[20] We believe our data demonstrates another example of video used to describe a significant clinical phenomenon that has been challenging to characterize through typical retrospective methods.

Limitations

The study was conducted at a single tertiary center. The center is a regional level 1 trauma center and tertiary referral center for a large metropolitan area with an active pediatric emergency medicine fellowship program. We believe that the incidence of cardiac arrest in our community and the baseline clinical experience of the healthcare providers in our center are comparable to those in other large urban tertiary pediatric centers. Nonetheless, our findings may not be generalizable to other centers.

Prolonged and/or multiple interruptions in chest compressions for airway management could negatively impact the compression fraction during a CPR event. In our cohort, compression fraction was uniformly greater than the recommended threshold of 80% and we did not find a significant difference in this parameter between patients with and without CPR pauses for TI attempts. We believe the combination of a small sample size and high compression fraction in this group of patients makes this parameter difficult to evaluate in this study. Similarly, we are unable to evaluate differences in important patient outcome measures of survival to admission and survival to discharge. Our cohort is comprised primarily of children with OHCA, a patient group known to have exceedingly poor outcomes, and therefore our small sample size leaves us unable to draw meaningful conclusions on the impact of CPR interruption for TI on survival in this cohort.

Our primary analysis used an intubation attempt as the unit of measure, as opposed to the patient. This approach treats each intubation attempt as an independent variable; it does not take into account the influence of multiple attempts by a single provider or the overall number of attempts prior to successful intubation. Published investigations on adverse events following repeated intubation attempts in adults and children have not focused on patients in cardiac arrest. These studies have demonstrated

a greater likelihood of physiologic deterioration when greater than two attempts are necessary, with oxyhemoglobin desaturation being the most common consequence during subsequent attempts.[20–22] While the risk of vital sign deterioration cannot be applied to a patient in cardiac arrest, repeated attempts at TI may alter the likelihood of success for other reasons (e.g. trauma to the oropharynx). Our analysis does not account for these factors.

Conclusions

We observed that, among children in cardiac arrest in the emergency department, tracheal intubation is a frequent cause of significant interruptions in chest compressions. While a higher proportion of TI attempts with compressions paused were successful than those with uninterrupted compressions, this difference was not statistically significant. Our data support the strategy of performing TI in the child with CPR in progress without pausing chest compressions. Future research should examine the optimal method for intubation in the arrested child, including the optimal provider group and methods to minimize the duration of chest compression interruptions that occur. Additionally, more research is needed to examine the association between TI and clinical outcomes from cardiac arrest in children.

Conflict of interest statement

There are no relevant conflicts of interest, financial or otherwise, for any authors to declare.

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