

ORIGINAL RESEARCH

Pediatrics

Vital sign monitoring during out-of-hospital pediatric advanced airway management

Matt Hansen MD, MCR¹ | Lynn White MS² | Geneva Whitmore MPH² |
Amber Lin MS¹ | Rob Walker BA³

¹ Center for Policy and Research in Emergency Medicine, Department of Emergency Medicine at Oregon Health & Science University, Portland, Oregon, USA

² Global Medical Response, Greenwood Village, Colorado, USA

³ Stryker, Redmond, Washington, USA

Correspondence

Matt Hansen, MD, MCR, Mailcode CR114, 3181 SW Sam Jackson Pk, Rd, Portland, OR, 97239, USA.

Email: hansemat@ohsu.edu

Funding and support: By JACEP Open policy, all authors are required to disclose any and all commercial, financial, and other relationships in any way related to the subject of this article as per ICMJE conflict of interest guidelines (see www.icmje.org). The authors have stated that no such relationships exist.

Abstract

Objective: To evaluate physiologic monitoring in pediatric patients undergoing out-of-hospital advanced airway management.

Methods: Retrospective case series of pediatric patients (<18 years) with advanced airways placed in the out-of-hospital setting. Patients given cardiopulmonary resuscitation (CPR) or defibrillation before the first advanced airway attempt were excluded. Reviewers abstracted physiologic data from the patient monitor files and patient care reports. The primary outcome was the proportion of time pulse oximetry was in place during airway management. Other outcomes included the proportion of time ECG monitoring and waveform end-tidal capnography were in place as well as the incidence of oxygen desaturation events.

Results: We evaluated 23 pediatric patients with a mean age of 10.7 years (SD 6.5). Eleven of 18 (61%) children with medication-facilitated intubation had pulse oximetry in place when the first medication was documented as given. Eight of 18 (44%) had ECG monitoring, 12 of 18 (66%) had waveform capnography, and 5 of 18 (28%) had a blood pressure check within the 3 minutes before receiving the first medication. In the 3-minute preoxygenation phase, pulse oximetry was in place for an average of 1.4 minutes (47%, SD 0.37) and a visible photoplethysmogram (PPG) waveform obtained from the pulse oximeter was present for 0.6 minutes (20%, SD 0.34). During airway device placement, pulse oximetry was in place 73% (SD 0.39) of the time and 30% (SD 0.41) of the time there was a visible PPG waveform.

Conclusions: Pediatric patients had critical deficits in physiologic monitoring during advanced airway management.

KEYWORDS

airway management, emergency medical services, endotracheal intubation, pediatrics

Supervising Editor: Benjamin T. Kerrey, MD, MS.

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1 | INTRODUCTION

1.1 | Background and importance

Airway management is critical for many emergencies encountered by paramedics in the field. During advanced airway management procedures, paramedics place an endotracheal tube or supraglottic airway to facilitate oxygenation and ventilation. Pediatric advanced airway management procedures have a high risk of adverse events given they involve skills infrequently performed by emergency medical services (EMS) professionals both in training and in practice. Children are also at notably high risk for oxygen desaturation given decreased safe apnea time compared to adults.

To minimize the risk of adverse events and poor outcomes associated with advanced airway management procedures, patients must have several physiologic monitors in place during preparation and throughout the procedure. Critical monitoring modalities include pulse oximetry (SpO₂), ECG, blood pressure (BP), and capnography (EtCO₂). Without these monitors in place, clinicians will not know when to abandon an airway management attempt in order to reoxygenate the patient. Also, they may fail to identify bradycardia as a marker of severe hypoxia and precursor to cardiac arrest. Lack of monitoring during airway management represents a critical and modifiable risk to patient safety. The expectation is that all patients who are not in cardiac arrest should have SpO₂, ECG, BP, and EtCO₂ in place during all advanced airway management procedures. This is consistent with recommendations by the National Organization of State EMS Officials for out-of-hospital airway management.¹

One previous study conducted in adults evaluated out-of-hospital intubation and found that in 18% of cases, pulse oximetry was absent and in 10% of cases ECG monitoring was absent for some period of time during the intubation.² In addition, this study found that 43% of intubations were complicated by hypoxemia to oxygen saturation levels of < 90%. Studies conducted in the emergency department have used video to continuously monitor intubation procedures and identify hypoxemic events in children, with up to 33% of cases complicated by a desaturation to < 90%.³⁻⁵ However, we currently do not know what physiologic monitoring is being used during out-of-hospital advanced airway management procedures and we also do not know how often oxygen desaturation is associated with airway management procedures.

1.2 | Goals of this investigation

Recent advances in technology allow upload, storage, and analysis of the complete data stream visible on the patient monitor during care. Physiologic data files are commonly used to evaluate quality of cardiac arrest resuscitation but have not been used to evaluate pediatric airway management. This data source offers a unique opportunity to understand use of monitoring equipment and patient physiology during pediatric out-of-hospital airway management. The objective of this study is to describe the use of physiologic monitoring modalities

The Bottom Line

In this pediatric out-of-hospital case series of 23 patients from one large, urban out-of-hospital system, the authors used the digital vital sign record to study the frequency and duration of patient monitoring during airway management. Less than half had adequate pulse oximetry and cardiac monitoring. Similar studies, using the actual patient monitor feed for data collection, are critically needed both to understand gaps in performance and contributors to higher rates of adverse events.

during out-of-hospital pediatric advanced airway management procedures and to determine the rate of hypoxic events in cases with pulse oximetry in place.

2 | METHODS

2.1 | Study design

This is a retrospective case series of pediatric patients (<18 years) who required positive pressure ventilation by an advanced airway and who were treated by EMS agencies in 1 large metropolitan area in the Pacific Northwest. Patients who experienced a cardiac arrest, which was defined as pulseless, receiving EMS-provided CPR or any defibrillation prior to the advanced airway procedure, were excluded. The study was approved by the institution's institutional review board.

2.2 | Setting

This study was conducted in an urban county with ≈ 800,000 residents served by 9-1-1 advanced life support ambulance transport during the calendar years of 2017–2019. Each transport ambulance was staffed with 2 paramedics at all times and carried advance-life-support equipment suitable for patients of all ages, including neonates. An additional fire department apparatus responded to each call with at least one paramedic. Both EMS and fire agency protocols allow endotracheal intubation for adult and pediatric patients for a wide range of indications, as well as medication-facilitated intubation requiring sedatives and paralytics. Local protocols specify that SpO₂, ECG, and EtCO₂ are to be in place before preoxygenation for advanced airway placement. Video laryngoscopy was not available. LIFEPAK 15 monitor/defibrillators (Stryker Emergency Care, Redmond, WA, USA) were used in this system. These monitors are capable of recording atomic clock-synchronized electronic data, including continuous physiologic waveforms and vital signs, and have the capability to upload the event data to a cloud server after each patient care event. The monitors

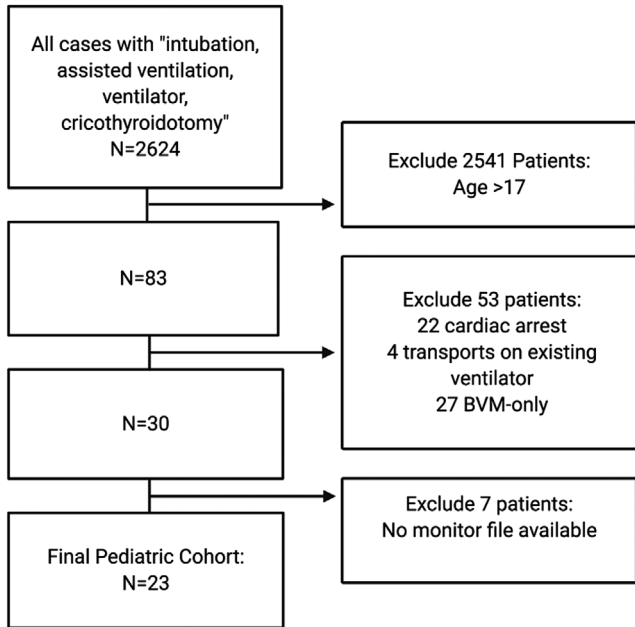


FIGURE 1 Flow diagram of case identification. BVM, bag-valve-mask

are capable of real-time simultaneous displays of pulse oximetry, ECG, BP, and waveform capnography among other modalities. An uploaded monitor file will reflect the data stream visible on the monitor screen while it was in use. In this study, all EMS agencies were required to use continuous waveform capnography to confirm advanced airway placement per existing airway management protocols. Colorimetric capnography was not available or used.

2.3 | Selection of participants

Participants were included if they were <18 years of age and had undergone an advanced airway management procedure by an EMS professional including endotracheal intubation or supraglottic airway device placement. Subjects were excluded if a physiologic data file from the monitor was unavailable for the patient encounter. Figure 1 depicts the case identification process. We initially identified 30 patients, 7 were excluded because monitor files were not available. We chose to focus on pediatric patients as we hypothesized that children were at high risk of both hypoxia and inadequate physiologic monitoring. These included problems with monitoring equipment (SpO₂ probes) and the stress caused by the rare nature of pediatric advanced airway procedures.

2.4 | Measurements and outcomes

Airway encounters were divided into 3 time periods to reflect the different phases of airway management. The first phase, the *preoxygenation*

phase, was defined as beginning 3 minutes prior to the administration of the first medication given, or as the time the monitor was turned on, if that time was < 3 minutes before the first medication. The preoxygenation phase extended to the time the first medication was administered. The second phase, the *device placement phase*, was defined as the time extending from when the first medication was administered to the successful insertion or when attempts were abandoned. The third phase, the *confirmation and monitoring phase*, started when an advanced airway was successfully placed or abandoned and extended to the time of arrival to the emergency department. These time intervals were abstracted from the electronic patient care report. During each time interval the duration of monitoring with SpO₂, ECG, and EtCO₂ was recorded. Also recorded were the number of BP measurements, including manual measurements documented in the electronic patient care report and automated measurements attempted using the monitor. The primary outcome was the proportion of time pulse oximetry was used during each time period. The secondary outcome was the number and duration of hypoxic events.

2.5 | Chart review process

Electronic data files uploaded from the monitors were reviewed using commercial software (CODE-STAT 11 Data Review, Stryker Emergency Care) that allows annotation and analysis of the recorded waveform, vital signs, and event data. One primary reviewer abstracted data from both the electronic patient care reports and the electronic monitor files. A second reviewer used the same methods to abstract data for 10 (43%) cases to establish agreement and evaluate the robustness and risk of human error during the review process. These reviewers had good agreement (89% of values within 10%) for 20 variables that were abstracted from each case including the proportion of time the monitoring modalities were in place over the 3 defined time intervals.

2.6 | Analysis

Characteristics of the study subjects were evaluated using descriptive statistics. We first measured the portion of patients with monitoring in place when the first medication was given for medication-facilitated intubation cases. This was followed by evaluating the total duration of out-of-hospital care and the proportion of time that each monitoring modality was in place. Next, for each of the 3 time periods we measured the total time of the interval (duration a monitor should have been in place), the time the monitoring modality was actually in place during the interval, and the percent of time the modality was used during the interval. The frequency and duration of hypoxic intervals was measured separately for 3 different SpO₂ thresholds: 90, 80, and 70%. The rate of these desaturation events evident in the monitoring data were compared to those documented in the electronic patient care record (ePCR), excluding desaturation events associated with a poor quality plethysmography (PPG) waveform on the monitor.

TABLE 1 Patient characteristics

	n = 23
Age in years, mean (SD)	10.7 (6.5)
Sex (% female)	10 (43.5%)
Indication for intubation (n, %)	
Seizure	3 (13.0%)
Toxicological (alcohol, over-the-counter and prescription medications)	2 (8.7%)
Penetrating trauma	1 (4.3%)
Blunt trauma	2 (8.7%)
Head injury	8 (34.8%)
Burn	2 (8.7%)
Airway obstruction	1 (4.3%)
Dyspnea	2 (8.7%)
Apnea	1 (4.3%)
Altered mentation	1 (4.3%)
Highest preoxygenation phase oxygen saturation, mean (SD)	0.95 (0.06)
Lowest device placement phase oxygen saturation, mean (SD)	0.73 (0.22)
Lowest confirmation and monitoring phase oxygen saturation, mean (SD)	0.76 (0.29)
Airway device successfully placed (n, %)	
Endotracheal tube	19 (82.6%)
Supraglottic airway device	3 (13.0%)
None	1 (4.3%)
Medication-facilitated intubation used (n, %) ^a	18 (78.3%)
Duration of preoxygenation phase in seconds, mean (SD)	282.1 (41.8)
Duration of device placement phase in seconds, mean (SD)	203.3 (180.8)
Duration of confirmation and monitoring phase in seconds, mean (SD)	898.6 (429.3)

^aExcluded 2 patients, ventilation via already placed endotracheal tube.

3 | RESULTS

3.1 | Characteristics of study subjects

There were a total of 23 pediatric patients with a mean age of 10.7 years (SD 6.5) included in the analysis. Head injury was the most common paramedic primary impression (34%) in the group. Patient and event characteristics are summarized in Table 1. Eighteen (83%) patients had a medication-facilitated intubation.

3.2 | Critical physiologic monitoring

Eleven of 18 subjects (61%) treated with medication-facilitated intubation had pulse oximetry in place at the time the first medication

administration was documented. Eight of 18 patients (44%) had ECG monitoring in place; 12 of 18 (66%) had waveform capnography; and 5 of 18 (28%) had a documented BP check within the 3 minutes prior to receiving the first medication.

Table 2 displays the portion of time each monitoring modality was in place during the 3 phases of airway management. The 3-phased concept only applies to those with medication-facilitated intubation, so this table is limited to 18 patients. In the 3-minute preoxygenation phase, pulse oximetry was in place an average of 1.4 minutes (47%, SD 0.37) and a visible PPG waveform was present for 0.6 minutes (20%, SD 0.34). PPG was available on all monitors used in the study but was not configured to be one of the displayed waveforms when a monitor was first powered on. In total, 6 patients were not monitored at all during the preoxygenation phase, and 4 of these 6 (66%) were patients with head trauma. During airway device placement, pulse oximetry was in place 73% (SD 0.39) of the time and a PPG waveform was displayed 30% (0.41) of the time. Waveform capnography was used more frequently than pulse oximetry.

3.3 | Hypoxic events and other complications

Table 3 lists the proportion of cases with oxygen desaturation among all 23 subjects at several thresholds as well as the duration of these events. We noted that 15 of 17 (88%) pediatric patients for whom an oxygen saturation was recorded during the preoxygenation phase started with an oxygen saturation >90%, and 9 of these 15 (60%) experienced an oxygen desaturation to <80% during the device placement phase. Twelve of 24 (50%) desaturation events were recorded in the ePCR. Figure 2 shows the nadir oxygen saturation value for each patient during each airway management phase. We compared the monitoring between patients who did and did not experience an oxygen desaturation to <90% among those who started with an oxygen saturation of >90% (Table 2). In general, monitoring was less intense among those who experienced a desaturation, with the exception of having a visible PPG waveform, which was more common among those with a desaturation, though the sample size was very small. No patient in this study experienced a documented cardiac arrest during the course of out-of-hospital care. We were not able to evaluate for other potential adverse events with the data available.

4 | DISCUSSION

In this study of the use of physiologic monitoring during out-of-hospital advanced airway management procedures we used the entire physiologic data stream available to paramedics during care. Clinically significant deficits in pulse oximetry and ECG monitoring were noted during all phases of airway management, including the time when neuromuscular blockers were given. This places patients at risk for serious adverse events. We also noted a markedly high rate of oxygen desaturation with 60% of monitored patients experiencing a desaturation to < 80%. Half of the oxygen desaturation events recorded in

TABLE 2 Proportion of time with critical physiologic monitoring in place among patients with medication-facilitated intubation

	All patients	N = 15 Patients with initial O ₂ saturation >90% ^a	
		N = 9 (pre-airway SpO ₂ >90% and desaturation)	N = 6 (pre-airway SpO ₂ >90% and no desaturation)
n (%)	18	9 (50%)	6 (33%)
Percentage of time with SpO ₂ monitoring in the preoxygenation phase (SD)	42% (0.37)	39% (0.32)	49% (0.42)
Percentage of time with SpO ₂ monitoring with visible plethysmograph waveform in the preoxygenation phase, mean (SD)	18% (0.32)	21% (0.33)	5% (0.12) (5 of 6 cases)
Percentage of time with ECG monitoring in the preoxygenation phase, mean (SD)	41% (0.45)	25% (0.43)	47% (0.52)
Number of cases with any EtCO ₂ monitoring in the pre-oxygenation phase, n (%)	11 (61%)	4 (44%)	4 (67%)
Number of automated BP attempts in the preoxygenation phase, n (%)			
0	6 (33%)	2 (22%)	2 (33%)
1 or more	12 (66%)	7 (78%)	4 (67%)
Proportion of time with SpO ₂ monitoring in the device placement phase, mean (SD)	69% (0.39)	73% (0.34)	82% (0.36)
Proportion of time with SpO ₂ monitoring with visible plethysmograph waveform in the device placement phase, mean (SD)	28% (0.39)	38% (0.41)	14% (0.34)
Proportion of time with ECG monitoring in the device placement phase, mean (SD)	41% (0.46)	33% (0.47)	41% (0.47)
Number of cases with any EtCO ₂ monitoring in the device placement phase, n (%)	10 (59%)	4 (44%)	4 (67%)
Number of automated BP attempts in the device placement phase, n(%)			
0	16(94%)	9 (100%)	5 (83%)
1 or more	1(6%)	0 (0%)	1 (17%)

^aThis denominator is 15 for this group because 1 case started with SpO₂ <90, and 2 had missing data.

BP, blood pressure

the monitor file were not recorded in the ePCR. These findings call into question the safety of out-of-hospital pediatric advanced airway management in general and underline the importance of evaluating physiologic data rather than focusing solely on success rates for device placement.

This is the first study we are aware of that evaluates the use of physiologic monitoring during out-of-hospital pediatric airway management. Because the majority of patients received medication-facilitated intubation, the cases were not “crash” airways and time was available to place monitors and to prepare for the procedure. Pulse oximetry should be in place throughout the airway management procedure including the pre-oxygenation phase, but in this study the pulse oximetry monitoring was in place 47% of the time, with only 20% displaying a PPG waveform on the monitor. If the oxygen saturation is not measured during this phase, paramedics will not know if their preoxygenation efforts are adequate, putting patients at risk for bradycardia, anoxic injury, and cardiac arrest during device placement when patients are rendered apneic by medications.

There are several potential reasons that children could experience less intensive monitoring during airway management procedures. We noted a relatively high use of waveform capnography, so it is possible

that paramedics have shifted focus to this modality and have focused less on ECG and pulse oximetry. This could be an opportunity for education on the importance of comprehensive monitoring and the benefits of using each specific modality. Pediatric patients represent a wide range of body sizes from neonates to teens with adult physiology and body habitus. The equipment available to paramedics in some agencies may not function well in this large range of patient sizes, although that was not evaluated in this study. Further, the monitors in this study were not preset to view the PPG waveform, which is something the EMS system could change. It is also possible that environmental conditions at the scene such as bystander interference, specific location, or other factors may have limited pediatric monitoring. Advanced airway management procedures are also less common in pediatric patients than in adults. Previous reports have indicated that these scenarios are a significant source of stress and anxiety for paramedics which may create additional barriers to monitoring.⁶ Finally, there is general concern that there are high rates of safety events for the pediatric population in the out-of-hospital setting, and airway management scenarios have been found to be among the highest risk for adverse safety events.⁷⁻⁹ Further research is needed to identify specific modifiable barriers to monitoring.

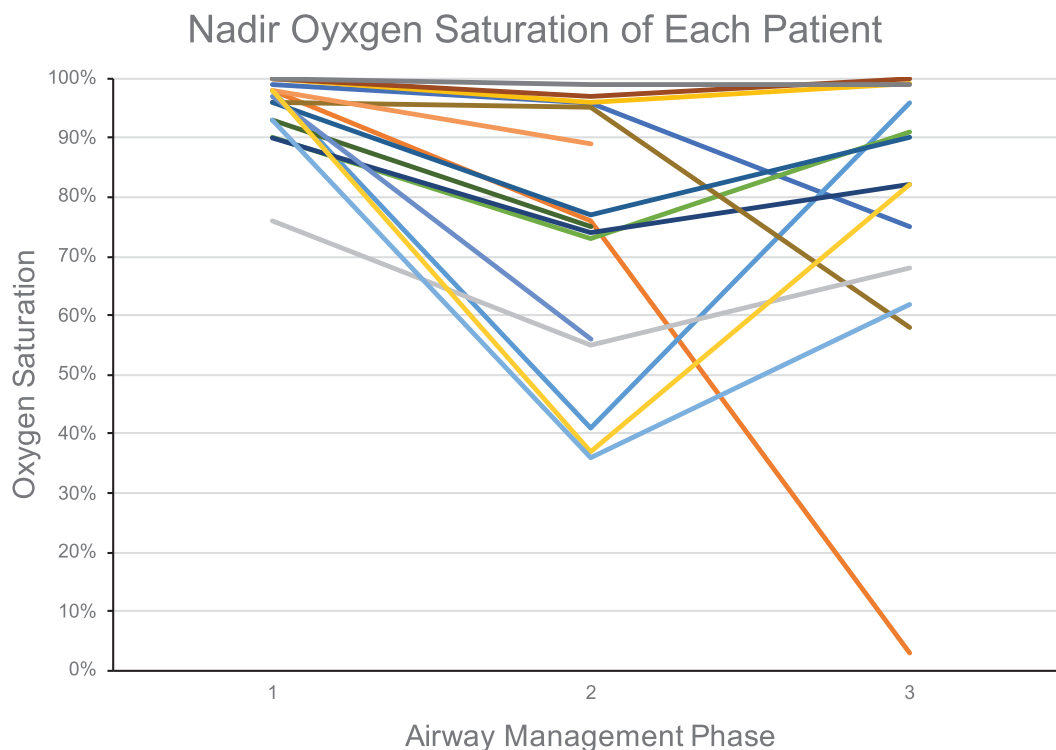


FIGURE 2 Nadir oxygen saturation for each patient during each phase of airway management

TABLE 3 Hypoxic events

	n = 23
Patients with SpO ₂ <90%, n (%)	16 (69.6%)
Duration of events with nadir SpO ₂ <90% in seconds, mean (SD)	380.3 (288.4)
Patients with SpO ₂ <80%, n(%)	14 (60.9%)
Duration of events with nadir SpO ₂ <80% in seconds, mean (SD)	412.3 (282.6)
Patients with SpO ₂ <70%, n(%)	9 (39.1%)
Duration of events with nadir SpO ₂ <70% in seconds, mean (SD)	526.0 (301.0)
Total burden of hypoxia (seconds below 90% saturation), mean (SD)	258.7 (348.5)
Total burden of hypoxia (seconds below 90% saturation) within patients with any hypoxia, mean (SD)	491.5 (340.2)

Sixty percent of patients had an oxygen desaturation to <80%. An out-of-hospital study published in 2003 found that 57% of adults undergoing medication-facilitated intubation experienced a desaturation and that 84% of these started with a saturation >90% before the airway management procedure.¹⁰ A previous emergency department-based study using video review of cases found that 33% of patients had a desaturation to < 90%, and another study using chart review noted a desaturation rate of 14%.^{4,11} We noted a substantially higher rate of oxygen desaturation in our study. Our data suggest that most desaturations could be related to the airway management procedure itself

rather than the underlying disease, as the majority of patients in this study started with an oxygen saturation of >90%. Children may be at particularly high risk for hypoxic events during airway management because of unique physiology.¹² Children have lower pulmonary functional residual capacity and higher basal metabolic rates resulting in more rapid oxygen consumption.^{13,14} This leads to less safe apnea time after sedatives and paralytics have been delivered to facilitate placement of an endotracheal tube.

Future research is needed to confirm these findings in a geographically diverse population. Also, it is important to identify specific risk factors for monitoring problems and oxygen desaturation, which we were not able to do in this study given its small sample size. Younger age groups would logically be at higher risk because of anatomic and physiologic differences compared to older children and adults, though this needs to be verified. Emphasis on short scene times for trauma patients could be a contributing factor to our finding that 66% patients without pulse oximetry during the preoxygenation phase for a medication-facilitated intubation were victims of head trauma, although this needs further study given the small numbers. Monitoring oxygen saturation in this group is particularly important given outcomes for head trauma patients are worsened by hypoxia.^{15,16}

This study has several important limitations. First, the sample size was small. This was conducted as a pilot study to provide preliminary estimates and hypotheses to be tested in future research. The specific time stamps in the chart may have been documented retrospectively and are subject to recall bias. The analysis of which monitoring was in place at the time the first medication was given would be most subject to this bias. We feel the analyses based on the phases of care

are less likely to suffer from this bias because they represent a larger period of time. We did not have sufficient numbers to evaluate specific risks for deficits in monitoring or hypoxic events among the pediatric patients, though this information is important in developing strategies to improve monitoring. Relatively few patients in the study had a visible PPG waveform, and in these cases, we were unable to evaluate the validity of the oxygen saturation, though neither were the treating paramedics during care. Finally, the average age of our population was 10.7 years indicating the population was somewhat skewed toward older children.

5 | CONCLUSIONS

This study finds significant deficits in ECG and SpO₂ monitoring during pediatric out-of-hospital advanced airway procedures, as well as high rates of oxygen desaturation. EMS agencies should carefully evaluate their current monitoring practices during pediatric airway management. Further research is needed to evaluate monitoring during pediatric airway management procedures in other geographic areas. In addition, further research should identify specific barriers and facilitators to pediatric monitoring and identify strategies to prevent hypoxemia.

CONFLICTS OF INTEREST

Rob Walker is an employee of Stryker, the manufacturer of the monitors used in this study. The remaining authors have no conflicts of interests.

AUTHOR CONTRIBUTIONS

MH, LW, and RW conceived and designed the study, drafted the article, give final approval and are accountable for all aspects of the work. GW made a substantial contribution to data acquisition, critically revised the article, gives final approval and is accountable for all aspects of the work. AL was the primary data analyst for the work, critically revised the article, gives final approval, and is accountable for all aspects of the work.

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AUTHOR BIOGRAPHY



Matt Hansen, MD, MCR, is associate professor of emergency medicine, School of Medicine and co-director, Innovative, Disruptive, Emergency Applications for Emergency Medicine at Oregon Health and Science University, Portland, OR.

How to cite this article: Hansen M, White L, Whitmore G, Lin A, Walker R. Vital sign monitoring during out-of-hospital pediatric advanced airway management. *JACEP Open*. 2020;1:1571-1577. <https://doi.org/10.1002/emp2.12273>