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Use of capnographs to assess quality of pediatric ventilation with 3 different airway modalities

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ABSTRACT

Objectives: Prehospital pediatric airway management is difficult and controversial. Options include bag-mask ventilation (BMV), endotracheal tube (ETT), and laryngeal mask airway (LMA). Emergency Medical Services personnel report difficulty assessing adequacy of BMV during transport. Capnography, and capnograph tracings in particular, provide a measure of real-time ventilation currently used in prehospital medicine but have not been well studied in pediatric patients or with BMV. Our objective was to compare pediatric capnographs created with 3 airway modalities.

Methods: This was a prospective study of pediatric patients requiring ETT or LMA ventilation during elective surgical procedures. Data were collected during BMV using 2 bag types (flow-inflating and self-inflating). The ETT or LMA was placed and ventilation with each bag type repeated. Ten- to 14-second capnographs were reviewed by 2 blinded anesthesiologists who were asked to assess ventilation and identify the airway and bag type used. Descriptive statistics, κ, and risk ratios were calculated.

Results: Twenty-nine patients were enrolled. Median age was 4.4 years (2 months to 16.8 years). One hundred sixteen capnographs were reviewed. Reviewers were unable to differentiate between airway modalities and agreed on adequacy of ventilation 77% of the time ($\kappa = 0.6$, $P < .001$). Bag-mask ventilation was rated inadequate more frequently than ETT or LMA ventilation. There were no difference between ETT and LMA ventilation and no difference between the 2 bag types.

Conclusion: Capnographs are generated during BMV and are virtually identical to those produced with ETT or LMA ventilation. Attention to capnographs could improve outcomes during emergency treatment and transport of critically ill pediatric patients requiring ventilation with any of these airway modalities.

1. Introduction

Controversy surrounds the optimal prehospital management of the pediatric airway. Options include bag-mask ventilation (BMV), endotracheal intubation (ETI), and supraglottic devices, such as the laryngeal mask airway (LMA). However, the clinical effectiveness of these 3 modalities has not been adequately compared within the pediatric population.

Although ETI has been considered the criterion standard for airway management, failure and complications associated with prehospital ETI range from 5% to 50% [1–5]. Because ETI is used infrequently in prehospital pediatric resuscitation, it is difficult for Emergency Medical Services (EMS) personnel to maintain this skill [3,6]. In fact, recent literature has questioned the safety and benefit of prehospital intubation in certain patient populations.

In 2000, Gausche et al [7] demonstrated equivocal neurologic outcome and survival to discharge with pediatric mask and endotracheal tube (ETT) ventilation in the prehospital setting. Emphasis has now been placed on providing sustained mask ventilation rather than prehospital ETI in pediatric patients. However, mask ventilation is difficult to sustain for long periods of time, particularly in a moving vehicle [8].

Laryngeal mask airways are an attractive alternative to both ETI and mask ventilation because they do not require direct visualization, can be placed more quickly than an ETT [9–13], and may be easier to maintain than mask ventilation. Laryngeal mask airways have also been placed and used successfully while maintaining inline cervical spine stabilization [14], in chest compressions [10,11], and in situations in which access to the airway is restricted as may occur during extrication after motor vehicle collision [12]. Successful utilization of an LMA requires minimal training [15,16] and skill retention for LMA placement may also be better than that for ETIs [17].

Regardless of which advanced airway modality is used, confirmation of proper placement, adequate ventilation, and prompt recognition of device displacement are central to improving outcomes in prehospital

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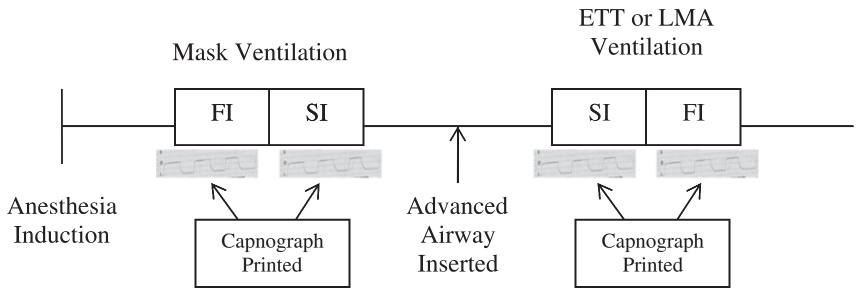

Fig. 1. Data collection timeline. Subjects received mask ventilation with an FI bag while a real-time capnograph was captured. An SI bag was then used to create a second capnograph. After the advanced airway was inserted, capnographs were again printed for each bag type.

pediatric advanced airway management. Pulse oximetry, a noninvasive measurement of arterial blood oxygenation, has become a standard measure of respiratory status in prehospital emergency medicine. However, pulse oximeters require adequate plethysmographic pulsations to distinguish arterial from background venous and tissue light absorption. The plethysmography may be affected by motion, hypothermia, vasoconstriction, and poor perfusion—all common complications during prehospital and emergency department (ED) care [18–20]. Measurement of carbon dioxide in the exhaled breath ($ETCO_2$) can be used to confirm both correct airway device placement and effectiveness of assisted ventilation. A prospective study by Silvestri et al found 100% recognition of ETT placement when paramedics used continuous $ETCO_2$ monitors [21]. Without the use of $ETCO_2$ monitors, 23% of misplaced ETTs went unrecognized. Attention and response to continuous $ETCO_2$ monitoring can also prevent hyper- and hypoventilation [22], which has been shown to improve neurologic outcomes [23].

Colorimetric $ETCO_2$ detectors are now routinely used to detect proper initial placement of ETTs in pediatric patients [24]. More advanced electronic capnometers display a single numerical value of detected $ETCO_2$ with each cycle of ventilation. "Capnography," in contrast to "capnometry," displays carbon dioxide levels over time. The terms *capnogram* and *capnograph* refer to the pictorial waveform associated with the $ETCO_2$ concentration as it changes throughout the respiratory cycle. Capnography has been shown to improve time to detection and correction of ETT dislodgement among paramedics and pediatric residents after minimal capnography training [25,26]. Handheld capnometers have been shown to be effective in the prehospital setting in pediatric patients who undergo ETI [27], and $ETCO_2$ values have been demonstrated during ETT and LMA ventilation [28,29]. However, the continuous capnograph has not been studied with LMA or mask ventilation in the pediatric population.

The aim of this study is to describe capnographs obtained during effective ventilation of pediatric patients with a mask, ETT, and LMA. We hypothesized that the capnographs obtained with each of these modalities would be indistinguishable and that capnography could therefore be used to guide ventilation of pediatric patients, regardless of the airway modality used.

2. Materials and methods

2.1. Study design, patient population, and setting

This was a prospective descriptive study examining capnographs in pediatric patients in the controlled operating suite setting. Because different bag types are used in prehospital vs ED resuscitations, both flow-inflating (FI) and self-inflating (SI) BMV were studied. In total, 4 airway modalities were studied: FI mask ventilation; SI mask ventilation; ETT, studied with each bag type; and LMA, studied with each bag type. There were 2 study groups based on type of advanced airway used: ETT or LMA. All subjects received mask ventilation with each bag type before placement of an advanced airway (Fig. 1).

Patients between the ages of 1 month and 17.9 years who met American Society of Anesthesiologist (ASA) physical status class I-III criteria and required ventilatory support with an ETT or LMA as part of their surgical procedure were eligible for the study. Patients were excluded from the study if they were determined to be ASA Class >III; were intubated before the surgical procedure; were undergoing airway, cardiothoracic, or abdominal procedures; were less than 1 month of age; or had preexisting cardiac or pulmonary disease or if caregivers refused consent. In addition, only patients undergoing supplemental intravenous anesthesia induction were included because complete apnea (without hyperventilation) was necessary to study manual ventilation. A convenience sample was used. We recruited subjects in each of 4 weight categories for each group (ETT or LMA). Weight groups were based on manufacturer-suggested LMA[1] sizes, as follows: 5-10 kg = size 1.5, 10-20 kg = size 2, 20-30 kg = size 2.5, and 30-50 kg = size 3. However, the LMA size used for each case was ultimately left up to the discretion of the anesthesiologist.

2.2. Data measurement

Subject weight, date of birth, date of visit, ASA physical status class, pertinent medical history, medications administered during the study period, and planned surgical procedure were recorded. After anesthesia induction, each subject was mask-ventilated per routine via the FI bag attached to the anesthesia circuit, and apnea was induced. Each subject was then ventilated with a size-appropriate SI bag,[2] and an $ETCO_2$ capnograph of 10- to 30-second duration was captured. The bag was then changed to an FI, and mask ventilation was continued while a second capnograph was captured. Additional measures of ventilation including numeric $ETCO_2$ values and oxygen saturation were recorded at the beginning and end of each tracing period.

When the subject was ready for placement of the advanced airway, either an ETT or LMA was inserted per routine by a board-certified pediatric anesthesiologist. The use of ETT or LMA was left up to the discretion of the anesthesiologist and predetermined. The subject was again ventilated with each bag type, this time with the ETT or LMA in place instead of a mask, and the same data were recorded (Fig. 1). In total, 4 capnograms were collected for each subject (one with the FI bag, one with the SI bag, and one with each bag type with the advanced airway in place). The manual ventilation limb of the anesthesia machine[3] with the anesthesia circuit[4] was used as the FI bag in this study. The sidestream gas-sampling line was attached at the "elbow connector" during $ETCO_2$ recordings with each bag type. Tracings and numerical values were recorded on the standard anesthesia monitor.[5] Capnograph strips were printed from the monitor in real time. All measurements

[1] LMA Unique; Teleflex, San Diego, CA.
[2] "The Bag II Adult Disposable BVM" or Laerdal "The Bag II Pediatric Disposable BVM"; Laerdal, Wappingers Falls, NY.
[3] Aestiva 7900; GE Healthcare, Wauwatosa, WI.
[4] Pediatric Expandable Disposable Anesthesia Breathing Circuit; Portex, Dublin, OH.
[5] Aestiva 7900; GE Healthcare, Wauwatosa, WI.