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Commentary and concepts

Mechanisms linking advanced airway management and cardiac arrest outcomes☆

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ABSTRACT

Advanced airway management – such as endotracheal intubation (ETI) or supraglottic airway (SGA) insertion – is one of the most prominent interventions in out-of-hospital cardiac arrest (OHCA) resuscitation. While randomized controlled trials are currently in progress to identify the best advanced airway technique in OHCA, the mechanisms by which airway management may influence OHCA outcomes remain unknown. We provide a conceptual model describing potential mechanisms linking advanced airway management with OHCA outcomes.

1. Introduction

Advanced airway management – such as endotracheal intubation (ETI) or supraglottic airway (SGA) insertion – is one of the most prominent interventions in out-of-hospital cardiac arrest (OHCA) resuscitation. In the United States, paramedics have performed ETI in OHCA for over 30 years [1]. However, many studies highlight the pitfalls of ETI, including unrecognized misplacement and dislodgement, multiple or failed ETI attempts, and impairment of cardiopulmonary resuscitation (CPR) chest compression continuity [2,3].

To help expedite advanced airway management, minimize chest compression interruptions, and improve outcomes, many prehospital practitioners substitute ETI with SGA insertion, which generally involves simpler techniques. Ironically, observational studies suggest that OHCA outcomes may be *worse* with SGA than ETI [21]. Other studies suggest that a bag-valve mask (BVM) alone may be associated with better OHCA outcomes than either ETI or SGA [4]. Randomized controlled trials are currently in progress to better clarify the influence of advanced airway technique on OHCA outcomes. Yet, a critical question remains unanswered: what are the underlying mechanisms by which advanced airway management influences outcomes? The answer to this question could help us to better understand the results of past and future research and to identify potential solutions.

In this concepts paper, we describe potential mechanisms linking advanced airway management with OHCA outcomes.

2. Benefits of advanced airway management

Cardiopulmonary arrest involves sudden ischemia to all organ systems, including the heart and brain. Delivery of oxygen to these organs is vital to (1) restore normal cardiac function, and (2) preserve organ function until spontaneous circulation is achieved. Preservation of organ function likely involves optimization of cellular metabolism by decreasing hypercapnia, normalizing intracellular pH, and reducing damage from ongoing cellular hypoxia [5]. In this context, advanced airway management may have two important goals (Fig. 1):

2.1. Control of oxygenation and ventilation

OHCA patients are apneic and have no protective airway reflexes. Advanced airways create and maintain a patent and direct conduit to the lungs, allowing for delivery of oxygen, and control of ventilation and exhaled carbon dioxide. Advanced airway devices may be especially useful in patients with existing lung conditions such as chronic obstructive pulmonary disease.

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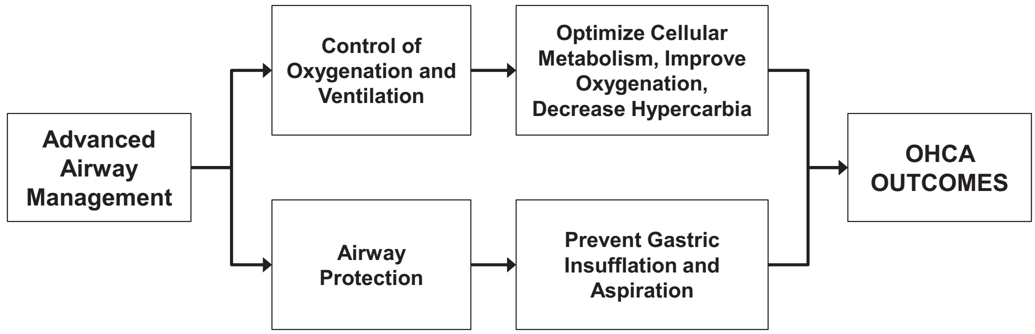

Fig. 1. Conceptual model of mechanisms linking advanced airway management with improved cardiac arrest outcomes. OHCA = out-of-hospital cardiac arrest.

2.2. *Airway protection*

Aspiration of vomitus or secretions and gastric insufflation may hinder oxygen delivery during and after resuscitation. In the post-arrest state, vomitus and secretions may trigger pneumonitis, impairing pulmonary recovery [6]. The cuff of the endotracheal tube is intended to protect the lungs from these potentially harmful processes. The ability of SGA to protect the airway from aspiration is less clear.

3. Potential harmful mechanisms of advanced airway management

We propose that advanced airway management may encompass (1) technical errors, (2) cognitive errors, and (3) adverse anatomic effects. These errors or events may individually or synergistically cause harm in OHCA by causing (1) loss of chest compression control, (2) loss of ventilation and oxygenation control, or (3) loss of normal anatomy (Fig. 2):

3.1. *Technical errors*

The technique of advanced airway management is difficult. Errors associated with ETI or SGA include multiple, prolonged or failed attempts, unrecognized misplacement of the advanced airway, or dislodgement of the advanced airway after correct placement [7–10]. These technical errors may result in *loss of chest compression control*, manifesting as chest compression interruptions and/or suboptimal chest compression fraction. In a series of 100 OHCA, Wang et al. demonstrated that chest compression interruptions totaling over one-and-one half minutes may occur as a result of ETI efforts [11]. While this study did not link chest compression interruptions to outcomes, Cheskes et al. showed that even brief 20-s pauses for defibrillation may be associated with poorer OHCA survival [12]. Similarly, multiple or prolonged airway insertion efforts may result in *loss of ventilation and oxygenation control*, manifesting as periods of hypoxia [13]. Collectively, these airway technical errors may result in impaired systematic circulation and delivery of oxygen.

3.2. *Cognitive errors*

Advanced airway management is also cognitively difficult. Examples of complex cognitive tasks involved in airway management include assessing the airway, selecting the types and sequence of airway interventions, and maintaining a proper ventilation rate and tidal volume. The overall complexity of airway management may distract rescuers, leading to *inattention* and *overcompensation* errors. Inattention may result in *loss of chest compression control* (manifesting as inadequate rate or depth of compressions), or *loss of ventilation and oxygenation control* (manifesting as hypoventilation from prolonged or multiple airway insertion efforts). Overcompensation may also impact chest compression control (manifesting as an excessive chest compression rate) or ventilation control (manifesting as iatrogenic hyperventilation) [14]. Aufderheide et al. observed that hyperventilation occurs frequently during OHCA resuscitation and is associated with impaired CPR coronary perfusion pressure [15]. In addition, hyperoxemia may result from overcompensated oxygenation during or after resuscitation and may independently decrease survival [16]. These cognitive errors may result in multiple adverse mechanisms, including cerebral vasoconstriction, impaired oxygen delivery and cellular oxidative injury.

3.3. *Anatomic effects*

Oropharyngeal trauma with subsequent edema or bleeding can result from advanced airway insertion efforts. This *loss of normal anatomy* may complicate subsequent airway management efforts in the Emergency Department or Intensive Care Unit. For example, case reports describe significant tongue engorgement occurring from prehospital SGA use [9]. In addition, advanced airway devices may impinge upon vascular structures. In a porcine OHCA model, Segal et al. observed decreased carotid artery blood flow after the insertion of an SGA [17]. While not validated in humans, carotid impingement may alter OHCA outcomes by impairing cerebral arterial blood flow, altering intracranial pressure and oxygen delivery to ischemic brain cells.

4. Timing of resuscitation interventions

An additional consideration is the timing and sequence of advanced airway interventions. Airway interventions represent only a fraction of numerous time-dependent interventions necessary during OHCA resuscitation, including delivery of chest compressions, defibrillation, obtaining intravenous or intraosseous access, and administering antiarrhythmic and vasoactive medications. An interaction may exist between the relative timing of advanced airway management and other interventions that could independently influence OHCA outcomes (Fig. 3). For example, Weisfeldt et al. postulated that three phases of cardiac arrest exist, each with differing pathophysiology: (1) the electrical phase, (2) the circulatory phase, and (3) the metabolic phase [18]. During the early electrical phase, immediate defibrillation may be preferable over airway management in patients with ventricular dysrhythmia. Conversely, during the later circulatory phase, advanced airway management may have a stronger influence on outcomes by enhancing oxygen delivery. In the final metabolic phase, interventions that reduce reperfusion injury, such as therapeutic hypothermia, may be more critical.

The notion of airway timing impacting OHCA outcomes is plausible. Bobrow et al. observed higher OHCA survival when advanced

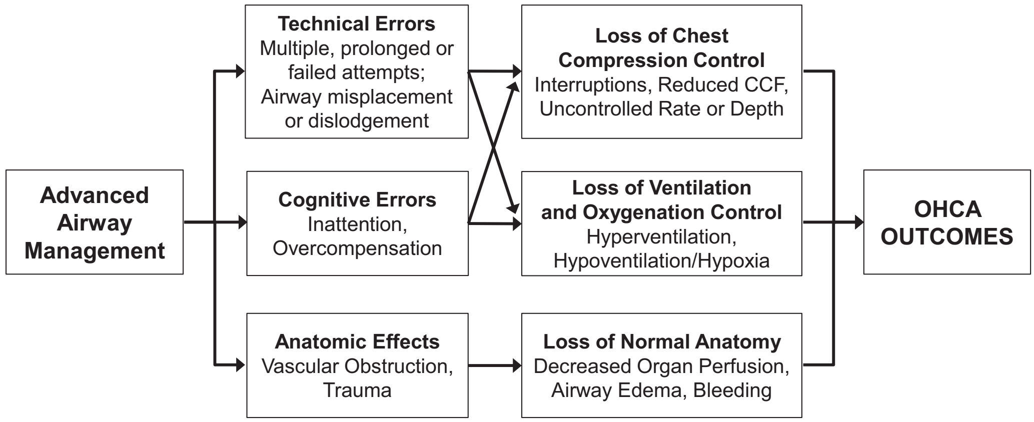

Fig. 2. Conceptual model of mechanisms linking advanced airway management with adverse events, clinical effects and cardiac arrest outcomes. OHCA = out-of-hospital cardiac arrest.

airway management was delayed in favor of early chest compressions and intravenous drugs [19]. However, select studies that have directly address intubation timing found better outcomes with early airway interventions [20].

5. Scientific and clinical implications

This conceptual model has important scientific and clinical implications. Our current understanding of the connection between advanced airway management and OHCA outcomes is based upon observational data, which have inherent limitations because the fundamental study design does not control for confounding variables. Even after statistical adjustment, the potential for unknown and unmeasured confounders remains. Investigators in the United Kingdom and United States are currently planning large randomized controlled trials to help identify the best OHCA advanced airway management approach. The UK AIRWAYS-2 study (www.isrctn.com ISRCTN08256118) will randomize 9000 adult OHCA patients to ETI or i-gel. The US Pragmatic Airway Resuscitation Trial (PART—www.clinicaltrials.gov NCT02419573) will randomize 3000 patients to ETI or King-LT. An understanding of the mechanisms linking advanced airway management with OHCA outcomes is essential to help guide the interpretation of the results of these trials. For example, if the trials should discover that differences in OHCA outcomes between advanced airway devices are due to differences in rates of hyperventilation, then the correct intervention may involve measures to control ventilation—not a change in airway device.

Assuming the validity of this concept, an important corollary is that we must develop new techniques and technologies to measure important physiologic parameters central to these mechanisms. For example, while it may be feasible to measure carotid blood flow in a porcine bench model as done by Segal et al., this goal is far more challenging in the clinical environment. Attention must also focus on innovative ways to analyze existing mechanistic data. For example, studies of CPR chest compression fraction have used a range of numerical approaches with varying inclusion criteria and analytic time frames [11]. Other novel chest compression metrics such as peri-shock pause and chest compression segment length may merit additional investigation [12]. While hyperventilation has been identified as harmful in OHCA, there have been few efforts to standardize its definition or detection methods [14].

Our conceptual model presents a simplified framework linking advanced airway management and OHCA outcomes. In reality,

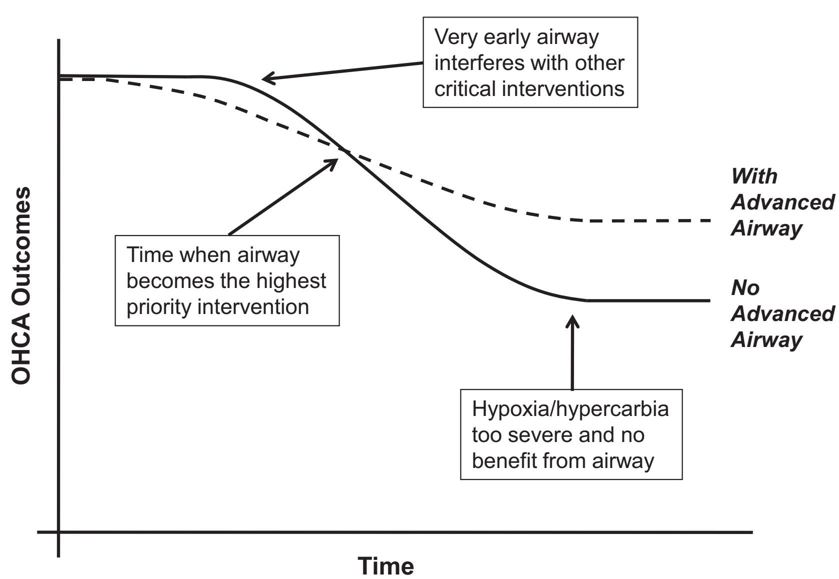

Fig. 3. Conceptual model of the time-dependent benefit of advanced airway management relative to other cardiac arrest interventions. Depicts a hypothetical survival curve for patients with and without an advanced airway intervention as a function of elapsed time. OHCA = out-of-hospital cardiac arrest.

multiple physiologic factors likely interact simultaneously, with outcomes dependent upon the trade-offs between competing risks and benefits. For example, as highlighted earlier, the benefits of early airway control and oxygen delivery may be outweighed by the risks of delayed defibrillation. Risks and benefits may also combine synergistically. For example, concomitant hyperventilation and highly interrupted CPR could cause multiplicative harm. Future scientific efforts must account for these interactions.

While our conceptual model focuses upon potential benefits and harms of advanced airway techniques, an important additional consideration is airway management by a BVM-only strategy. Observational series have associated BVM-only with increased OHCA survival compared with advanced airway techniques [2,3]. Our conceptual model can reasonably accommodate evaluations of a BVM-only strategy, as this technique may have similar technical and cognitive errors linked to loss of chest compression or ventilation control, balanced by a potentially different proportion of benefits. As future clinical trials evaluate airway management by BVM-only, similar consideration must be given to studying the inherent physiologic mechanisms. Only in this way can we strive to optimally target airway interventions to the specific pathophysiologic cohorts most likely to see benefit.

6. Conclusions

We provide a conceptual model identifying potential mechanisms linking advanced airway management with OHCA outcomes. Prospective study is required to evaluate and validate these postulated mechanisms. Scientists and clinicians must strive to understand these processes to best guide scientific research and clinical care.

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Conflict of interest statement

The authors have no conflict of interest to disclose.

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