ARTICLE IN PRESS

American Journal of Emergency Medicine xxx (2015) xxx–xxx

Contents lists available at ScienceDirect

American Journal of Emergency Medicine

journal homepage: www.elsevier.com/locate/ajem

Research Seminar

Mitigating hyperventilation during cardiopulmonary resuscitation☆,☆☆,★,★★

Dhimitri Nikolla, DO [a,*,1], Tyler Lewandowski, DO [b,1], Jestin Carlson, MD, MS [a,1]

[a] Department of Emergency Medicine, Allegheny Health Network Saint Vincent Hospital, Erie, PA
[b] Department of Emergency Medicine, UPMC Hamot Hospital, Erie, PA

ARTICLE INFO

Article history:
Received 21 October 2015
Accepted 24 November 2015
Available online xxxx

ABSTRACT

Although multiple airway management and ventilation strategies have been proposed during cardiac arrest, the ideal strategy is unknown. Current strategies call for advanced airways, such as endotracheal intubation and supraglottic airways. These may facilitate hyperventilation which is known to adversely affect cardiopulmonary physiology. We provide a summary of conceptual models linking hyperventilation to patient outcomes and identify methods for mitigating hyperventilation during cardiac arrest.

1. Introduction

Airway management has long been advocated as a critical step in the resuscitation of out-of-hospital cardiac arrest (OHCA) patients. Although oxygenation and ventilation can be achieved through bag-valve-mask (BVM) ventilation, advanced airway interventions such as endotracheal intubation (ETI) and supraglottic airways (SGAs) have been suggested as techniques to both secure the airway and provide oxygenation and ventilation, although there remains equipoise over the preferred airway management strategy [1].

Each airway management strategy (ETI, SGA, and BVM) have unique advantages and challenges. Although ETI and SGA may allow for better control of the airway, they may also facilitate hyperventilation. Hyperventilation is common during OHCA and is likely a major contributing factor in the association between advanced airways and worse patient outcomes in OHCA [1–3]. Although ongoing randomized trials may help to define the preferred advanced airway management strategy in OHCA, providers must be conscious of the adverse effects associated with hyperventilation, regardless of airway management strategy. We discuss the potential mechanisms linking hyperventilation to patient outcomes in OHCA and present methods to help mitigate hyperventilation.

2. Prevalence of hyperventilation

The 2010 American Heart Association Basic Life Support Guidelines recommend ventilations during cardiopulmonary resuscitation (CPR) in adults, with an advanced airway connected to a BVM, at 1 breath every 6 to 8 seconds or 8 to 10 breaths/min at a tidal volume of approximately 600 mL [4]. Hyperventilation is the administration of ventilations either at a rate or tidal volume in excess.

Despite these recommendations, hyperventilation often occurs during OHCA with ventilation rates greater than 10 breaths/min 63% of the time and greater than 20 breaths/min 20% of the time [5]. Ventilation rates have been reported up to 37 breaths/min with advanced airways [6–8]. Although hyperventilation is common during resuscitation, the effect of hyperventilation on survival or return of spontaneous circulation (ROSC) is more ambiguous.

3. Theoretical frame for the effects of hyperventilation

Human studies measuring the association between hyperventilation during CPR and neurologically intact survival or ROSC are limited [5,9,10]. Despite the lack of definitive data in human trials, animal studies show clearer adverse effects related to hyperventilation. Lower ventilation rates were associated with an increased coronary perfusion pressure as well as a reduced mean intrathoracic pressure [6,7]. Tidal volumes greater than 10 mL/kg and elevated positive end-expiratory pressure (PEEP) have been associated with elevations in pulmonary vascular resistance and reductions in cardiac output, right ventricular output, and inferior vena cava flow [11,12]. Survival has also been shown to be inversely related to increased ventilation rates in a porcine model [6,7].

Although these data are limited to animal studies, the detrimental effects of hyperventilation have been well described in other disease states, such as traumatic brain injury (TBI). In the setting of TBI,

☆ Financial disclosure: The authors have no financial conflicts of interest to disclose.
☆☆ Conflict of interest: The authors have no other conflicts of interest to disclose.
★ Funding: None.
★★ This is our original work. It does not overlap with previous work. It has not been published previously, nor is it under consideration elsewhere.
* Correspondence author at: Department of Emergency Medicine, Allegheny Health Network, Saint Vincent Hospital, 232 West 25th St, Erie, PA 16544.
E-mail address: dhimitri.nikolla@med.lecom.edu (D. Nikolla).
[1] All 3 authors have made substantial contributions to the concept and design of the manuscript, have partaken in the drafting and revising of the manuscript, and have approved the final version.

http://dx.doi.org/10.1016/j.ajem.2015.11.070
0735-6757/© 2015 Elsevier Inc. All rights reserved.

hyperventilation is associated with reductions in cerebral artery flow and increases in oxygen metabolism resulting in poor neurologic outcome [13–15]. Maximizing cerebral recovery is critical in both TBI and cardiac arrest. As a result, these conditions may be more susceptible to hyperventilation than other conditions requiring advanced airway management. Theoretically, these resultant physiologic effects occur and could also be detrimental in the setting of cardiac arrest. Hyperventilation may also result in hyperoxia which has been shown to worsen outcomes in the setting of cardiac arrest [16].

4. Mitigating hyperventilation

Despite these effects, providers are often unable to ventilate within the recommended rate [5–8]. The cause of hyperventilation is likely multifactorial including resuscitator inexperience, lack of advanced cardiac life support certification, periodic auscultation to confirm successful airway placement, and CPR delivered at off-hours, nights, or weekends [17]. Fortunately, there are several methods available to help mitigate these adverse effects.

4.1. Retraining

Retraining is the standard method of quality control for performing adequate CPR. Several studies have documented the deterioration of CPR skills over time after initial training [18–21]. However, even immediately after retraining, hyperventilation can still occur. Aufderheide et al [6,7] prospectively measured ventilation rates by emergency medical services providers in cardiac arrest patients. Before retraining, the average ventilation rate was 37 ± 4 breaths/min; after retraining, it improved but still resulted in hyperventilation (22 ± 3 breaths/min). Other studies have also found minimal improvements in excessive ventilation rates after retraining [22]. Although these results suggest that retraining does not prevent hyperventilation, there are other benefits from retraining including providing updates on advances in medical care and provider feedback. As such, it may need to be combined with other methods to ensure appropriate ventilation rates.

4.2. Compression-to-ventilation ratio

Compression-to-ventilation ratio is a method of delivering a predetermined number of compressions after a specified number of ventilations sequentially and alternating. This has long been advocated for ventilating OHCA patients without an advanced airway including ratios such as 15:2 (15 compressions for every 2 ventilations) or 30:2. Although the best ratio is unclear, Park et al [17] suggested that using a compression to ventilation ratio may help prevent hyperventilation. While a large, randomized, prospective trial comparing continuous compressions with positive pressure ventilations vs interrupted chest compressions with pauses for ventilations is in progress [23], continuous compressions have been shown to improve coronary perfusion pressure, pulmonary artery oxygenation, global ventilation/perfusion, survival, and neurologic outcome in porcine models [24,25]. In addition, pausing for breaths reduces the compression rate resulting in reduced compression fraction and coronary perfusion pressure, which are associated with survival or ROSC in cardiac arrest [26–29]. Despite these limitations, compression-to-ventilation ratios can help to mitigate hyperventilation in the clinical setting and may warrant further study in select populations.

4.3. Compression-adjusted ventilation

Where compressions and ventilations are performed sequentially with a compression-to-ventilation ratio, compression-adjusted ventilation (CAV) refers to timing breaths based off of the number of compressions that have been performed since the last breath simultaneously without pausing compressions. Cho et al [30] randomly divided providers (medical students and emergency medical services providers) into 2 groups: conventional ventilation (CV) every 6 to 8 seconds or CAV. The adequacy of the ventilations, or percent of providers whose average ventilation rate was 8 to 10 breaths/min, was higher in the CAV group (85.7%) compared with the CV group (47.9%; $P < .001$). Other studies with similar methods found improvements in the adequacy of ventilation rates with CAV over CV [31,32]. Although the compression-adjusted method improves the adequacy of the ventilation rates, the method is highly dependent on a precise compression rate. Observed compression rates in the literature range from 45 to 202 compressions per minute [27]. As such, CAV may best be used in conjunction with an automatic mechanical compression device; however, further work will be needed to answer this question in the clinical setting.

4.4. Metronomes

One method to prevent hyperventilation is to use a metronome that indicates to the provider when to deliver a breath and relieves the provider of the responsibility of timing ventilations. Lim et al [33] conducted a randomized, prospective study of 52 volunteers comparing BVM ventilations in simulated CPR on manikins with and without guidance by a metronome. The group with the metronome had 100% accuracy with administering a target rate of 8 to 10 breaths/min, whereas the group without had only 38.5% accuracy. Others have observed similar results comparing CVs with metronome-guided ventilations [26,22]. Nevertheless, these studies were limited to metronomes with audible tones without any visual indicators. These tones may be difficult to follow in an ambulance with a siren in the background or during the commotion of a resuscitation. Despite these limitations, metronomes are a simple yet effective adjunct that allows providers to deliver breaths at a target rate with more accuracy than CVs.

4.5. Feedback devices

Feedback devices monitor measurements of CPR, such as the compression and ventilation rates, and have the ability to provide real-time feedback to the provider allowing them to make any necessary adjustments. Previous work has found that cardiac arrests resuscitated with feedback enabled monitor/defibrillators reduced the variability in ventilation rates but did not change average ventilation rates compared with those treated without feedback (18 ± 8 vs 20 ± 10 breaths/min). The authors cite misinterpretation of the ventilation rate by the devices due to excess noise, rescuer crowding distracting the providers, and a lack of training or expertise as possible explanations for why the average ventilation rates did not differ [34]. Although feedback devices present one option for mitigating hyperventilation, providers must have experience and sufficient knowledge to recognize and adjust to the feedback being provided by the device. These challenges may be heightened when providing care in the prehospital setting.

4.6. Automatic mechanical ventilators

The use of an automatic mechanical ventilator during CPR may alleviate the responsibility of ventilation delivery from the provider, thereby eliminating the potential for inaccurate ventilation rates and tidal volumes. Currently, the American Heart Association recommends against using these ventilators due to a lack of research and the potential for elevating PEEP, resulting in increased intrathroacic pressure and impeding venous blood return to the heart [35]. Although human data are lacking, porcine studies suggest that the use of continuous positive airway pressure may be effective during CPR despite the potential adverse effects caused by PEEP [36,37]. An alternative approach is the use of the Oxylator (Lifesaving Systems Inc, Rosewell, GA) which has been studied in porcine models [38]. An Oxylator is a mechanical ventilator that automatically delivers short breaths during the decompression phase of CPR. Additional research is necessary to examine the

Please cite this article as: Nikolla D, et al, Mitigating hyperventilation during cardiopulmonary resuscitation, Am J Emerg Med (2015), http://dx.doi.org/10.1016/j.ajem.2015.11.070