Novel Pharyngeal Oxygen Delivery Device Provides Superior Oxygenation during Simulated Cardiopulmonary Resuscitation

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Abbreviations:
BVM: bag-valve-mask
CC-CPR: continuous compression cardiopulmonary resuscitation
CPR: cardiopulmonary resuscitation
$EtCO_2$: end-tidal carbon dioxide
LPM: liters per minute
NRFM: non-rebreather face mask
OPA: oropharyngeal airway
PODD: pharyngeal oxygen delivery device
PPV: positive pressure ventilation

Abstract

Introduction: Passive oxygenation with non-rebreather face mask (NRFM) has been used during cardiac arrest as an alternative to positive pressure ventilation (PPV) with bag-valve-mask (BVM) to minimize chest compression disruptions. A dual-channel pharyngeal oxygen delivery device (PODD) was created to open obstructed upper airways and provide oxygen at the glottic opening. It was hypothesized for this study that the PODD can deliver oxygen as efficiently as BVM or NRFM and oropharyngeal airway (OPA) in a cardiopulmonary resuscitation (CPR) manikin model.

Methods: Oxygen concentration was measured in test lungs within a resuscitation manikin. These lungs were modified to mimic physiologic volumes, expansion, collapse, and recoil. Automated compressions were administered. Five trials were performed for each of five arms: (1) CPR with 30:2 compression-to-ventilation ratio using BVM with 15 liters per minute (LPM) oxygen; continuous compressions with passive oxygenation using (2) NRFM and OPA with 15 LPM oxygen, (3) PODD with 10 LPM oxygen, (4) PODD with 15 LPM oxygen; and (5) control arm with compressions only.

Results: Mean peak oxygen concentrations were: (1) 30:2 CPR with BVM 49.3% (SD = 2.6%); (2) NRFM 47.7% (SD = 0.2%); (3) PODD with 10 LPM oxygen 52.3% (SD = 0.4%); (4) PODD with 15 LPM oxygen 62.7% (SD = 0.3%); and (5) control 21% (SD = 0%). Oxygen concentrations rose rapidly and remained steady with passive oxygenation, unlike 30:2 CPR with BVM, which rose after each ventilation and decreased until the next ventilation cycle (sawtooth pattern, mean concentration 40% [SD = 3%]).

Conclusions: Continuous compressions and passive oxygenation with the PODD resulted in higher lung oxygen concentrations than NRFM and BVM while minimizing CPR interruptions in a manikin model.

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Introduction

Cardiopulmonary resuscitation (CPR) is required to treat out-of-hospital cardiac arrest in more than 350,000 Americans each year.[1] Minimizing chest compression interruptions during CPR preserves coronary perfusion and improves neurologically intact survival and post-survival quality of life.[2,3] Positive pressure ventilation (PPV) during CPR via bag-valve-mask (BVM) is being re-examined as potentially harmful due to increased

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intrathoracic pressure (diminishing coronary perfusion and right heart filling) and circulatory interruption (reducing end organ perfusion).[4,5] National and international CPR guidelines have shifted to prioritizing compressions while de-emphasizing PPV. In 2005, the American Heart Association (AHA; Dallas, Texas USA) increased the adult CPR compression-to-breath ratio from 15:2 to 30:2.[6] In 2008, continuous compression CPR (CC-CPR), also known as "hands-only CPR," was recommended for out-of-hospital cardiac arrest, eliminating rescue breaths altogether and providing continuous compressions until emergency medical personnel arrive.[7] In 2010, resuscitation algorithms were rearranged from "airway>-breathing>circulation" to "circulation>airway>breathing," further prioritizing compressions and perfusion.[8]

During CC-CPR, lung gas exchange occurs during passive chest recoil *between* compressions without interrupting compressions to administer breaths (as occurs during traditional 30:2 CPR).[3,9,10] Passive oxygen delivery methods during CC-CPR have been investigated as an alternative to 30:2 CPR after witnessed cardiac arrest in both prehospital and hospital settings.[5,11,12] In one study, paramedics witnessing out-of-hospital cardiac arrest chose to administer 30:2 CPR or CC-CPR with non-rebreather face mask (NRFM) and oropharyngeal airway (OPA) with 15 liters-per-minute (LPM) supplemental oxygen.[5] When adjusting for neurologically intact outcomes, survival was higher in ventricular fibrillation patients receiving CC-CPR with NRFM passive oxygenation than 30:2 CPR. Considering the diverse airway management skills and training in prehospital providers, devices that simplify and expedite rescue efforts and require little or no additional usage instructions may improve survival by reducing interruptions to high-quality compressions.

A pharyngeal oxygen delivery device (PODD) that delivers oxygen directly above the glottic opening has recently been described as an alternative to passive oxygenation with NRFM during CPR (Figure 1).[13] The dual-lumen PODD nests within the side channel of a standard OPA, allowing rapid and easy placement without advanced airway management training (Figure 2). The PODD's primary (larger) lumen bypasses the most common areas of upper airway obstruction while delivering oxygen from either a wall or cylinder oxygen source. The secondary (smaller) lumen simultaneously monitors end-tidal carbon dioxide ($EtCO_2$) concentration. When used during CC-CPR, the PODD relieves upper airway obstruction, minimizes CPR interruptions, and avoids increasing intrathoracic pressure seen with PPV. Furthermore, the PODD continuously delivers oxygen during intubation without obscuring the laryngoscopy view. It was hypothesized for this study that the PODD can deliver oxygen to the lungs as efficiently as PPV with BVM or passive oxygenation with NRFM.

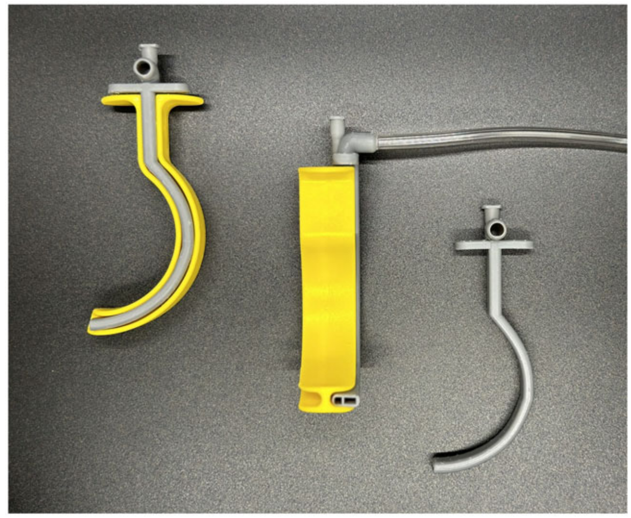

Figure 1. Pharyngeal Oxygen Delivery Device (PODD) that Delivers Oxygen Directly Above the Glottic Opening.

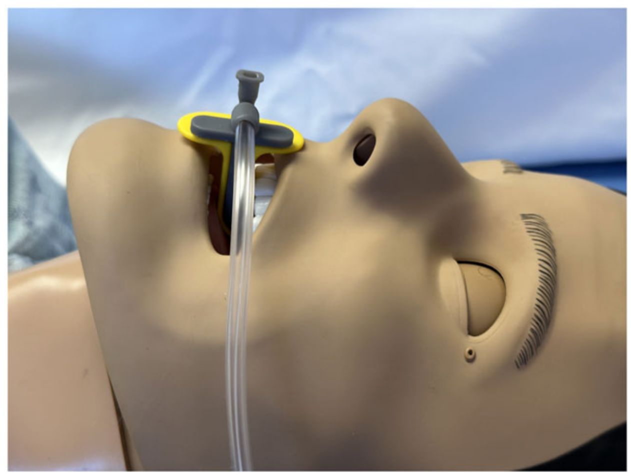

Figure 2. The Dual-Lumen Pharyngeal Oxygen Delivery Device (PODD) Nests within the Side Channel of a Standard OPA.

Methods

A cardiac resuscitation manikin (Laerdal SimMan ACLS; Laerdal Medical; Stavanger, Norway) was modified using lungs with physiologic reserve volume that expand during PPV, collapse during chest compressions, and passively recoil to a baseline shape and volume. To minimize inter-provider variability during chest compressions, an automated external CPR device (LUCAS 3; Stryker Medical; Kalamazoo, Michigan USA) provided consistent compressions at a rate of 100 per minute. The manikin and test lungs were validated during automated compressions for expansion, collapse, and recoil using spirometry data from a Draeger Perseus A500 anesthesia workstation (Drägerwerk AG & Co. KgaA; Laback, Germany).

Thereafter, five arms were studied: (1) 30:2 compression-to-breath CPR using BVM with 15 LPM oxygen; continuous compressions with passive oxygenation using (2) NRFM with OPA with 15 LPM oxygen, (3) PODD with 10 LPM oxygen, (4) PODD with 15 LPM oxygen; and (5) control arm with compressions only and no supplemental oxygen. Five randomized trials were performed for each arm, for a total of 25 trials. At the beginning of each trial, the lungs were filled with room air (21% oxygen). Oxygen concentrations were measured via a multi-gas analyzer at the base of the manikin lungs every five seconds for six minutes. Data were analyzed using descriptive statistics and one-way ANOVA, with $P < .05$.

Results

Oxygen concentration to start each trial was 21% (SD = 0%). The following mean peak oxygen concentrations were reached: (1) 30:2

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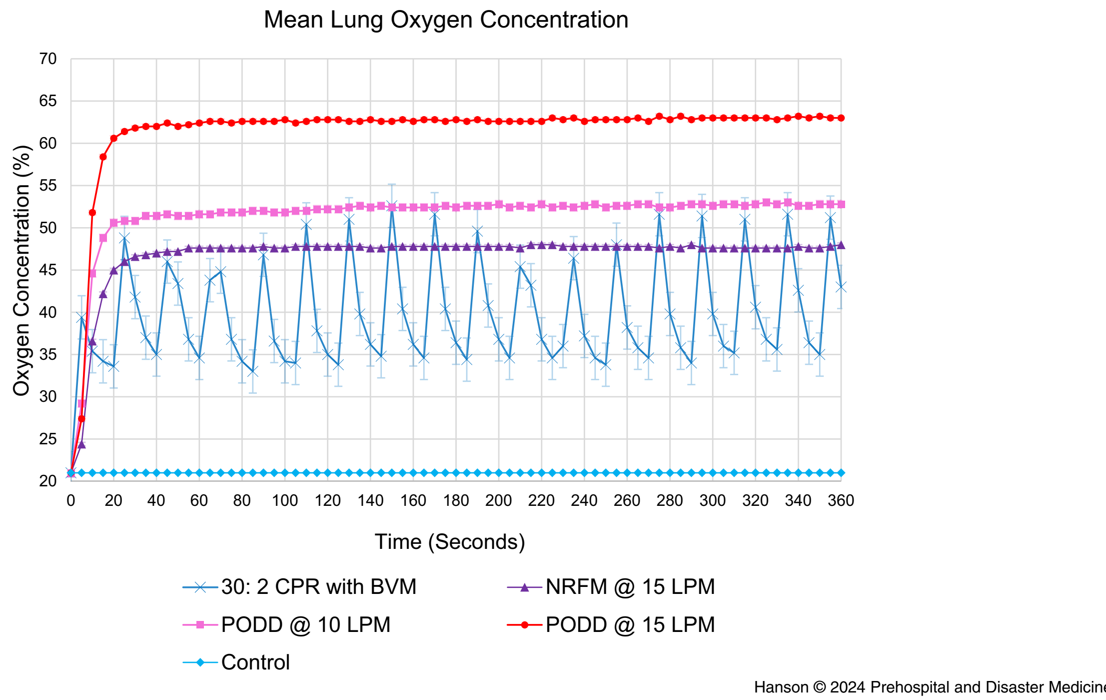

Figure 3. Mean Lung Oxygen Concentration.
Abbreviations: CPR, cardiopulmonary resuscitation; BVM, bag-valve-mask; NRFM, non-rebreather face mask; LPM, liters per minute; PODD, pharyngeal oxygen delivery device.

CPR with BVM 49.3% (SD = 2.6%; 95% CI, 48.1-50.5); (2) NRFM with 15 LPM oxygen 47.7% (SD = 0.2%; 95% CI, 47.6-47.7); (3) PODD with 10 LPM oxygen 52.3% (SD = 0.4%; 95% CI, 52.3-52.5); (4) PODD with 15 LPM oxygen 62.7% (SD = 0.3%; 95% CI, 62.7-62.8); and (5) control 21% (SD = 0%; Figure 3). In all continuous compression passive oxygenation arms (ie, NRFM arm and two PODD arms), the oxygen concentration rose within the first 30 seconds and remained unchanged for the remainder of each trial. Conversely, in the 30:2 CPR arm, the oxygen concentration rose after each mask ventilation and fell thereafter until the next ventilation cycle, resembling a sawtooth pattern.

Discussion

In this pilot study using a manikin resuscitation model with customized simulated lungs, continuous cardiac compressions coupled with passive oxygenation via the PODD provided higher lung oxygen concentration than NRFM, BVM, and room air control. The PODD delivered oxygen continuously at the glottic opening without interrupting chest compressions. Higher lung oxygen concentrations combined with continuous compressions should result in improved arterial oxygen delivery and end-organ perfusion. Thus, the PODD may potentially improve efficiency and clinical outcomes within life support algorithms, being easily placed for oxygen delivery and $EtCO_2$ monitoring without interrupting chest compressions or compromising vital organ perfusion. Pausing compressions during CPR detrimentally affects hemodynamics by reducing cardiac output, mean coronary perfusion pressure, and left ventricular myocardial blood flow.[3,14] Each cessation of compressions increases morbidity due to the lack of perfusion until compressions are resumed.[2,15] Conversely, CC-CPR is easy to perform and may improve outcomes by avoiding complications demonstrated in 30:2 CPR, including inadequate BVM seal, asynchrony between compressions and rescue breaths, and long compression interruptions that compromise coronary and cerebral perfusion.[16,17] Simplifying resuscitation algorithms through CC-CPR with passive oxygenation could potentially eliminate these common pitfalls and reduce guideline deviations, with the overarching goal of maximizing systemic perfusion. Additionally, using the PODD may avoid increased intrathoracic pressure and impaired cardiac filling, while still providing comparable or superior alveolar oxygen concentrations compared to other available techniques, based on these preliminary data.

The PODD offers additional advantages to CC-CPR. Because OPA placement is a basic airway management skill, PODD placement and passive oxygenation can similarly be achieved by any emergency medical technician, nurse, or physician with Basic Life Support training. For out-of-hospital cardiac arrest, one person can easily perform CC-CPR and simultaneously deliver oxygen via the PODD, allowing the second prehospital provider to transport to a higher level of care rather than administer rescue breaths or attempt intubation.[18] During in-hospital cardiac arrest, the first responder can activate the emergency response system upon arrival and initiate CC-CPR and the next responder can place the PODD to deliver oxygen. In either scenario, using the PODD facilitates uninterrupted CPR, except for standard pulse checks and defibrillation as indicated.

While CC-CPR with PODD passive oxygenation may provide advantages over standard 30:2 CPR, disadvantages exist. Evidence supporting CC-CPR is emerging, but traditional CPR has been the standard of care for decades. Secondly, oxygenation during CC-CPR relies on chest recoil between compressions for effective gas diffusion, and human data (though limited) demonstrate that tidal volume with each compression is well-below physiologic volumes.[2,14,19] Furthermore, patients with a non-compliant chest wall or CPR-related rib fractures may experience a decrease in chest recoil and passive oxygen entrainment over time resulting in a greater reliance on dead space gas diffusion for effective lung oxygenation. Human studies are needed to determine whether delivering oxygen directly above the glottic opening with the PODD increases oxygenation and ventilation at the lung alone or improves arterial oxygen and carbon dioxide concentrations in clinical practice.

Limitations

Limitations to this study include the use of a manikin model, which may not perfectly mimic in vivo results. The standard lungs of the ACLS manikin were replaced with prototypes having physiologic volumes and function (expansion, collapse, and recoil) but were not otherwise validated for use in resuscitation. Finally, lung oxygen concentrations were higher during simulated CPR with the PODD, but this may not necessarily improve outcomes in vivo for two reasons. First, higher lung oxygen concentration should lead to higher arterial oxygen concentration, but variables present in vivo may adversely affect this relationship. At the other extreme, arterial hyperoxia during CPR and the immediate post-resuscitation period may be injurious, so optimal oxygenation must be determined and oxygen concentration adjusted accordingly.[20,21] Further study is needed to determine underlying etiology and differentiate from risks associated with PPV, hypoxia, or hyperoxia.

Conclusion

Despite limitations, this early pilot study demonstrates the potential utility of a pharyngeal oxygenation device during CC-CPR to facilitate oxygenation without use of PPV while limiting interruptions in chest compressions. The PODD couples with a standard Berman OPA, allowing its use by health care professionals across a broad range of training levels, during both in-hospital and out-of-hospital cardiac arrest. The findings of this simulation model suggest that the PODD warrants additional clinical investigation to determine potential benefits in CC-CPR.

Author Contributions

Jeramie B. Hanson, MD made substantial contributions to the pharyngeal oxygen delivery device prototype design and development; study conception and design; data acquisition, analysis, and interpretation; manuscript drafting; manuscript revision for important intellectual content; and final approval of the version to be published. He agrees to be accountable for all aspects of the work.

John R. Williams, MD made substantial contributions to study design; data acquisition, analysis, and interpretation; manuscript drafting; manuscript revision for important intellectual content; and final approval of the version to be published. He agrees to be accountable for all aspects of the work.

Emily H. Garmon, MD made substantial contributions to study design; data acquisition, analysis, and interpretation; manuscript revision for important intellectual content; and final approval of the version to be published. She agrees to be accountable for all aspects of the work.

Phillip M. Morris, MD made substantial contributions to study design; data acquisition, analysis, and interpretation; manuscript revision for important intellectual content; and final approval of the version to be published. He agrees to be accountable for all aspects of the work.

Russell K. McAllister, MD made substantial contributions to study design; data acquisition, analysis, and interpretation; manuscript revision for important intellectual content; and final approval of the version to be published. He agrees to be accountable for all aspects of the work.

William C. Culp, Jr., MD made substantial contributions to study conception and design; data acquisition, analysis, and interpretation; manuscript revision for important intellectual content; and final approval of the version to be published. He agrees to be accountable for all aspects of the work.

References

1. American Heart Association. CPR & First Aid Emergency Cardiovascular Care. CPR Facts & Stats. https://cpr.heart.org/en/resources/cpr-facts-and-stats. Accessed December 4, 2023.
2. Ewy GA. Cardio cerebral resuscitation: the new cardiopulmonary resuscitation. *Circulation.* 2005;111(16):2134–2142.
3. Cunningham LM, Mattu A, O'Connor RE, Brady WJ. Cardiopulmonary resuscitation for cardiac arrest: the importance of uninterrupted chest compressions in cardiac arrest resuscitation. *Am J Emerg Med.* 2012;30(8):1630–1638.
4. Aufderheide TP, Sigurdsson G, Pirrallo RG, et al. Hyperventilation-induced hypotension during cardiopulmonary resuscitation. *Circulation.* 2004;109(16): 1960–1965.
5. Bobrow BJ, Ewy GA, Clark L, et al. Passive oxygen insufflation is superior to bag-valve-mask ventilation for witnessed ventricular fibrillation out-of-hospital cardiac arrest. *Ann Emerg Med.* 2009;54(5):656–662.e1.
6. ECC Committee, Subcommittees, and Task Forces of the American Heart Association. 2005 American Heart Association Guidelines for Cardiopulmonary Resuscitation and Emergency Cardiovascular Care. *Circulation.* 2005; 112(24 Suppl):IV1–IV203.
7. Sayre MR, Berg RA, Cave DM, et al. Hands-only (compression-only) cardiopulmonary resuscitation: a call to action for bystander response to adults who experience out-of-hospital sudden cardiac arrest: a science advisory for the public from the American Heart Association Emergency Cardiovascular Care Committee. *Circulation.* 2008;117(16):2162–2167.
8. Berg RA, Hemphill R, Abella BS, et al. Part 5: Adult Basic Life Support: 2010 American Heart Association Guidelines for Cardiopulmonary Resuscitation and Emergency Cardiovascular Care. *Circulation.* 2010;122(18 Suppl 3):S685–S705.
9. Saïssy JM, Boussignac G, Cheptel E, et al. Efficacy of continuous insufflation of oxygen combined with active cardiac compression-decompression during out-of-hospital cardiorespiratory arrest. *Anesthesiology.* 2000;92(6):1523–1530.
10. Bobrow BJ, Spaite DW, Berg RA, et al. Chest compression-only CPR by lay rescuers and survival from out-of-hospital cardiac arrest. *JAMA.* 2010;304(13): 1447–1454.
11. Steen S, Liao Q, Pierre L, Paskevicius A, Sjöberg T. Continuous intratracheal insufflation of oxygen improves the efficacy of mechanical chest compression-active decompression CPR. *Resuscitation.* 2004;62(2):219–227.
12. Toner AJ, Douglas SG, Bailey MA, et al. Effect of apneic oxygenation on tracheal oxygen levels, tracheal pressure, and carbon dioxide accumulation: a randomized, controlled trial of buccal oxygen administration. *Anesth Analg.* 2019;128(6):1154–1159.
13. Hanson JB, Williams JR, Garmon EH, et al. Pharyngeal oxygen delivery device sustains manikin lung oxygenation longer than high-flow nasal cannula. *Baylor University Medical Center Proceedings*. Published online November 14, 2023.
14. Berg RA, Sanders AB, Kern KB, et al. Adverse hemodynamic effects of interrupting chest compressions for rescue breathing during cardiopulmonary resuscitation for ventricular fibrillation cardiac arrest. *Circulation.* 2001;104(20):2465–2470.
15. Brouwer TF, Walker RG, Chapman FW, Koster RW. Association between chest compression interruptions and clinical outcomes of ventricular fibrillation out-of-hospital cardiac arrest. *Circulation.* 2015;132(11):1030–1037.
16. Wang HE, Simeone SJ, Weaver MD, Callaway CW. Interruptions in cardiopulmonary resuscitation from paramedic endotracheal intubation. *Ann Emerg Med.* 2009;54(5):645–652.e1.
17. Idris AH, Aramendi Ecenarro E, Leroux B, et al. Bag-valve-mask ventilation and survival from out-of-hospital cardiac arrest: a multicenter study. *Circulation.* 2023; 148(23):1847–1856.
18. Valenzuela TD, Kern KB, Clark LL, et al. Interruptions of chest compressions during emergency medical systems resuscitation. *Circulation.* 2005;112(9):1259–1265.
19. Vanwulpen M, Wolfskeil M, Duchatelet C, Hachimi-Idrissi S. Do manual chest compressions provide substantial ventilation during prehospital cardiopulmonary resuscitation? *Am J Emerg Med.* 2021;39:129–131.
20. Kilgannon JH, Jones AE, Shapiro NI, et al. Association between arterial hyperoxia following resuscitation from cardiac arrest and in-hospital mortality. *JAMA.* 2010;303(21):2165–2171.
21. Kilgannon JH, Jones AE, Parrillo JE, et al. Relationship between supranormal oxygen tension and outcome after resuscitation from cardiac arrest. *Circulation.* 2011;123(23):2717–2722.