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COMPARING THE EFFICACY OF SIMULATED OUT-OF-HOSPITAL VENTILATION WITH SMART BAG-VALVE AND TRADITIONAL BAG-VALVE DEVICES

Ian Dawson, BHthSc, BSc(ParamedSc)*[1]; Brennen W. Mills, PhD[1,2]; David Ford[1]

Author Affiliations: 1. School of Medical and Health Sciences, Edith Cowan University, Joondalup, WA, Australia; 2. Simulation & Immersive Digital Technology Group, Edith Cowan University, Joondalup, WA, Australia.

**Corresponding Author*: idawson0@our.ecu.edu.au

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ABSTRACT

Aim: Optimal Bag Valve Mask (BVM) ventilation is crucial during the management of cardiac arrest because it provides gas exchange to patients, improving chances of survival until advanced care becomes available. Clinicians often hyperventilate patients, leading to an increased risk of aspiration and barotrauma. The SMART BVM has been released, incorporating a pressure-responsive valve limiting airflow if/when the operator is hyperventilating. The aim of this study was to compare mean ventilation rates, singular tidal volume, and one-minute volume of asynchronous ventilations of the SMART BVM and the more traditionally used Adult, and the Pediatric BVMs during an out-of-hospital (OHCA) cardiopulmonary resuscitation simulation amongst a group of novice paramedicine students.

Methods: Thirty paramedic students, working in pairs, completed three simulated cardiopulmonary resuscitation exercises (SIMEXS) inside a stationary ambulance utilizing the three BVMs (randomised order of exposure), lasting four minutes each with one participant providing two minutes of asynchronous ventilations and the second participant providing chest compressions at a rate of 100–120 per minute for two minutes before defibrillating. Measures of ventilation rates, singular tidal volume, and one-minute volume were taken for comparison against international recommendations.

Results: The SMART and Adult BVM mean ventilation rates were within recommended guideline parameters (i.e., 10–12 BPM). Adult BVM mean singular tidal volume (524mLs, $p=0.179$) and one-minute volume (5894mLs, $p=0.399$) were not dissimilar to the International Liaison Committee on Resuscitation (ILCOR) recommendations (i.e., 500mLs per inspiration and 5000–6000 mLs minute volume). However, mean tidal volumes for the SMART BVM and Pediatric BVM were below ILCOR recommendations (443mLs, $p<0.010$ and 280mLs, $p<0.001$, respectively), as was the Pediatric BVM mean one-minute volume (2992mLs, $p<0.001$).

Conclusion: In a simulated OHCA cardiac resuscitation, novice paramedic students were able to meet ILCOR recommendations for tidal and one-minute volume using a standard Adult BVM; however, when using the Pediatric and SMART BVM, the ventilatory provisions were below ICOR guidelines, thus resulting in hypoventilation due to insufficient tidal volume and one-minute volume.

INTRODUCTION

Out-of-Hospital-Cardiac-Arrest (OHCA) is a leading cause of mortality worldwide, with survival rates being low, ranging from 3.1–20.4% internationally when patients are resuscitated by emergency medical service clinicians (Meaney et al., 2013; Nishiyama et al., 2023; The, 2018). During cardiopulmonary resuscitation (CPR), the Bag Valve Mask (BVM) provides lifesaving positive pressure ventilations to the compromised patient with absent or ineffective breathing, delivering oxygen to the respiratory tract, thus enabling gas exchange, and the BVM has been the mainstay of prehospital ventilation since its creation in 1953 (Ambu., 2023; Australia., 2020a; O-Two et al., 2015). The design of the Adult BVM allows a large variability in volume delivery, and research has historically identified a lack of compliance with ventilation guidelines during OHCA CPR (Aufderheide & Lurie, 2004; Baskett et al., 2005). Studies indicate clinicians can overzealously ventilate patients when using a self-inflating bag valve mask at rates two to three times above the International Committee on Resuscitation (ILCOR) recommended 10 breaths per minute (BPM) (Abella et al., 2005; Aufderheide & Lurie, 2004; Soar et al., 2020). Hyperventilation can lead to aspiration, barotrauma, and raised cerebral pressure (Bucher et al., 2019; Wenzel et al., 2001). However, despite the international ventilatory guideline incrementally decreasing from the measurable 1992 recommendation of 12–15 BPM, singular tidal volume ventilation of 800–1200mLs to the 2015–2020 ventilatory recommendation of 10 BPM and singular tidal volume ventilation of 500mLs (Baskett et al., 1996; Monsieurs et al., 2015), prehospital, clinical, and simulated studies still indicate poor compliance with ventilatory guidelines on both unprotected and advanced airways, leading to both hypo/hyper-ventilation and insufficient or excessive tidal and minute volumes (Culbreth & Gardenhire, 2021; Dafilou et al., 2020; Kroll et al., 2019; Siegler et al., 2017; Vissers et al., 2019).

Thus, the traditional Pediatric BVM has been trialled within in-hospital and tabletop studies to assess if the reduced size of the self-inflating bag decreases inadvertent hyperventilation within OHCA. Results indicate the traditional Pediatric BVM may well provide more efficacious ventilations compared to the Adult BVM (Dafilou et al., 2020; Doerges et al., 1999; Siegler et al., 2017). Alternatively, the Synchronous Manual Actuation Response Technology (SMART) BVM has been engineered with an incorporated pressure-responsive valve (an actuating mechanism) that limits the inspiratory gas flow depending on the operator’s applied squeeze of the bag into the patient's airway. The SMART BVM-activated valve increases the bag's resistance when squeezed too hard, indicating to the clinician that they are ventilating too forcefully. A red-coloured indicator valve within the neck of the BVM indicates if gas is flowing too rapidly (Figures 1 and 2). In-hospital tabletop studies found the SMART BVM provided ventilations and tidal volumes closer to recommended guidelines than other Adult BVMs (Wagner-Berger, Wenzel, Stallinger, et al., 2003; Wagner-Berger, Wenzel, Voelckel, et al., 2003).

ILCOR has identified that additional research is required to inform optimal ventilation, airway, and compression practices in pre-hospital environments (Olasveengen et al., 2017). Additionally, improvements in CPR outcomes need a high-quality chain of survival from essential to advanced life support, including optimal ventilation from a BVM (Soar et al., 2021). The present study investigated which of three established BVMs (SMART, traditional Pediatric, and traditional Adult) provided efficacious ventilation rates and tidal volumes most closely aligned with ILCOR guidelines during a simulated OHCA amongst novice paramedicine students.

METHODS

Thirty paramedic students, working in pairs, completed three simulated cardiopulmonary resuscitation exercises (SIMEXS) utilizing three BVMs (randomised order of exposure), lasting four minutes each with one participant providing two minutes of asynchronous ventilations at a rate of 10–12 breaths per minute, and inspired volume of 500mLs, and the second participant providing chest compressions at a rate of 100–120 per minute for two minutes before defibrillating. Measures of ventilation rates, singular tidal volume, and one-minute volume were taken to compare against international recommendations (i.e., mean ventilations per minute of 10–12 BPM (Australia., 2020a) mean singular tidal volume of 500mLs per inspiration and one-minute tidal volume of 5000–6000mLs (Australian Resuscitation Council, 2021)).

Participants

Participants in this study were first-year undergraduate paramedical science students enrolled at Edith Cowan University (ECU) in Western Australia (WA) who had undertaken CPR training. First-year students were deemed most appropriate given they possessed a foundational understanding of CPR, removing the need to provide basic CPR training (as would be the case with non-specialists) whilst simultaneously limiting the variability of experience that would have occurred in higher-year level student cohorts. Clinicians and volunteers responding to OHCA vary with respect to clinical

Figure 1. SMART B VM (Smart Bag Specifiation, 2022).

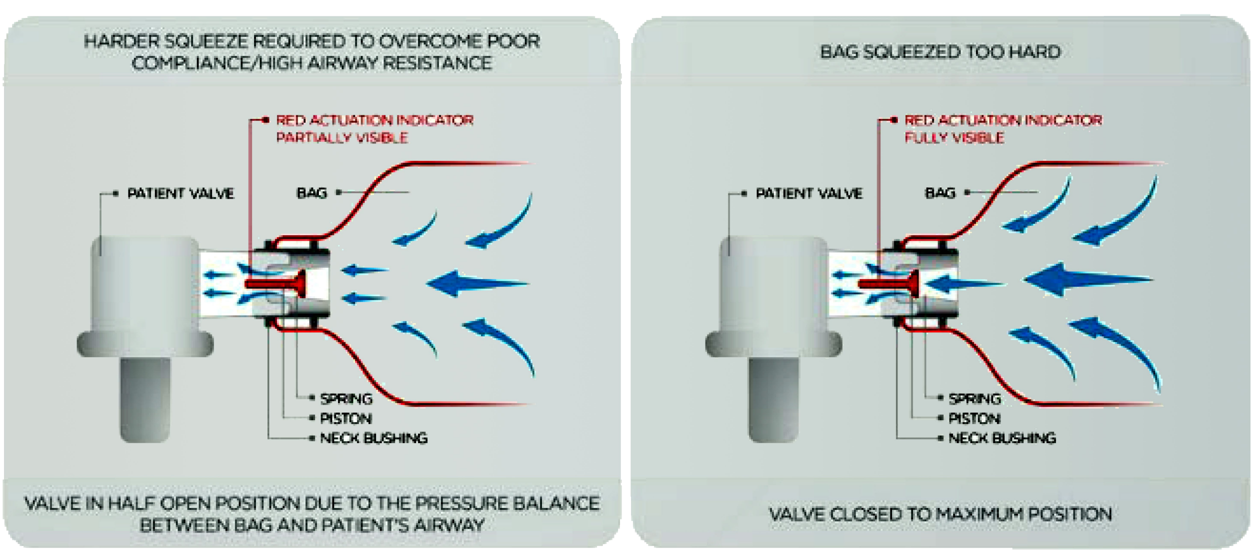

Figure 2. SMART BVM Valve (Smart Bag Specification, 2022).

experience and training. Thus, novice students were also chosen for the research given they emulate (if not exceed) the more inexperienced clinicians that could be exposed to OHCA patients.

A short demographic questionnaire collected data about age, sex (male/female/other), prior CPR training such as first aid training, certificates or diplomas, surf lifesaving, or paid employment in health care, including any previous exposure to CPR events.

Equipment

AMBU Adult and Pediatric SPUR II BVM (traditional)

The Artificial Manual Breathing Unit (Ambu) has been formulated as a highly responsive self-inflating BVM with minimal mechanical ventilation resistance. It has been developed with a disc valve for forward airflow and positive pressure ventilation. The traditional Adult and Pediatric BVM vary only in self-inflating bag sizes (1574mLs and 683mLs, respectively), with a single-hand delivery of approximately 600mls and 450mls, respectively (Ambu, 2021).

O-Two-O Adult SMART BVM

The SMART BVM has been developed with an actuating mechanism to intentionally limit the potential for excessive gas flow into the patient's airway. The SMART BVM has a single-hand delivery of approximately 900mls (O-Two Medical Technologies, 2000, 2015, 2021).

Collection of Outcome Variables

This study required the measurement of manual singular ventilation rates and singular-inspired tidal volumes, thus quantifying the calculation of one-minute volume (ventilation rate × tidal volume) per BVM, including the capacity for participants to receive visual and audible feedback throughout chest compression (100–120 CPM) (Australia, 2020; Olasveengen et al., 2017). The pre-hospital ZOLL X Series Advanced with REAL BVM Help (ZOLL et al.. Ltd) measures ventilatory rate and tidal volume for intubated (and non-intubated) patients through an AccuVent sensor; the sensor was interconnected between the BVM neck connector and a 7.5mm endotracheal tube (ETT) and intubated into a full-bodied Laerdal QCPR Resusci Anne mannequin (Laerdal et al.). Furthermore, the ZOLL X series chest compressor puck was placed on the lower half of the Laerdal mannequin sternum and connected to the monitor via the monitor defibrillator with training defibrillation pads applied, thus enabling live participant feedback, and measurements of chest compression rate, depth, recoil, and providing an avenue to view post-case data online (ZOLL Medical, 2015). The research team tested all the equipment to manufacturer protocol specifications before each SIMEX began, ensuring the reliability of the data. During SIMEXs, the ventilation rate and tidal volume measurements on the display screen were covered from the participant's view (Figure 3).

Research Protocol

Following receipt of signed informed consent, participants completed the demographic questionnaire. Each participant pair was positioned in the rear of a stationary ambulance. A member of the research team provided a standardised demonstration of how

Figure 3. Laerdal mannequin positioned within the ambulance, and ZOLL X series AccuVen attached to SMART BVM.

to apply pressure to each BVM using the dominant hand positioned in an inverted grip, with the thumb, pointer, and middle finger, whilst supporting the BVM using the ring and little finger upon the air-inlet one-way valve and O2 reservoir socket. Participants were allowed to familiarize themselves with each BVM to their satisfaction and ask questions before beginning the OHCA SIMEX. At the beginning of each of the three SIMEXs, one of the two participants (allocated at random) was instructed to administer asynchronous ventilations at the rate of 10–12 BPM, aiming for an approximate tidal volume of 500mLs per inspiration using an inverted hand grip, whilst simultaneously the second participant provided cardiac chest compressions at a rate of 100–120 per minute (Australia., 2020a, 2020b). The mannequin was defibrillated at the two-minute mark, following ILCOR guidelines (Soar et al., 2021) at which time participants swapped roles and continued for a further two minutes before ending the SIMEX.

SIMEXs comprised three successive CPR sessions (each utilizing a different BVM in a randomized order) lasting four minutes each. There was a six-minute allocated rest period between the three scenarios, replicating the rotation of paramedic cardiac compressors throughout CPR to reduce compressor fatigue following Australian and New Zealand Committee on Resuscitation (ANZCOR) CPR guidelines (Australian Resuscitation Council, 2021). During this time, the research team exchanged the randomized BVM.

Statistical Analysis

Data were recorded by the ZOLL X series defibrillator series software package (ZOLL et al. Ltd) and imported into Microsoft Excel (Version 11) before being manually transferred into IBM SPSS Statistics (Version 26.0) for analysis. Outcome variables of mean ventilations per minute, mean singular tidal volume per minute, and mean one-minute volume were calculated across the three BVM study conditions and compared using a series of one-way repeated measure ANOVAs. Further, a series of one-sample t-tests were used to compare outcome variable means against upper and lower ventilatory guideline boundaries (i.e. mean ventilations per minute of 10–12 BPM (Australia., 2020a) mean singular tidal volume of 500mLs per inspiration and one-minute tidal volume of 5000–6000mLs (Australian Resuscitation Council, 2021)). An alpha value $p<0.05$ was considered statistically significant. Shapiro-Wilks normality tests suggested that all outcome variable data for each BVM did not violate assumptions of normality ($p>0.05$).

Ethical Approval

Ethics approval was granted by the ECU Human Research Ethics Committee in alignment with the National Health and Medical Research Council National Statement on Ethical Conduct in Human Research. Participants returned signed consent forms prior to the beginning of data collection.

RESULTS

Thirty first-year ECU undergraduate paramedic students (12 male, 18 female) with an average age of 24±7 years participated in the study. Independent samples t-tests indicated no differences between sexes or experience levels (0–30 months versus 31–60 months) across BVMs for all outcome measures. Technological faults led to data not being captured for two participants from the traditional Adult BVM condition. Therefore, comparative analyses between the three BVMs were examined on the remaining 28 complete data sets.

Mean Ventilations Per Minute

A total of 1930 ventilations were analysed. Mean ventilation rates did not significantly differ across BVMs (Table 1[a–c]). While the SMART and Adult BVMs mean ventilation rates were within the St John clinical guidelines recommended rate of 10–12 BPM (St John Ambulance Australia, 2020b), the Pediatric BVMs mean ventilation rate was slightly lower than the state ambulance ventilation rate (St John Ambulance Australia, 2020b) (Table 1[b]).

Mean Tidal Volume

The mean singular tidal volume for the traditional Pediatric BVM (280.5 mLs) (Table 1[e]) was significantly lower than both the SMART BVM (443.4 mLs) (Table 1[d]) and traditional Adult BVM (524 mLs) (Table 1[f]). Further, the SMART BVM had a mean singular tidal volume significantly lower than the traditional Adult BVM (80.1 mLs; $p<0.001$*) (Table 2[a]). Whilst in comparison to ILCORs recommended singular tidal volume (500mLs), both the SMART BVM (-56.5 mLs; $p<0.010$) (Table 3[a]) and traditional Pediatric BVM ($p<0.001$*; -219.4 mLs) (Table 3[b]) were significantly below ILCORs recommendation, yet the traditional Adult BVM was no different to ILCORs singular (500mLs) tidal volume guidelines (24.0 mLs; $p>0.179$) (Table 3[c]).

Mean One-Minute Volume

The traditional Pediatric BVMs mean one-minute tidal volume was lower than both the SMART BVM (1918.3 mLs; $p<0.001$*) (Table 2[b]) and traditional Adult BVM (2828.7 mLs;

p<0.001*) (Table 2[c]). Further, the SMART BVM had a mean one-minute tidal volume lower than the traditional Adult BVM (910.4 mLs; p<0.008*) (Table 2[d]). The SMART BVM mean one-minute tidal volume (4893.5 mLs) (Table 1[g]) was no different than the lower boundary of ILCORs recommended 5000mLs (-106.5 mLs; p=0.386) (Table 3[d]) and the traditional Adult BVM one-minute tidal volume (5894.2mLs) (Table 1[i]) was no different to the upper boundary of ILCORs recommended 6000 mLs (-105.7mLs; p=0.399) (Table 3[e]). However, the traditional Pediatric BVM mean one-minute tidal volume (2992.8mLs) (Table 1[h]) was significantly below the lower boundary of the ILCOR recommended 5000mLs (-3007.2; p<0.001) (Table 3[f]).

	SMART BVM	Pediatric BVM	Adult BVM
Bag size volume (mLs)	1700	683	1547
One-minute ventilation rate	11.1 ± 3.06 (CI: 10.0 – 12.1)[a]	10.4 ± 3.70 (CI: 9.0 – 11.7)[b]	11.3 ± 3.17 (CI: 10.1 – 12.4)[c]
Singular tidal volume (mLs)	443.4 ± 126.7 (CI: 396.0 – 490.7)[d]	280.5 ± 61.4 (CI: 257.4 – 303.3)[e]	524 ± 135.7 (CI: 471.3 – 576.6)[f]
One-minute volume (mLs)	4893.5 ± 1999.3 (CI: 4178.0 – 5608.9)[g]	2992.8 ± 1389.7 (CI: 2495.5 – 3490.0)[h]	5894.2 ± 2165.6 (CI: 5106.7 - 6681.6)[i]
CI is defined as 95% Confidence Intervals.			

Table 1. Bag size volume, mean one-minute ventilation rate, mean singular tidal volume and mean one-minute tidal volume for each of the three BVMs.

	Singular-Inspired Tidal Volume			One-Minute Volume		
	Mean Diff (mLs)	95% CI	p-value	Mean Diff (mLs)	95% CI	p-value
Adult vs SMART BVM	80.1	(41.9–118.3)	<0.001* [a]	910.4	(212.7-1608.0)	<0.008* [d]
Pediatric vs Smart BVM (b)	163.3	(111.3–215.4)	<0.001*	1918.3	(1167.8-2668.9)	<0.001* [b]
Adult vs Pediatric BVM (c)	243.5	(194.7–292.3)	<0.001*	2828.7	(2273.7-3383.7)	<0.001* [c]
*Denotes statistically significant difference at α=0.05						

Table 2. Pairwise Comparisons for mean singular inspired tidal volumes and one-minute volumes.

BVM	Breathes per Minute				Singular Tidal Volume		One-Minute Volume			
	Mean Diff (Lower Boundary)	p-value	Mean Diff (Higher Boundary)	p-value	Mean Diff from Test Value	p-value	Mean Diff (Lower Boundary)	p-value	Mean Diff (Higher Boundary)	p-value
SMART	1.1	<0.030	-0.9	<0.059	-56.5	<0.010 [a]	-106.5	0.386 [d]	-1106.5	<0.003
Pediatric	0.4	0.271	-1.6	<0.013	-219.4	<0.001 [b]	-2007.2	<0.001	-3007.2	<0.001 [f]
Adult	1.3	<0.019	-0.6	0.128	24.0	0.179 [c]	894.2	<0.019	-105.7	0.399 [e]
*Denotes statistically significant difference at =0.05										

Table 3. One sample t-test comparisons to upper and lower boundaries of established guidelines for breaths per minute (10–12 BPM), singular tidal volume (500 mLs per inspiration) and one-minute volume (5000–6000 mLs).

DISCUSSION

While the efficacy of positive pressure ventilation during cardiac arrest can be challenging to measure, particularly in prehospital settings, utilizing equipment that best optimizes ventilation to meet recommendations is imperative to improving clinical outcomes (Wang et al., 2023). Our study utilized the ZOLL X series, providing access to post-case review data on ventilation rate, singular tidal volume, and one-minute tidal volume (ventilation rate × tidal volume) from participants applying ventilations. This allowed a clear comparison of the ventilation efficacy of three self-inflating BVMs upon an endotracheal intubated (ETT) mannequin within an OHCA-simulated setting using a procedural inverted hand grip. We believe this to be the first study leveraging the ZOLL X series comparing traditional Adult and Pediatric BVMs with the SMART BVM, making it an important first step in analyzing equipment best suited to the prehospital environment.

No differences were noted across mean ventilation rates for the SMART and Adult BVM, with the mean ventilation rates falling within the Western Australian state ambulance service guidelines of 10–12 BPM (Australia., 2020a). However, although the Pediatric BVMs mean ventilation rate was within the 10–12 BPM boundary (10.4 ± 3.70 BPM), the mean rate did approach the lower boundary of the ambulance service guideline (95% CI [9.0 – 11.7] p>0.271), with the SJAWA ventilation rate allowing more flexibility than the more rigid ILCOR recommendation of 10BPM (Soar et al., 2020). Nevertheless, taken together these data indicate the type of BVM had little to no impact on the operator's ability to deliver ventilations at an appropriate rate, particularly when leveraging the inverted hand grip. This result is of particular interest when considering that the actuating mechanism inside the SMART BVM is designed to intentionally limit gas flow, having seemingly little to no impact on ventilation rate in comparison to the traditional Adult and Pediatric BVM.

However, mean singular tidal volume delivery did differ among the three devices. When using the traditional Pediatric BVM, participants delivered, on average, a smaller singular tidal volume compared to the SMART and traditional Adult BVMs—on average, 219.5mLs per inspiration lower than the ILCOR recommended mean tidal volume of 500mLs per inspiration. The SMART BVM also delivered mean singular tidal volume significantly lower than the ILCOR recommendation of 500mLs per inspiration, however, by a far smaller margin of (on average) 56.6mLs per inspiration. The traditional Adult BVM provided mean singular tidal volume most closely aligned to the ILCOR guideline.

The differentiation noted across BVMs with respect to mean singular tidal volumes, coupled with the lack of apparent differentiation across BVMs for mean ventilation rates, explain one-minute tidal volume findings. Participants using the traditional Pediatric BVM delivered one-minute tidal volumes that were far lower in comparison to the other two BVMs and well below the lower boundary of ILCOR recommendations of 5000–6000mLs per minute. The traditional Adult BVM mean one-minute tidal volume fell within ILCOR recommendation boundaries, and the mean SMART BVM one-minute tidal volume was below the prescribed 5,000mLs, but this difference was not statistically significant.

Reviewing study ventilation and tidal volume findings together, the traditional Adult BVM was utilized most optimally amongst this group of novice undergraduate paramedicine students, with the SMART BVM and Pediatric BVM both providing tidal volume below that recommended by ILCOR. These findings are at odds with previous literature examining tidal volume efficacy of both the Pediatric and SMART BVM. Previous studies, both with in-hospital and pre-hospital focus, demonstrate a decreased risk of hyperventilation when using the Pediatric and SMART BVM whilst still maintaining adequate singular tidal volume and minute volume in comparison to more traditional Adult BVMs (Doerges et al., 1999; Kroll et al., 2019; Siegler et al., 2017; Wagner-Berger, Wenzel, Voelckel, et al., 2003; Wenzel et al., 1999). While our findings similarly demonstrated minimal risk of hyperventilation, the traditional Pediatric BVM (and, to a lesser extent, the SMART BVM) demonstrated an increased risk of hypoventilation. In contrast, the traditional Adult BVM performed within accepted ILCOR recommendations.

It is possible the variations of our study findings in comparison to previous literature could be due to methodological differences across existing studies. For example, previous research makes use of a range of different professional cohorts acting as research participants, some with prior experience of administering ventilations in simulated and/or real-world in-hospital or pre-hospital settings, each with varied experience with different BVMs. Contrasting findings between novice and more experienced clinicians can be managed. However, they are made more difficult, particularly amongst those more experienced, when pre-exposure to different BVMs may impact measured outcomes. Our study targeted novice paramedicine students to mitigate between-participant comparison issues resulting from differing prior BVM experience and exposure. While advantageous to mitigate the risk of non-homogeneity, generalizability to practicing clinicians is unclear. Also, different hand grip techniques have been demonstrated to impact ventilatory efficacy (Kroll et al., 2019; A. J. Nitzsky et al., 2018), with many studies not standardizing grip technique across participants. While not standardizing grip technique potentially provides a more accurate reflection of real-world ventilatory behaviours (occurring at the discretion of each individual clinician), it also makes comparing findings across studies problematic. Future research may provide stronger and more comparable contributions to the evidence-base by seeking to standardize (or at the minimal record) grip technique application across participants. In addition, over the previous three decades, ILCOR clinical recommendations have incrementally decreased target ventilation rates and tidal volumes, with resultant research studies changing prescribed target ranges to match. With participants and resultant analyses actively applying different clinical target parameters over time, the viability of cross-comparisons to dated research becomes more problematic. However, it is worth noting that despite ventilation rate and tidal volume guideline reductions over time, hyperventilation and hyperinflation above ILCOR guidelines does seem to be commonplace in simulation-based research with both in-hospital and pre-hospital clinicians. (Charlton et al., 2021; Culbreth & Gardenhire, 2021; Vissers et al., 2019; Wang et al., 2023). Lastly, our leveraging of the ZOLL X Series has provided an accurate and reliable measure of tidal volume with the ventilation feedback sensor placed between the catheter mount and ETT during OHCA scenarios.

Limitations of cross-research contrasts comparing different BVMs notwithstanding, our findings demonstrated clear hypoventilation using the traditional Pediatric BVM and some risk of the same with the SMART-BVM. The activated restrictor valve alerts rescuers when they are forcefully ventilating to directly combat hyperventilation, but (as per other BVMs) has no embedded functionality to combat or alert rescuers to the risks of hypoventilation. The Laerdal mannequin used in this study had an advanced airway in situ, which provides further contrast difficulties to some of the prior studies which used unprotected airways, laryngeal mask airways (LMA), and supraglottic airways (SGA) with only a few previous studies inserting an ETT. However, the ZOLL X series Accu-Vent sensor was located between the catheter mount and ETT and not within the simulated mechanical lung. Thus, we would expect higher tidal volumes compared to prior studies using unprotected airways (and some LMA and SGA), given the increased risk of gas leakage around inspiratory sites (oropharynx/nasal cavity or laryngeal inlet). Yet, in comparison to many previous investigations using unprotected airways (Doerges, Ocker, Wenzel, et al., 1999; Soar, 2015; Wagner-Berger, Wenzel, Voelckel et al., 2003), present study tidal volume findings were lower. A potential explanation for these variations could be due to differences in tidal volume measurement instruments across studies or the potential impact of the inverted hand grip technique. Interestingly, respective BVM instruction manuals (Ambu, 2022; Bucher et al., 2019; O-Two Medical Technologies, 2015) do not specify where the clinician should grip the BVM or how many digits should be applied to squeeze the self-inflating section. Nor do most prior related investigations report on what hand grip techniques were employed (or whether they were standardized) across participants (Aufderheide et al., 2004; Busko et al., 2009; Doerges et al., 1999; Meaney et al., 2013). Accordingly, research has demonstrated that one versus two hands, or varying the number of digits used to squeeze the self-inflating bag, hand size, hand grip strength, glove size, levels of experience, and that grip strength decreases over time whilst applying ventilatory inspiration can impact tidal and one-minute volumes (if the ventilation rate is standardized) (Hess & Spahr, 1990; Kroll et al., 2019; Lee et al., 2008; McCabe, 1993; Austin J Nitzsky et al., 2018; Sall et al., 2018). Thus, use of the inverted hand grip when administering ventilations using any of the BVMs may have a more noticeable effect on the inspiratory tidal volume. Moreover, the inverted hand grip may have intermittently activated the inspiratory-pressure valve within the SMART BVM, thus reducing tidal volumes compared to prior studies (note that activation was not measured within the study). Furthermore, the student’s prior education and training regarding the risks of hyperventilation during CPR might have led to a more cautious approach when ventilating with the devices. This cautionary approach could have impacted inspiratory volume, especially given that Pediatric BVMs are typically smaller, resulting in lower inspiratory volumes. As the BVMs lack an inspiratory gauge, the combined effect of using the inverted grip and the student's education may have further decreased overall one-minute volumes.

STUDY LIMITATIONS

Like most studies evaluating BVM efficacy in simulated environments (Doerges et al., 1999; Siegler et al., 2017; Wagner-Berger, Wenzel, Stallinger, et al., 2003), the present study setting, whereby we attempted to simulate realistic conditions of a prehospital OHCA in the back of a stationary ambulance, would have fallen short of wholistically reflecting real-world OHCA pre-hospital conditions. For example, utilizing a Laerdal mannequin in a stationary ambulance is unlikely to duplicate the highly stressful and dynamic prehospital OHCA environment, including respiratory complications during CPR such as secretions, aspiration, vomiting, airway obstruction, or difficult ventilation. Further, using SMART and traditional Pediatric BVMs could distort findings due to a lack of familiarity with these more novel BVMs. However, this effect was likely mediated by choosing a study cohort with basic training only and allowing participants unlimited time to familiarize themselves and practice with all BVMs before data collection began. In addition, following the 2020 ILCOR scientific review, guidelines were revised to the less prescriptive patient chest rise and fall instead of a specific tidal volume of mLs/per/kg (Soar et al., 2021). Present study participants were instructed to inflate the adult mannequin to ~500mLs per ventilation. Another consideration of this study is the use of novice student practitioners. If the study were to be repeated with experienced healthcare clinicians, the results may differ. Repeating the study with different cohorts of clinicians may add to the knowledge base and provide further evidence of the efficacy of each type of BVM.

CONCLUSION

The efficacy of positive pressure ventilatory parameters is critical for favorable neurological outcomes post-OHCA, yet these aspects are challenging to measure in the pre-hospital setting. Thirty first-year undergraduate paramedic students performed asynchronous ventilations using the SMART and traditional Adult and Pediatric BVMs upon an intubated ETT mannequin within an OHCA-simulated setting using a procedural inverted hand grip. The ZOLL X series measured ventilation rates and singular inspired tidal volume, allowing calculation of one-minute tidal volume, each compared against ILCOR clinical guidelines. The SMART and Adult BVM mean ventilation rates were within the recommended guidelines, and Pediatric BVM slightly lower. Traditional Adult BVM mean singular tidal volume and one-minute volume were no different to ILCOR recommendations; however, mean singular tidal volumes for the SMART BVM and traditional Pediatric BVM were below ILCOR recommendations, as was the traditional Pediatric BVM mean one-minute volume. Our findings suggest that bag-valve-mask ventilation during a simulated OHCA using the procedural inverted hand grip with the SMART BVM and traditional Pediatric BVM may result in hypoventilation due to insufficient tidal volume and minute volume.

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