Manual bag valve mask ventilation performance among respiratory therapists

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ABSTRACT

Background: High peak pressures delivered via bag valve mask (BVM) can be dangerous for patients.
Objective: To examine manual ventilation performance among respiratory therapists (RTs) in a simulation model.
Methods: Respiratory therapists (*n*=98) were instructed to ventilate a manikin for 18 breaths. Linear regression was utilized to determine associated predictors with the outcomes: delivered tidal volume, pressure and flow rate.
Results: Among all participants, the mean ventilation parameters include a tidal volume of 599.70 ml, peak pressure of 26.35 cmH$_2$O, and flow rate of 77.20 l/min. Higher confidence values were positively associated with delivered peak pressure (*p*=0.01) and flow rate (*p*=0.008). Those with the most confidence in using the BVM actually delivered higher peak pressures and flow rates compared to those with lower confidence levels.
Conclusions: Our results emphasize the urgent need to create an intervention that allows providers to deliver safe and optimal manual ventilation.

Introduction

The bag valve mask (BVM) serves as an important tool for ventilating patients in an acute care setting. Also known as a manual resuscitator, the BVM is frequently used by respiratory therapists (RTs) during cardiopulmonary resuscitation (CPR), patient transport, rapid response scenarios, and other emergencies. Proper ventilation techniques with the BVM should consider safe ventilation parameters for each individual patient and their conditions. Excessive volume, pressure or flow may result in morbidity from lung damage, stomach insufflation, or hemodynamic and pulmonary compromise.[1,2] Previous research has shown that providers consistently demonstrate unsafe performance with manual ventilation in all populations.[2−5] In one study, healthcare providers of all experience levels hyperventilated patients 79% of the time.[6]

Manual ventilation with excessive volume and pressure can cause severe complications for patients, particularly vulnerable patients suffering from Acute Respiratory Distress Syndome (ARDS), including those infected with COVID-19. Since acute care facilities are currently treating large amounts of COVID-19 patients, understanding the implications of poor BVM techniques among this population is

urgent.[7] A recent meta-analysis reported a range of 17%−67% of COVID-19 patients suffered from ARDS.[7] Since the goal of ARDS is to minimize lung injury as much as possible,[8] delivering high tidal volumes, high pressures, and high flow rates can be detrimental to COVID-19 patients with ARDS.

Poor manual ventilation performance may be due to difficulty in observing the quality of ventilation delivered and a misunderstanding of patient specific requirements. Remedies for unsafe manual ventilation range from training reinforcement to accessory safety devices.[4,6,9] Indicators of appropriate ventilation include but are not limited to patient chest rise, skin color, electronic vital sign monitoring,[4] resistance on bag squeeze according to patient lung pathology, CO_2 monitoring, and a flashing light on the BVM for rate of breath delivery.

While several studies have evaluated BVM performance among general healthcare providers, this study, to our knowledge, is the largest to examine BVM performance among RTs. This study sought to examine manual ventilation performance among RTs with varying experience levels to compare the mean tidal volume, peak pressure, peak flow rate, inspiratory time and inspiratory rise time in a simulation model. We also aim to discuss the implications of our findings in the context of the current COVID-19 pandemic. Our hypothesis was that RT's will deliver high peak pressures, high tidal volumes, and high flow rates compared to the recommended guidelines, regardless of sex, frequency of bag valve mask use, experience or confidence.

Methods

Following the approval from Georgia State University's Institutional Review Board (H20101), this study was conducted at the American Association for Respiratory Care Congress 2019 (New Orleans, Louisiana, November 9-12, 2019). Additionally, 110 volunteer RTs gave verbal consent to participate in this study. RTs were requested to manually ventilate a manikin (IMT Analytics SmartLung 2000 2L test lung and Citrex H5 Gas Flow Analyzer, Switzerland) using a BVM (AMBU, Denmark) while observing chest rise. The experiment sought to recreate field settings for ventilating an average healthy adult American male, 5'10", 200 pounds.[10] Participants were instructed to normally ventilate the manikin for 18 breaths following a preset variable frequency indicated by a flashing light for 90 s. This scenario results in a target tidal volume based on ideal body weight (between 6 ml−8 ml/kg) of 440−580 ml,[11] respiratory rate of 12 breaths/minute and a minute ventilation of 5.28−6.96 l/min. The participants were informed that during the test they would be asked a few survey questions. The survey questions included sex (male or female), years of experience, how often the participant used the BVM, and how confident they were in using the BVM (scale of 1−5, with 5 being more confident). The survey during the ventilation served as distractions to create an environment closer to real clinical practice. During the test, RTs were unable to see their performance results and were also blinded to the results of other RTs. This study was conducted in accordance with the amended Declaration of Helsinki.

Ventilation parameters (respiratory rate, tidal volume, peak pressure, peak flow rate, inspiratory time, and inspiratory rise time) were gathered every 10 ms of ventilation using the IMT Citrex H5 Gas Flow Analyzer. Among the total sample, 12 providers (final analytic sample n=98) were excluded from the study due to the following exclusion criteria: providers who live outside the United States of America, providers who are retired, providers who delivered less than 10 breaths above 350 ml of air (this criterion results in an approximate minute volume of 2.3 L/min, thus eliminates providers with a minute volume of < 2.33 L/min), and providers who generated a positive end-expiratory pressure greater than 1 cmH$_2$O. A Python program was created to analyze data points and summary statistics for the aforementioned ventilation parameters. SAS 9.4 was utilized to conduct statistical analyses. Descriptive statistics were computed to determine the mean ventilation performance estimates by participant level of experience. One-way ANOVA and Fisher tests were conducted to determine differences in mean ventilation performances by participant level of experience. Finally, multivariable linear regression was conducted to determine statistically significant demographic and participant characteristics associated with delivered tidal volume, peak pressure, and peak flow rate. These multivariable linear regression models assumed that provider demographics and experience levels would predict the delivered parameters via BVM. Additionally, the intercept is presented in the tables, which is the value of the outcome when all covariates are equal to 0. All assumptions related to the linear regression models were analyzed and deemed to be sufficient.

Results

Overall, 98 RTs were included in the study. Among the participants, 67 (68.4%) were female and 31 (31.6%) were male. Approximately 30% had 0−5 years of experience, 15% had 6−10 years of experience, 13% had 11−20 years of experience and 42% had more than 20 years of experience. 59% used a BVM 0−5 times per month, 9% used the BVM 5−10 times per month and 32% used a BVM 10 or more times per month. Among RTs with more than 10 years of experience, the majority reported using BVM 0−5 times per month, which was a higher percentage compared to RTs of less than 10 years of experience.

Table 1 presents the descriptive statistics among ventilation parameters and demographic characteristics for participants by years of experience. The mean ventilation parameters among all participants include a tidal volume of 599.70 ml, pressure of 26.35 cmH$_2$O, flow rate of 26.35 l/min, inspiratory time of .75 s and an inspiratory rise time of .49 s. The RT's with greater than 21 years of experience had the highest peak pressure (26.94 cmH$_2$O) (F=3.03, p=0.02) and flow rate (79.31 l/min) (F=3.13, p=0.02). Providers with greater than 10 years of experience demonstrated a higher mean tidal volume administration than those with less than 10 years of experience (619.84 l/min vs 574.09 l/min); however, this was not statistically significant. The mean inspiratory time (0.75 s) and inspiratory rise time (0.48 seconds) and were similar across all levels of experience.

Table 2 presents descriptive statistics among RTs who have over 10 years of experience and self-rated their confidence with the BVM the highest (5/5). When compared to the ventilation parameters of all participants, those who had greater than 10 years of experience and the highest self-rated confidence (n=28), ventilated the most unsafe with the highest mean values of volume (631.43 ml), peak pressure (30.55 cm H$_2$O) and flow (86.10 l/min).

Multiple linear regression results for tidal volume are presented in Table 3. The model examining tidal volume resulted in no statistically significant predictors, although years of experience approached statistical significance (p=0.06). Table 4 presents multiple linear regression results for pressure. Confidence level was associated with higher peak pressure delivered via BVM (p=0.01). On average, each additional one-unit difference in confidence level (0−5 scale) corresponded to a 3.31 positive difference in pressure delivered via BVM, adjusting for sex, years of experience, and how often participants used the BVM. Thus, higher confidence levels were associated with

Table 1
Summary of manual ventilation performance among respiratory therapists by years of experience (n=98)

	Experience					Total
	0-5 years N=29 (29.6%)	6-10 years N=15 (15.3%)	11-20 years N=13 (13.3%)	21+ years N=41 (41.8%)	F-value or Fisher, p-value	98 (100%)
Mean Tidal Volume (ml)	586.21	553.04	621.64	619.35	F=1.00, p=0.41	599.70
Flow Rate (l/min)	76.43	73.16	76.95	79.31	F=3.13, p=0.02	77.20
Pressure (cmH2O)	26.12	25.03	26.53	26.94	F=3.03, p=0.02	26.35
Inspiratory Time (sec)	0.71	0.75	0.81	0.75	F=0.77, p=0.55	0.75
Rise Time (sec)	0.47	0.52	0.54	0.47	F=0.53, p=0.71	0.49
Sex						
Male	2 (6.9%)	8 (53.3%)	3 (23.1%)	18 (43.9%)	P=0.21	31 (31.6%)
Female	27 (93.1%)	7 (46.7%)	10 (76.9%)	23 (56.1%)		67 (68.4%)
Frequency of BVM use						
0-5	14 (48.3%)	8 (53.3%)	9 (69.2%)	27 (65.9%)	P<0.001	58 (59.2%)
5-10	4 (13.8%)	2 (13.3%)	1 (7.7%)	2 (4.9%)		9 (9.2%)
10+	11 (37.9%)	5 (33.3%)	3 (9.7%)	12 (29.3%)		31 (31.6%)

Table 2
Summary of manual ventilation performance among the most experienced and most confident respiratory therapists (n=98)

	No. of providers (n)	Volume (ml)	No. of providers who delivered >600 ml	Pressure (cmH2O)	No. of providers who delivered >20 cmH2O	Flow (l/min)	Inspiratory time (sec)	Inspiratory Rise time (sec)
All	98	599.70	41 (41.8%)	26.35	69 (70.4%)	77.20	0.75	0.49
Experience >10 Years	54 (55.1%)	619.90	27 (50.0%)	26.84	35 (64.8%)	78.74	0.76	0.48
Self-Rated Confidence 5/5	49 (50.0%)	616.22	24 (49.0%)	29.80	39 (79.6%)	84.01	0.71	0.47
Experience >10 years and Self-Rated Confidence 5/5	28 (28.6%)	631.43	15 (53.6%)	30.55	20 (71.4%)	86.10	0.71	0.46

Table 3
Associated predictors of bag valve mask administered tidal volume among respiratory therapist participants (n=98)

Variable	Estimate	Standard Error	P-value
Intercept	489.36	56.07	<.**0001**
Sex	8.08	22.25	0.71
Years of Experience	1.40	0.74	0.06
Frequency of BVM Use	6.99	10.82	0.52
Confidence	17.62	11.77	0.14

Table 4
Associated predictors of bag valve mask administered pressure among respiratory therapist participants (n=98)

Variable	Estimate	Standard Error	P-value
Intercept	15.02	6.03	**0.01**
Sex	-2.77	2.39	0.25
Years of experience	-0.02	0.08	0.78
Frequency of BVM Use	-0.78	1.16	0.50
Confidence	3.31	1.26	**0.01**

higher peak pressures delivered, even after accounting for other covariates. Years of experience was not associated with higher peak pressures. Table 5 presents multiple linear regression results for flow rate. Similar to the model for pressure, confidence was statistically significantly associated with delivering higher flow rates via BVM (p=0.008). On average, each additional one-unit difference in confidence level corresponded to a 6.75 positive difference in flow rate delivered via BVM, adjusting for sex, years of experience, and how often participants used the BVM. Thus, higher confidence values were associated with higher flow rates delivered. Similarly to the model for peak pressure, years of experience was not associated with delivery of high flow rates.

Discussion

Our study was conducted to assess the quality of manual ventilation given by respiratory therapists with different levels of confidence or experience. Our hypothesis was that the majority of providers would hyperventilate patients with elevated peak pressures, high tidal volumes, and high flow rates delivered. Volunteer RTs were chosen for this study as they represent a provider

Table 5
Associated predictors of bag valve mask administered flow rate among respiratory therapist participants, (n=98)

Variable	Estimate	Standard Error	P-value
Intercept	52.48	11.89	<.**0001**
Sex	-4.97	4.72	0.29
Years of experience	-0.002	0.16	0.99
Frequency of BVM Use	-1.10	2.30	0.63
Confidence	6.75	2.50	**0.008**

population that is often responsible for manual ventilation in the acute care setting.

"Safe" parameters for tidal volume, peak pressure, peak flow rate, and inspiratory time were identified using Z-vent transport ventilator (AsahiKASEI ZOLL Medical, Japan) and the identical Smart Lung 2000 2 L test lung (IMT Analytics, Switzerland) parameters for resistance and compliance.[10] On volume control mode with a tidal volume of 600 ml and an inspiratory time of 1 s, peak pressure delivered by the ventilator was 15 cmH$_2$O and the flow rate was 40 l/min. These values were reported by both the Z-vent ventilator and double checked by the Citrex H5 Gas Flow Analyzer (IMT Analytics, Switzerland). For all providers in our study, mean tidal volume delivered was 599.70 ml with a mean inspiratory time of 0.75 s, yielding a mean pressure of 26.35 cmH$_2$O, and mean flow rate of 77.20 l/min (Table 1). These values exceeded those of the safe parameters of the transport ventilator. Previous literature has reported that inspiratory time for a breath should between 1−2 s[12] and that a reduction of inspiratory time results in a significant increase of peak airway pressure and peak inspiratory flow rate.[13]

Previous research has shown that pressures above 15−20 cmH$_2$O may be unsafe and lead to gastric insufflation.[14] Bouvet et al. examined adult anesthetized patients and found that an inspiratory pressure of 15 cmH$_2$O provided less gastric insufflation than a pressure of 20 cmH$_2$O. They conclude that 15 cmH$_2$O provided the best balance between the probability of sufficient pulmonary ventilation and the probability of absence of gastric insufflation.[14] In our study the mean pressure delivered was 26.35 cmH$_2$O (Table 1), exceeding the safe ventilation values in the literature. Turki et al looked at peak pressures during manual ventilation with RTs and also noted that they delivered high peak pressures.[15] As mentioned previously, delivering high pressures can induce lung injury among patients with ARDS,[8] such as those infected with COVID-19.[7] However, the link between peak pressures specifically and detrimental effects in ARDS patients is questionable. Interventions which aim at reducing high plateau pressures during manual ventilation, particularly among the most vulnerable patients, are urgently warranted.

In our study, provider experience was defined by years working in the field. Multivariable analyses, when adjusting for other covariates, did not show a significant difference between experience levels when compared to tidal volume, pressure or flow rate delivered among RTs (Table 3, 4, 5). However, bivariate analyses (Table 1) did show statistically significant differences by experience levels with delivered flow rate and pressure. Perhaps a higher-powered study would yield a statistically significant result in the multivariable analysis, though prior studies also report that years of experience do not impact ventilation quality in the context of other variables.[6,16,17]

The data were also analyzed based on a provider's self-rated confidence. The effect of confidence on pressures (Table 4) delivered among RTs with BVM was statistically significant. Additionally, confidence was statistically significantly associated with higher flow rates delivered (Table 5). To our knowledge of the literature, this is the first assessment of self-rated confidence in relation to provider delivered tidal volume, pressure, and flow rate. As such, targeted approaches towards improving safe manual ventilation techniques should include all providers, regardless of self-rated confidence in BVM techniques.

Excess delivery of pressure and flow rate is known to lead to increased morbidity. Our study found those who had greater than 10 years of experience and the highest self-rated confidence (*n*=28), ventilated the most unsafe with the highest mean values of volume (631.43 ml), pressure (30.55 cm H$_2$O) and flow (86.10 l/min) (Table 2). Not only should an increase in morbidity be noted, but as mentioned by Khoury et al "the fact that professional experience does not impact ventilation performance means that ventilation self-improvement is difficult to achieve with current devices".[6]

Literature reports the risk of gastric insufflation and potential complications are significantly reduced while giving pressure-controlled face mask ventilation, when compared with manual or volume-controlled face mask ventilation.[18] As self-improvement is difficult to achieve with current devices,[6] several methods of improvement through augmentation or supplementation to the BVM device have been proposed for safer manual ventilation pressures. Other research has shown that feedback video training was beneficial in improving the overall delivery of cardiopulmonary resuscitation (chest compressions, manual ventilation, teamwork).[19] Additionally, techniques like cricoid pressure have seen mixed efficacy in the literature for pressure control. A recent meta-analysis reported that cricoid pressure failed to show any increase in protection from aspiration and may increase difficulty of intubation.[20]

This study supports the need for further research in manual ventilation safety. Though there are many mechanisms that have been tried, cost effectiveness, access, ease of use, and consistent efficacy remain drawbacks with existing methods. Additionally, interventions and mechanisms which improve the safety of manual ventilation should target those with highest risk for lung injury, such as COVID-19 patients, particularly in situations with limited healthcare supplies.

Limitations

Several limitations exist in our study. First, our study providers were limited to a convenience sample of RTs attending the American Association for Respiratory Care conference. Therefore, the results might not be generalizable to the larger population of RTs. We also acknowledge this population may not be reflective of the larger population that utilizes BVM in all critical care settings. Specific factors on training, work area, and other characteristics were not collected from the RTs participating in this study. Future studies should evaluate these criteria in a larger sample of RTs. Second, our results were obtained from a simulation model rather than in a clinical setting. It is difficult to determine how much variation is present between simulation models and real-world clinical settings. A total of 12 participants were excluded based on our exclusion criteria, which was originally intended to reduce bias from the analytic sample but may have inadvertently introduced bias. Lastly, most volunteers (nearly 60%) identified as providers who use the BVM in their places of work less than 5 times per month. Results may also be different among providers who use BVM more often.

Conclusions

To our knowledge, this is the largest study to evaluate manual ventilation techniques among RTs. In all participant groups, RTs delivered higher tidal volumes, pressures and flow rates with a lower inspiratory time than ideal. The RT group with the highest confidence level delivered higher peak pressures and flow rates compared to their peers. Based on the high peak pressures, tidal volumes, and flow rates delivered in this study, there is an urgent need to create an intervention that allows providers to deliver safe manual ventilation. However, future studies should examine BVM techniques among providers who consistently and frequently use BVM. Also, future studies should evaluate different combinations of ventilation, including combination patterns of high respiratory rates and low volumes, as well as low respiratory rates and high volumes. Manual ventilation delivered at safe tidal volumes, pressures and flow rates will provide patients with protection from lung injury, particularly vulnerable patients such as those infected with COVID-19.

Declaration of Competing Interest

The authors report no conflicts of interest.

Statement of originality

This work has not been published previously or submitted elsewhere.

Acknowledgements

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