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Comparison of Bag-Valve-Mask Hand-Sealing Techniques in a Simulated Model

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Abstract

Study objective—Bag-valve-mask ventilation remains an essential component of airway management. Rescuers continue to use both traditional 1- or 2-handed mask-face sealing techniques, as well as a newer modified 2-handed technique. We compare the efficacy of 1-handed, 2-handed, and modified 2-handed bag-valve-mask technique.

Methods—In this prospective, crossover study, health care providers performed 1-handed, 2-handed, and modified 2-handed bag-valve-mask ventilation on a standardized ventilation model. Subjects performed each technique for 5 minutes, with 3 minutes' rest between techniques. The primary outcome was expired tidal volume, defined as percentage of total possible expired tidal volume during a 5-minute bout. A specialized inline monitor measured expired tidal volume. We compared 2-handed versus modified 2-handed and 2-handed versus 1-handed techniques.

Results—We enrolled 52 subjects: 28 (54%) men, 32 (62%) with greater than or equal to 5 actual emergency bag-valve-mask situations. Median expired tidal volume percentage for 1-handed technique was 31% (95% confidence interval [CI] 17% to 51%); for 2-handed technique, 85% (95% CI 78% to 91%); and for modified 2-handed technique, 85% (95% CI 82% to 90%). Both 2-handed (median difference 47%; 95% CI 34% to 62%) and modified 2-handed technique (median difference 56%; 95% CI 29% to 65%) resulted in significantly higher median expired tidal volume percentages compared with 1-handed technique. The median expired tidal volume

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percentages between 2-handed and modified 2-handed techniques did not significantly differ from each other (median difference 0; 95% CI −2% to 2%).

Conclusion—In a simulated model, both 2-handed mask-face sealing techniques resulted in higher ventilatory tidal volumes than 1-handed technique. Tidal volumes from 2-handed and modified 2-handed techniques did not differ. Rescuers should perform bag-valve-mask ventilation with 2-handed techniques.

INTRODUCTION

Background

Bag-valve-mask ventilation is an essential element of emergency airway management. Rescuers usually accomplish mask sealing against the face with 1-handed or 2-handed techniques, with the thumb and index finger wrapped in a “C” shape around the mask apex and the remaining fingers lifting the jaw.[1,2] Limited literature has shown that the 2-handed mask-face sealing technique is likely superior to the 1-handed bag-valve-mask technique.[3–6] However, previous studies and clinical experience suggest that mask-face sealing with the traditional 2-handed technique can be difficult in certain patients.[2,7,8] Some clinicians use a newer modified 2-handed technique that shifts the third fingers of both hands down to the angle of the jaw to pull upward and uses the thenar eminence and thumb to apply downward force on the mask (Figure 1).[9]

Importance

The modified 2-handed bag-valve-mask technique could enhance the effectiveness of the 2-handed sealing technique by creating a tighter seal between the mask and face, especially for providers with small hands or weaker grip strength or for patients predicted to be difficult for bag-valve-mask ventilation.[7] The efficacy of the modified 2-handed technique has not been studied.

Goals of This Investigation

Our primary aim was to compare the efficacy of 2-handed and modified 2-handed bag-valve-mask mask-face sealing techniques among health care providers using a simulated ventilation model. We also compared the efficacy of each 2-handed bag-valve-mask technique to the 1-handed technique. We hypothesized that the modified 2-handed technique would provide greater expired tidal volume than the 2-handed technique. We also hypothesized that both 2-handed techniques would provide greater expired tidal volume than the 1-handed technique.

MATERIALS AND METHODS

Study Design

In this prospective, crossover study, study participants performed 1-handed, 2-handed, and modified 2-handed bag-valve-mask technique on a simulated ventilation model. The Colorado Multiple Institutional Review Board approved this study, and written informed consent was obtained from all subjects.

We designed a semiclosed-circuit simulated model specifically for this study (Figure 2). This model consisted of a mechanical ventilator (Puritan Bennett 7200 Mechanical Ventilator; Covidien-Nellcor and Puritan Bennett, Boulder, CO) attached to a mask (Medline Adult Resuscitation Mask; Medline Industries, Inc., Mundelein, IL). A Novametrix NICO (Philips Respironics, Andover, MA) cardiopulmonary monitor was attached inline where the ventilator tubing connected with the mask to measure expired tidal volume. Separately, a realistic airway trainer head (Laerdal Airway Management Trainer; Laerdal Medical, Wappingers Falls, NY) was connected to a mechanical test lung (Michigan Instruments Vent-Aid Training Test Lung; Michigan Instruments, Inc., Grand Rapids, MI). This model isolated the only possible source of air leak to the contact point between the mask and the mannequin face. All connections in this system were tested and confirmed to be closed by replacing the mask with an endotracheal tube to create a completely closed circuit system and then using a simulated breath hold on the ventilator to test for air leakage. We internally validated the ability of the model to detect differences in expired tidal volume with varying degrees of air leak (Appendix E1, available online at http://www.annemergmed.com).

The airway trainer head and mechanical test lung were placed on a table at approximately the standard height of a stretcher, and a thin pillow was placed underneath the airway trainer. We inserted a pillow to provide some tactile feedback on the degree of downward pressure applied to the trainer head. Oral or nasal airways were not used. To reduce the variation in tidal volumes from manual ventilation, we used a mechanical ventilator to provide insufflation. The mechanical ventilator was configured with controlled mandatory ventilation to provide an inspired tidal volume of 600 mL, respiratory rate of 20 breaths/min, peak inspiratory flow rate of 100 L/minute, and positive end-expiratory pressure of 0. The mechanical test lung was set at a constant lung compliance of 0.04 L per cm H_2O. These settings were chosen to best approximate the typical values expected during emergency bag-valve-mask ventilation.[8]

Selection of Participants

We recruited subjects from a convenience sample of current health care providers at Denver Health Medical Center, Denver, CO. Recruitment included respiratory therapists, medical students, resident physicians, attending physicians, critical care or emergency department registered nurses, and paramedics. Subjects were excluded only if they could not be expected to physically perform the necessary tasks required for this study. Subjects were recruited from July 2010 to January 2011.

Outcome Measures

The primary outcome for this study was expired tidal volume (in milliliters), which was continuously obtained and electronically recorded in real time with a Novametrix NICO (Novametrix Medical Systems, Wallingford, CT) cardiopulmonary monitor during a 5-minute period for each hand-sealing technique. This outcome was expressed as a percentage of the maximum possible expired tidal volume during the 5-minute period. The primary outcome, expired tidal volume, was converted to a percentage of the maximum possible expired tidal volume during the 5-minute technique session by using the trapezoidal rule to calculate the area under the plotted expired tidal volume values over time, assuming adjacent

expired tidal volume values are connected by a straight line (an example of the area under the plotted expired tidal volume values and outcome calculation is provided in Appendix E1, available online at http://www.annemergmed.com). We chose this outcome as it provided a more granular summary of the data compared to an outcome derived from absolute thresholds. Our goal was to differentiate these approaches, not to identify or match optimal threshold tidal volumes.

Methods of Measurement

Six study investigators were trained in the method of enrollment and data collection by the primary investigator and observed by the primary investigator until the study protocol could be completed without questions, further instruction, or errors. These investigators were not blinded to the study hypothesis; however, study subjects were blinded to the study purpose and hypothesis. After informed consent, each subject provided demographic data. These data included provider type, health care experience level, previous bag-valve-mask ventilation experience, sex, hand size, and handedness. Hand size was measured with 2 methods; first, from the fifth finger to the thumb spread as far apart as possible, and second, from the distal volar wrist crease to the distal tip of the third finger. The dominant hand was used in both instances. Objective dominant hand grip strength (in kilograms of force) was assessed with a Jamar hydraulic hand dynamometer (Lafayette Instrument Company, Inc, Lafayette, IN) before the start of the experiment.

Interventions

First, the subjects were shown a brief introductory video describing the experimental procedures. Subjects were then randomized by permuted 4-block randomization to one of 2 sequences for performing all 3 bag-valve-mask hand-sealing techniques (Figure 3). All subjects first performed 1-handed bag-valve-mask technique. The subjects then performed 2-handed or modified 2-handed bag-valve-mask technique in the order assigned by randomization. Before each ventilation bout, subjects were shown an approximately 90-second tutorial video describing each specific technique, followed by a period for practice and questions, totaling 180 seconds for tutorial and practice. Each ventilation bout consisted of a 15-second run-in followed by a 5-minute data collection period.

Study investigators were instructed not to provide unsolicited coaching or to show bias toward any particular technique. No feedback or questions were allowed during the testing sessions. Subjects were blinded to all the model settings and measured data values, including expired tidal volume. Subjects were able to view the rise and fall of the mechanical test lung. Total experiment time was approximately 30 minutes for each subject.

Primary Data Analysis

The primary outcome measure, expired tidal volume, was automatically recorded by the Novametrix NICO (Novametrix Medical Systems) cardiopulmonary monitor, using linking software (Novametrix Analysis Plus!; Philips Respironics) and then electronically extracted to an Excel spreadsheet (Microsoft, Redmond, WA). Additional data were collected on a paper data collection instrument and then transferred to Excel. All statistical analyses were performed with SAS (version 9.2; SAS Institute, Inc., Cary, NC) or Stata (version 10.1;

StataCorp, College Station, TX). Descriptive statistics were calculated with medians and interquartile ranges or proportions where appropriate.

Confidence intervals (CIs) for medians were estimated with bias-corrected and accelerated bootstrap, with 2,500 repetitions.[10] We chose CIs instead of interquartile ranges to describe median expired tidal volume percentile data to allow direct comparison of significance within the table. Wilcoxon signed rank test was used to compare paired median values, and Wilcoxon rank sum test was used to compare independent median values. Nonparametric point estimates and CIs were estimated with the centile and cendif functions of Stata for paired and independent comparisons, respectively.[11] The calculation of median differences with these methods may differ slightly from the value obtained from simple subtraction of group medians. No clinically significant threshold difference in expired tidal volume percentage was defined a priori. Given the limitations of previous data in this area and the uniqueness of our study, we did not perform a power calculation a priori.

RESULTS

Characteristics of Study Subjects

We enrolled a total of 52 subjects. The majority of subjects were attending physicians, residents, or medical students (Table 1). The subjects had a diversity of experience levels for bag-valve-mask ventilation in both emergency and difficult situations.

Main Results

All subjects completed the study protocol. Because of a failure in the Novametrix NICO device, data were missing for 1 subject during the 1-handed bag-valve-mask technique session; this observation was omitted from all comparisons involving 1-handed bag-valve-mask.

In all instances, 1-handed bag-valve-mask technique resulted in lower median expired tidal volume percentage than either 2-handed bag-valve-mask technique (Table 2). Female subjects performing 1-handed bag-valve-mask technique had the lowest median expired tidal volume percentage.

Stratified by elapsed protocol time, 1-handed bag-valve-mask technique achieved lower median expired tidal volume percentage than either 2-handed bag-valve-mask technique (Table 3). Expired tidal volume did not differ between 2-handed or modified 2-handed bag-valve-mask techniques at any point during the 5-minute session.

Women achieved lower median expired tidal volume percentage than men in both 1-handed and 2-handed bag-valve-mask techniques (Table 4). However, in the modified 2-handed bag-valve-mask technique, median expired tidal volume was similar between women and men; this was true regardless of elapsed protocol time. Conversely, experienced subjects (defined as having performed bag-valve-mask ventilation in 5 or more patients in emergency situations) performed similarly with all 3 bag-valve-mask hand-sealing techniques.

Female subjects exhibited smaller hand width than male subjects (median 19.1 versus 21.4 cm; median difference 0.9 cm [95% CI 0.6 to 1.0 cm]). Women also exhibited smaller hand length than men (median 17.8 versus 19.1 cm; median difference 0.5 cm [95% CI 0.5 to 0.8 cm]). Women exhibited weaker initial dominant hand grip strength than men (26 versus 44 kg force; median difference 19 kg force [95% CI 17 to 21 kg force]). Emergency bag-valve-mask ventilation experience (emergency bag-valve-mask ventilation on 5 or more patients) was similar between men and women (odds ratio 1.08; 95% CI 0.35 to 3.35).

LIMITATIONS

We used a simulated model mimicking the bag-valve-mask ventilation of actual patients. Although our model allowed us to test our hypothesis in a highly controlled and consistent environment, it is unclear whether the same results would be achieved in a human model. Even with appropriate mask-face sealing technique, effective bag-valve-mask ventilation in practice can depend on factors not evaluated in our study, such as nasal or oral airways, head positioning, and patient facial characteristics.

Because of the concern of subject fatigue, we instructed all subjects to first perform 1-handed ventilation. We accepted this limitation to improve feasibility of the study and allow better focus on the comparison of the two 2-handed techniques. Subjects may not have remained blinded to the study purpose as the experiment proceeded and may have exaggerated differences between ventilation techniques. However, our results are consistent with those of previous studies that suggest the superiority of 2-handed techniques.[3–5]

Differences in sex hand width, length, strength, and experience may have influenced the results of the study. We avoided multivariable adjustment because of the modest sample size.

DISCUSSION

In this comparison of bag-valve-mask hand-sealing techniques in a simulated ventilation model, subjects achieved high and similar expired tidal volume with both the 2-handed and modified 2-handed techniques. Consistent with previous studies, both 2-handed techniques exhibited higher expired tidal volume percentages than the 1-handed technique.[3–6] An exploratory examination of subgroups showed that men were able to achieve a greater expired tidal volume percentage than women with both 1-handed and 2-handed techniques but that the sexes exhibited similar expired tidal volume percentage with the modified 2-handed technique. Experience did not seem to influence bag-valve-mask performance with any of the techniques.

In theory, all bag-valve-mask hand-sealing techniques require matching an upward jaw thrust with downward sealing pressure applied to the mask. With a 1-handed technique, these forces may be weaker on the side opposite to the hand grip, potentially allowing for air leakage. This observation likely explains why the 2-handed techniques performed better than the 1-handed techniques in our study. Our results suggest that simply having 2 hands to provide matching upward-downward forces on both sides of the mask, regardless of hand-sealing technique, is sufficient to improve the mask-face seal.

However, we note key differences between the traditional and modified 2-handed techniques. In the traditional "C"-shaped technique, the fifth finger is the only finger pulling up on the angle of the jaw. Additionally, the traditional technique orients the hands and forearms more parallel to the supine body. This approach is appropriate when the patient is at the provider's chest height. However, it forces the provider to rely primarily on forearm and hand muscles to create the upward-downward forces.

With the modified 2-handed bag-valve-mask technique, the third finger is shifted down to the angle of the jaw, potentially increasing the upward jaw thrust forces. Additionally, the hands and forearms may be oriented more perpendicular to the supine body. This technique may be beneficial if the patient is at waist level or lower. The approach also allows the provider to use the upper body to facilitate downward force on the mask.

Our findings have potential clinical applications. Our study suggests that 2-handed techniques should be favored over 1-handed bag-valve-mask techniques. Practitioners should also select the 2-handed approach that best suits individual comfort or the ergonomic constraints of individual scenarios. Although the results merit further validation, we believe that the modified 2-handed technique may have particular advantages in situations in which the provider has smaller hands or weaker grip strength or is faced with a difficult patient for mask-face seal.[7]

Although validating results in human subjects is always preferred, we recognize the enormous challenges such research would face. Most patients who require bag-valve-mask ventilation present as an emergency and with altered mentation or loss of consciousness. Thus, any human validation study likely must involve exception from informed consent.[12,13] An alternative is performing research on consenting patients undergoing elective surgery requiring general anesthesia, but this setting may not accurately reflect the challenges posed by emergency airway scenarios.

In summary, we observed similar bag-valve-mask ventilation expired tidal volume between the traditional and modified 2-handed techniques. Female subjects were able to generate expired tidal volume more similar to that of male subjects with the modified 2-handed technique. Both 2-handed techniques exhibited higher expired tidal volume than the 1-handed technique. Providers should favor 2-handed over 1-handed bag-valve-mask techniques.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

Acknowledgments

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Editor's Capsule Summary

What is already known on this topic

Achieving a mask seal during bag-valve-mask ventilation is difficult.

What question this study addressed

Is bag-valve-mask seal best with 1-handed, 2-handed, or modified 2-handed technique?

What this study adds to our knowledge

In this controlled trial using a standardized ventilation mannequin, 2-handed mask sealing resulted in higher tidal volumes than 1-handed technique. Tidal volumes for 2-handed and modified 2-handed techniques were similar.

How this is relevant to clinical practice

Although these mannequin-based results require in vivo validation, the findings support bag-valve-mask ventilation with 2-handed mask-sealing techniques.

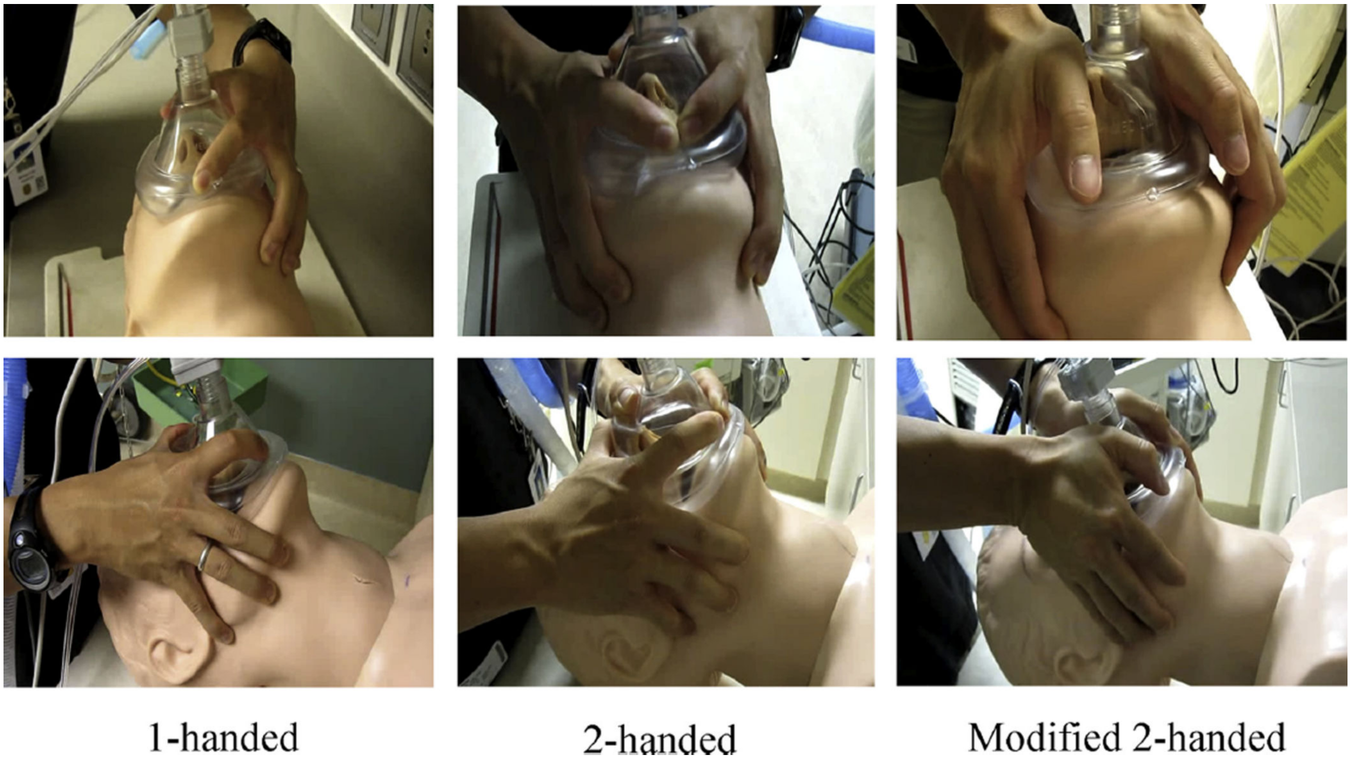

Figure 1.
Examples of 3 different bag-valve-mask hand-sealing techniques.

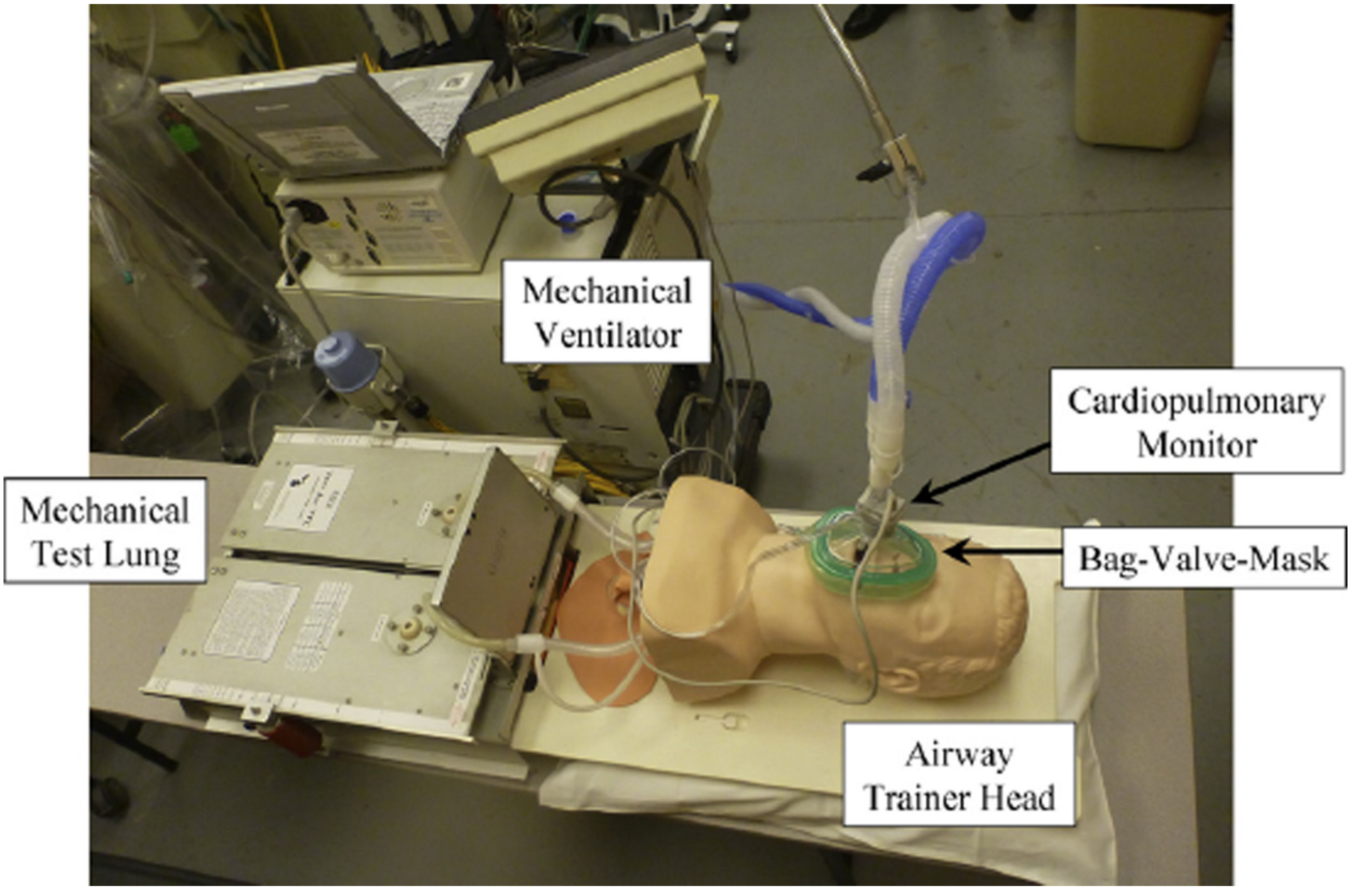

Figure 2.
A semiclosed-circuit simulated model for bag-valve-mask ventilation.

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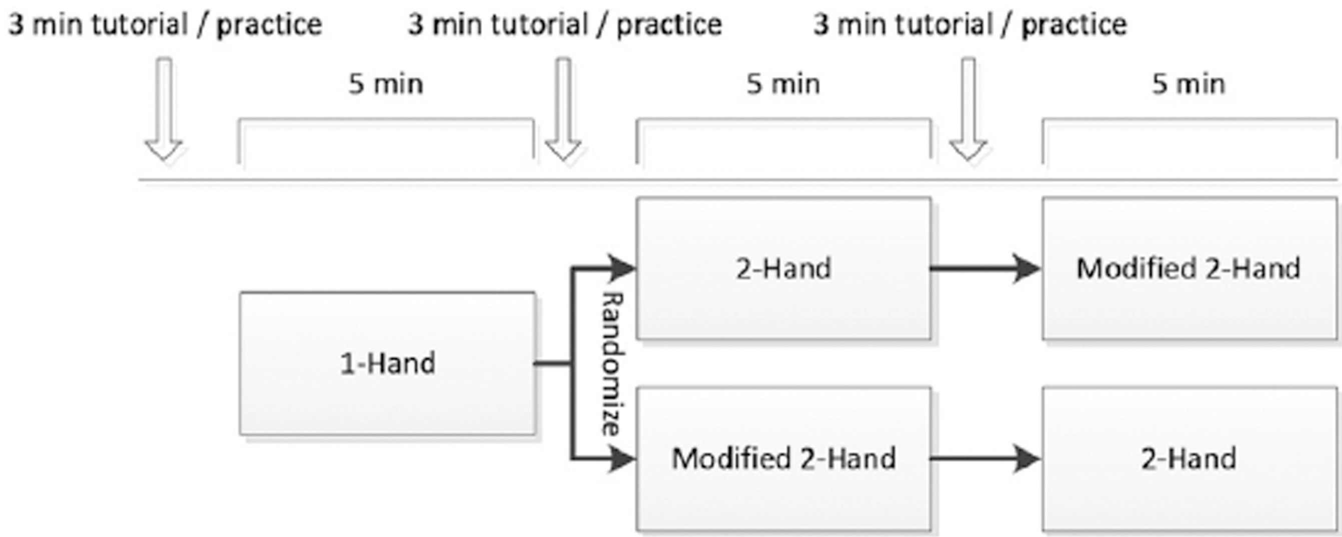

Figure 3.

Experiment timeline and randomization scheme for 3 bag-valve-mask hand-sealing techniques.

Table 1

Characteristics of subjects enrolled.

Subject Characteristics	Subjects, No. (%), n = 52	
Male sex	28	(54)
Provider type		
Medical student/resident/attending physician	36	(69)
Respiratory therapist	11	(21)
Other	5	(10)
BVM experience level in emergency situations		
None	5	(10)
Models only	5	(10)
<5 patients	10	(19)
≥ patients	32	(62)
Encounters with difficult BVM		
Never had difficult BVM	14	(27)
Experienced a few difficult BVMs	29	(56)
Experienced many difficult BVMs	9	(17)
Hand size		
Fifth finger to thumb (width) (IQR), median cm	20.2	(19.1, 21.6)
Wrist distal crease to tip of third finger (length) (IQR), median cm	18.9	(17.8, 19.4)
Right-handed	48	(92)

BVM, Bag-valve-mask ventilation; IQR, interquartile range.

Table 2.

Median percentage of total possible expired tidal volume for 52 subjects overall and within subgroups during each of 3 bag-valve-mask hand-sealing techniques performed for 5 minutes.

	1-Handed BVM, n = 51*		2-Handed BVM, n = 52		Modified 2-Handed BVM, n = 52	
Subject Categories	Median (%)	(95% CI)†	Median (%)	(95% CI)	Median (%)	(95% CI)
All subjects	31	(17–51)	85	(78–91)	85	(82–90)
Female subjects	10	(7–17)	76	(67–87)	83	(74–91)
Male subjects	57	(33–67)	88	(82–94)	90	(83–92)
Experienced subjects‡	28	(14–58)	87	(81–92)	89	(83–93)
Inexperienced subjects	33	(10–56)	77	(72–91)	80	(74–90)

CI, confidence interval.

*One subject was missing data on 1-handed BVM because of a failure in the recording instrument transmitting data during the session; thus, only 51 subjects were analyzed.

†Median 95% CIs estimated with bias-corrected and accelerated bootstrap.

‡Experienced subjects defined as having performed BVM ventilation in 5 or more patients in emergency situations.

Table 3

Median difference in the percentage of total possible expired tidal volume between each pair of 3 bag-valve-mask hand-sealing techniques.

Comparisons	Median Difference, %	95% CI
All 5 min		
1H–2H*	−47	−62 to −34
1H–m2H*	−56	−65 to −29
2H–m2H	−0	−2 to 2
First 4 min		
1H–2H*	−45	−59 to −33
1H–m2H*	−54	−65 to −28
2H–m2H	−1	−2 to 1
First 3 min		
1H–2H*	−47	−60 to −32
1H–m2H*	−52	−67 to −28
2H–m2H	−1	−2 to 2
First 2 min		
1H–2H*	−47	−59 to −30
1H–m2H*	−51	−68 to −28
2H–m2H	−0	−2 to 1
First 1 min		
1H–2H*	−46	−59 to −25
1H–m2H*	−53	−66 to −20
2H–m2H	−1	−4 to 2

1H, 1-Handed BVM technique; *2H*, 2-handed BVM technique; *m2H*, modified 2-handed BVM technique.

*One subject was missing data on 1-handed BVM because of a failure in the recording instrument transmitting data during the session; thus, only 51 subjects were analyzed.

Table 4

Median difference in the percentage of total possible expired tidal volume between sexes and experience levels within the strata of 3 bag-valve-mask hand-sealing techniques.

	1-Handed BVM*		2-Handed BVM		Modified 2-Handed BVM	
Comparisons	**Median Difference, %**	**95% CI**	**Median Difference, %**	**95% CI**	**Median Difference, %**	**95% CI**
Female-male (all 5 min)	−35	(−53 to −17)	−10	(−21 to −3)	−5	(−12 to 1)
Female-male (first 4 min)	−37	(−55 to −20)	−10	(−21 to −2)	−5	(−12 to 1)
Female-male (first 3 min)	−41	(−57 to −19)	−10	(−20 to −2)	−4	(−11 to 1)
Female-male (first 2 min)	−42	(−60 to −18)	−9	(−18 to −2)	−4	(−9 to 0)
Female-male (first 1 min)	−40	(−60 to −17)	−10	(−18 to −3)	−4	(−8 to 2)
Inexperienced-experienced (all 5 min)†	−0	(−16 to 16)	−4	(−14 to 5)	−6	(−14 to 1)
Inexperienced-experienced (first 4 min)	0	(−14 to 18)	−4	(−13 to 4)	−6	(−14 to 0)
Inexperienced-experienced (first 3 min)	0	(−15 to 16)	−3	(−12 to 4)	−6	(−14 to 0)
Inexperienced-experienced (first 2 min)	−3	(−17 to 15)	−2	(−10 to 4)	−5	(−12 to 0)
Inexperienced-experienced (first 1 min)	−1	(−17 to 17)	1	(−6 to 8)	−4	(−9 to 2)

CI, confidence interval.

*One subject was missing data on 1-handed BVM because of a failure in the recording instrument transmitting data during the session; thus, only 51 subjects were analyzed.

†Experienced subjects defined as having performed BVM ventilation in 5 or more patients in emergency situations.