An Audible Indication of Exhalation Increases Delivered Tidal Volume During Bag Valve Mask Ventilation of a Patient Simulator

Samsun Lampotang, PhD, D. E. Lizdas, BSME, N. Gravenstein, MD, and S. Robicsek, MD

Departments of Anesthesiology and Neurosurgery, University of Florida College of Medicine and the Departments of Mechanical and Aerospace Engineering and Electrical and Computer Engineering, University of Florida College of Engineering, Gainesville, Florida

Self-inflating manual resuscitators (SIMRs) can mislead caregivers because the bag, unlike a Mapleson-type device, reinflates even without patient exhalation. We added a whistle as an audible indicator to the exhalation port of a SIMR. In randomized order, each participant provided two sets of breaths via mask ventilation with a SIMR, one with and one without audible feedback, to a Human Patient Simulator modified to log lung volume changes. The last three breaths in each set were used to compare average tidal volume (VT) under both conditions. Eighty-seven advanced cardiac life support trainees (54 males, 33 females) with clinical experience averaging 6.4 ± 9.4 yr were recruited. Average VT delivered with the standard SIMR was 486 ± 166 mL and 624 ± 96 mL with the modified SIMR. Average VT delivered by a modified SIMR was significantly larger by 40% when it followed standard SIMR use and 19% when using the modified SIMR first. Use of a SIMR with an audible indicator of exhalation significantly ($P < 0.001$) increased mask ventilation of a patient simulator, suggesting that mask ventilation of a patient with a SIMR may also be increased by objective, real-time feedback of exhaled VT.

(Anesth Analg 2006;102:168–71)

The design and user interface of self-inflating manual resuscitators (SIMR), also known as self-inflating resuscitation bags and commonly known as "Ambu bags," can mislead caregivers because the bag reinflates after compression regardless of whether the patient is exhaling or is being properly ventilated. The refilling of the bag may be mistakenly interpreted as an indication that the lungs are being effectively ventilated and that the patient is exhaling based on the function of Mapleson-type ventilating systems and an anesthesia machine breathing bag where, at low or typical fresh gas flows, bag reinflation is in large part both a result and an indication of adequate patient exhalation. Furthermore, novices, or those who do not use SIMRs regularly, may not achieve an effective seal when using an SIMR with a facemask, potentially diminishing the effectiveness of resuscitation efforts.

Accepted for publication July 27, 2005.

Address correspondence and reprint requests to Samsun Lampotang, PhD, Department of Anesthesiology, PO Box 100254, Gainesville, FL 32610–0254. Address e-mail to slampotang@anest.ufl.edu.

DOI: 10.1213/01.ANE.0000181833.23904.4E

We conducted a simulator-based study to determine if an audible indicator of exhalation would assist caregivers across a broad range of clinical experience in delivering tidal volume (VT) that reflects the volume squeezed out of the SIMR and facemask seal.

Methods

In consultation with our IRB, it was determined that IRB approval and informed consent were not required because a device (not the participants) was being evaluated on a patient simulator (not a patient). The majority of the volunteers were anesthesia and surgery residents. Other participants included nurses and other clinical personnel attending Advanced Cardiac Life Support courses. There were no exclusion criteria.

We added a reed whistle as an audible indicator of exhalation to the exhalation port of a standard adult SIMR (1st Response™, Manual Resuscitator; SIMS Portex Inc., Keene, NH) (Fig. 1). The adult facemask provided by the manufacturer with the SIMR was used for the study. The reed whistle can be readily removed from the exhalation port to return the SIMR to its standard configuration.

0003-2999/06

Figure 1. Self-inflating manual resuscitator with reed whistle on exhalation port used for study. The reed whistle is at the bottom of the photograph.

A Human Patient Simulator (HPS, Version C, software version 6.1; Medical Education Technologies, Inc., METI, Sarasota, FL) was used to simulate a patient. With prior approval from the manufacturer and technical assistance from METI engineers, we modified the configuration file of the HPS to log to a file the individual volumes of the 2 bellows simulating the right and left lungs and the patient time at a sampling rate of 10 Hz (10 samples/s). The bellows volume tracking system was calibrated in 100-mL increments using a 500 mL calibration syringe (Model H7410; McGaw Respiratory Therapy, San Marcos, CA). The calibration sequence was repeated 3 times and the averaged values were used to generate the calibration plot. The total bellows volume was linearly correlated to the calibration volume ($R^2 = 0.998$). A program was written in Director (Macromedia, San Francisco, CA) to sum the volumes for the right and left lung bellows. The peaks and troughs in the total bellows volume trace were automatically identified through feature extraction algorithms and used to calculate the delivered Vt by subtracting the peak volume from its immediately preceding trough volume. Vt was then adjusted via the calibration constant to reflect true delivered Vt. Vt values less than 100 mL were not counted; this kept the breath detection threshold well above the noise level of the bellows tracking system. The start time, switch time, and end time for each participant was manually recorded to the nearest second and used to identify the two sets of breaths delivered by each participant.

The Standard Man patient provided with the HPS was loaded and allowed to reach steady-state, i.e., start breathing in response to build-up of CO_2 before it was paralyzed by setting neuromuscular blockade to 100%. Participants in the study were then requested to provide at least 5 breaths to the HPS using an SIMR with and without audible feedback. When using the modified SIMR, the participant was asked to deliver at least 5 breaths where the audible feedback was readily discernible during exhalation. Each participant acted as their own control. Each participant was assigned a consecutively numbered questionnaire to fill out before manually ventilating the HPS. If the questionnaire number was odd, the participant was asked to provide 5 breaths with an unmodified SIMR first followed by at least 5 breaths with the modified SIMR. If the participant gave the first set of breaths with a modified SIMR, the facemask was lifted off the simulator's face and a new seal had to be created before the last set of breaths was delivered with an unmodified SIMR. A new seal was requested in the study protocol so that the original seal created using the audible feedback is not carried over to the second set of breaths without the audible feedback. To address potential variability among SIMRs or reed whistles, the modified SIMR was the same as the unmodified one, only differing by the addition of the same reed whistle on the exhalation port. Available multi-variable physiological monitors were turned off so that they would not cue or distract the participants and to simulate emergent conditions.

The average Vt delivered by all participants with and without the modified SIMR was calculated. Only the last three breaths in each set were used to calculate the average Vt to allow participants at least two breaths to adjust their technique in establishing a seal on the face of the HPS. A paired Student's *t*-test (Origin v 5.0; Microcal Software Inc., Northampton, MA) was used to analyze average Vt.

Results

There were 87 participants in the study (54 males, 33 females; age 34.4 ± 11.2 yrs). The data for years of experience were 6.44 ± 9.36 yr with a range of 0–53 yr. Participants included anesthesia faculty and residents, surgery residents, medical students, respiratory therapists, and nurses. The ages were 35.4 ± 12.3 yr for the group using the modified SIMR first and 33.4 ± 10.4 for those using the standard SIMR first. The years of experience were 7.5 ± 10.3 yr for the group using the modified SIMR first and 5.3 ± 8.2 yr for those using the standard SIMR first. One participant was excluded because it could not be determined whether he or she used the modified or unmodified SIMR first ($n = 86$). Two other participants were excluded from analysis involving years of experience ($n = 84$) because they failed to enter that data; these two participants were included for other data analysis.

Counting only the last 3 breaths, the average and standard deviation for Vt delivered by all participants ($n = 86$) was 486 ± 166 mL with the standard SIMR and 624 ± 96 mL with the modified SIMR. The average Vt using the modified SIMR was 138 mL larger

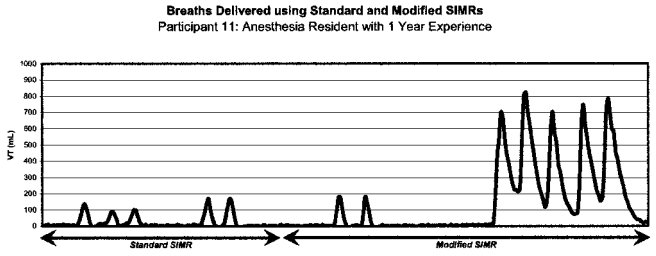

Figure 2. Tidal volumes delivered by one participant without (standard self-inflating manual resuscitator, SIMR), and with (modified SIMR), audible feedback.

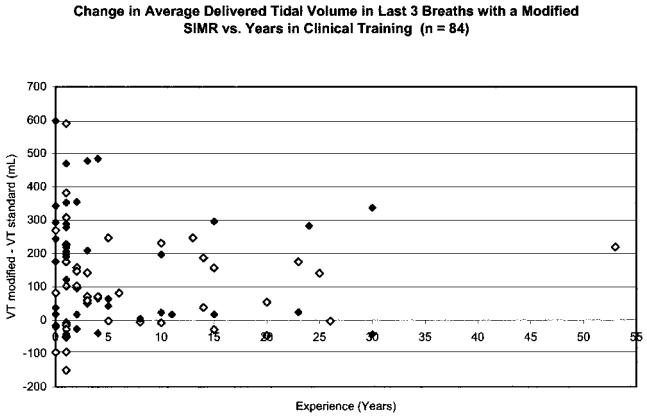

Figure 3. Change in delivered tidal volume with audible feedback as a function of experience. ◇, participants who used a modified self-inflating manual resuscitator (SIMR) first; ◆, participants who used a standard SIMR first.

than with a standard SIMR representing an overall increase of 28%. A paired Student's *t*-test indicated that the average VT delivered was significantly different ($P < 0.001$).

For participants who used the standard SIMR first ($n = 43$), the average and standard deviation for delivered VT was 439 ± 180 mL with the standard SIMR and 614 ± 98 mL with the modified SIMR, an increase in delivered VT of 175 mL (40%). A paired Student's *t*-test analysis revealed a significant difference in delivered VT ($P < 0.001$). For participants who used the modified SIMR first ($n = 43$), the average and standard deviation was 533 ± 138 mL with the standard SIMR and 633 ± 95 mL with the modified SIMR, an increase in VT of 100 mL (19%). A paired Student's *t*-test analysis revealed a significant difference in delivered VT ($P < 0.001$).

Figure 2 is a record of the performance of an individual participant with and without audible feedback. Gas trapping at end-exhalation can be observed with the modified SIMR. The trapped volume at end-exhalation with a standard SIMR was 46 ± 38 mL; with a modified SIMR it was 131 ± 99 mL. The ventilation rate with a standard SIMR was 30.1 ± 9.6 bpm; with a modified SIMR it was 30.6 ± 8.4 bpm.

Figure 3 plots the increase in delivered VT with the modified SIMR versus experience. The volume plots over time (similar to Fig. 2) for each individual study participant can be viewed at http://vam.anest.ufl.edu/sirb. In an approach for presenting extensive study data that we call transparent data, each data point in the plot at the above URL is a hyperlink to a complete set of ventilation data for a participant represented by a data point.

Discussion

Participants in the study provided unsolicited comments that the audible feedback was helpful and intuitively easy to understand and use. The experimental data support the feedback from the participants. For all participants, average delivered VT increased by 28% with audible feedback.

The reed whistle produces a discernibly louder sound with a larger exhalation and may have helped participants in delivering more consistent VT from breath to breath. The standard deviation for delivered VT for all participants ($n = 86$) was 166 mL and 96 mL for the standard and modified SIMR, respectively. The standard deviation data indicate that there was less variability in delivered VT with the modified SIMR, probably because participants could adjust their technique in real time based on the auditory feedback. The reed whistle also provided real-time feedback about exhalation and by inference the facemask seal and the volume squeezed from the bag, without necessarily being able to discriminate between the latter two. In Figure 2, the participant gave a set of 5 small (<200 mL) breaths with a standard SIMR and then switched to a modified SIMR. During the first two breaths with the modified SIMR, no audible feedback was present during exhalation, as indicated by the small VT. The participant accordingly adjusted the seal until audible feedback was discernible and thereafter proceeded to deliver 5 breaths (each exceeding 500 mL) that each produced audible feedback.

The percentage increase in delivered VT with a modified SIMR more than doubled, increasing from 19% to 40% when participants used the standard SIMR first. These data suggest that in the group that used the modified SIMR first, learning occurred and was retained when subsequently using the standard SIMR.

It can be observed in Figure 3 that an overall increase in delivered VT was attained across the entire range of clinical experience. Even though there was no correlation ($R^2 = 0.0037$) between increase in delivered VT and years of experience, we speculate that the audible indicator of exhalation will have the most value to novices and as a training tool. We envision that the device will assist in developing better techniques for obtaining a facemask seal and for providing

adequate time for exhalation, thus reducing the tendency of novices to ventilate at rapid breathing rates. Because the audible signal is broadcast to the whole room, experienced caregivers can monitor a novice's bag-valve-mask performance without needing to look at them.

The gas trapping at end-exhalation evident in Figure 2 is probably caused by the flow resistance of the reed whistle compared with the unobstructed exhalation port of an unmodified SIMR. Even with a standard SIMR, the average trapped volume at end exhalation was non-zero (46 ± 38 mL), which may partly be explained by participants ventilating at a fast rate that does not provide enough time for complete exhalation. The average rate of about 30 bpm for both groups is twice as fast as the recommended rate of 15 bpm. In Figure 2, the HPS does not exhale fully with the modified SIMR, as it does with the standard SIMR. However, complete exhalation is promoted if the delivered V_T is small, as is the case in Figure 2 and, conversely, is harder to attain with the significantly larger V_T delivered with the modified SIMR. Also, the reed whistle used in the study was an off-the-shelf component designed for another application that was not optimized for use as an exhalation indicator. Optimization of the reed whistle design to minimize flow resistance and to continue providing an audible signal at the low flows typical of end-exhalation should help attenuate gas trapping, which may be a problem with actual patients. Caregivers can refrain from squeezing the SIMR when the audible feedback is present to promote full exhalation and minimize gas trapping.

The current literature indicates that there has been no or minimal improvement in the success rate of cardiopulmonary resuscitation in the last two decades (1). Anesthesia faculty members have commented on the number of times that they have observed poor bag-valve-mask ventilation technique when responding to a code "the rescuer was ventilating the room." The addition of audible real-time feedback based on exhalation may be one way to improve the technique and efficacy of bag-valve-mask ventilation.

The authors thank Hugo Azevedo, Nikolaus Lee Gravenstein, Kelly Spaulding, Greg Yoder, John Hardcastle and Anita Yeager as well as the study participants.

Reference

1. Cobb LA, Fahrenbruch CE, Walsh TR, et al. Influence of cardiopulmonary resuscitation prior to defibrillation in patients with out-of-hospital ventricular fibrillation. JAMA 1999;281:1182–8.