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Comparison of Ventilation and Cardiac Compressions When Utilizing the Impact Model 730 Automatic Transport Ventilator Versus a Conventional Bag Valve with a Facemask in a Model of Adult Cardiopulmonary Arrest

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Abstract

The purpose of this investigation was to evaluate the delivery of ventilation and compressions during two person CPR on an instrumented manikin. Basic Life Support was provided by registered nurses using a conventional bag valve mask ventilation or mask ventilation with an automatic transport ventilator, the Impact Model 730 (Impact Instrumentation, Inc., West Caldwell, NJ), that incorporates a metronome to facilitate chest compression timing. Twenty-eight nurses alternated performing 4 minutes of CPR using the BVM or Impact 730 to deliver breaths with a mask while the other performed compressions. Flow, volume and pressure were measured using a pneumotach and pressure transducer and ease of use was measured using a 10 cm visual analog scale.

There was no statistical or clinical difference between the actual and recommended tidal lung volume. Ventilation with the bag valve mask resulted in a mean of 137.7 ml of air per breath entering the simulated stomach versus a mean of 14 ml when using the Impact 739. The reduced mask leak likely resulted from the nurse being able to manage the mask with 2 rather than 1 hand and is reflected in the higher ease of use score with the Impact 730.

Key Words: Advanced Life Support (ALS), Airway management, Cardiopulmonary resuscitation (CPR), Chest compression, Ventilation

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1. Introduction

During the initial stages of cardiopulmonary resuscitation (CPR), ventilation is often delivered by a self-inflating bag valve mask device (BVM).[1] Results of investigations examining the effectiveness of the BVM suggest two main problems when one rescuer attempts to perform ventilation with this device: difficulty in establishing and maintaining a leak-proof mask seal and gastric insufflation.[2].

The Guidelines 2000 for Cardiopulmonary Resuscitation and Emergency Cardiovascular Care: International Consensus on Science (hereafter referred to as the Guidelines 2000) called for increased use of automatic transport ventilators (ATVs) during CPR.[3] Use of an ATV with a facemask during CPR may help reduce the leakage of air between the mask and victim's face by allowing the rescuer to use two hands to manage the mask. Use of an ATV may also reduce stomach insufflation by delivering breaths with a slower inspiratory flow compared to breaths delivered with a BVM. The slower inspiratory flow helps reduce the airway pressure and the likelihood that a portion of the breath will enter the stomach rather than the lungs. [4]

The purpose of this investigation was to determine the performance of two person CPR on an instrumented manikin by experienced registered nurses using conventional bag valve mask (BVM) ventilation or the Impact Model 730 automatic transport ventilator (Impact 730, Impact Instrumentation, Inc., West Caldwell, NJ) in CPR mode using a face mask. The hypotheses were:

1. The delivered tidal volume during CPR using the Impact 730 versus a BVM will better approximate the tidal volume suggested in the Guidelines 2000 when two person CPR is performed by subjects on an instrumented manikin.

2. The mask leak volume during two person CPR performed on an instrumented manikin by subjects using the Impact 730 will be less than the mask leak volume using the BVM.

3. The stomach volume per breath during two person CPR performed on an instrumented manikin by subjects using the Impact 730 will be less than the stomach volume using the BVM. The stomach volume was defined as the volume per breath entering the manikin's stomach.

4. The frequency of breaths during two person CPR performed on an instrumented manikin using the Impact 730 will better approximate the frequency of breaths suggested in the Guidelines 2000 than when the breaths are delivered by the same subjects using a BVM.

5. The frequency of compressions during two person CPR performed on an instrumented manikin by subjects using the Impact 730 will better approximate the frequency of compressions suggested in the Guidelines 2000 than when compressions are delivered by the same personnel when ventilation is delivered using a BVM.

6. Subjects will indicate that the Impact 730 is easier to use compared to the BVM during two person CPR performed on an instrumented manikin.

The Impact 730 is a pneumatically powered automatic transport ventilator. In CPR mode, the operator sets the victims estimated weight.[5] When CPR is started, the device delivers the breaths at the recommended volume and rate. Between breaths, the device delivers an audible reminder using a metronome that sounds at the proper compression rate to remind the rescuer of proper compression timing.

2. Materials and Methods

The study was approved by the Uniformed Services University of the Health Sciences Institutional Review Board (#TO61EH-01). This investigation used a randomized crossover quasi-experimental design using a sample of 28 experienced registered nurses trained in performing adult CPR. Results of a power analysis suggested this sample size was necessary to for a power of 0.8 with $p <$ or equal to 0.05.[4] All of the registered nurses had completed a Basic Life Support course and all but one had completed a Advanced Cardiac Life Support Course. In a randomized fashion and after an orientation period where the subjects all received the same 5 minute verbal presentation and a one minute practice period, subjects alternated performing 4 minutes of CPR on a simulated 80 kg victim using the BVM (Ambu USA, Linthicum, MD) or Impact 730 to deliver breaths with a mask while the other subject performed compressions. The same mask (Ambu USA, Linthicum, MD) was used with both devices.

CPR was performed on an instrumented manikin. The airway portion of the manikin consisted of a Laerdal Airway Management Trainer (Laerdal Medical Corporation, Wappingers Falls, NY) and a Training Test Lung (Michigan Instruments, Grand Rapids, MI) with the compliance set to 100 ml/cm water. Any leaks in the airway management trainer were sealed using silicone sealant. A lower esophageal sphincter was constructed using a 5 cm water positive end expiratory pressure valve (Boehringer Laboratories, Norristown, PA).[6]

Chest compressions were performed on a compression simulator (Actar 911, via Armstrong Medical Industries, Inc., Lincolnshire, IL). An air-filled one liter intravenous fluid bag was placed within the compression simulator which was attached via an air-filled noncompressible tubing to the auxiliary pressure port on the Hans Rudolph RSS 100HR. The transducer in the Hans Rudolph RSS 100HR (Hans Rudolph, Kansas City, MO) measured the change in air pressure within this an air-filled bag. The pressure change occurring during a compression was seen as a spike in pressure and recorded on a personal computer (Dell, Austin, TX). See Figure 1.

Inspired and expired flow, volume, pressure, and number of cardiac compressions were measured using a RSS 100HR Research Pneumotach System and downloaded directly to a personal computer. Stomach volume per breath was measured using a mechanical respirometer (Boehringer Laboratories, Norristown, PA) and manually recorded. Ease of use for both devices was measured using a 10 cm visual analog scale. A one-tailed paired Student's t-test was used to compare difference in actual and recommended number of breaths and compressions per minute, tidal volume, mask leak, stomach volume per breath; and ease of use ($p <$ or $= 0.05$). The recommended number of breaths and compressions per minute and tidal volume was those described in the Guidelines 2000.[3] Data analysis was facilitated by the use of a commercially available statistical package (SPSS for Windows 11.0, SPSS, Inc, Chicago, IL).

3. Results

Demographic data of the subjects are described in Table 1. The differences between the actual and recommended number of breaths and compressions per minute, lung tidal volume, mask leak, stomach volume per breath, and ease of use scores are offered in Table 2.

4. Discussion

Using this model of cardiopulmonary arrest, subjects tended to under-inflate the test lung with both devices with no significant difference seen between the actual and recommended lung tidal volume, not supporting the first hypothesis. More than twice the volume was lost due leaking between the mask-simulated face interface with the BVM (367.6 ml, SD 337.7 ml) compared to the Impact 730 (14.0 ml, SD 16.8 ml). This finding supported the second hypothesis. Almost ten times the amount of air was insufflated into the simulated stomach per breath when the subjects used the BVM (137.7 ml, SD 143.9 ml) versus when the subjects used the Impact 730 (14.0 ml, SD 16.8 ml), supporting the third hypothesis. Despite the audible reminder of proper compression timing, subjects delivered about seven less compressions per minute than is recommended. When using the BVM, subjects delivered about eleven more compressions and about two more breaths per minute than recommended. These findings did not support the fourth and fifth hypotheses. The ease of use scores suggested the subjects found the Impact 730 easier to use than the BVM, supporting the final hypothesis.

The orientation to the Impact 730 likely reminded the subjects of the recommended frequency of breaths and compressions. This resulted in the subjects delivering breaths and compressions at a faster rate, not at the anticipated slower than recommended rate.

Combining the results of lung tidal volume, mask leak per breath, and stomach volume per breath suggests the subjects aggressively compressed the BVM. This aggressive compression resulted in a large volume leaving the BVM with a large portion of this volume leaking between the mask-simulated face interface and a large portion entering the simulated stomach. Subjects found the Impact 730 easier to use chiefly because the face mask could be held using both hands compared to having to manage the BVM with one hand and the face mask with the other hand.

The aggressive compression of the BVM is confirmed by examining a representative flow and peak airway pressure curves (Figures 2 and 3). In these representative tracings, the peak inspiratory flow attained when using the BVM is over 80 l/min while the peak inspiratory flow attained with the Impact 730 is about 20 liters per minute. Concomitantly, the peak airway pressure with the BVM is over 8 cm water while the peak airway pressure attained with the Impact 730 is about 6 cm water. This increase in flow and resulting airway pressure with the BVM explains the greater mask leak and stomach volume per breath that resulted when using this device. Conversely, the Impact 730 delivered the breath in the recommended two-second period using a smooth, controlled inspiratory flow that resulted in a lower airway pressure, mask leak, and volume per breath that was insufflated into the stomach.[3] If the subject using the BVM would have delivered the breath in a manner similar to that of the Impact 730, then the inspiratory flow, peak airway pressure, mask leak and stomach volume per breath all would have been lower.

The inexperience in using ATV's, specifically the Impact 730, may have led to a delayed response in starting compressions. The subjects did not begin compressions as soon as the metronome began. The subjects often seemed startled when the metronome sounded after the breaths completion. Many subjects commented that the breaths delivered by the Impact 730 were very quiet compared to the breaths delivered by the

BVM. Subjects indicated they were used to the characteristic "whoosh" made by the BVM and this sound prompted them to get ready to continue compressions.

Results of investigations examining the effectiveness of the BVM suggest two main problems when one rescuer attempts to perform ventilation with a BVM: difficulty in establishing and maintaining a leak-proof mask seal and stomach insufflation.[2,7,8] A portion of the tidal volume leaking from the mask-face interface can lead to hypoventilation with resulting hypercarbia, acidemia, and potentially hypoxemia that can lower the fibrillation threshold and increase defibrillation tolerance.[9] When ventilation is performed with one rescuer using a BVM, it can be difficult to establish and maintain a leak-proof seal when using one hand to manage the mask-face interface and the other hand to squeeze the bag.[7,10] The results of the current investigation confirm these findings. Use of the Impact 730 better enabled the rescuer to maintain a leak-proof seal.

This problem can also be overcome by two rescuers delivering ventilation when using a BVM with one rescuer managing the facemask and the other squeezing the bag.[11] This technique is recommended by the AHA as an alternative ventilation method.[3] However, two-person BVM ventilation increases the number of personnel needed to deliver CPR from two to three rescuers. This may be not be possible in a field environment where personnel are in short supply.

The risk of gastric insufflation is the second major obstacle when using a BVM during CPR.[12] This may be due to the shorter inspiratory time with resulting higher inspiratory flow when ventilation is delivered by a BVM.[4] The results are airway pressures that exceed the pressure of the lower esophageal sphincter thus allowing air to enter the victim's stomach.[13] An adverse cycle of ventilation caused by stomach insufflation has been described by Ruben, Knudsen, and Carugati.[14] With gastric insufflation, gastric pressure is increased thereby causing the diaphragm to move cephalad resulting in decreased lung movement and decreased lung compliance. This decreased lung compliance results in increased airway pressure favoring a redistribution of tidal volume from the lung to the stomach that causes further stomach insufflation, reduced pulmonary compliance, and decreased lung ventilation.

The Guidelines 2000 called for two strategies to help reduce gastric insufflation: using smaller tidal volumes during BVM ventilation (six to seven ml per kg when oxygen supplementation is used and 10 ml per kg when oxygen supplementation is not available) and delivering inspiration over one or two seconds.[3] These recommendations are supported by investigations using smaller BVMs and modified BVMs that limit inspiratory flow using both simulators and human models.[4,15,16] The results of one other investigation that used a model of cardiopulmonary resuscitation and compared inpiratory times of one versus two seconds did not support the Guidelines 2000.[17] The results of the current study are congruent with the majority of these investigations.[4,10,15,16]. Like a BVM that uses a flow-limiting device, the Impact 730 delivered the breaths using a controlled inspiratory flow that resulted in less insufflation of the simulated stomach.

Newer automatic resuscitators used with a facemask may also deliver the breaths in this manner. These newer devices, including the Oxylator EM-100, provide a lower fixed inspiratory flow. These investigations suggest incidence of stomach insufflation is less than with a BVM and there have been no reports of barotrauma.[18,19,20]

Cardiac compressions should be performed on an adult at a frequency of 100 per minute.[1] Using an instrumented manikin, two other groups reported that while the frequency of compressions did not diminish over three to five minutes of CPR, the quality (depth and hand position) did decrease over these same times.[21,22] Ninety three percent of compressions were accomplished with proper hand placement and depth during the first minute of CPR compared to 18% of compressions during the fifth minute of CPR.

However, studies by others do suggest compression rate does diminish over time. One group found that over five minutes of CPR on a manikin, compression frequency diminished from a mean of 95 compressions during the first minute to a mean of 69 beats per minute during the fifth minute of CPR.[23] Milander et al. also found the frequency of compressions were often done too slowly. They reported that cardiac compressions were done at the correct rate in only two of 12 observed cardiac arrests.[24] Their finding supported using an audio prompt to remind the rescuer of proper compression timing. Using a porcine model of cardiopulmonary arrest, an audio prompt increased the compression rate from a mean of 74 compressions per minute to a mean of 100 compressions per minute. This evidence suggests that cardiac compression frequency will diminish over time. The findings were confirmed in a human model of CPR.[25] Findings of the present study did not confirm those of prior investigations. This was likely due to the aforementioned reasons of subject contamination during the Impact 730 orientation and the quietness of the Impact 730.

The first limitation of this study is the use of a simulator. Although it is necessary to at least initially use manikins because this study cannot ethically be performed in a clinical setting, it is difficult to duplicate the respiratory mechanics of a victim in cardiac arrest. Second, the study was performed in a lab setting, eliminating the stress of a true cardiac arrest and limiting the time established for CPR performance. As mentioned above, the orientation to the Impact 730 may have alerted the subjects to the proper ventilation and compression rate. Third, the test lung compliance was set to 100 ml/cm water. While this compliance is not uncommon in normal weight ambulatory subjects as well as a minority of subjects with adult respiratory distress syndrome, it is a higher compliance than that found in subjects who suffered out of hospital cardiac arrest.[26,27,28] Branson et al. found the mean compliance in this subgroup to be approximately 50 ml/cm water. CPR had been performed on subjects for a period of time before their compliance was measured in the emergency department.[28] Finally, the Wright's respirometer relies on a person to read the instrument and record the data. The results of this study can only be generalized to the population from which the data was obtained. Further studies need to avoid introducing bias during the orientation period and ensure adequate familiarity with the device before starting CPR.

5. Conclusions

The results of this investigation indicated there were no statistical or clinical differences between the actual and recommended tidal lung volume when Basic Life Support was delivered by registered nurses used the Impact 730 or the BVM when performing CPR on a model of cardiorespiratory arrest. There was less air entering the stomach and a reduced mask leak when the using the Impact 730. Subjects tended to deliver slightly more compressions and breaths when using the BVM. Overall the subjects indicated their preference to using the Impact 730. These finding warrant future studies using the Impact 730 with a human model of cardiopulmonary arrest.

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Conflict of Interest Statement

None of the authors have any financial and/or personal relationships with other people or organizations that could inappropriately influence (bias) their work.

Table 1. Demographics of subjects, n=28, mean, (SD)

Age	36.4
	(5.6)
Number of males/females	11/17
Years as an RN	8.2
	(2.9)
Number qualified in Basic Life Support	28
Number qualified in Advanced Cardiac Life Support	27

Table 2. Differences between the actual and recommended number of breaths and compressions per minute, lung tidal volume, mask leak, stomach volume per breath, and ease of use scores, mean, (SD),

	Difference between actual and recommended number of breaths in 1 minute	Difference between actual and recommended number of compressions in 1 minute	Difference between actual and recommended lung tidal volume (ml)	Mask leak per breath (ml)	Stomach volume per breath (ml)	Ease of use score (cm)
Impact 730	0* (0.3)	-7.7* (3.2)	-120.4 (91.5)	176.1* (98.3)	14.0* (16.8)	8.06* (1.35)
BVM	2.41 (0.8)	11.1 (6.5)	-119.8 (187.3)	367.6 (337.7)	137.7 (143.9)	6.46 (2.46)

*p< or = 0.05