

Comparison of Ventilation Volume and Airway Pressure of an Advanced Airways in Virtual Reality Ambulance Simulation

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Abstract

Background/Objectives: It is convenient to apply C-E technique during ventilation using bag-valve mask in the moving ambulance. Purpose of the study is to investigate the effective ventilation volume and airway pressure.

Methods/Statistical analysis: The National Fire Service Academy conducted Virtual Reality (“VR”) based ambulance simulations from April 17, 2018 to April 28, 2018. The mean and standard deviations of mean ventilation and airway pressure were analyzed using descriptive statistics and ANOVA and SPSS software 12.0 (SPSS Ins., Chicago, IL, USA) program.

Findings: When VR-based intubation was performed, the ventilation volumes were 375 ml (± 30.71), 225 ml (± 8.48), 324 ml (± 6.56), 244 ml (± 7.79), and 427 ml (± 10.42) when using bag-valve mask, laryngeal mask, laryngeal tube, I-gel, and intubation, respectively. Airway pressure was 17.48 cmH₂O (± 0.28) from endotracheal intubation, 14.79 cmH₂O (± 1.51) from bag-valve mask, 13.49 cmH₂O (± 0.78) from laryngeal tube, 8.66 cmH₂O (± 0.80) from I-gel, 6.73 cmH₂O (± 0.53) from laryngeal mask showed airway pressure.

Improvements/Applications: The present study has significance in that basic data for the method of using a professional airway are provided by adequate ventilation for each professional airway in transit.

Keywords: *Virtual Reality, Ventilation Volume, Bag-Valve mask, Airway Pressure, Advanced Airway, RespiTrainer® Advance*

Introduction

Since free airway and assisted respiration before the admission affect the patient’s life directly, successful airway management is an essential emergency treatment. For the patients with heart failure, they require onsite professional cardiopulmonary resuscitation (CPR) depending on the situations such as disease status, existence of witness, witness’ CPR, and so on. However, for those who are difficult to perform professional CPR at the site and who do not recover with CPR, professional CPR should be performed during the transportation. It is difficult to perform proper chest compression and

artificial respiration during the transportation due to multiple elements of obstacles.

Artificial respiration is very critical emergency treatment for the patients not only with heart failure but also with apnea. Airway should be secured, and efficient ventilation should be provided at the site applying good airway management. Generally, ventilation is provided by bag-valve mask when CPR is performed at the heart failure state before the admission.

In the ventilation of bag-valve mask, airway management, close contact between mask and face, 1/3 bag compression, prevention of hyperventilation, bag compression during chest compression, and so on may affect the ventilation, which may be worsened during the transportation. In addition, efficient delivery of ventilation may be difficult during the transportation by

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movement of ambulance and unstable posture. According to the recent guideline, efficient ventilation at the heart failure state is recommended to deliver 500 ~ 600 ml ($6 \sim 7 \text{ ml/kg}$)^[1], because the seat of ambulance crew in the ambulance is located beside the patient, it is not convenient to apply C-E technique in case of ventilation using bag-valve mask and also efficient ventilation is difficult due to obstacles despite intubation. Even in case of intubation, it can be pushed out of the mouth during chest compression, hence, it is not easy to deliver ventilation during the transportation.

Many previous studies^[2-4] were conducted related to the delivery of one-time respiration while no study was done related to the ventilation during the transportation. This study was conducted with the subjects of manikins to compare the ventilation volume and airway pressure using bag-valve mask between the situation of basic airway management and the situations of laryngeal mask, I-gel, laryngeal tube, and intubation to the bronchus in the VR-based ambulance. Also, it aimed to compare the results of VR-based study with the previous studies performed in the fixed situation and to apply this to the sites so as to suggest the fundamental data for the efficient delivery of ventilation during the transportation.

Materials and Method

1. Research design and data collection

This is a comparative study to measure the ventilation volume of bag-valve mask with RespiTrainer® Advance in the situation applying special ventilator in the VR-mock ambulance. To do so, VR-based simulation ambulance was used in National Fire Service Academy and “urban beltway scenario” was applied among developed scenarios. Transportation time was for 6 minutes maintaining 60 to 80 km/hour. In the test, 150 times of ventilation volume were compared between the case only using bag-valve mask and the cases using bag-valve mask in the states of intubation, laryngeal tube, I-gel, and laryngeal mask. For the data, ventilation volume to be delivered to the lung and airway pressure were collected using RespiTrainer® software.

2. VR based simulation ambulance

The VR based ambulance designed to enable the education and training of emergency services in various road environments was developed as a fire research and development (R&D) project. VR based simulation ambulance implemented VR by applying Ambulance

Driving Simulation S/W to computer controlled moving platform design [Figure 1]. Six scenarios have been developed to suit the surrounding environment, such as rural, urban and suburban environments, and are designed so that the rescuer can drive while monitoring scenarios set up outside the ambulance.

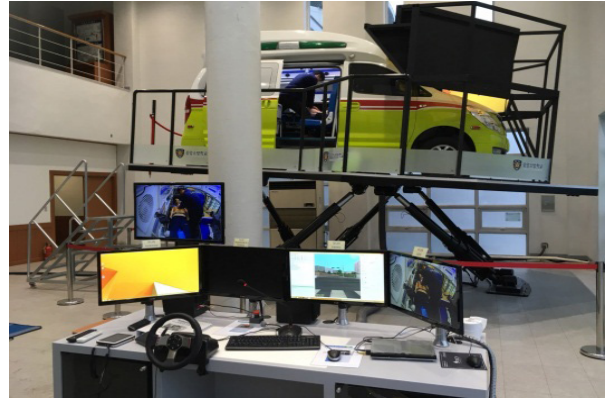


Figure 1. VR-based simulation ambulance

2. RespiTrainer® Advance

RespiTrainer® Advance (version 1.1, Ingmar, Pittsburgh, USA) is the equipment that is optimized for a wide range of special air intubation training and skills, and has realistic materials and anatomical structures. High-performance test lungs (QuickLung®) can achieve realistic lung capacity in adults, and software can be used to verify data such as ventilation and airway pressure. Airway resistance and compliance were set at $5 \text{ cmH}_2\text{O/L/s}$ and $50 \text{ ml/cmH}_2\text{O}$, which are the mean values of healthy persons without lung disease [Figure 2].

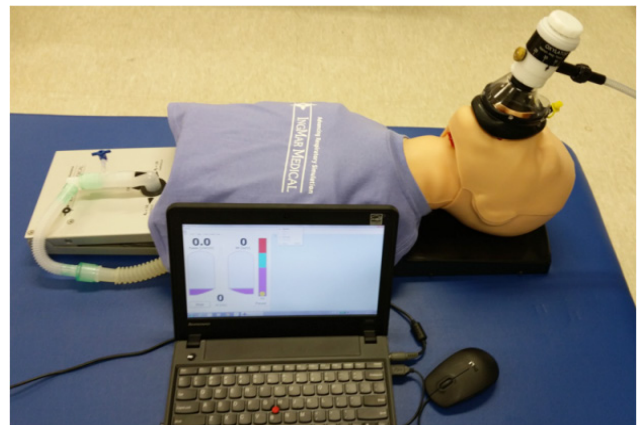


Figure 2. RespiTrainer® Advance

3. Advanced Airway

For BVM, storage sac was attached to Laerdal® Silicone Resuscitator, and volume of bag was used with 1,600 ml. #4 of I-gel® was used after closing opened end

for reducing pressure of stomach. King LTS-D™ #4 was used for laryngeal tube, injecting 80 ml of air to the cuff after closing upper esophageal opening for reducing pressure of stomach. With respect to the tube for intubation, Mallinckrodt® I.D. 7.5 was used fixing 22 cm of intubation depth. Cuff was fixed by Thomas® Tube Holder not to be moved or pulled out after injecting 10 ml of air [Figure 3].

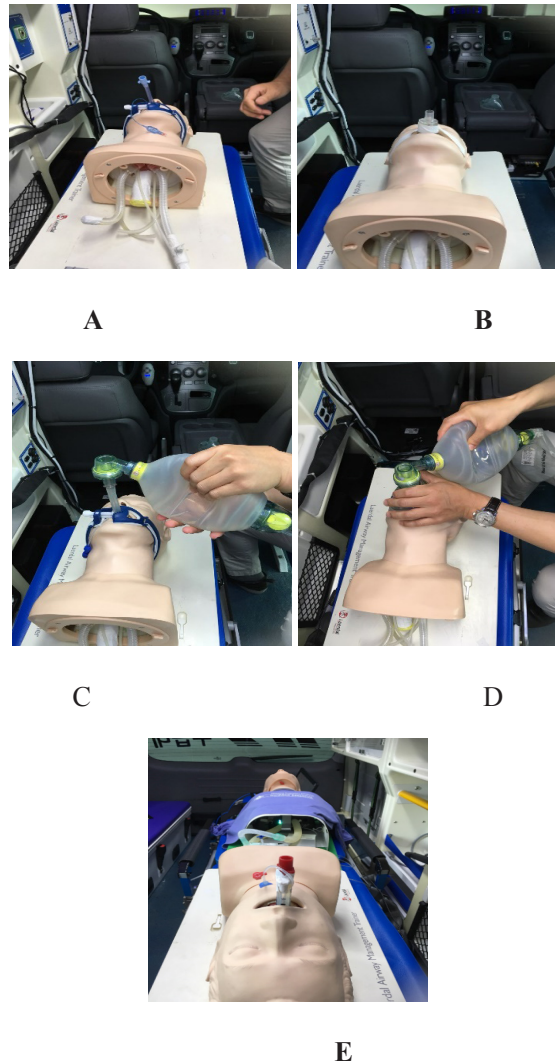


Figure 3. Advanced Airway. Endotracheal intubation(A), I-gel(B), Laryngeal mask airway(C), Bag-valve mask (D), Laryngeal tube (E)

All experiments were conducted within a VR-based simulation ambulance and were conducted at the National Fire Service Academy from April 17, 2018 to April 28, 2018. All data were collected using RespiTrainer® software (version 1.1, Ingmar, Pittsburgh, USA) to collect ventilation and airway pressure. The collected data were analyzed using SPSS software 12.0 (SPSS Inc., Chicago, IL, USA). The mean and standard deviation of ventilation and airway pressure were analyzed using descriptive statistics and ANOVA.

Result

1. Ventilation volume

Ventilation volumes delivered to the lung were compared between the case using VR-based bag-valve mask and the cases using bag-valve mask in the states of intubation. Ventilation volumes were 375 ml (± 30.71), 225 ml (± 8.48), 324 ml (± 6.56), 244 ml (± 7.79), and 427 ml (± 10.42) when using bag-valve mask, laryngeal mask, laryngeal tube, I-gel, and intubation, respectively [Table 1].

Table 1. Comparison of delivered volume

	Mean (ml)	Min	Max	SD	F	p	Scheff'e
ETa	427.15	399.0	463.0	10.42	4449.09	.000	a>bcd
BVMb	375.18	168.0	436.0	30.71			b<a, b>cde
LTc	324.66	305.0	346.0	6.56			c<ab, c>de
I-geld	244.60	229.0	270.0	7.79			d>e, d<abc
LMAe	225.64	205.0	252.0	8.48			e<abcd

ET: Endotracheal tube

BVM: Bag-valve mask

LT: Laryngeal tube

LMA: Laryngeal mask airway

2. Airway pressure Ventilation volume

Table 2 shows the results of airway pressure analysis with VR-based endotracheal intubation. The endotracheal tube showed an average airway pressure of $17.48 \pm .28$ cmH₂O, with a minimum airway pressure of 16.70 cmH₂O and a maximum airway pressure of 18.30 cmH₂O. The bag-valve mask showed an average airway pressure of $14.79 \pm .151$ cmH₂O, with a minimum airway pressure of 4.60 cmH₂O and a maximum airway pressure of 17.40 cmH₂O. Laryngeal tube showed an average airway pressure of $13.49 \pm .78$ cmH₂O, with a minimum airway pressure of 11.40 cmH₂O and a maximum airway pressure of 15.40 cmH₂O. I-gel showed an average airway pressure of $8.66 \pm .80$ cmH₂O, with a minimum airway pressure of 6.70 cmH₂O and a maximum airway pressure of 12.10 cmH₂O. Laryngeal mask airway showed an average airway pressure of $6.73 \pm .53$ cmH₂O, with a minimum airway pressure of 5.70 cmH₂O and a maximum airway pressure of 8.10 cmH₂O [Table 2].

Table 2. Comparison of airway pressure

	Mean	Min	Max	SD	F	p	Scheff'e
ET ^a	17.48	16.70	18.30	0.28	3752.02	.000	a>bcd
BVM ^b	14.79	4.60	17.40	1.51			b<a, b>cde
LT ^c	13.49	11.40	15.40	0.78			c<ab, c>de
I-gel ^d	8.66	6.70	12.10	0.80			d>e, d<abc
LMA ^e	6.73	5.70	8.10	0.53			e<abcd

ET: Endotracheal tube

BVM: Bag-valve mask

LT: Laryngeal tube

LMA: Laryngeal mask airway

DISCUSSION

Airway management is very important for emergency patients. If breathing of a patient is erratic or a patient does not breath, assisted respiration should be provided. The optimization of ventilation during CPR is a broad of research^[5]. A bag-valve mask is used being connected with intubation or with a laryngeal tube, I-gel, laryngeal mask, and so on also in a state it is intubated during positive pressure ventilation^[6,7]. The present study comparatively analyzed ventilation volume delivered to the lung when air was ventilated using a bag-valve mask after a professional airway was intubated in a moving ambulance.

Ventilation volumes were found to be in the order of intubation, bag-valve mask, laryngeal tube, I-gel, and laryngeal mask, showing values of 427 ml, 375 ml, 324 ml, 244 ml, and 225 ml, respectively ($p = .000$). In previous studies, ventilation volumes of intubation, bag-valve mask, laryngeal tube, and laryngeal mask were found to be 497 ml, 386-421 ml, 365 ml, and 351 ml, respectively^[8,9]. However, these studies were conducted in a stationary situation. The surest method to secure an airway is to insert a tube into the airway. While intubation is the method most widely used in hospitals to maintain an airway^[10,11], successful intubation is not easy in a pre-hospital situation. It is possible only when the performer has sufficient experience and is prepared at all times. Thus, intubation is not much performed in a pre-hospital situation in practice^[12,13]. For such a reason, supraglottic airway devices (laryngeal tube, I-gel, and laryngeal mask) are recommended in a pre-hospital situation because they make intubation relatively easy. However, while intubation of a supraglottic airway device is easy, the ventilation state may be poor as it is difficult to achieve adhesion in a moving site and it can be pushed superior and it is difficult to prevent inhalation of stomach contents^[8].

It is also difficult to continuously deliver air required for ventilation volume in a moving ambulance. When the maximum volume and the minimum volume were compared, these values were shown to be in the order of intubation (min. 399 ml, max. 463 ml), bag-valve mask (min. 168 ml, max, 436 ml), laryngeal tube

(min. 305 ml, max. 346 ml), I-gel (min. 229 ml, max. 270 ml), and laryngeal mask (min. 205 ml, max. 252 ml) with the exception of the minimum of bag-valve mask. Differences between minimums and maximums of intubation, bag-valve mask, laryngeal tube, I-gel, and laryngeal mask were shown to be 64 ml, 268 ml, 41 ml, 26 ml, and 47 ml, respectively. All ventilation methods excluding intubation showed low respirations [Figure 4].

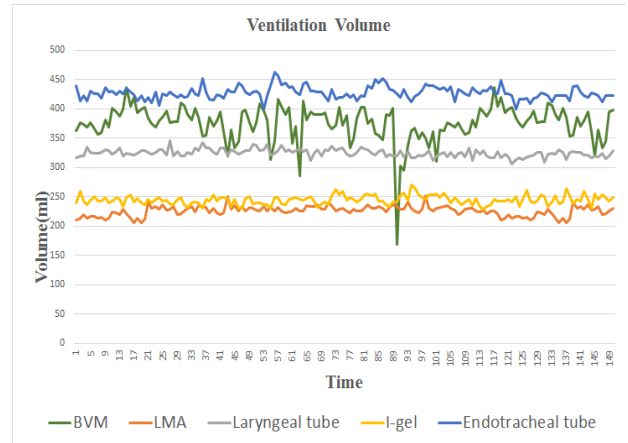


Figure 4. Ventilation volume in a VR-based moving ambulance. Minimum and maximum volumes of the ventilation method for which only a bag-valve mask was used continued to be in an unstable state

If the pressure inside the airway exceeds 20 to 25 cmH₂O, it might cause lung damage with reflux and aspiration complication^[13-15]. In previous studies, intubation, laryngeal tube, laryngeal mask, I-gel, and bag-valve mask showed values of 8 to 11 cmH₂O, 8 to 10 cmH₂O, 7.86 cmH₂O, 10 cmH₂O, and 8 to 10 cmH₂O, respectively [8, 16, 17]. In the present study, intubation, bag-valve mask, laryngeal tube, I-gel, and laryngeal mask showed pressure values of 17.48 cmH₂O (±.28), 14.79 cmH₂O (±1.51), 13.49 cmH₂O (±.78), 8.66 cmH₂O (±.80), and 6.73 cmH₂O (±.53), respectively ($p=.000$). It was difficult to continuously deliver airway pressure in a moving ambulance. The minimum and maximum pressures were shown to be in the order of intubation (min. 16 cmH₂O, max. 18 cmH₂O), bag-valve mask (min. 4 cmH₂O, max. 17 cmH₂O), laryngeal tube (min. 11 cmH₂O, max. 15 cmH₂O), I-gel (min. 6 cmH₂O, max. 12 cmH₂O), and laryngeal mask (min. 5 cmH₂O, max. 8 cmH₂O) with the exception of the minimum pressure of bag-valve mask [Figure 5].

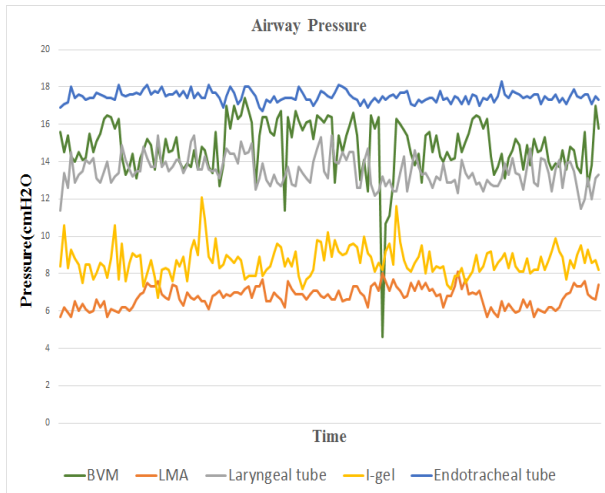


Figure 5. Airway pressure in a VR-based moving ambulance. In the case of the ventilation method for which only a supraglottic airway device and a bag-valve mask were used, the minimum and maximum pressures continued to be in an unstable state.

It is convenient to apply C-E technique during ventilation using bag-valve mask in the moving ambulance. Upon the results of VR-based simulation ambulance study, ventilation was high in the order of intubation, bag-valve mask, laryngeal tube, I-gel, and laryngeal mask while laryngeal mask and I-gel had less efficient ventilation.

As not an actual patient but an experimental lung was used, the present study had limitations in that airway resistance or anatomical difference could not be taken into account; VR-based urban outer road scenario failed to sufficiently reflect the field road situation; and it was not clear whether VR-based computer-controlled moving platform design sufficiently reflected the suspension of an ambulance actually driven. However, the present study has significance in that basic data for the method of using a professional airway are provided by analyzing adequate ventilation for each professional airway in transit.

Conclusion

Bag-valve mask is a device to be able to provide the patients who require assisted ventilation with positive pressure ventilation. In case of assisted respiration, 500-600 ml (6-7 ml/kg) is recommended and it is hard to provide proper ventilation volume during the transportation. This is a study performed in the subjects with manikins showing the highest ventilation volume in case of intubation followed by bag-valve mask,

laryngeal tube, I-gel, and laryngeal mask in VR-based ambulance. Compared to the previous studied conducted in the fixed state, ventilation volumes showed lower by 69 ml, 19 ml, and 125 ml in intubation, laryngeal tube, and laryngeal mask, respectively; and minimum and maximum ventilation volumes showed the differences by 168 - 436 ml, 205 - 252 ml, 305 - 346 ml, 229-270 ml, and 399 - 463 ml, in bag-valve mask, laryngeal mask, laryngeal tube, I-gel, and intubation, respectively; demonstrating difficulty in delivering constant amount of respiration in the transportation. Among supraglottic airway devices, laryngeal tube and I-gel showed with 225 ml and 244 ml, demonstrating difficulty in close contact with airway.

Ethical Clearance: Not required

Source of Funding: Self

Conflict of Interest: Nil

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