

The Adequacy of a Conventional Mechanical Ventilator as a Ventilation Method during Cardiopulmonary Resuscitation: A Manikin Study

Hong Joon Ahn, M.D., Kun Dong Kim, M.D., Won Joon Jeong, M.D., Jun Wan Lee, M.D.,
In Sool Yoo, M.D., and Seung Ryu, M.D.

Department of Emergency Medicine; *Intensivist of Regional Emergency Medical Center, College of Medicine, Chungnam National University Hospital, Daejeon, Korea

Background: We conducted this study to verify whether a mechanical ventilator is adequate for cardiopulmonary resuscitation (CPR).

Methods: A self-inflating bag resuscitator and a mechanical ventilator were used to test two experimental models: Model 1 (CPR manikin without chest compression) and Model 2 (CPR manikin with chest compression). Model 2 was divided into three subgroups according to ventilator pressure limits (P_{limit}). The self-inflating bag resuscitator was set with a ventilation rate of 10 breaths/min with the volume-marked bag-valve procedure. The mode of the mechanical ventilator was set as follows: volume-controlled mandatory ventilation of tidal volume (V_t) 600 mL, an inspiration time of 1.2 seconds, a constant flow pattern, a ventilation rate of 10 breaths/minute, a positive end expiratory pressure of 3 cmH₂O and a maximum trigger limit. Peak airway pressure (P_{peak}) and V_t were measured by a flow analyzer. Ventilation adequacy was determined at a V_t range of 400-600 mL with a P_{peak} of ≤ 50 cmH₂O.

Results: In Model 1, V_t and P_{peak} were in the appropriate range in the ventilation equipments. In Model 2, for the self-inflating bag resuscitator, the adequate V_t and P_{peak} levels were 17%, and the P_{peak} adequacy was 20% and the V_t was 65%. For the mechanical ventilator, the adequate V_t and P_{peak} levels were 85%; the P_{peak} adequacy was 85%; and the V_t adequacy was 100% at 60 cmH₂O of P_{limit} .

Conclusions: In a manikin model, a mechanical ventilator was superior to self-inflating bag resuscitator for maintaining adequate ventilation during chest compression.

Key Words: cardiopulmonary resuscitation; peak airway pressure; pressure limit; self-inflating bag resuscitator; tidal volume; ventilator.

Introduction

Although ventilation plays an important role in high quality cardiopulmonary resuscitation (CPR), it is difficult to perform appropriate ventilation during CPR.[1-3] To address this problem, studies for preventing excessive ventilation have been conducted using simple methods such as a metronome, thoracic impedance, capnography, and tracheal pressure monitoring.[4-8] However, it is difficult to maintain a proper tidal volume (V_t) and ventilation rate with a self-inflating bag resuscitator during CPR. One study on actual CPR showed that use of a self-inflating bag resuscitator is likely to result in excessive ventilation

and high airway pressure in practice,[9] whereas using an automatic transport ventilator instead of a self-inflating bag resuscitator shows better outcomes.[10-12]

Despite various efforts, the study of ventilation during CPR has not provided adequate evidence on ventilation rate, V_t , or peak airway pressure (P_{peak}). Moreover, when unexpected cardiac arrest occurs in patients, no studies or guidelines direct

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Correspondence to: Seung Ryu, Department of Emergency Medicine, College of Medicine, Chungnam National University Hospital, 282 Munhwa-ro, Jung-gu, Daejeon 301-721, Korea

Tel: +82-42-280-8007, Fax: +82-42-280-8082

E-mail: rs0505@cnuh.co.kr

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the use of a mechanical ventilator. We conducted this study to determine whether the use of a mechanical ventilator during CPR is adequate to maintain the ventilation rate, Vt, and P_{peak} .

Materials and Methods

1) Experimental protocol and data collection

We conducted this study at a tertiary teaching hospital from March 2013 to May 2013.

One manual self-inflating bag resuscitator (Ambu® Resuscitator Mark IV, Ambu, Ballerup, Denmark), and 1 mechanical ventilator were used in Model 1 (CPR manikin without compression) and Model 2 (CPR manikin with compression).

A CPR manikin (Resusci Anne Skill Reporter™, Laerdal, Stavanger, Norway), which allows the evaluation of the adequacy of CPR, was connected to a flow analyzer by a 7.0 mm endotracheal tube and a 1-way valve (Fig. 1).

With a self-inflating bag resuscitator, we performed ventilation at 10 breaths/min and used the volume-marked bag-valve procedure[13] to control Vt. The mechanical ventilator (MV2500 SU:M3, MEK-ICS CO., Seongnam, Korea) was used under the same conditions for volume-controlled mandatory ventilation: Vt 600 mL, inspiration time (Ti) 1.2 sec, constant flow pattern, ventilation rate 10 breaths/min, and positive end expiratory pressure (PEEP) 3 cmH₂O. We set the triggering limit to maximum and divided the pressure limit (P_{limit}) into 3 subgroups to test Model 2 (P_{limit} : 40, 50, 60 cmH₂O). We used a flow analyzer (Flowanalyser™



Fig. 1. Closed loop manikin circuit connected to flow analyzer.

PF-300, Imtmedical, Switzerland) to measure P_{peak} and Vt in each group. Ventilation was considered adequate when Vt was in the range of 400–600 mL[14-16] and P_{peak} was ≤ 50 cmH₂O.

Chest compression was performed by 4 emergency medicine residents on the floor, and ventilation was performed by 1 emergency medicine resident; all residents were certified advanced cardiac life support providers. A total of 10 minutes of chest compressions were used in each subgroup, and chest compression depth (5–6 cm) and rate (100/min) were maintained, as verified by a skilled reporter. The ventilation (10 breaths/min) was verified by the flow analyzer. The 4 chest compression performers took 2-minute turns to reduce the effect of performer fatigue.

2) Statistical analysis

We used the Kruskal-Wallis test to compare the continuous variables; each value represented the median value and quartile. We used the χ^2 test or Fisher's exact test to analyze the discrete variables. PASW 18.0 (SPSS Inc., Chicago, IL, USA) was used to compile statistics, and the significance level was $p < 0.05$.

Results

1) Comparison between the ventilation equipment used on the manikin

Compliance and resistance were 35 mL/cmH₂O and 20 cmH₂O/L/sec, respectively, with the manikin prepared as shown in Fig. 1. Ventilation equipment Vt and P_{peak} were in an appropriate range (Table 1).

2) Comparison between the ventilation equipment during chest compression (Table 1 and Fig. 2)

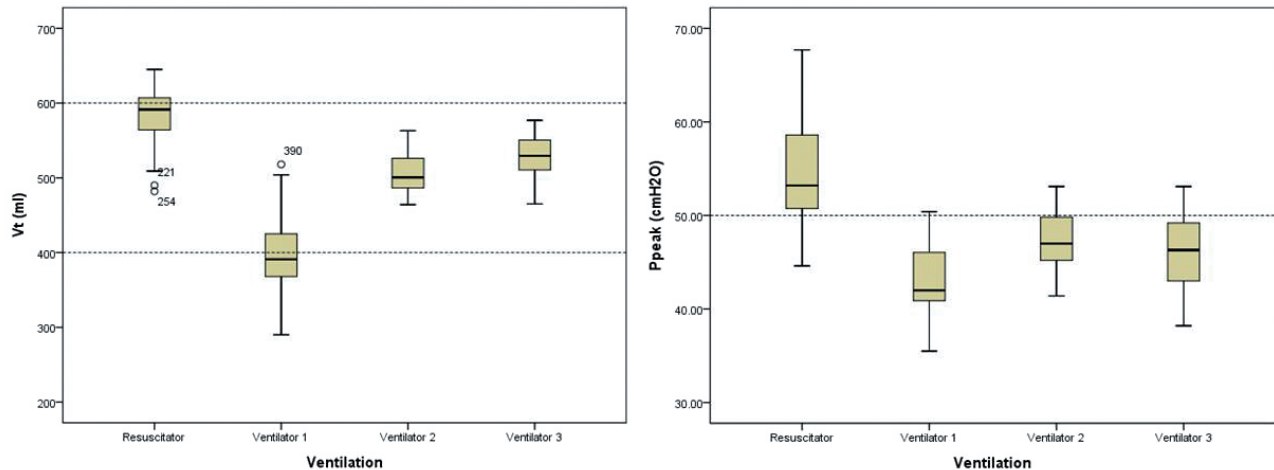
When a self-inflating bag resuscitator was used during chest compression, an adequate Vt and P_{peak} were observed at 17%. When an adequate Vt was maintained, P_{peak} over 50 cmH₂O was 48%.

A mechanical ventilator with CPR produced the following results: With P_{limit} set at 40 cmH₂O, it was possible to maintain P_{peak} at 94% and Vt at 42%; an adequate Vt and P_{peak} level was 37%. With P_{limit} set at 50 cmH₂O, it was possible to maintain P_{peak} at 79% and Vt at 100%; an adequate Vt and P_{peak} level was 79%. With P_{limit} set at 60 cmH₂O, it was pos-

Table 1. Comparison of median value (IQR) between the ventilation equipment used on the manikin in Model 1 (CPR Manikin without compression)

Type of ventilation	Tidal volume (mL)	Peak airway pressure (cmH ₂ O)
Resuscitator (n = 100)	613.50 (599.00 - 620.00)	23.15 (22.00 - 24.77)
Ventilator (n = 100)	559.5 (556.00 - 565.00)	25.75 (25.60 - 25.90)

Resuscitator; self-inflating bag resuscitator, Ventilator; mechanical ventilator.

**Fig. 2.** Changes of the tidal volume and peak airway pressure in Model 2. Model 2; CPR Manikin with compression, Resuscitator; self-inflating bag resuscitator, ventilator 1; P_{limit} 40 cmH₂O, 2; P_{limit} 50 cmH₂O, 3; P_{limit} 60 cmH₂O, Tidal volume adequacy; Vt 400-600 mL, Peak airway pressure adequacy; $P_{\text{peak}} \leq 50$ cmH₂O, Adequate ventilation; Vt 400-600 mL and $P_{\text{peak}} \leq 50$ cmH₂O.

sible to maintain P_{peak} at 85% and Vt at 100%; an adequate Vt and P_{peak} level was 85%.

Discussion

In its 2010 guidelines, the American Heart Association (AHA) suggested that high-quality CPR should maintain a rate of at least 100 compressions/min and a compression depth of at least 2 inches (5 cm) in adults to allow complete chest recoil after each compression, minimize interruption in chest compression, and prevent excessive ventilation. The AHA also advised that CPR should be performed at the rate of 8–10 breaths/min, allowing 400–600 mL of ventilation without interruption of chest compression when an endotracheal tube is inserted.[17] Despite those guidelines on ventilation, proper ventilation has not yet been clearly set. Despite many studies, the effort to determine an optimal Vt and ventilation rate has been unsuccessful.[18,19] Meanwhile, the more hyperventilation occurs during CPR, the

more positive pressure is created, leading to increased intrathoracic pressure,[9,20] which could decrease survival rates by reducing venous return, cardiac output, and coronary perfusion pressure.[21–23] Those side effects in hemodynamics tend to be caused by changes in the ventilation rate rather than changes in Vt.[9, 24–27] Therefore, guidelines based on recent studies suggest reduced Vt, compared with the past, and a restricted ventilation rate.

According to a study by Aufderheide et al.,[22] rescuers consistently hyperventilated patients during pre-hospital CPR, and subsequent animal studies showed that mean intrathoracic pressure increased from 7.1 ± 0.7 mmHg/min to 17.5 ± 1.0 mmHg/min when the ventilation rate increased from 12 breaths/min to 30 breaths/min during CPR. To solve this problem, a real-time audiovisual feedback system that maintains the ventilation rate at a certain level has been suggested for use with a self-inflating bag resuscitator. However, although a self-inflating bag resuscitator with an additional device could control the ventilation rate, it might not control Vt. The volume-marked bag-valve procedure,

Table 2. Comparison among the ventilation equipment during chest compression in model 2 (CPR Manikin with compression)

Type of ventilation	Tidal volume		Peak airway pressure		Adequate ventilation	
	Adequacy (%)	p-value	Adequacy (%)	p-value	Adequacy (%)	p-value
Resuscitator (n = 100)	65	< 0.001	20	< 0.001	17	< 0.001
Ventilator						
P _{limit} 40 cmH ₂ O (n = 100)	42		94		37	
P _{limit} 50 cmH ₂ O (n = 100)	100		79		79	
P _{limit} 60 cmH ₂ O (n = 100)	100		85		85	

Resuscitator; self-inflating bag resuscitator, Ventilator; mechanical ventilator.

Tidal volume adequacy; Vt 400-600 mL, Peak airway pressure adequacy; P_{peak} ≤ 50cmH₂O.

Adequate Ventilation; Vt 400-600 mL and P_{peak} ≤ 50 cmH₂O.

p-value was analyzed by Chi-square or Fischer's exact test.

Table 3. Comparison of median value (IQR) among the ventilation equipment during chest compression in model 2 (CPR Manikin with compression)

Type of ventilation	Tidal volume (mL)	Peak airway pressure (cmH ₂ O)
Resuscitator (n = 100)	591.50 (563.50 - 607.00)	53.20 (50.73 - 58.75)
Ventilator		
P _{limit} 40 cmH ₂ O (n = 100)	391.00 (368.00 - 425.50)	42.00 (40.90 - 46.08)
P _{limit} 50 cmH ₂ O (n = 100)	500.50 (486.25 - 526.00)	47.00 (45.20 - 49.85)
P _{limit} 60 cmH ₂ O (n = 100)	529.50 (510.25 - 550.75)	46.30 (42.90 - 49.20)

Resuscitator; self-inflating bag resuscitator, Ventilator; mechanical ventilator

which we used in this study, could solve that problem, but its effectiveness has not yet been proved, and that is beyond the scope of this study. In fact, it is not easy to simultaneously obtain a certain level of Vt and P_{peak} with a self-inflating bag resuscitator.

For this reason, we determined whether a mechanical ventilator might be used during CPR to maintain ventilation rate, Vt, and stable intrathoracic pressure. We found that when volume-controlled mandatory ventilation was set at Vt 600 mL, Ti 1.2 sec, constant flow type, ventilation rate 10 breaths/min, PEEP 3 cmH₂O, maximum pressure triggering, and P_{limit} 60 cmH₂O, Vt and P_{peak} retained relatively high adequacy, as compared with the other subgroups of the mechanical ventilator and the self-inflating bag resuscitator. According to Maertens et al.,[8] the ventilation rate was higher than the setting when a transport ventilator was used because the chest compression caused assisted ventilation from the flow triggering. Therefore, we set the triggering limit to its maximum to prevent assisted ventilation.

In a real situation, very high P_{peak} was observed as a result of hyperventilation, suggesting a higher risk of barotrauma. In this context, it is necessary to set an adequate P_{limit} to

prevent barotrauma when proper Vt is guaranteed. In Model 2, the self-inflating bag resuscitator P_{limit} median value was 53.2 cmH₂O (IQR 50.73–58.75), and the mechanical ventilator was 46.3 cmH₂O (IQR 42.90–49.20) with a P_{limit} of 60 cmH₂O (Table 3). We suggest that a P_{limit} of 60 cmH₂O is adequate to prevent barotrauma.

The manikin we used showed lower compliance and higher resistance than a normal human being, which might be a limitation to this study. Compliance was lower because the manikin's artificial lung was stiff, and resistance was higher because the length of the circuit was longer than a human airway. In a human airway, inspiration and expiration occur through the same lumen, whereas we used separated lumens in this study. An adequate mechanical ventilator mode for human CPR needs to be identified in further studies. However, this study showed that the adequacy of Vt and P_{peak} using a mechanical ventilator was higher than that using a self-inflating bag resuscitator in CPR. Moreover, it is difficult to maintain Vt and P_{peak} during CPR when using a self-inflating bag resuscitator because excessive Vt or insufficient Vt occur often.[2,9] We suggest that a mechanical ventilator set to the proper mode can provide steadier and

more stable ventilation than a self-inflating bag resuscitator.

In our manikin model, the mechanical ventilator was superior to the self-inflating bag resuscitator for maintenance of adequate ventilation during chest compression. Using a mechanical ventilator that can maintain adequate Vt and ventilation rate can prevent excessive ventilation. A mechanical ventilator that can maintain $P_{\text{peak}} < 50 \text{ cmH}_2\text{O}$ can also prevent barotrauma.

Although we found differences according to the P_{limit} , we conclude that a mechanical ventilator might be used to achieve high quality CPR in patients with endotracheal intubation.

ORCID

Hong Joon Ahn <http://orcid.org/0000-0001-6809-6246>
 Kun Dong Kim <http://orcid.org/0000-0002-7635-0942>
 Won Joon Jeong <http://orcid.org/0000-0002-6320-230X>
 Jun Wan Lee <http://orcid.org/0000-0003-4630-597X>
 In Sool Yoo <http://orcid.org/0000-0003-3685-4561>
 Seung Ryu <http://orcid.org/0000-0003-0748-2543>

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