Original Article

Comparison between Pediatric-Sized and Adult-Sized Bag-Valve-Mask Ventilation for Achieving Appropriate Tidal Volume in Simulated Adult Out-of-Hospital Cardiac Arrest in a Moving Ambulance

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Background: Previous studies proposed that ventilation with pediatric-sized bag-valve-mask (BVM) ventilation resulted in more appropriate tidal volume (Vt) in adult patients than adult-sized BVM ventilation. However, those studies were conducted in stationary, non-moving environment. The authors hypothesized that the result of BVM ventilation in this treatment setting may be different when the investigation was conducted in a moving ambulance.

Objective: To compare pediatric-sized and adult-sized BVM ventilation for achieving appropriate Vt in simulated adult out-of-hospital cardiac arrest (OHCA) in a moving ambulance.

Materials and Methods: The present study was a randomized crossover trial. Registered nurses (RNs) and basic emergency medical technicians (EMT-Bs) were recruited to perform resuscitation ventilation on a medical training manikin. All participants performed both the pediatric-sized at 500 cc, and the adult-sized at 1,600 cc, BVM ventilation during 30 to 2 chest compressions to ventilation ratio during simulated OHCA in a moving ambulance. Adult-sized mask was used for both scenarios. The manikin was ventilated for 10 minutes during each scenario. The percentage of appropriate Vt was compared between scenarios. The percentages of low Vt at less than 400 cc and high Vt at more than 600 cc between groups were also evaluated.

Results: Fifty-two volunteers with 57.7% RNs and 42.3% EMT-Bs were included. Of those 52 volunteers, 44 had less than five years of pre-hospital ventilation experience. The mean Vt was 239.0 cc and 444.5 cc in the pediatric-sized and the adult-sized BVM groups, respectively ($p<0.001$). Low Vt was observed in 100% of pediatric-sized BVM ventilation. In the adult-sized ventilation group, 52.1±25.6% had appropriate Vt, 11.4±18.6% had high Vt, and 36.5±29.1% had low Vt ($p<0.001$).

Conclusion: A comparison between pediatric-sized and adult-sized BVM ventilation in simulated adult OHCA in a moving ambulance demonstrated the superiority of the adult-sized BVM over the pediatric-sized BVM for achieving appropriate Vt in adult OHCA.

Keywords: Bag-valve-mask ventilation; Tidal volume; Out-of-hospital cardiac arrest; Ambulance

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Out-of-hospital cardiac arrest (OHCA) is an important public health issue worldwide[1-4]. Although technological improvements and innovations have been developed to improve the outcomes, the survival rate in OHCA is still very low[3,4]. High-quality cardiopulmonary resuscitation (CPR) is an intervention that improves patient survival[5].

In addition to high-quality chest compression, adequate ventilation is a critical part of high-quality CPR[5]. Adequate ventilation involves not only rate control, but also appropriate regulation of tidal volume (Vt). The Basic Life Support (BLS) guideline recommends that the Vt in OHCA resuscitation should range within the range of 400 to 600 cc[6]. However, it is difficult to restrict the Vt during real-life emergencies, especially during pre-hospital care. Pre-hospital providers usually provide higher Vt than the guideline-recommended volume, and this is referred

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to as hyperventilation[7]. In OHCA, hyperventilation decreases venous return and coronary perfusion pressure, which decreases the chance of return of spontaneous circulation (ROSC)[8]. Hyperventilation also increases the risk of aspiration[9].

Vt control in real-life OHCA resuscitation is challenging since current technology is unable to measure the Vt during bag-valve-mask (BVM) ventilation. Therefore, simulation study is a useful method for investigating techniques that can be employed to control Vt[10]. Recent simulation studies reported that pediatric-sized BVM ventilation provided more appropriate mean Vt or more than adult-sized BVM ventilation in adult ventilation scenarios[7,11]. However, those studies were conducted in a dynamic, but stationary, non-moving environment, and not in an OHCA scenario[7,11].

The authors' review of the literatures revealed no data specific to BVM ventilation of patients in cardiac arrest in a moving ambulance. The authors hypothesized that the results of BVM ventilation in a moving ambulance may be different from the studies that assessed BVM in other settings. Accordingly, the aim of the present study was to compare pediatric-sized and adult-sized BVM ventilation for achieving appropriate Vt in simulated OHCA in a moving ambulance.

Materials and Methods

The present study was a randomized crossover trial conducted at the Department of Emergency Medicine, Faculty of Medicine Siriraj Hospital, Mahidol University, Bangkok, Thailand between the May 2018 and July 2018. Siriraj Hospital is the Thailand's largest national tertiary referral center. Registered nurses (RNs) and basic emergency medical technicians (EMT-Bs) that provide out-of-hospital emergency care in Thailand, were recruited to perform resuscitation ventilation on a medical training manikin in a moving ambulance during simulated OHCA. Volunteer candidates who were not certified BLS providers or having history of motion sickness were excluded. Appropriate Vt and number of ventilations were both compared between scenarios. The percentages of low Vt and high Vt between groups were also evaluated. The protocol for the present study was reviewed and approved by the Siriraj Institutional Review Board (SIRB) (COA no. 195/2018) and written informed consents to participate were obtained from all RN and EMT-B volunteers.

The present study was conducted in a large parking lot that had smooth areas, rough areas, and many turns (Figure 1). Volunteers were randomly divided into one of two groups, as group A or group B, by random allocation sequence. The sequence was generated by a randomization block of four and was concealed in a non-translucent envelope. The scenario in the present study involved an unconscious 50-year-old male with no pulse in a moving ambulance. Adult-sized facemasks were used in both pediatric and adult scenarios. All participants performed both pediatric-sized, at a volume of 500 cc, and adult-sized, at a volume of 1,600 cc, BVM ventilation. The participants in group A administered pediatric-sized BVM ventilation volume in the first scenario, then rested 30 minutes, and then administered adult-sized BVM ventilation. Group B participants performed the same steps, except that they administered the adult-sized BVM volume first and the pediatric-sized BVM second. Mechanical chest compression (Autopulse®; Zoll Medical Corporation, Chelmsford, MA, USA) was used in both scenarios to control the rate and duration of chest compression. BVM was administered at a compression to ventilation ratio of 30 to 2 for 10 minutes during each scenario. The ambulance speed was limited to 20 to 30 km per hour or 12 to 18 mph in all scenarios due to safety concerns.

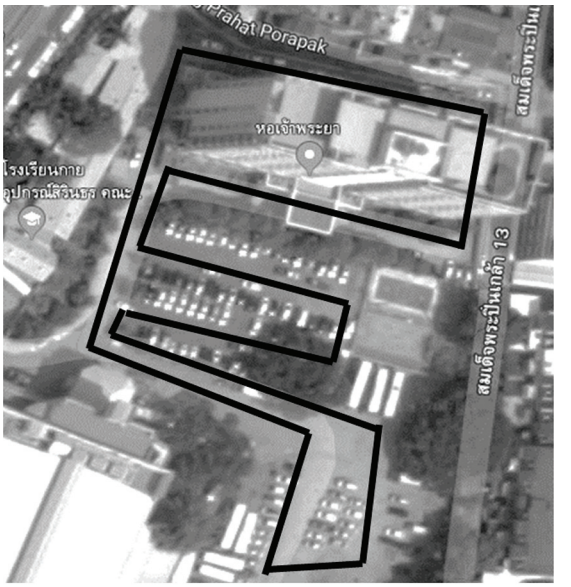

Figure 1. Ambulance study route at a parking lot in Siriraj Hospital, Bangkok, Thailand.

The Vt and the number of ventilations were measured by a standard medical training manikin (SimPad PLUS with SkillReporter; Laerdal Medical, Stavanger, Norway). Appropriate Vt was defined as

Table 1. Demographic, occupational, and training characteristics (n=52)

Characteristics	Group A (n=26); n (%)	Group B (n=26); n (%)	Total (n=52); n (%)
Age (years); mean±SD	28.1±6.7	32.2±9.9	30.2±8.6
Sex: female	19 (73.1)	19 (73.1)	38 (73.1)
Occupation			
Emergency nurse practitioner	2 (7.7)	3 (11.5)	5 (9.6)
Registered nurse	12 (46.2)	13 (50.0)	25 (48.1)
Basic emergency medical technician	12 (46.2)	10 (38.5)	22 (42.3)
Experience in emergency medicine (years); median (range)	4 (0, 22)	5 (1, 34)	4.5 (0, 34)
Experience in prehospital care (years); median (range)	0 (0, 10)	0 (0, 24)	0 (0, 24)
Experience in BVM ventilation on a moving ambulance	6 (23.1)	7 (26.9)	13 (25.0)

SD=standard deviation; BVM=bag-valve-mask

Vt within the range of 400 to 600 cc, as recommended by BLS guideline[5,6]. A Vt greater than 600 cc was defined as high Vt. Conversely, a Vt less than 400 cc was defined as low Vt. The SkillReporter feature reported the percentage of appropriate Vt relative to all ventilations in that scenario as the primary outcome. The SkillReporter feature also reported the percentage of high Vt and low Vt from each scenario. The lowest of Vt that the manikin can detect is 200 cc.

Sample size calculation and statistical analysis

Since there were no previous data specific to BVM ventilation in simulated OHCA in a moving ambulance, the authors assumed that 80% of adult-sized BVM ventilation and 30% of pediatric-sized BVM ventilation would achieve the appropriate Vt. Using a type I error of 5% and a power of 80%, a minimum sample size of 52 participants was calculated. The primary and secondary outcomes were analyzed using chi-square test and Student's t-test. PASW Statistics, version 18.0 (SPSS Inc., Chicago, IL, USA) was used for all data analyses. Categorical data were shown as frequency and percentage, and continuous data are shown as mean ± standard deviation for normally distributed data, or median and range for non-normally distributed data. Carryover effect, period effect, and treatment effect based on an AB-BA crossover design were evaluated using StatXact® 11.1 (Cytel, Cambridge, MA, USA). A p-value of less than 0.05 was defined as statistically significant.

Results

Fifty-two volunteers were recruited. Of those, 57.7% were RNs 42.3% were EMT-Bs. Among the 52 volunteers, 44 had less than five years of pre-hospital ventilation experience. No one was excluded

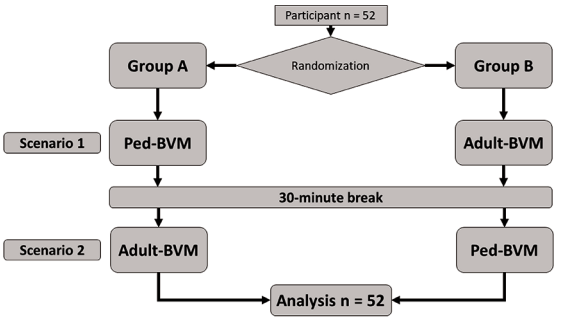

Figure 2. Flow diagram describing the study protocol.
OHCA, out-of-hospital cardiac arrest; BVM, bag-valve mask

or withdrew from the study, as shown in Figure 2. Demographic, occupational, and training experience data of study participants are shown in Table 1. The average age of participants was 30.2±8.6 years, and 73.1% were female. The 52 enrolled volunteers had a mean 4.5 years of work experience in emergency medicine. One fourth of the participants had ventilated patients by BVM in a moving ambulance prior to participating in the present study. The demographic, occupational, and training characteristics of volunteers were not significantly different between groups A and B, as shown in Table 1. Table 2 demonstrated the estimation of interaction bias in two-period crossover study. The results were not influenced by carryover effect or period effect ($p>0.05$).

From 52 adult-sized BVM ventilation scenarios, the average percentages of appropriate Vt, low Vt, and high Vt were 52.1±25.6%, 36.5±29.1%, and 11.4±18.6%, respectively. A statistically significant difference was observed between the adult-sized BVM and the pediatric-sized BVM groups for all three parameters because all three of those parameters in the pediatric-sized BVM group were in the low Vt

Table 2. Analysis of AB-BA crossover design

Outcome	Group	Period 1; mean±SD	Period 2; mean±SD	p-value		
				Carryover effect	Period effect	Treatment effect
Vt (cc)	1	234.3±55.4	444.5±83.3	0.755	0.704	<0.001
	2	445.6±94.4	244.8±30.2			
Number of ventilation in 10 minutes (times)	1	30.4±12.9	44.6±8.8	0.449	0.730	<0.001
	2	43.1±9.8	27.9±11.9			
Appropriate Vt (%) (400 to 600 cc)	1	0.0±0.0	54.7±25.1	0.477	0.477	<0.001
	2	49.6±26.4	0.0±0.0			
High Vt (%) (>600 cc)	1	0.0±0.0	10.0±15.9	0.617	0.617	<0.001
	2	12.7±21.2	0.0±0.0			
Low Vt (%) (<400 cc)	1	100±0.0	35.3±28.8	0.764	0.764	<0.001
	2	37.8±29.9	100±0.0			

Vt=tidal volume; SD=standard deviation

Group A: ventilated pediatric sized bag-valve mask in period 1 then ventilated adult sized bag-valve mask in period 2

Group B: ventilated adult sized bag-valve mask in period 1 then ventilated pediatric sized bag-valve mask in period 2

Table 3. Appropriate Vt, high Vt, and low Vt compared between the pediatric-sized and adult-sized BVM ventilation groups

Outcome	Pediatric (%); mean±SD	Adult (%); mean±SD	p-value
Appropriate Vt (400 to 600 cc)	0.0±0.0	52.1±25.6	<0.001
High Vt (>600 cc)	0.0±0.0	11.4±18.6	<0.001
Low Vt (<400 cc)	100±0.0	36.5±29.1	<0.001

Vt=tidal volume; SD=standard deviation

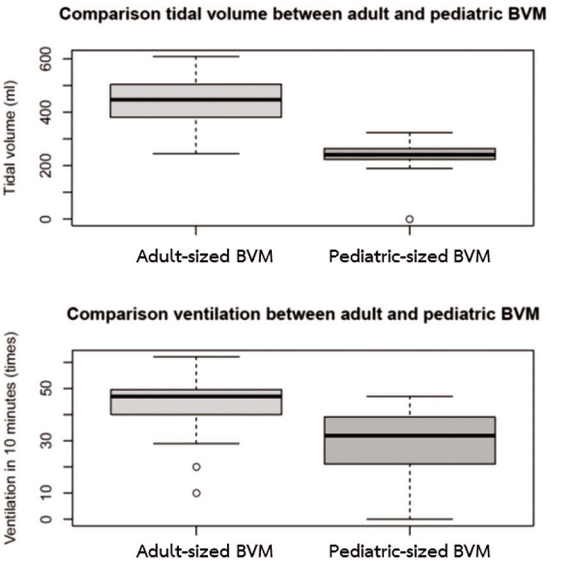

Figure 3. Distribution of tidal volume and ventilation compared between the pediatric-sized and adult-sized BVM ventilation groups.

zone (all p<0.001) (Table 3).

Distribution of Vt and number of ventilations between the pediatric-sized BVM group and the adult-sized BVM group are demonstrated in Figure 3. The average Vt in the pediatric-sized BVM group was 239.0±44.5 cc compared to 444.5±88.1 cc in the adult-sized BVM group, (p<0.001). The average number of ventilations was significantly lower in the pediatric-sized BVM ventilation group than in the adult-sized BVM ventilation group at 29.2±12.4 versus 43.8±9.3, respectively (p<0.001).

Discussion

The present study was a randomized crossover study comparing percentage of appropriate Vt between pediatric-sized and adult-sized BVM ventilation in an adult OHCA scenario in a moving ambulance. The authors found that the adult-sized BVM ventilation yielded a significantly greater percentage of appropriate Vt than the pediatric-sized BVM ventilation. The present study's results also revealed ventilation variability, defined as the difference in Vt during each ventilation. This observed variability may be due to the variations in the force used by providers to squeeze the BVM, or to air leakage during some ventilations[10]. These described inconsistencies may be the result of coordination- and movement-related issues caused by attempting to provide treatment within a fast-moving ambulance.

Although the average Vt in adult-sized BVM ventilation scenario was within BLS recommendation range of 400 to 600 cc[12], and similar to lung protective

strategy in post-cardiac arrest resuscitation[13], the measurement did not take into account intravariability of ventilation[10]. This was the main reason the authors decided to measure percentage of appropriate Vt as the primary outcome in the present study. The authors found that the average percentage of appropriate Vt in adult-sized BVM ventilation to be only 52%. The present study simulation also revealed 11% of adult-sized BVM ventilation to be high Vt. The condition could cause aspiration and decreased venous return, which together or individually, could adversely affect patient outcomes[14]. Previous studies suggested that a stressful situation like OHCA could cause hyperventilation[15,16]. There was a simulation study that evaluated adult-sized BVM ventilation from various types of providers in France[10]. The results of their study are quite similar to the present study. That study found a mean percentage of appropriate Vt of only 40%. Furthermore, their results showed evidence of both high Vt and low Vt when using adult-sized BVM ventilation[10]. The observed ventilation variability in the present study represents an opportunity to improve ventilation in pre-hospital resuscitation. There are potential interventions that may improve ventilation in OHCA resuscitation, including training the effective techniques[17-19] and the use of monitoring tools that provide direct and immediate feedback.

The present study controlled the number of ventilations by using mechanical CPR with a 30 to 2 compression to ventilation ratio. However, the pediatric-sized BVM ventilation provided a significantly lower number of ventilations than the adult-sized BVM ventilation. This was due to some ventilations from pediatric-sized BVM were below the minimum Vt that the manikin could detect. Therefore, the average Vt in pediatric-sized BVM ventilation might be lower than the results shown in the present study.

The present study results suggest the use of adult-sized BVM ventilation to achieve appropriate Vt in OHCA situations in a moving ambulance. This finding is in contrast to the previous studies conducted in ventilation only scenarios[7,11]. Siegler et al compared pediatric-sized BVM ventilation with adult-sized BVM ventilation in a stationary and controlled environment[7]. Kroll et al compared Vt among different handgrip techniques and both adult and pediatric sizes of BVM ventilation[11]. Both studies reported that pediatric-sized BVM ventilation provided more appropriate Vt than adult-sized BVM ventilation, regardless of handgrip technique[7,11]. There are reasons that may explain the difference of the present study results from those two previous studies. First, the authors conducted the OHCA scenario in a moving ambulance. This setting would likely lead to more air leakage and lower percentage Vt than in a stationary treatment environment. Second, the majority of the present study participants were Asian females, which is the demographic representing most of the advanced pre-hospital care in Thailand. The two previous studies included 76% to 90% male volunteers[7,11]. Females may have weaker grip strength and may lead to variability in ability to squeeze the BVM, and less strength to seal the face mask while the ambulance is moving. The present study participants also had less years of experience than the participants in the two previous studies. Moreover, the BVMs used in the present study were commonly used for resuscitation in Thailand, they were different brand from the BVMs used in the previous studies conducted in the U.S.[7,11]. These factors may have affected different outcomes between those two studies and the present study. However, the simulated BVM ventilation from France used both brands of BVMs from the present study and the previous American studies[10]. The French study reported non-significantly different Vt among those brands(10). Lastly, the present study used a different type of manikin than in the two previous studies from the U.S.[7,11]. Differences in manikin resistance and airway dead space may influence different Vt values[20].

Limitation

The present study has some mentionable limitations. First, it was a simulation study, which means that some or several factors that could or would be occurring during a real-life ambulance journey to the hospital during OHCA were not occurring during the ambulance ride in the present study. For example, the stress that develops among treatment staff in a real-life emergency could not be replicated in the scenario. A second example was the 30 km per hour speed limitation of the ambulance. Due to concerns for the safety of other drivers and pedestrians, the speed limit was much lower than the speed an ambulance would normally travel in an emergency. Second, the use of a medical training manikin makes it easier to ventilate than the real patients in an OHCA situation. There are several patient factors that the manikin could not simulate, including obesity, unshaven or bearded, edentulous, snoring, and elderly[21]. Third, this was a single-center

study. Fourth, the present study used a mechanical chest compression device to control the number and intensity of chest compressions. This device was likely not available in all settings. Fifth, there was no control of face mask sealing and hand grip technique. However, most of the volunteers used a standard E-C technique, and one-hand technique to squeeze the BVM. Sixth and last, these limitations taken together limit the generalizability of the present study findings to all settings that involve BVM ventilation in adult OHCA in a moving ambulance. The strengths of the present study include its randomized design, the fact that the authors included only certified BLS RNs and EMT-Bs, used current technology to control chest compressions and to collect Vt percentage and number of ventilations, and made every effort to replicate an environment, situation, and setting that are extremely difficult to study in real-life OHCA emergency situations.

Conclusion

A comparison between pediatric-sized and adult-sized BVM ventilation volumes in simulated adult OHCA in a moving ambulance demonstrated the superiority of adult-sized BVM volume over pediatric-sized BVM volume for achieving appropriate Vt in adult OHCA according to BLS guideline recommendations.

What is already known on this topic?

Appropriate ventilation is one of the essential factors in the successful resuscitation of OHCA patients. Previous studies proposed that ventilation with pediatric-sized BVM ventilation resulted in more appropriate Vt in adult patients than adult-sized BVM ventilation. However, those studies were conducted in stationary, non-moving environment. Sometime, EMS providers resuscitate OHCA patients in the moving ambulance. There is no study that investigated the choice of BVM ventilation among OHCA patients in a moving ambulance.

What this study adds?

This randomized cross-over trial was conducted in simulated OHCA scenario in a moving ambulance. The study demonstrated the adult-sized BVM ventilation achieved appropriate Vt and number of ventilations according to BLS guideline recommendations significantly better than the pediatric-sized BVM ventilation. Furthermore, this study also identified ventilation variability, which was an area of improvement in OHCA resuscitation ventilation. The result supported using adult-sized BVM in adult OHCA resuscitation and might encourage effective ventilation training in this unique scenario in the future.

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Conflicts of interest

All authors declare no personal or professional conflicts of interest, and no financial support from the companies that produce or distribute the drugs, devices, or materials described in the present report.

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