Bag-Valve-Mask versus Laryngeal Mask Airway Ventilation in Cardiopulmonary Resuscitation with Continuous Compressions: A Simulation Study

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Abbreviations:
AHA: American Heart Association
BVM: bag-valve-mask
CPR: cardiopulmonary resuscitation
EMS: Emergency Medical Services
ERC: European Resuscitation Council
ETI: endotracheal intubation
ILCOR: International Liaison Committee on Resuscitation
LMA: laryngeal mask airway
OHCA: out-of-hospital cardiac arrest

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Abstract

Introduction: The 2017 International Liaison Committee on Resuscitation (ILCOR) guideline recommends that Emergency Medical Service (EMS) providers can perform cardiopulmonary resuscitation (CPR) with synchronous or asynchronous ventilation until an advanced airway has been placed. In the current literature, limited data on CPR performed with continuous compressions and asynchronous ventilation with bag-valve-mask (BVM) are available.

Study Objective: In this study, researchers aimed to compare the effectiveness of asynchronous BVM and laryngeal mask airway (LMA) ventilation during CPR with continuous chest compressions.

Methods: Emergency medicine residents and interns were included in the study. The participants were randomly assigned to resuscitation teams with two rescuers. The cross-over simulation study was conducted on two CPR scenarios: asynchronous ventilation via BVM during a continuous chest compression and asynchronous ventilation via LMA during a continuous chest compression in cardiac arrest patient with asystole. The primary endpoints were the ventilation-related measurements.

Results: A total of 92 volunteers were included in the study and 46 CPRs were performed in each group. The mean rate of ventilations of the LMA group was significantly higher than that of the BVM group (13.7 [11.7-15.7] versus 8.9 [7.5-10.3] breaths/minute; P <.001). The mean volume of ventilations of the LMA group was significantly higher than that of the BVM group (358.4 [342.3-374.4] ml versus 321.5 [303.9-339.0] ml; P = .002). The mean minute ventilation volume of the LMA group was significantly higher than that of the BVM group (4.88 [4.15-5.61] versus 2.99 [2.41-3.57] L/minute; P <.001). Ventilations exceeding the maximum volume limit occurred in two (4.3%) CPRs in the BVM group and in 11 (23.9%) CPRs in the LMA group (P = .008).

Conclusion: The results of this study show that asynchronous BVM ventilation with continuous chest compressions is a reliable and effective strategy during CPR under simulation conditions. The clinical impact of these findings in actual cardiac arrest patients should be evaluated with further studies at real-life scenes.

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Introduction

The gold standard airway management procedure is endotracheal intubation (ETI) during cardiopulmonary resuscitation (CPR).[1,2] However, other basic and advanced airway tools, such as bag-valve-mask (BVM), laryngeal mask airway (LMA), and laryngeal tube, have been widely used by rescuers because ETI requires advanced training and skills.[3–6]

The best airway strategy to be used during CPR and the most appropriate time to perform ETI are still unclear.[6] Most of the recent studies on out-of-hospital cardiac arrest (OHCA) patients have revealed that the survival rate is higher in patients resuscitated without an advanced airway than those resuscitated with an advanced airway.[3,7–9] On the other hand, Jabre, et al failed to demonstrate non-inferiority or inferiority for survival and neurological outcome after OHCA in their study comparing BVM and ETI.[10] Recently published 2019

International Liaison Committee on Resuscitation (ILCOR) guideline suggests using BVM or an advanced airway strategy during adult CPR in any setting.[6]

When BVM is selected as the first-line ventilation tool in CPR, the second important issue is whether the ventilation should be synchronized or unsynchronized with compressions. In the 2015 CPR guidelines, synchronous compression and ventilation cycles with a ratio of 30:2 are recommended prior to obtaining an advanced airway.[1,2] The 2017 ILCOR guideline recommends that Emergency Medical Service (EMS) providers can perform CPR with synchronous or asynchronous ventilation until an advanced airway has been placed.[5] In the 2019 ILCOR guideline, there is no additional recommendation on synchronization of ventilation and compression.[6]

Hence, a dilemma is encountered at this point. On the one hand, minimally interrupted compressions during asynchronous CPR may increase the chance of survival. On the other hand, patients may not adequately be ventilated with BVM during asynchronous CPR due to overlapping. Liu, et al reported that approximately 20% of the study participants preferred asynchronous continuous compressions before ETI during in-hospital CPR.[11] Nichol, et al reported that survival between OHCA patients who received continuous compressions and those who received interrupted compressions by EMS providers had no difference.[12]

In the current literature, limited data on CPR performed with continuous compressions and asynchronous ventilation with BVM are available. A recent animal study conducted by Manrique, et al revealed that asynchronous ventilation with BVM and metronome-guided compressions had higher return of spontaneous circulation rates and better ventilation parameters than synchronous ventilation.[13] To the best of the authors' knowledge, no study has compared asynchronous ventilation with BVM and advanced airways in the literature. In this study, researchers aimed to compare asynchronous ventilations via BVM and LMA during CPR with continuous chest compressions in terms of ventilation-related measurements, including ventilation rate, tidal volume, and minute ventilation.

Materials and Methods

This prospective, randomized, single-blind, cross-over simulation study was conducted in the Simulation Center of Necmettin Erbakan University (Konya, Turkey). The study was approved by the Ethical Committee of Necmettin Erbakan University Meram Faculty of Medicine (Decision Number: 2018/1359).

Study Population

The study was conducted from June 1, 2019 through October 1, 2019. Interns and residents in the emergency medicine internship and residency program were included in the study on a voluntary basis. All participants had successfully completed theoretical and practical trainings on CPR at least three times during their medical education. The participants were randomly assigned to resuscitation teams, with two rescuers per resuscitation team. Gender, height, weight, and age parameters were not taken into consideration when the resuscitation teams were formed. Informed consent was obtained from all participants.

Devices and Simulation Scenarios

All CPRs were performed using Laerdal Resusci Anne Advanced Skill Trainer with SimPad PLUS (Laerdal Medical; New York USA). The Resusci Anne simulator was placed on the floor and simulated an arrest patient with asystole. In accordance with manufacturer's recommendation, a BVM with a number five face mask and a number five cuffed reusable silicone LMA (Canack Technology; Vancouver, British Columbia, Canada) inflated with 30ml air were used for ventilation. The same bag was used for all CPR performances.

The study was conducted on two CPR scenarios: asynchronous ventilation via BVM during a continuous chest compression (Scenario A) and asynchronous ventilation via LMA during a continuous chest compression (Scenario B). The detailed information on the CPR scenarios is shown in Figure 1. The teams were informed in which order they would perform the CPR scenarios through the closed-envelope method just before the first scenario.

The following measures were considered for the standardization of the CPR performances. The simulator was introduced to the rescuers by the researchers. The rescuers were given a 15-minute exercise time to correctly perform compression and ventilation on the simulator. During this exercise, the rescuers were allowed to monitor their performances via SimPad PLUS QCPR. The simulator simulated an arrest patient with asystole throughout the CPR scenarios. Return of spontaneous circulation was not achieved at the end of CPR. There was no additional stress factor in the CPR scenarios. SimPad PLUS QCPR feedback was not shown to the rescuers during the CPR scenarios. In addition, they were not given feedback about their compression and ventilation performances during the CPR scenarios. One rescuer was positioned next to the simulator and one rescuer was positioned over the head of the simulator to eliminate the difference from the position when using the BVM and LMA. To improve compliance with the compression rate as recommended by the 2015 American Heart Association/European Resuscitation Council (AHA [Dallas, Texas USA]/ERC [Niel, Belgium]) Resuscitation Guidelines (100-120/minute), a metronome with 110 beats/minute was used throughout the CPR scenarios. The target ventilation rate of 10 breaths/minute was told by the researchers before the first scenario of the team, but visual or audible warning about ventilation was not used during the CPR scenarios. In both CPR scenarios, two-minute intervals for CPR and 10-second intervals for rhythm and pulse check were followed by the researchers using a timer. The researchers prompted the rescuers to start CPR, stop CPR, and change over at the end of intervals. At least two hours of resting time was given during the transition of resuscitation teams between scenarios to minimize the effect of rescuer fatigue on the quality of CPR. To minimize the effect of LMA insertion procedure on ventilation, LMA was inserted by the researchers before the CPR scenarios were performed.

Data Collection and Study Protocol

The age, weight, height, and gender of the rescuers were recorded (Table 1). The evaluation of CPR performances for both scenarios was performed by using SimPad PLUS QCPR log files. The simulator settings were in compliance with the 2015 AHA/ERC Resuscitation Guidelines, including a compression depth of 5.0-6.0cm, compression rate of 100-120/minute, ventilation volume of 400-700ml, and ventilation rate of 10 breaths/minute.[1,2]

The primary end points of the study were the ventilation-related measurements. Mean rate of all ventilations (breath/minute), mean volume of ventilations (ml), minute ventilation (L/minute), rate of ventilations with adequate volume (%), rate of ventilations with insufficient volume (%), and rate of ventilations exceeding the maximum volume limit (%) were recorded as the ventilation-related measurements.

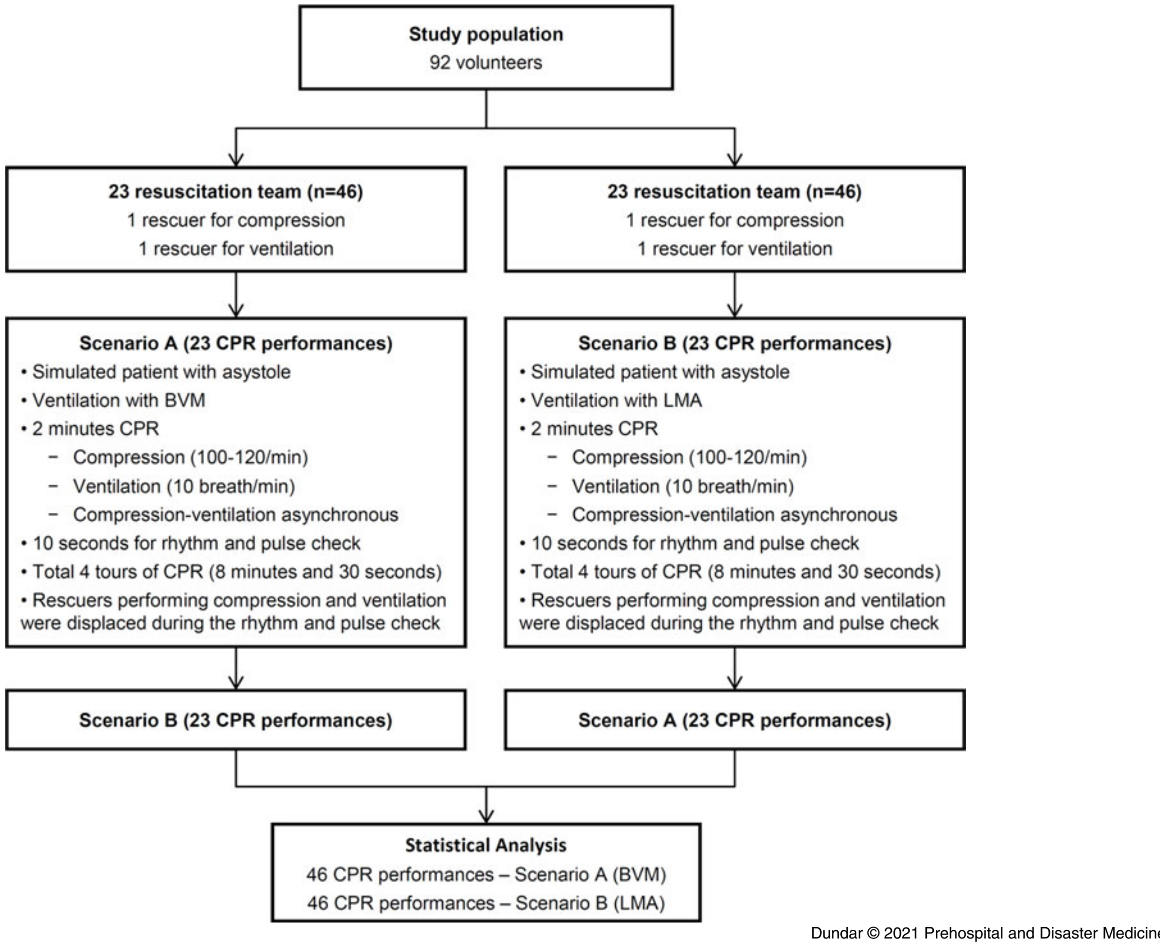

Figure 1. The Study Flow Chart.
Abbreviations: BVM, bag-valve-mask; CPR, cardiopulmonary resuscitation; LMA, laryngeal mask airway.

The secondary endpoints of the study were the compression-related measurements. Mean rate of all compressions (compression/minute), mean depth of compressions (cm), rate of compressions fully released (%), rate of deep-enough compressions (%), and rate of compressions with adequate rate (%) were recorded as the compression-related measurements. The researchers prompted the rescuers to start and stop CPR so the expected no flow times were the same for all of the CPRs. The differences of primary and secondary endpoint parameters between the BVM and LMA groups were compared.

Statistical Analyses

The statistical analyses of the data were performed using SPSS version 20.0 (IBM Corp.; Armonk, New York USA). The normality analyses of the data were performed using histograms and the Kolmogorov–Smirnov test. The non-normally distributed quantitative variables were expressed as the median (25^{th}-75^{th} percentiles), the normally distributed quantitative variables were expressed as the mean (95% confidence interval), and the categorical variables were expressed as frequency (percentage). The distribution of the mean rates of fully released compressions was non-normal and the distributions of all other quantitative parameters were normal in the BVM and LMA groups. The differences between the BVM and LMA groups were compared using the Mann–Whitney U test for non-normally distributed quantitative variables and the Student's t-test for normally distributed quantitative variables. The differences of the categorical variables between BVM and LMA groups were evaluated using the chi-square test. P <.05 was considered statistically significant.

Results

A total of 92 rescuers were included in the study, and 46 CPR performances were completed in each CPR scenario. The mean age of the rescuers was 24 (23-24) years and 63% (n = 58) of them were female. Eight (8.7%) of the rescuers were underweight, 70 (76.1%) of them were of normal weight, and 14 (15.2%) of them were overweight.

Ventilation-Related Measurements

The mean rate of ventilations of the LMA group was significantly higher than that of the BVM group (13.7 [11.7-15.7] breaths/minute versus 8.9 [7.5-10.3] breaths/minute, respectively; P <.001). The mean volume of ventilations of the LMA group was significantly higher than that of the BVM group (358.4 [342.3-374.4] ml versus 321.5 [303.9-339.0] ml, respectively; P = .002). The mean minute ventilation volume of the LMA group was significantly higher than that of the BVM group (4.88 [4.15-5.61] L/minute versus 2.99 [2.41-3.57] L/minute, respectively; P <.001). The mean rate of ventilations with an adequate volume of the LMA group was significantly higher than that of the BVM group (35.3% [30.9%-39.6%] versus 26.5%

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Parameters	n = 92
Age, years[a]	24 (23–24)
Gender, n (%)	
Male	34 (37.0)
Female	58 (63.0)
Height, cm[b]	167.5 (165.8–169.2)
Weight, kg[b]	63.5 (61.1–65.9)
Body Mass Index, kg/m^2 [b]	22.6 (21.9–23.3)

Table 1. Demographic Characteristics of the Study Participants
[a] Presented as median (25%-75% percentiles).
[b] Presented as mean (95% confidence interval).

[20.9%-32.1%], respectively; P = .01). The mean rate of ventilations with an insufficient volume of the LMA group was significantly lower than that of the BVM group (62.8% [58.3%-67.3%] versus 73.3% [67.6%-79.0%], respectively; P = .004). Ventilations exceeding the maximum volume limit occurred in two (4.3%) CPRs in the BVM group and in 11 (23.9%) CPRs in the LMA group (P = .008; Figure 2).

Compression-Related Measurements
There was no statistically significant difference between the BVM and LMA groups in terms of all compression-related measurements. In both scenarios, the rescuers achieved the target average rate of 110 compressions/minute (109.9 [108.8-111.0]/minute in the BVM group versus 110.6 [108.9-112.3]/minute in the LMA group; P = .48). The mean depths of compressions were 5.37 (4.79-5.95) cm in the BVM group and 5.46 (4.84-6.08) cm in the LMA group (P = .17). The mean rates of compressions with adequate rate were approximately 80% in both scenario groups, and no statistically significant difference was found (85.4% [81.3%-89.5%] in the BVM group versus 79.1% [73.7%-84.5%] in the LMA group; P = .068). The mean rates of deep-enough compressions were 54.4% (46.0%-62.8%) in the BVM group and 64.0% (55.8%-72.2%) in the LMA group (P = .10). The mean rates of fully released compressions were 67% (54%-81%) in the BVM group and 77% (60%-91%) in the LMA group (P = .10).

Discussion
To the best of the authors' knowledge, this study is the first to compare asynchronous ventilation with BVM and LMA during continuous compressions. The researchers found that the ventilation rate in the BVM group was closer to the recommended rate and the achieved tidal volume in the BVM group was lower than that in the LMA group. In addition, the minute ventilation with LMA was 1.6-times that of BVM, and ventilations exceeding the maximum volume limit were six-times more common in the LMA group.

To avoid excessive ventilation is one of the high-quality CPR components. The current CPR guidelines recommend ventilating arrest victims at a rate of 10 breaths/minute and with an adequate volume of visible chest rise to avoid excessive ventilation.[1,2] Sulzgruber, et al revealed that the ventilation rate with BVM was slower than those with laryngeal tube and ETI.[7] Similarly, Kramer-Johansen, et al reported that the ventilation rates increased in ventilations with advanced airway tools.[14] In both studies, a 30:2 ratio was used in BVM ventilation, and asynchronous ventilation was performed in advanced airway management. By contrast, Sall, et al reported that the ventilation rates were the same and higher than the recommended rates with BVM and ETI. However, this study was designed only to evaluate ventilation techniques and no compression was used in their simulation scenarios.[15] The current study findings reveal that the ventilation rate of asynchronous ventilation with BVM was also slower than that with LMA, and the ventilation rate with BVM was closer to the recommended rate.

In this study, researchers used a metronome for compression guidance, but a warning system was not used for ventilation and rescuers were expected to reach the target ventilation rate with their own methods. Although the study participants achieved the target compression rates in both of the scenarios, they failed to achieve the target ventilation rate in the LMA group. Nikolla, et al showed that rescuers easily reach their target ventilation rates when they were informed to give one breath per 12 beats of a metronome used for compressions.[16] To improve the compliance with the rate of 10 breaths/minute, the use of audible warning systems for ventilation during on-going CPR seems to be reasonable. Another reason for the faster rates with LMA may be related with the difference between required techniques for BMV and LMA. The study participants needed to coordinate both hands for different motor activities during BVM ventilation (sealing mask with one hand and squeezing bag with other hand). The effort to coordinate two hands may slow down the respiration rate during BVM ventilation.

Although the CPR guideline recommendation on the target tidal volume is 400-700ml during CPR, the previous studies have showed that a tidal volume of 300-500ml is sufficient to achieve a visible chest rise and ensure gas exchange in the lungs.[4,17] On the other hand, the recommended tidal volumes vary between 4.0-8.0ml/kg (280-560ml for a 70kg adult) in lung-protective ventilation strategies.[18] A recent experimental study revealed that ultra-low-volume ventilation (tidal volume of 2.0-3.0ml/kg) strategy during CPR might provide neurological outcome improvement and lung protective benefits.[19] In this study, the mean tidal volume in the BVM group was 60ml less than that of the LMA group, but the mean tidal volumes were above 300ml and none of the measured tidal volumes were below 200ml in both groups. These findings support that asynchronous ventilation with BVM provides a sufficient tidal volume to achieve a visible chest rise during CPR.

Cierniak, et al compared asynchronous LMA ventilation with synchronous BVM ventilation, and they found that the minute ventilation was 3.47L/minute with BVM and 5.54L/minute with LMA (BVM:LMA ratio of 1:1.6).[20] In the current study, asynchronous ventilations were compared with BVM and LMA. The researchers found that the mean minute ventilation of the LMA group was 1.6-times that of the BVM group, similar to the results of Cierniak, et al. These finding suggests that asynchronous and synchronous ventilations with BVM have no significant difference during CPR in terms of minute ventilation. Thus, not giving up continuous compressions seems reasonable, with the concern of not being able to ventilate the lungs with BVM.

Limitations
This was a simulation study designed to compare basic and advanced airway tools in terms of ventilation rate, tidal volume, and minute ventilation and the results do not reflect actual CPR settings in the field. Actually, the most important ventilation parameters that affect gas exchange in lungs, blood gases, survival,

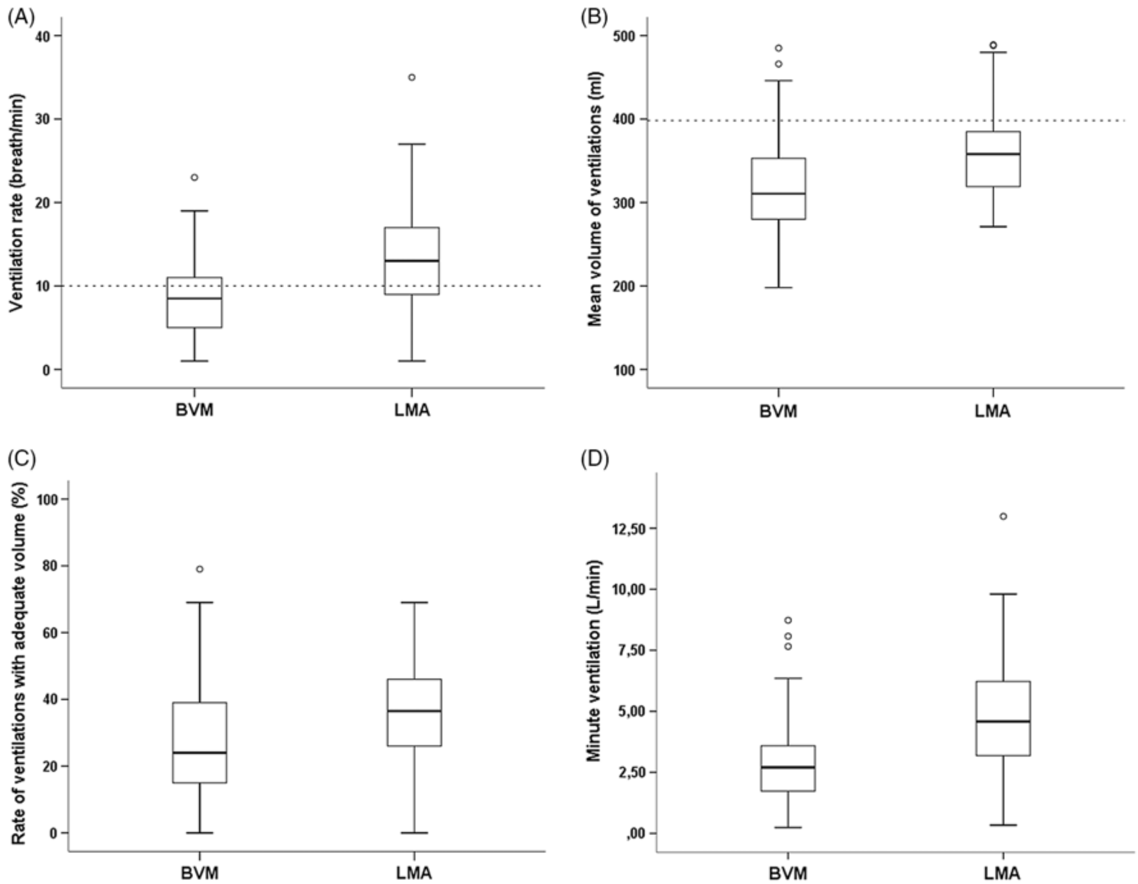

Figure 2. (A) Comparison of Ventilation Rates. The dotted line is the preset ventilation rate of the simulator (10 breaths/minute). **(B)** Comparison of the Mean Volumes of Ventilation. The dotted line is the preset minimum tidal volume of the simulator (400ml). **(C)** Comparison of the Rates of Ventilations with Adequate Volume. **(D)** Comparison of the Minute Volumes.

and neurological recovery during CPR are unclear, and the outcomes could not be evaluated. In this study, researchers tried to minimize the CPR skill differences of the participants, so they were asked to perform ventilations with a ready-to-ventilate LMA. Therefore, the disadvantages or advantages of LMA insertion during CPR could not be evaluated.

Conclusions

This study shows that asynchronous BVM ventilation with continuous chest compressions is a reliable and effective strategy during CPR under simulation conditions. The clinical impact of these findings in actual cardiac arrest patients should be evaluated with further studies at real-life scenes.

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