Original Article

Effect of metronome rates on the quality of bag-mask ventilation during metronome-guided 30:2 cardiopulmonary resuscitation: A randomized simulation study

Ji Ung Na, Sang Kuk Han, Pil Cho Choi, Dong Hyuk Shin

Department of Emergency Medicine, Kangbuk Samsung Hospital, Sungkyunkwan University School of Medicine, Seoul, Korea

Corresponding Author: *Dong Hyuk Shin, Email: shindhk@daum.net*

BACKGROUND: Metronome guidance is a feasible and effective feedback technique to improve the quality of cardiopulmonary resuscitation (CPR). The rate of the metronome should be set between 100 to 120 ticks/minute and the speed of ventilation may have crucial effect on the quality of ventilation. We compared three different metronome rates (100, 110, 120 ticks/minute) to investigate its effect on the quality of ventilation during metronome-guided 30:2 CPR.

METHODS: This is a prospective, randomized, crossover observational study using a RespiTrainer©. To simulate 30 chest compressions, one investigator counted from 1 to 30 in cadence with the metronome rate (1 count for every 1 tick), and the participant performed 2 consecutive ventilations immediately following the counting of 30. Thirty physicians performed 5 sets of 2 consecutive (total 10) bag-mask ventilations for each metronome rate. Participants were instructed to squeeze the bag over 2 ticks (1.0 to 1.2 seconds depending on the rate of metronome) and deflate the bag over 2 ticks. The sequence of three different metronome rates was randomized.

RESULTS: Mean tidal volume significantly decreased as the metronome rate was increased from 110 ticks/minute to 120 ticks/minute (343±84 mL vs. 294±90 mL, P=0.004). Peak airway pressure significantly increased as metronome rate increased from 100 ticks/minute to 110 ticks/minute (18.7 vs. 21.6 mmHg, P=0.006).

CONCLUSION: In metronome-guided 30:2 CPR, a higher metronome rate may adversely affect the quality of bag-mask ventilations. In cases of cardiac arrest where adequate ventilation support is necessary, 100 ticks/minute may be better than 110 or 120 ticks/minute to deliver adequate tidal volume during audio tone guided 30:2 CPR.

KEY WORDS: Non-invasive ventilation; Resuscitation; Cardiac arrest; Cardiopulmonary resuscitation

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INTRODUCTION

The quality of cardiopulmonary resuscitation (CPR) is a very important prognostic factor for cardiopulmonary arrest.[1–3] Various feedback devices have been studied and metronome guidance is one of the most effective and feasible feedback techniques that are known to improve the quality of CPR.[4–6] Furthermore, widespread use of smartphones has greatly enhanced the applicability of metronome if one can just install a free metronome application.

The current 2015 guideline recommends a chest compression rate between 100 to 120/minute and the rate of metronome should therefore be set between 100 to 120 ticks/minute. When rescuers perform metronome-guided CPR, the speed of ventilation should follow the rate of metronome. The rescuer can deliver inspiration over two ticks so that one inspiration takes 1.2 seconds, 1.09 seconds, or 1 second depending on whether the metronome rate is set at 100 ticks/minute, 110 ticks/minute, or 120 ticks/minute respectively. Thus, two ventilations can take up to 4.8 seconds at the metronome rate of 100 ticks/minute, 4.36 seconds at the metronome rate of 110 ticks/minute, and 4.0 seconds at the metronome rate of 120 ticks/minute. At any rate between 100 ticks/minute to 120 ticks/minute, rescuers can comply with the current guideline's recommendation to complete 2 ventilations within 5 seconds.[7]

The ability of metronome guidance in regulating ventilation rate has been confirmed by many previous studies.[5,6,8,9] However, its effect on the quality of ventilation other than the "rate control" is not well known. Authors have hypothesized that the difference in speed of ventilation as a result of different metronome rates may affect the quality of ventilation. To test our hypothesis, we recruited physicians and compared tidal volumes and airway pressures among three different metronome rates (100, 110 and 120 ticks/minute) on a manikin model simulating two-person 30:2 CPR.

METHODS

This study is a randomized crossover observational simulation study conducted in a tertiary university hospital located in Seoul, Korea. To ensure certain level of skill in bag-mask ventilation, participants were recruited among physicians who have attended American Heart Association (AHA) accredited BLS provider course for health care providers (HCPs). Participants were informed of the study brief, contents and extent of data collection, and process of the study. The present study was carried out on the same day after the AHA BLS provider course. Exclusion criteria were refusal to participate and health problems predicted to interfere with the capacity to perform bag-mask ventilation.

The manikin model used in our study was RespiTrainer® Advance (IngMar Medical, Pittsburgh, PA, USA). Airway resistance was set at normal resistance of 5 $cmH_2O/L/s$. Noticeable rise of QuickLung® of the RespiTrainer® was used as an indicator of visible chest rise. An air-cushioned face mask (SOLCO Surgical Instrument, Pyungtaek-Si, Gyeonggi-Do, Korea) and self-inflating resuscitator bag (1.6 L) was used during the study. Participants used their left hand to maintain the head-tilt/chin-lift position of the manikin and provide an air-tight seal using the single left-handed "E-C clamp" mask hold technique. Participants were instructed to squeeze the central part of the self-inflating bag with their right hand and to deliver inspiration over two ticks and expiration over two ticks of metronome sound, which is between 1 to 1.2 second depending on the rate of the metronome. To simulate 30:2 CPR, one investigator counted out loud from 1 to 30 in cadence with the metronome rate, and participants performed 2 consecutive ventilations following the count. In this manner, participants performed 5 sets of 2 consecutive ventilations (10 ventilations in total). Mean tidal volumes of 10 ventilations were obtained by reading the values reported on a Personal Data Assistant (PDA) connected to the RespiTrainer®. The sequence for the three different rates (100 ticks/minute, 110 ticks/minute and 120 ticks/minute) was randomized by a random table generation of the Excel program (Microsoft, Redmond, WA, USA).

One investigator obtained data regarding the physical characteristics of all participants. Hand width was measured from the tip of the little finger to the tip of the thumb, and hand length was measured from the middle fingertip to the distal skin crease at the wrist. A JAMAR® hydraulic hand dynamometer (Sammons Preston, Bolingbrook, IL, USA) was used to measure the grip power of both hands.

The primary end point of this study was mean ventilation volume, and the secondary end point was mean airway pressure at three different metronome rates. Based on our previous study, we estimated that the mean tidal volume would be 548 mL with a standard deviation of 159 mL.[10] A sample size of more than 26 were calculated to detect 15% difference in the mean tidal volume between different metronome rates (100, 110, 120 ticks/minute) with a power of 0.80. G*Power 3.1 (Heinlich-Hein Universität, Düsseldorf, Germany) was used to calculate the sample size.[11] Normality of the data was evaluated using the Shapiro-Wilk test. The difference of mean ventilation volume and peak airway pressure was compared using the nonparametric Wilcoxon signed rank test. The number of tidal volumes below threshold and the number of peak airway pressures above threshold was also compared using the nonparametric Wilcoxon signed rank test. Effect size was calculated by dividing the z value by the square root of the number of observations. Variables were presented as median with IQR. Statistical analyses were performed using STATA 11.0 for Windows (StataCorp, TX, USA).

RESULTS

Thirty young medical doctors consented to participate in the present study. Demographic characteristics of the participants are presented in Table 1. The dominant hand was the right hand in all participants.

At a metronome rate of 120 ticks/minute, rescuers delivered inspiration over 1.0 second (2 ticks) followed by expiration over 1.0 second (2 ticks). Two cycles of ventilations took 4.0 seconds. At a metronome rate of 110 ticks/minute, rescuers delivered inspiration over 1.09 seconds (2 ticks) followed by expiration over 1.09 seconds (2 ticks). Two cycles of ventilations took 4.36 seconds. At a metronome rate of 100 ticks/minute, rescuers delivered inspiration over 1.2 seconds (2 ticks) followed by expiration over 1.2 seconds (2 ticks). Two cycles of ventilations took 4.8 seconds (Table 2).

Mean tidal volume was not statistically different between the metronome rate of 100 ticks/minute and 110 ticks/minute. However, mean tidal volume significantly decreased as the metronome rate increase from 110 ticks/minute to 120 ticks/minute with medium effect size (r=0.369) (Table 2, Figure 1).

Mean peak airway pressure increased significantly as the metronome rate increased from 100 ticks/minute to 110 ticks/minute. Mean peak airway pressure was not statistically different between 110 ticks/minute and 120 ticks/minute with medium effect size (r=0.357). The number of peak airway pressure >20 mmHg significantly increased as the metronome rate increased from 100 ticks/minute to 110 ticks/minute with medium effect size (r=0.373). More than half of the ventilations resulted in a peak airway pressure of more than 20 mmHg in 110 ticks/minute and 120 ticks/minute (Table 2, Figure 2).

Table 1. Demographic characteristic of the participants

Characteristics	Median (IQR)
Age (years)	26.5 (26, 28)
Male, n (%)	16 (53.3)
Hand width (cm)	
Right	19.6 (18.6, 20.7)
Left	20 (19.1, 20.7)
Hand length (cm)	
Right	18.2 (17.2, 19.1)
Left	18.25 (17.4, 19.2)
Hand grip power (kg)	
Right	45 (28, 52)
Left	42 (28, 46)
Self confidence of bag mask ventilation*	2 (2, 3)

IQR: interquartile range; *Likert 5 scale (1: none ~ 5: very confident)

DISCUSSION

Audio tone guidance ensures better chest compression rate and ventilation rate. However, audio tone guidance does not necessarily result in a better ventilation quality.

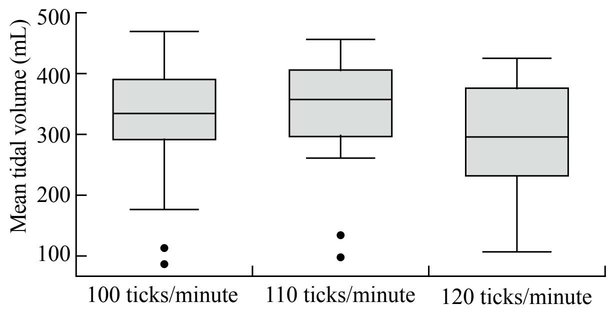

Figure 1. Box plot diagram for mean tidal volume of three different metronome rates.

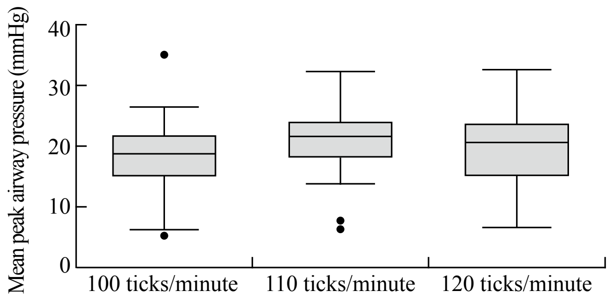

Figure 2. Box plot diagram for mean peak airway pressure of three different metronome rates.

Table 2. Effects of different metronome rates on bag-mask ventilation

Parameters	100 ticks/minute	110 ticks/minute	120 ticks/minute	*P* value*		
				100 vs. 110	100 vs. 120	110 vs. 120
Inspiration time (seconds)	1.2	1.09	1.0			
Maximum time required for 2 ventilations (seconds)	4.8	4.36	4.0			
Tidal volume (mL), median (IQR)	335 (291, 390)	358 (297, 405)	297 (230, 375)	0.163	0.122	0.004#
Tidal volume<500 mL, median (IQR)	8 (6, 10)	6 (5, 9)	9.5 (6, 10)	0.026	0.418	0.021
Ppk (mmHg), median (IQR)	18.7 (15.1, 21.6)	21.6 (18.2, 23.9)	21.1 (15.2, 23.6)	0.006#	0.417	0.225
Ppk>20 mmHg, median (IQR)	3 (1, 8)	7 (4, 10)	6.5 (0, 10)	0.004#	0.351	0.297

*: *P* value of nonparametric test (Wilcoxon matched-pairs signed-ranks test); Statistical significance under Bonferroni correction, #P<0.017; IQR: inter-quartile range; Ppk: peak airway pressure.

As far as authors know, this is the first study to specifically evaluate the effect of metronome rate on the quality of ventilation. The present study demonstrated that the ventilation quality deteriorated as the metronome rate increased from 100 ticks/minute to 110 ticks/minute or 120 ticks/minute during metronome-guided CPR. Mean tidal volume significantly decreased as metronome rate increase from 110 ticks/minute to 120 ticks/minute and the number of peak airway pressure>20 mmHg significantly increased as metronome rate increase from 100 ticks/minute to 110 ticks/minute. Although ventilation is not as important as external chest compressions and defibrillation for the first few minutes after sudden cardiac arrest (electrical phase), it becomes as important as other measures of resuscitation after the electrical phase. In cases of cardiac arrest due to respiratory etiologies, ventilatory support may be more important than any other measures of resuscitation for a favorable outcome of the patient. When performing metronome-guided CPR, it may be better for rescuers to tailor the rate of the metronome depending on the probable cause of cardiac arrest and elapsed time after collapse.

When applying metronome guidance, one should choose a rate between 100/minute to 120/minute to comply with current CPR guidelines. Chung et al[12] reported that the quality of chest compression following the metronome rate of 100 ticks/minute was significantly worse than the chest compression without metronome guidance. The quality of chest compression improved as the metronome rate increases during metronome-guided CPR, and they concluded that a higher metronome rate may be necessary for metronome-guided CPR. Therefore, it may be better to choose 120 ticks/minute when the presumed cause of cardiac arrest is of cardiac etiologies during metronome-guided CPR. However, it may be better to choose 100 ticks/minute when presumed cause of cardiac arrest is of respiratory etiologies during metronome-guided CPR.

Bag-valve-mask (BVM) ventilation is a fundamental airway skill that is most commonly used to provide oxygen and ventilation for a cardio-pulmonary arrest victim until definitive airway is secured. In out-of-hospital cardiac arrest situations, BVM ventilation was associated with increased survival to hospital discharge when compared with advanced airway methods.[13] Current 2015 CPR Guidelines recommend to give each rescue breath with enough volume to make the victim's chest rise.[7] Several variables such as patient factors,[14–16] device factors,[2,17] and rescuer factors[18–21] can affect successful bag-mask ventilation (visible chest rise) during CPR. Authors have realized that delivering adequate tidal volume (visible chest rise) over 1 second while maintaining peak airway pressure less than 20 mmHg is an extremely difficult task. More than half of total ventilations in metronome rates of 110 ticks/minute and 120 ticks/minute surpassed the upper threshold of peak airway pressure. Also, mean peak airway pressure drastically increased as metronome rates increase from 100 ticks/minute to 110 ticks/minute. Rescuers need ample amount of practice to deliver adequate tidal volume (visible chest rise) over 1 second while keeping the peak airway pressure below the threshold at the same time.

One big issue observed in this study is that mean tidal volumes were much lower than expected. Low mean tidal volume is difficult to attribute to participant's poor performance because participants were recruited from physicians who had completed the AHA accredited BLS provider course on the same day prior to the study. The authors have observed that some participants had poor sense of rhythm and had difficulties in synchronizing bag squeezing with fast rhythmic sound of the metronome. This may have resulted in low mean tidal volumes. Audio tone guided CPR may not be suitable for certain rescuers with a poor sense of rhythm, especially when performing the ventilation in cadence with fast rhythmic sound. Another possible explanation for overall low mean tidal volume is that participants used QuickLung® of the RespiTrainer® as an indicator of visible chest rise. Current BLS education program instruct trainee to deliver tidal volume to make a visible chest rise. In fact, even small tidal volume such as 200 mL actually make visible movement of QuickLung®. Therefore, we believe that the overall low tidal volumes acquired in this study may have originated from difficulty in synchronizing with fast metronome rate and the manikin factor rather than from the poor performance of participants.

Several limitations of our study should be noted. First, this simulation study was not performed on a human population but on a single manikin model with normal airways. Another study on real patients (especially for cardiac arrest due to presumed respiratory etiologies) would be necessary to validate the findings of this study. Second, our study did not test various clinical situations of difficult bag-mask ventilations. Third, subjects of our study were a homogenous group of young physicians and the findings of our study may not hold true if bag-mask ventilation is performed either by a novice or by an expert. Fourth, although we used mean tidal volume of 5 sets of 2 consecutive ventilations

(10 ventilations in total), each tidal volume is dependent on the performance of each rescuer. One major error in bag-mask ventilation among 10 ventilations can distort the result. Fifth, actual chest compressions were not performed but only simulated by counting the numbers because the RespiTrainer® does not have a compressible chest wall. Potential effect of chest compression and decompression on the tidal volume was not considered in this study. These limitations may limit the generalizability and applicability of the study findings. However, we believe that our simulation study eliminated many confounding variables and successfully compared the performance of bag-mask ventilations following different rate of metronome for the first time.

CONCLUSION

During metronome-guided 30:2 CPR, the quality of ventilation deteriorated as the metronome rate increases from 100 ticks/minute to 110 ticks/minute or 120 ticks/minute. Rescuers need to be aware of the fact that the rate of 100 ticks/minute may be better than 110 ticks/minute or 120 ticks/minute to deliver adequate ventilation during audio tone guided 30:2 CPR.

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Ethical approval: Since actual patients were not involved in the study and because participation was voluntary the ethics committee referred approval to the work council. Full approval was given after reviewing the questionnaires.
Conflicts of interest: The authors declare there is no competing interest related to the study, authors, other individuals or organizations.
Contributors: Na JU proposed the study and wrote the first draft. All authors read and approved the final version of the paper. Na JU and Han SK equally contributed to this study.

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