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ORIGINAL RESEARCH

Cardiopulmonary resuscitation: difficulty in maintaining sufficient compression depth at the appropriate rate

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Abstract

Over the last 50 years, the recommended chest compression for cardiopulmonary resuscitation (CPR) has become faster and deeper, but maintaining deep compressions may be difficult at higher rates. Our study aimed to determine whether adequate compression (chest compression at an appropriate depth and rate) is being performed in emergency departments (ED). We also investigated the effect of adequate compression performance on the return of spontaneous circulation (ROSC). This prospective observational study was conducted at the EDs of two urban academic medical centers. We included adult patients (age $\geq$18 years) with cardiac arrest who underwent CPR in the ED between May and November 2020. We excluded patients with cardiac arrest related to trauma, repeated arrest except the first, and those for whom a monitor-defibrillator (ZOLL X-series) was not used. The following data were obtained from the monitor-defibrillator devices: compression depth, rate, chest compression fraction, CPR time, and percentage of compressions at the recommended rate and, at the recommended depth, at over and below rates, and depth, and at the appropriate depth and rate. Our study included 50 patients, from whom 441 chest compression sequences were obtained and analyzed. The mean compression depth, rate, and fraction were 6.48 $\pm$ 0.87 cm, 117 $\pm$ 5/min, 92.1 $\pm$ 3.70%, respectively. As the compression rate increased, the depth decreased, and most compressions were over-depth. Adequate compression (appropriate depth at recommended rate) was observed in 97 of the 441 compression sequences (21.9%). Below-depth and below-rate percentages were higher in the deceased group than that in the ROSC group (9.7 $\pm$ 15.2% *vs.* 3.3 $\pm$ 3.5%, $p = 0.27$; 2.7 $\pm$ 2.6% *vs.* 1.2 $\pm$ 0.9%, $p = 0.06$). The global ratio of chest compression showed low compliance with the recommended rate and depth, even when performed by skilled ED staff.

Keywords

CPR; Compression depth; Compression rate

1. Introduction

The quality of cardiopulmonary resuscitation (CPR) is affected by several factors. Adequate chest compression rate, compression depth, and allowing chest recoil, and minimizing interruption during chest compressions may increase the chance of survival [1–3].

High-quality chest compressions with minimal interruption are the cornerstone of CPR [1–3]. Recent clinical studies have reported that inadequate performance of chest compressions is associated with worse outcomes [4–9]. Recovery with good neurological function after arrest shows a good correlation with the target ranges of chest compression rate and depth [4–9]. However, several studies reported that when the compressions are faster, the depth decreases [10–12]. The recommended rate and depth of chest compression have increase gradually over the last 50 years.

However, it may be difficult to simultaneously maintain deep and fast compressions. Moreover, because most studies have been performed using manikins and in prehospital situations, it is difficult to assess the case in real-life hospital settings [10–12].

Therefore, our study aimed to determine the relationship between the chest compression depth and rate, and whether adequate compression at the appropriate depth and/or rate is being performed at emergency departments (ED). We also investigated effect of adequate compression performance on the return of spontaneous circulation (ROSC) and death.

2. Methods

2.1 Study design and participants

This prospective observational study was conducted at the emergency medical center of two urban academic medical centers in South Korea. The institutions are 1000-bed tertiary-level university hospitals located in Yangsan City and Busan City, Korea, respectively.

We included adult patients with cardiac arrest who underwent CPR in the ED between 01 May and 30 November 2020. The inclusion criteria were as follows: (1) age $\geq$18 years and (2) no traumatic cardiac arrest. We excluded patients with cardiac arrest related to trauma, repeated arrest except the first, and patients who did not undergo treatment with a monitor-defibrillator (Zoll X series).

The sample size was calculated based on correlation analysis between the compression depth and rate.

2.2 Equipment and data collection

Chest compression performance was measured using a monitor defibrillator (X series; ZOLL Medical, Chelmsford, MA, USA) with an integral accelerometer-based chest compression sensor. Emergency medicine residents, emergency medical technicians, and nurses performed CPR. CPR was supervised by an emergency medicine specialist and end-tidal carbon dioxide ($EtCO_2$) was continuously monitored for quality. The resuscitation team was blinded to their performance by disabling the real-time audio-visual CPR feedback. The results were obtained automatically from minute-by-minute sequences; data collected sequentially per minute. The following data were obtained from these devices: compression depth, rate, chest compression fraction (CCF), CPR time, percentage of compressions at the recommended rate (appropriate rate), percentage of compressions at the recommended depth (appropriate depth), percentage of compressions exceeding and below the recommended rates and depth (over-rate, below-rate, over-depth, and below-depth), and percentage of compressions with an appropriate depth at the appropriate rate (adequate compression). The rate of chest compression compliance to the guidelines, *i.e.*, the rate of compressions between 100 to 120/min and depth of 5 to 6 cm, was calculated.

We recorded the patients' demographic characteristics (age, sex, ROSC, initial rhythm at arrest, CPR time, out-of-hospital arrest, in-hospital arrest, and time elapsed from the event to arrival at the hospital, the cause of cardiac arrest).

2.3 Outcomes and statistical analysis

The primary outcome was the change in chest compression depth as the rate increased in clinical. The secondary outcome was the percentage of adequate compression in the clinical setting and the effect of compression performance on ROSC and death. Chest compression performance was analyzed using minute-by-minute sequences, and the effect of compression performance on the ROSC was analyzed using the mean depth, mean rate, and mean adequate compression percentage of each patient. The CPR time in the deceased group is usually longer. We reanalyzed the CPR performance for the average CPR time in the ROSC group because the prolonged CPR time may increase the rescuer's fatigue and affect the results.

Data were analyzed using the predictive analytics software (PASW) statistical software package for Windows, version 27 (SPSS, Inc., Chicago, IL, USA), and standard descriptive summaries appropriate for the distribution of the variables were calculated. The analysis of variance (ANOVA) or *t*-test was used to compare normally distributed continuous variables among the groups. Correlation analysis was performed using bivariate analysis with the Pearson correlation coefficient. The chi-squared or Fisher's exact test was used to evaluate the differences between categorical variables. Statistical significance was defined as a two-tailed p-value < 0.05.

The sample size was calculated based on the correlation analysis between compression depth and rate. The required sample sizes was calculated to be 138 with a correlation coefficient of 0.3, α error of 0.5, and power of 0.95 based on previous studies. The data (compression depth, rate, *etc.*) were obtained from minute-by-minute sequences and the minimum sample size was 150 compression sequences. Assuming that 10 min of CPR was performed per cardiac arrest patient, 50 cardiac arrest events were considered to be a sufficient sample size for verification.

3. Results

3.1 General characteristics

Fifty patients were enrolled during the 7-month study period. A total of 441 chest compression sequences were obtained and analyzed.

The mean age was 62.0 $\pm$ 13 years, and 32 (64%) patients were male. Out-of-hospital arrest occurred in 43 patients (86%) and ROSC in 17 patients (34%). The mean CPR time was 15.5 $\pm$ 8.1 min and the mean time elapsed from the event to arrival at the hospital in cases of out-of-hospital arrest was 31.4 $\pm$ 13.0 min. The initial electrocardiogram (ECG) rhythm was asystole in 38 cases, ventricular fibrillation in 4 cases and pulseless electrical activity in 8 cases (Table 1).

3.2 Chest compression performance

The mean chest compression depth, rate, and CCF were 6.48 $\pm$ 0.87 cm, 117 $\pm$ 5/min, 92.1 $\pm$ 3.70%, respectively (Table 1).

The chest compression depth tended to decrease when the rate increased (Pearson coefficient = −0.295, p = 0.038; Fig. 1).

Appropriate depth was observed in 157 of 441 compression sequences (35.6%), and the appropriate rate was observed in 300 of 441 compression sequences (68%). Most chest compressions were over-depth (>6 cm) at the appropriate rate (100~120/min). Adequate compression was observed in 97 of 441 compression sequences (21.9%). Appropriate depth was high in the over-rate group (Table 2). The depth of chest compression decreased as the rate of compression increased. Most compressions were over-depth, and the proportion of compressions of appropriate depth was higher in the over-rate group.

TABLE 1. General characteristics.

Characteristics	Data (N = 50)
Average age (Yr)	62.0 ± 13
Gender (n)	
Male	32 (64%)
Female	18 (36%)
Arrest place (n)	
Out-of hopital	43 (86%)
In hospital	7 (14%)
ROSC* (N, %)	17 (34%)
CPR† time (min)	15.5 ± 8.1 min
Mean elapsed time to arrival at hospital in out-of-hospital arrest (min)	31.4 ± 13.0 min
Mean compression depth (cm)	6.48 ± 0.87 cm
Mean compression rate (numbers/min)	117 ± 15/min
Compression fraction (%)	92.1 ± 3.7%
Initial arrest rhythm	
Asystole	38 (76%)
Ventricular fibrillation	4 (8%)
Pulseless electrical activity	8 (16%)
Bystander CPR† (N, %)	25 (50%)
Witness arrest (N, %)	25 (50%)
Cause of arrest (N, %)	
Cardiogenic	7 (14%)
Non-cardiogenic	28 (56%)
Unknown	15 (30%)

** Return of spontaneous circulation.*
† cardiopulmonary resucitation.

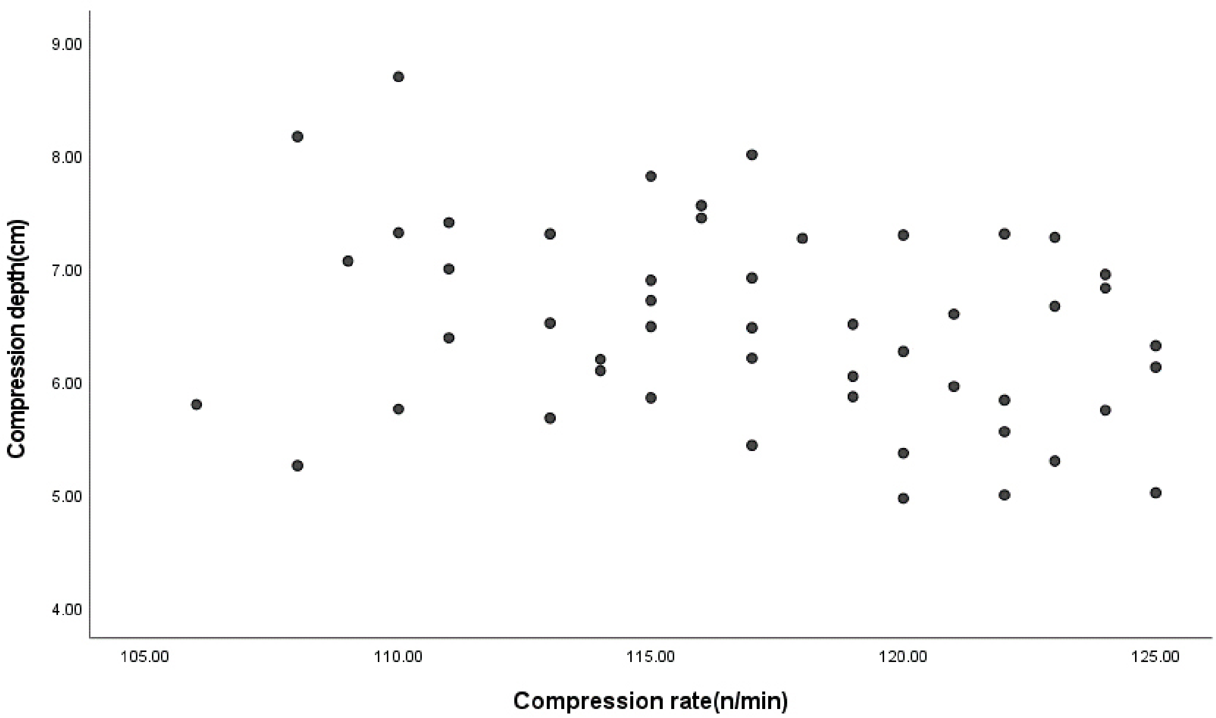

FIGURE 1. The relationship of chest compression depth and rate.

TABLE 2. chest compression performance.

rate	Below-rate <100/min	Appropriate rate 100–120/min	Over-rate >120/min	Total (N, %)	*p* value
depth					
Below-depth <5 cm	0 (0.0%)	7 (2.3%)	17 (12.5%)	24 (5.4%)	
Appropriate depth (5–6 cm)	1 (20.0%)	97 (32.3%)	59 (43.4%)	157 (35.6%)	<0.001
Over-depth >6 cm	4 (80.0%)	196 (65.4%)	60 (44.1%)	260 (59.0%)	
Total (N, %)	5 (1.1%)	300 (68.0%)	136 (30.8%)	441 (100.0%)	

TABLE 3. The effect of compression performance on ROSC.

	ROSC*(17)	Death (33)	*p* value
Compression depth (cm)	6.70 ± 0.64	6.37 ± 0.95	0.205
Compression rate (n/min)	118 ± 4	116 ± 5	0.343
Chest Compression fraction	91.8 ± 2.7	92.9 ± 3.2	0.360
Depth (mean value, %)			
Over-depth	68.8 ± 29.4%	54.4 ± 33.8%	0.260
Appropriate depth	27.9 ± 29.1%	36.0 ± 25.9%	0.146
Below depth	3.3 ± 3.5%	9.6 ± 15.2%	0.027
Rate (mean value, %)			
Over-rate	44.1 ± 26.3%	37.8 ± 26.3%	0.435
Appropriate rate	54.7 ± 25.8%	59.5 ± 23.9%	0.471
Below rate	1.2 ± 0.9%	2.7 ± 2.6%	0.006
Adequate chest compression	12.5%	18.8%	0.160

**Return of spontaneous circulation.*

TABLE 4. The effect of compression performance on ROSC of 10 minutes.

	ROSC*(17)	Death (33)	*p* value
Compression depth (cm)	6.71 ± 0.71	6.39 ± 1.02	0.252
Compression rate (n/min)	117 ± 4	116 ± 5	0.346
Chest Compression fraction	92.8 ± 4.4	93.9 ± 2.2	0.340
Depth (mean value, %)			
Over-depth	69.3 ± 30.2%	55.2 ± 34.2%	0.130
Appropriate depth	27.3 ± 27.9%	33.9 ± 26.2%	0.399
Below depth	3.4 ± 3.7%	10.9 ± 15.3%	0.015
Rate (mean value, %)			
Over-rate	42.8 ± 24.7%	39.6 ± 27.9%	0.700
Appropriate rate	55.8 ± 24.5%	57.3 ± 25.1%	0.638
Below rate	1.4 ± 1.3%	3.1 ± 3.9%	0.030
Adequate chest compression	10.8%	18.0%	0.164

**Return of spontaneous circulation.*

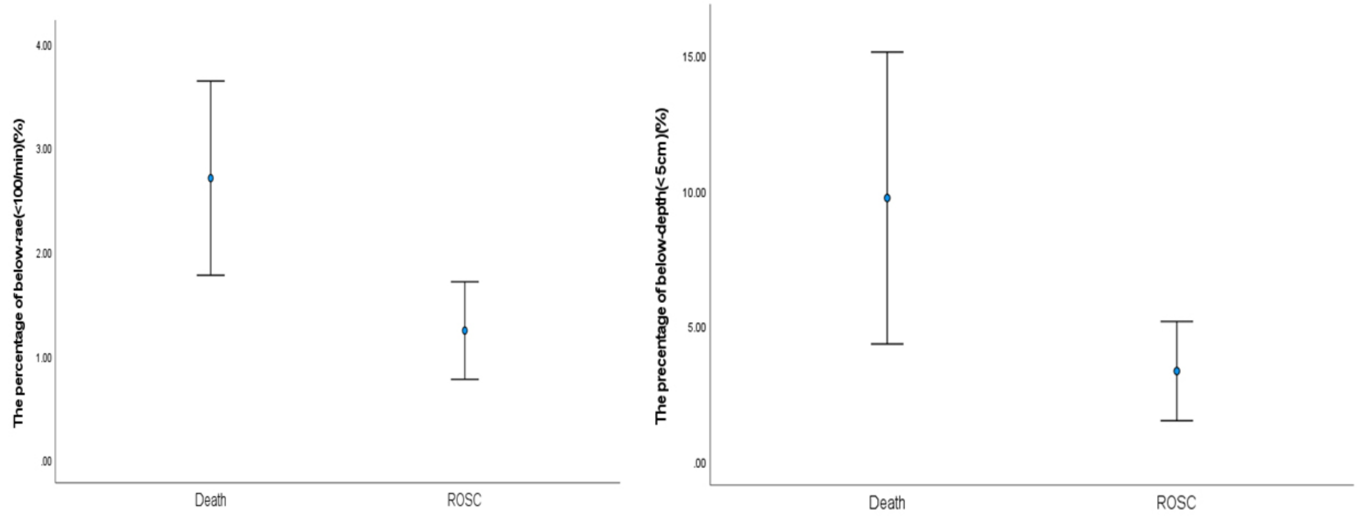

FIGURE 2. The effect of chest compression on ROSC. ROSC: return of spontaneous circulation.

3.3 Effect of compression performance on ROSC

The CPR time was shorter in the ROSC group than that in the deceased group. The other variables (initial ECG rhythm, place of arrest, time elapsed from arrest to arrival at the hospital, witness to the cardiac arrest, and bystander CPR) did not differ significantly between the deceased and ROSC group. However, the proportion of cardiogenic origin was higher in the ROSC group (cardiogenic 5/7, 71.4% *vs.* non-cardiogenic 11/28, 39.2%).

Chest compressions in the ROSC group were deeper and faster than those in the deceased group, but the difference was not significant (6.7 ± 0.64 cm *vs.* 6.3 ± 0.95 cm, $p = 0.20$; 118 ± 4 *vs.* 116 ± 5/min, $p = 0.34$). Appropriate depth, rate percentage, and adequate compression did not differ significantly between the two groups. However, the proportion of below-depth and below-rate was higher in the deceased group than that in the ROSC group (9.6 ± 15.2% *vs.* 3.3 ± 3.5%, $p = 0.027$; 2.7 ± 2.6% *vs.* 1.2 ± 0.9%, $p = 0.006$). (Table 3, Fig. 2)

The CPR time in the ROSC group was 9.8 min, which was shorter than that in the deceased group (18.5 min). Because the prolonged CPR time in the deceased group could have increased the fatigue of rescuers and affected the results, we reanalyzed CPR performance for 10 min (average CPR time in the ROSC group).

During CPR for 10 min, the proportion of below-depth and below-rate compression was higher in the deceased group than that in the ROSC group (10.9 ± 15.3% *vs.* 3.4 ± 3.7%, $p = 0.015$; 3.1 ± 3.9% *vs.* 1.4 ± 1.3%, $p = 0.03$). The other variables did not differ significantly between the two groups (Table 4).

4. Discussion

Chest compression is important for CPR and is affected by several factors such as hand position, rate and depth of compressions, chest relaxation time, hands-off time, *etc*.

Several CPR guidelines have described the criteria for chest compression, and the most recent International Liaison Committee on Resuscitation guidelines recommend a chest compression depth of 5–6 cm and rate of 100–120/min [1–3].

Over the last 50 years, the recommended chest compression has become gradually faster and deeper. However, several studies have suggested an inverse relationship between the chest compression rate and depth, viz. as the compression rate increases, it is more difficult to maintain deep chest compression [10, 11, 13]. However, most of these studies were conducted on mannequins or in prehospital settings.

Unlike these studies, our study was conducted at two hospitals reflecting the clinical setting and showed the same results: as the compression rate increased, the depth decreased. It is meaningful that the same results were shown in clinical situations, particularly in the ED.

The components of chest compression are not mutually exclusive processes and influence other chest compression quality variables. For example, a higher chest compression rate increases the compression number/min and the duty cycle but decreases the compression depth and time in diastole (a decreased diastolic time results in decreased time to perfuse the coronary arteries) [4, 10, 11, 13–17].

Increasing the compression depth alone has been associated with improved hemodynamics in animal studies as well as improved survival in observational studies of adult humans following in-hospital cardiac arrest [18, 19].

It may be more difficult to reach the recommended rate and depth simultaneously during CPR because the chest compression rate and depth might be incompatible. In our study, the adequate compression percentage was as low as 21.9%. Agostinucci *et al*. [10] also reported low adequate compression (15%). Therefore, more attention should be paid to simultaneously attaining the recommended rate and depth during CPR.

Several studies have reported that professional rescuers often do not deliver high-quality CPR with respect to the compression depth and rate [11, 20–22]. Most showed a lower compression depth than the recommendation. However, in our study, a compression depth of less than 5 cm was very low at 5%, while most showed a compression depth >6 cm

(59.0%). The appropriate depth percentage was higher in the over-rate group than that of the appropriate rate because the chest compression rate and depth were inverted and most compressions were over-depth.

The reason for the low below-depth compression is that CPR is performed more frequently in the ED than in the prehospital setting or other hospitals; therefore, rescuers are familiar with CPR. Healthcare providers performing CPR have basic life support (BLS) provider certification purveyed by the American Heart Association (AHA), and most have a BLS instructor certified by the AHA. The higher CCF than other studies may indirectly refute the degree of education [8, 11, 14, 20–22].

As unexpected CPR is common in the ED and the ED itself is a more tense milieu, it is possible that this tension may have caused over-depth of compression. The more familiar the staff are with CPR, the more likely they are to perform deep compression, as emphasized during CPR training. This tendency may also have been responsible for the increase in over-depth compressions.

However, the below-depth percentage was higher in the deceased group than that in the ROSC group, and below-depth is thought to be much worse than over-depth for the patient's ability to achieve ROSC. However, we did not investigate the complications of over-depth compression (*i.e.*, rib fracture, pneumo-hemothorax, and organ injury). Therefore, it is difficult to determine the effects of over-depth compression based on the results of this study.

The use of real-time audio-visual CPR feedback is recommended to improve CPR quality (particularly depth and rate). This feedback equipment may increase adequate chest compression (recommended depth performed at the recommended rate).

This study had limitations. First, all CPR patients in the ED were not included because of insufficient Zoll equipment and urgency of CPR. Second, rescuer-related characteristics (weight, height, fatigue, and ED experience) were not analyzed. During CPR, several rescuers alternate at delivering compressions, but it is currently not possible to determine the individual contribution of each rescuer. Third, although incomplete release is an important determinant of the quality of resuscitation, the defibrillator could not measure this. Fourth, assisted ventilation, which is an important aspect of CPR, was provided during CPR in EMS and ED, but it was not clear whether ventilation was performed during bystander CPR.

Finally, unlike other studies, the average chest compression depth exceeded 6 cm. As mentioned above, the tense milieu and CPR training may have caused over-depth compression. However, since this study was prospective in design, all participant rescuers may have been aware of being monitored while performing CPR, resulting in deeper compressions.

5. Conclusions

The compression depth decreased as the chest compression rate increased even in the ED. The global ratio of chest compression in compliance with the recommended rate and depth was low, even in skilled staff. We found that the proportion of below-depth and below-rate compression was higher in the deceased group than that in the ROSC group.

AVAILABILITY OF DATA AND MATERIALS

The data are contained within this article.

AUTHOR CONTRIBUTIONS

MKM—Conceptualization & methodology. DSL, MJL, MSC, TH and SWS—Investigation. MKM and JHR—Analysis. DSL and MKM—Original draft preparation. JHR and SWS—Review.

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

The study protocol was reviewed and approved by the Institutional Review Board of Yangsan Busan National University Hospital (05-2022-085). The need for informed consent has been waived owing to the nature of the study.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

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