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Obstacles delaying the prompt deployment of piston-type mechanical cardiopulmonary resuscitation devices during emergency department resuscitation: A video-recording and time-motion study

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Abstract

Background—The quality of cardiopulmonary resuscitation (CPR) is important to survival after cardiac arrest. Mechanical devices (MD) provide constant CPR, but their effectiveness may be affected by deployment timeliness.

Objectives—To identify the timeliness of the overall and of each essential step in the deployment of a piston-type MD during emergency department (ED) resuscitation, and to identify factors associated with delayed MD deployment by video recordings.

Methods—Between December 2005 and December 2008, video clips from resuscitations with CPR sessions using a MD in the ED were reviewed using time-motion analyses. The overall deployment timeliness and the time spent on each essential step of deployment were measured.

Results—There were 37 CPR recordings that used a MD. Deployment of MD took an average 122.6 ± 57.8 s. The 3 most time-consuming steps were: (1) setting the device (57.8 ± 38.3 s), (2)

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Conflict of interest statement

None.

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positioning the patient (33.4 ± 38.0 s), and (3) positioning the device (14.7 ± 9.5 s). Total no flow time was 89.1 ± 41.2 s (72.7% of total time) and associated with the 3 most time-consuming steps. There was no difference in the total timeliness, no-flow time, and no-flow ratio between different rescuer numbers, time of day of the resuscitation, or body size of patients.

Conclusions—Rescuers spent a significant amount of time on MD deployment, leading to long no-flow times. Lack of familiarity with the device and positioning strategy were associated with poor performance. Additional training in device deployment strategies are required to improve the benefits of mechanical CPR.

Keywords

Mechanical devices; Cardiopulmonary resuscitation (CPR); Video-recording; Time-motion analysis; No-flow time Quality

1. Introduction

High-quality cardiopulmonary resuscitation (CPR) is necessary to maximize the survival and neurological outcomes in cardiac arrest victims. Worldwide guidelines on high quality CPR were established by the International Liaison Committee on Resuscitation (ILCOR)¹ and the European Resuscitation Council (ERC),² yet poor compliance during in-hospital and out-of-hospital resuscitation by health care providers and lay persons have been reported.³ Suboptimal performance of CPR was most often related to rescuer skill deterioration over time^{4,5} fatigue factors,^{6–8} as well as interruptions in chest compressions.^{9,10} Some studies have indicated that rescuer fatigue is an important contributor to poor CPR quality.^{6,11–13}

Mechanical chest compression devices were introduced more than 20 years ago, which negated the need for individuals to manually perform traditional chest compression. Currently, there are three main types of commercially available mechanical CPR devices, worldwide, the piston-type chest compression machines (Thumper®, Michigan Instruments, Grand Rapids, MI, USA), the active decompression machine (LUCAS®, Physio-Control, Redmond, WA, USA), and the load-distributing band machine (Autopulse®, Zoll Medical, Chelmsford, MA, USA).^{14,15} While some studies have shown improved coronary artery perfusion pressures, increased rates of return of spontaneous circulation (ROSC), and survival to hospital discharge¹⁶; others did not show a significant difference in survival to 4 h between the mechanical vs. manual CPR groups.¹⁷

Limitations of mechanical CPR have been previously discussed.¹⁸ First, long periods of time without blood flow (no-flow times) has been associated with mechanical CPR usage. However, the no-flow time associated with mechanical CPR may be shorter than for manual CPR if rapidly deployed.¹⁹ Second, internal injuries to the ribs and sternum^{20,21} have been reported; however, studies have shown no difference in autopsy-detected injuries among those receiving manual versus mechanical CPR.^{20,21} Third, incorrect application of mechanical CPR may lead to compressions that are too shallow. All the above limitations stem from a lack of user familiarity with the operation of the devices and increases CPR interruptions.²²

This study was conducted to identify the timeliness of the overall and essential steps in the deployment of piston-type mechanical CPR devices during actual emergency department (ED) resuscitations, defined as the time from the start of the deployment of the mechanical CPR machine to the first constant mechanical compression. We also attempt to identify possible factors affecting device deployment times.

2. Material and methods

2.1. Study design and settings

This retrospective study was conducted in the ED of the National Taiwan University Hospital, a tertiary-care university hospital with 2000 beds and an annual ED volume of 110,000 patients. All resuscitation attempts in the ED designated areas were recorded as part of a quality assurance program.

Mechanical resuscitations in the department were performed using a piston-type pneumatic device (Thumper[®] CPR, Model 1007), consisting of a backboard and one main unit that included the pneumatic piston providing ventilation function.

2.1.1. Selection of participants—Video recordings of the resuscitation of adult, non-traumatic, out-of-hospital cardiac arrest (OHCA), or in-hospital cardiac arrest patients between December 2005 and December 2008 were evaluated. Patients < 18-year-old or those suffering cardiac arrest due to traumatic events were excluded from the analysis. Events with mechanical CPR deployment were reviewed by experienced emergency physicians using a structured review instrument.

2.1.2. Steps of mechanical device deployment (Fig. 1)—The deployment of the mechanical CPR device was divided into the following steps (Fig. 1):

Tilt the patient: An ED staff member pulls one side of patient up so that the backboard can be slipped under the patient.

Insert the CPR backboard: Position the backboard of the mechanical CPR device under the patient.

Place the patient on the backboard and adjust the position: Correctly position the patient on the backboard.

Position the Thumper[®]: Correctly position the main unit of the mechanical device.

Set the Thumper[®] for initial compression: Check that the piston position is over the middle of the sternum, fix the piston's vertical position, and switch on the compression switch.

Check the compression depth: Adjust the CPR device to achieve the ideal compression depth, with regular chest compressions.

2.2. Outcomes

The primary outcome of the study was the overall timeliness of deployment, defined as the time from tilting the patient to the first regular mechanical compression, and the time spent

on each essential step of the deployment (Fig. 1). The ending time of each step was defined as the beginning of the next step.

Secondary outcomes included the overall and stepwise no-flow times and the no-flow time ratios. No-flow time was defined as the sum of all pauses, longer than 2.0 s, between compressions; the no-flow ratio was defined as the sum of no-flow time divided by the segment length.

The third outcome was the performance of non-technical skills during mechanical device deployment. Non-technical skills were scored by reviewing video recordings for behavior markers in four domains: leadership, situation awareness, mutual support and communication as follows:

Leadership: one identifiable leader during mechanical device deployment

Situation awareness: team members performed continuous chest compressions after positioning the patient

Mutual support: more than one rescuer helped position or set up the Thumper

Communication: verbal or action response to team members' request was noted from the video recordings

Presence of each of the behavior markers during the deployment process was given 1 point. The total non-technical skills ranged from 0 to 4 points.

2.3. Other factors

Other factors that may have influenced cardiac arrest outcomes, including number of staff, time of day of resuscitation, and body size of the patient were examined. The number of staff participating in the deployment process was identified from each video. Day shift was defined as the period between 8 a.m. and 8 p.m. and the night shift was defined as the period between 8 p.m. and 8 a.m. As body weight was not available from the medical records for out-of-hospital cardiac arrest patients, body sizes were estimated by consensus of two experienced reviewers, and categorized into small, medium and large by comparing the patient habitus with size of the stretcher.

2.4. Descriptive statistics

The study data were entered into and analyzed using Microsoft Excel (Microsoft Excel 2007; Microsoft Corporation, Seattle, WA) and SAS 9.2 (SAS Institute, Cary, NC, USA). Continuous variables, such as timeliness, are reported as means $\pm$ standard deviation (SD) and ninety-five percent confidence intervals (95% CI) were presented when appropriate. Categorical variables are presented as frequencies and percentages.

2.5. Statistical analysis

The differences in provider numbers during day and night shifts were compared using the Wilcoxon rank-sum test. Total times, no-flow times, and no-flow ratios were compared between time of day, rescuer number, and body size using independent *t*-tests, linear regression model and analysis of variance (ANOVA) respectively. Fisher's exact test was

used to examine the difference of the technical and nontechnical skills between the top and least performing groups in total deployment time. The top performing groups were defined as total deployment time shorter than first quartile while the least performing groups spent longer than third quartile. All p values were two-sided, with $p < 0.05$ being considered statistically significant.

2.6. Ethical considerations

The study protocol was approved by the Institutional Review Board (IRB) of the National Taiwan University Hospital (NTUH). All of the video reviewers signed a non-disclosure agreement to protect patient and staff member privacy.

3. Results

3.1. Characteristics of study subjects

From December 2005 to December 2008, a total 112 resuscitation recordings with CPR were available, with 40 (35.7%) receiving mechanical device deployment. Three of the 40 mechanical CPR recordings were major trauma cases, and were excluded. The remaining 37 mechanical CPR recordings were reviewed by the principal investigators. The characteristics of patients enrolled are summarized in Table 1.

3.2. Major findings

The average time spent on each of the 6 steps of Thumper[®] deployment and the associated no-flow times are shown in Table 1. Deploying the mechanical CPR device (Thumper[®]) took a total of 122.6 ± 57.8 s, and resulted in 89.1 ± 41.2 s (72.7% of the total time) of no-flow time. The 3 most time-consuming steps were setting the Thumper[®] (57.8 ± 38.3 s), placing the patient on the backboard and adjusting the position (33.4 ± 38.0 s), and positioning the Thumper[®] (14.7 ± 9.5 s). The other steps included inserting the CPR backboard (6.6 ± 3.7 s), checking the compression depth (6.1 ± 10.6 s), and tilting the patient from the bed (3.9 ± 2.9 s) (Table 2).

Among the 37 mechanical CPR recordings, there were 20 resuscitations performed during day shifts and 17 during night shifts. The average number of rescuers was 8.2 ± 1.7 (9.3 ± 1.3 during the day shift, and 6.9 ± 1.3 during the night shift, $p < 0.001$). There was no statistically significant difference between the 2 shifts in terms of no-flow times, no-flow ratios or the total timeliness of mechanical device deployment (Table 3).

No statistical differences were noted in regards to the no-flow times, no-flow ratios, and the total timeliness when compared by rescuer numbers (Table 3). Among 37 patients, there were 11 small, 19 medium and 7 large size patients, and there was no difference in timeliness of device deployment or at each step with body size (Table 1). No associations were noted after examining the characteristics, day or night shift, rescuer numbers, and body size with total deployment time in a linear model.

To further explore factors associated with variability of overall timeliness, we looked specifically at the differences between the top (total deployment time shorter than first quartile, $n = 11$) vs. the least (total deployment time longer than third quartile, $n = 10$)

performing groups in terms of (1) patient characteristics, (2) timeliness of essential steps, and (3) non-technical skills. There were no differences between the top vs. least performing groups in terms of patients characteristics (Table 1). Among the six steps, the top performing groups spent significantly less time in two steps: placing the patient on the board and setting the Thumper ($p < 0.05$). There were no differences in the total and individual non-technical skill scores between the two groups (Table 4).

4. Discussion

This paper is the first to identify the timeliness of the overall process and the essential steps involved in deploying a piston-type mechanical CPR device (Thumper®) by reviewing video recordings of ED resuscitations. The resuscitation teams spent an average of 122.6 s setting up the device and over 70% of that time was associated with no blood flow.

Compared with the deployment times of the Autopulse® (141 s)¹⁹ and LUCAS® (162 s),²³ the timeliness of mechanical device deployment in the current study was not very different. Through video-based time-motion analysis, the most time-consuming steps involved in the deployment were setting the Thumper® (57.8 ± 38.3 s) and placing the patient on the backboard (33.4 ± 38.0 s). These steps were also associated with the longest no-flow times (51.4 ± 32.2 s and 18 ± 17.3 s, respectively) (Table 3).

In this study, the participation of additional rescuers were not associated with improved mechanical CPR deployment (Table 3). Deployment timeliness, no-flow time, and the no-flow ratios were not affected by the shift during which resuscitations were performed or by the number of rescuers present.

From Table 4, the total deployment time between the top versus least performing groups was different (73.3 s vs. 201.0 s, $p < 0.01$). The variability of performance between these two groups was substantial, and most of the variability originated from time to place the patients (65.8 s vs. 17.5 s) and setting the Thumper (104.6 s vs. 34.6 s, $p < 0.05$). We found that poor deployment strategy and unfamiliarity with the mechanical device may be the reasons that led to delay. Unfamiliarity with the mechanical device led to poor performance: some rescuers could start the Thumper within seconds once the mechanical CPR device was properly positioned, while others needed more than 20 s to get the device functioning. All these may lead to prolonged Thumper deployment time and poor CPR quality.

Though no difference was noted both in each domain or total scores of non-technical skills, some efforts should be made to understand CPR performance. From video recordings, the least performing groups seem to have less identifiable leaders than the top performing groups. Furthermore, poor situational awareness with neglecting the importance of continuous chest compression resulted in long CPR interruptions and high no-flow time ratio during Thumper deployment (Table 2). The prolonged hands-off among some rescuers during thumper setting accounted for long no-flow time and high no-flow time ratio. It is believed that good leadership and improved situation awareness could contribute to a streamlined device deployment process and better CPR quality.

In this study, the most no-flow time occurred during setting the Thumper[®] and placing the patient on the backboard. We propose the following improvement strategies to improve mechanical device deployment and increase CPR quality.

First, increase familiarity with the mechanical CPR device. Initiating regular mechanical CPR deployment training for resuscitation personnel helps all members familiarize themselves with the operation of the mechanical device.

Second, streamline and standardize deployment strategy. A good mechanical device deployment strategy should be built in to mechanical CPR processes in order to shorten the time required to fully deploy the device.

Third, emphasize no-flow time awareness during mechanical device deployment. Resuscitation participants should be consistently reminded of the importance of no-flow times.

Fourth, include mechanical CPR and teamwork in Advanced Life Support (ALS) course. The addition of an emphasis on team-work and mechanical CPR training during ALS course may improve the performance of health care providers performing mechanical CPR in resuscitations. Fifth, regular reviewing of videos and team feedback. The regular reviewing of performance videos and team feedback should be conducted to improve CPR quality, if video recording of resuscitations is available.^{24–27}

5. Limitation

There are several limitations to this study. This study focused only on the piston-type device (Thumper[®]), and extrapolation to other mechanical devices will need further study. This definition may have underestimated the total no-flow time for each step, as compared with the definition of 1.5 s, suggested by Kramer-Johansen et al.²⁸ However, it appeared that only a small percentage of the no-flow time was within the range of 1–2 s. The small sample size of this study does not allow us to develop linear regression models accounting for all factors related to the resuscitation. Nevertheless, this study still provides valuable insights into the process of deployment of mechanical CPR devices and may help to foster the development of training programs and education to improve the prompt deployment of mechanical CPR devices during ED resuscitation.

6. Conclusion

The essential steps and times for mechanical CPR device (Thumper[®]) deployment were identified by reviewing video recordings; and human factors, such as the lack of familiarity with the mechanical device and the lack of patient positioning strategy were associated with poor deployment performance. Rescuers spent too much time on mechanical device deployment that this resulted in periods with no-flow. More education in device deployment and better deployment strategies are needed to improve the benefits and quality of mechanical CPR.

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Fig. 1.
Steps involved in Thumper® deployment.

Table 1

Baseline characteristics of cardiac arrest patients enrolled in video time-motion analysis.

Characteristics	All	Top performing group ^a (<Q1)	Least performing group ^b (>Q3)	p-Value
Patient characteristics	<i>n</i> = 37	<i>n</i> = 11	<i>n</i> = 10	
Age, median (range), in years	67.0 (54.0–79.0)	64.0 (52.8–79.0)	70.0 (42.0–81.0)	0.75
Men	25 (67.6%)	6 (54.5%)	7 (70.0%)	0.66
Collapse in public place	4 (15.4%)	0 (0.0%)	2 (20.0%)	0.21
Witnessed collapse	14 (37.8%)	4 (36.4%)	4 (40.0%)	1.00
Bystander CPR	3 (8.1%)	1 (9.1%)	1 (10.0%)	1.00
Cardiac cause	29 (78.4%)	9 (81.8%)	6 (60.0%)	0.36
Initial shockable rhythm (missing data = 3)	1 (2.7%)	1 (9.1%)	0 (0.0%)	1.00
Outcome variable				
ROSC	6 (16.2%)	2 (18.2%)	2 (20.0%)	1.00
Survival to admission	2 (5.4%)	0 (0.0%)	1 (10.0%)	0.48
Survival to discharge	0 (0.0%)	0 (0.0%)	0 (0.0%)	–
Body size				
Large	7 (18.9%)	1 (9.1%)	2 (20.0%)	0.73
Median	19 (51.4%)	7 (63.6%)	5 (50.0%)	
Small	11 (29.7%)	3 (27.3%)	3 (30.0%)	
Total time of thumper deployment				
Median (Q1–Q3)	97.0 (82.0–150.0)	76.0 (64.0–80.0)	203.0 (151.0–254.0)	<0.01
Mean ± SD	122.6 ± 57.8	73.3 ± 9.5	201.7 ± 49.9	<0.01

^aTop performing groups: the total deployment time shorter than the first quartile (Q1) groups.^bLeast performing groups: the total deployment time longer than the third quartile (Q3) groups.

Table 2

Average time, no-flow time and no-flow time ratios for each step of Thumper[®] deployment.

	Average time (s)	No-flow time (s)	No-flow time ratio
Tilt the patient	3.9 ± 2.9	3.8 ± 2.9	99%
Insert the CPR backboard	6.6 ± 3.7	6.62 ± 3.7	100%
Place the patient on the board	33.4 ± 38.0	18 ± 17.3	54%
Position the Thumper [®]	14.7 ± 9.5	9.4 ± 8.6	62%
Set the Thumper [®]	57.8 ± 38.3	51.4 ± 32.2	89%
Check depth	6.1 ± 10.6	0 ± 0	0%
Total time	122.6 ± 57.8	89.1 ± 41.2	72.65%

Table 3

Comparison of total time, no-flow time, and no-flow time ratio between time of day and number of rescuers.

	Number of rescuers Mean $\pm$ SD	Total time Median (Q1–Q3)	No flow time Median (Q1–Q3)	No flow ratio (%) Median (Q1–Q3)
Total ($n = 37$)		97.0 (82.0–150.0)	84.0 (62.0–105.0)	78.0 (61.6–92.0)
Day shift ($n = 20$)		102.0 (83.0–166.0)	90.5 (66.5–125.5)	76.6 (64.5–91.4)
Night shift ($n = 17$)		96.0 (76.0–147.0)	70.0 (76.0–147.0)	79.2 (46.9–92.0)
p -Value	<0.001*	0.210	0.061	0.602
Rescuers less than median (<8 rescuers) ($n = 14$) (mean $\pm$ SD)	6.4 $\pm$ 0.7	124.5 (79.0–151.0)	86.5 (61.5–106.3)	78.8 (46.9–94.1)
Rescuers more than median (≥ 8 rescuers) ($n = 23$) (mean $\pm$ SD)	9.3 $\pm$ 1.1	93.0 (82.0–146.0)	84.0 (58.0–101.0)	78.1 (62.2–90.7)
p -Value		0.467	0.439	0.860
Rescuers $\leq$ the first quartile (≤ 7 rescuers) ($n = 14$) (mean $\pm$ SD)	6.4 $\pm$ 0.7	124.5 (79.0–151.0)	86.5 (61.5–106.3)	78.8 (46.9–94.1)
Rescuers $\geq$ the third quartile (≥ 10 rescuers) ($n = 9$) (mean $\pm$ SD)	10.4 $\pm$ 0.5	97.0 (84.0–134.0)	88.0 (66.5–115.5)	78.1 (70.6–90.2)
p -Value		0.668	0.929	0.567

Table 4

Comparing technical and non-technical performance between the top versus least performing groups.

Time spent on every step of thumper deployment (mean (s) $\pm$ SD)	Top performing groups (<i>n</i> = 11)	Least performing groups (<i>n</i> = 10)	<i>p</i> -Value
Tilt the patient	2.9 $\pm$ 2.4	3.9 $\pm$ 2.4	0.353
Insert the CPR backboard	4.5 $\pm$ 2.3	7.5 $\pm$ 4.5	0.063
Place the patient on board	17.7 $\pm$ 7.6	65.8 $\pm$ 62.2	0.037*
Position the Thumper®	10.5 $\pm$ 3.0	11.0 $\pm$ 4.9	0.798
Set the Thumper®	34.6 $\pm$ 15.3	104.6 $\pm$ 37.1	<0.01*
Check depth	3.0 $\pm$ 5.2	8.9 $\pm$ 15.7	0.253
Total time	73.3 $\pm$ 9.5	201.0 $\pm$ 49.9	<0.01*
Non-technical skill			
Leadership	3 (27.3%)	0 (0.0%)	0.21
Situation awareness	8 (72.8%)	7 (70.0%)	1.00
Mutual support	11 (100.0%)	10 (100.0%)	–
Communication	8 (72.8%)	7 (70.0%)	1.00
Total score (mean $\pm$ SD)	2.7 $\pm$ 1.0	2.4 $\pm$ 0.8	0.43

* Top performing group: the total deployment time shorter than the first quartile (Q1). Least performing group: the total deployment time longer than the third quartile (Q3). *p* value < 0.05.