

Evaluation of a novel device that maintains the balance of a cardiopulmonary resuscitation performer in a moving ambulance to improve chest compression quality

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INTRODUCTION According to the findings of some studies, instability due to inertia during changes in speed may negatively impact the quality of chest compressions performed during cardiopulmonary resuscitation (CPR) in a moving environment. This study thus aimed to introduce a simple device that maintains the balance of a person performing CPR in a moving environment, such as an ambulance. We also sought to evaluate the effectiveness of this device in the improvement of the quality of chest compressions.

METHODS The experiment comprised a total of 40 simulated cardiopulmonary arrest scenes (20 in the experimental group and 20 in the control), in which CPR was conducted by eight paramedics. Each simulation involved two paramedics randomly selected from the eight. The ambulance took the same route from the simulated site to the hospital, and continuous CPR was performed on a manikin in the ambulance with or without the aid of our proposed novel device.

RESULTS The average number of chest compressions per simulation in the experimental and control groups was 1330.75 and 1266.60, respectively ($p = 0.095$). The percentage of chest compressions with adequate depth achieved in the experimental and control groups was $72\% \pm 4\%$ and $50\% \pm 3\%$, respectively ($p < 0.0001$).

CONCLUSION By maintaining the balance of the CPR performer, our proposed novel device can offset the negative impact that instability (due to a moving environment) has on chest compressions. The device may also lead to an increase in the percentage of chest compressions that achieve adequate depth.

Keywords: ambulance, cardiopulmonary resuscitation, chest compression, instability, quality

INTRODUCTION

Improving the rate of successful treatment of out-of-hospital cardiac arrest is a challenge for medical staff. Many factors affect the quality of cardiopulmonary resuscitation (CPR), including quality of bystander CPR,⁽¹⁾ traffic conditions, timeliness of advanced life support,⁽²⁾ body mass index (BMI) and physical fitness of CPR performers,⁽³⁾ competency of rescue staff, and quality of the chest compressions performed. The stability of the environment in which CPR is performed plays a significant role in the quality of chest compression. This is important because continuous chest compression are frequently performed during the transport of patients. While the instability caused by changes in speed (during transport) is inevitable, this instability decreases the quality of chest compressions during transport. As such, the environment in a moving ambulance results in a lower percentage of chest compressions that achieve adequate depth, compared to chest compressions performed on an unmoving ground.⁽⁴⁾

In this study, we introduce the use of a novel device, that was designed to minimise the adverse effects of changes in speed in a moving vehicle on the quality of chest

compressions. We conducted a randomised experiment to evaluate the effectiveness of this device in improving the quality of chest compressions.

METHODS

A randomised experiment was conducted to assess the effectiveness of the use of a novel device in improving the depth of chest compressions performed during CPR in a moving environment. Individuals who were not implementers in the experiment were assigned the tasks of grouping, design, data collection and analysis. The randomisation method, including sequence generation, allocation concealment and implementation, is detailed in the Appendix. We used the same route, timing, paramedics and ambulance driver for both the preliminary experiment and actual experiment.

Each simulation required two randomly selected paramedics (out of a total of eight paramedics) to perform CPR. In the experimental group, paramedics performed CPR with the aid of our proposed device, whereas in the control group, the paramedics performed CPR without the aid of the proposed device. A sample size of 40 ambulance trips was required to

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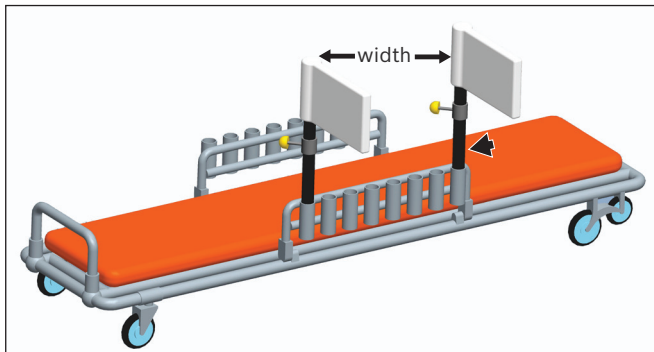


Fig. 1 Schematic diagram shows the proposed device attached to a stretcher. The pole of the device (arrowhead) enables it to be anchored to the stretcher. The width of the proposed device is decided based on the width of the performer's hips.

detect a significant difference in the primary outcome between the experimental and control groups, with a power of 80% and a significance level of 0.05.

The proposed novel device is made of stainless steel and has a rigid structure (Fig. 1). The pole of the device (arrowhead in Fig. 1) can be inserted into a jack anchored to the stretcher. The height of the device can be adjusted so that the rectangular plastic boards are at the same height as the hips of the paramedic performing the chest compression. The device can be installed without interrupting the compressions.

The manikin used in this study was connected to a simple microcomputer (CPR600; Shanghai Medical Device Co Ltd, Shanghai, China) to record the number of chest compressions performed and detect whether adequate compression depth is achieved, using a reference value of > 5 cm. Bag-valve mask ventilation was also performed, but its quality was not evaluated. All the paramedics were blinded to the depth and frequency of the chest compressions, which were displayed on a monitor.

All the paramedics included in this study had at least four years of experience in emergency medicine, was trained according to the 2010 international guidelines for CPR, which recommends a chest compression to ventilation ratio of 30:2, and had volunteered to participate. In each simulation, the two paramedics performing chest compressions alternated every 2 mins. The ambulance driver employed in the experiment was randomly selected from 12 ambulance drivers familiar with the travel route used in the study, and was the same for both the experimental and control groups. The ambulance driver was blinded to what occurred in the patient compartment during the experiment.

The present study conducted a total of 40 cardiopulmonary arrest simulations, which were equally divided into experimental and control groups. In each simulation, the ambulance departed from the same simulated site and drove to the hospital along the same route while continuous CPR was performed on a manikin. The distance between the hospital and the simulation site (i.e. where the cardiopulmonary arrest occurred) was approximately 10.4 km. Simulations

Table 1. Biometric data of the paramedics in the experimental and control groups.

Data	Median (interquartile range)		p-value
	Experimental group	Control group	
Gender			1.00
Female	22	22	
Male	18	18	
Age (yrs)	32.00 (8.75)	34.00 (6.75)	0.191
Weight (kg)	67.00 (11.00)	67.50 (8.00)	0.574
Height (cm)	165.00 (7.00)	165.50 (8.00)	0.397
BMI (kg/m²)	23.00 (3.80)	23.00 (1.80)	0.961

*Data is presented as number. BMI: body mass index

were conducted at both 9 am and 3 pm on weekdays (i.e. two simulations were performed each day). The experiment required 20 days to complete.

Chest compressions began when the ambulance started to leave the simulation site (i.e. the start time) and ended when the ambulance stopped at the hospital gate (i.e. the end time). Chest compressions continued *en route*, regardless of the speed of the ambulance. The duration of each ambulance's journey was consistent with the time spent on chest compressions.

Data pertaining to the depth of the chest compressions performed was collected via the aforementioned micro-computer, using a reference value of > 5 cm. Statistical analyses were conducted using the Statistical Package for the Social Sciences version 13.0 (SPSS Inc, Chicago, IL, USA). Data was assessed using independent sample *t*-test and presented as mean \pm standard deviation when the data fit a normal distribution. Otherwise, data was assessed using independent sample and non-parametric tests, and presented as median (interquartile range). A p-value of < 0.05 was considered statistically significant.

RESULTS

The biometric data of the paramedics are summarised in Table 1. There were no significant differences in age, weight, height or BMI between the paramedics in the experimental and control groups ($p = 0.191, 0.574, 0.397$ and 0.961 , respectively). The results of the preliminary experiment showed that chest compressions of adequate depth was achieved in 78% of the experimental group, while it was achieved in 48% of the control group. The results of the actual experiment are summarised in Table II.

The average speed of the ambulance was 54.73 ± 3.76 km/hr in the experimental group, and 56.37 ± 3.43 km/hr in the control group. There was no statistically significant difference between the two speeds ($p = 0.158$). The number of chest compressions per simulation in the experimental and control groups were 1330.75 and 1266.60, respectively. The difference in the number of chest compressions per simulation between the experimental and control groups was not statistically significant ($p = 0.095$).

Table II. Summary of results of actual experiment.

Parameter	Mean \pm SD		p-value
	Experimental group	Control group	
No. of chest compressions per simulation	1330.75 \pm 123.22	1266.60 \pm 113.55	0.095
Time taken for each simulation (mins)	11.45 \pm 0.80	11.11 \pm 0.70	0.156
No. of compressions per min	116.32 \pm 9.12	114.04 \pm 7.88	0.403
Compressions with adequate depth (%)	72 \pm 4	50 \pm 3	< 0.0001
Average speed of ambulance (km/hr)	54.73 \pm 3.76	56.37 \pm 3.43	0.158

SD: standard deviation

The percentage of chest compressions that achieved adequate depth using the proposed novel device in the experimental group (72% \pm 4%) was more than that achieved without the device in the control group (50% \pm 3%). The difference in percentage of chest compressions that achieved adequate depth between the two groups was statistically significant ($p < 0.0001$).

DISCUSSION

The provision of timely and effective chest compressions by a bystander or medical staff is a key element for patient survival during cardiac arrest, with the quality of chest compressions largely dependent on the depth achieved.⁽⁵⁾ Animal studies have proven that mean aortic pressure, total systemic blood flow⁽⁶⁾ and cardiac output⁽⁷⁾ steadily increase with the depth of the chest compression. Additionally, a clinical study by Kramer-Johansen et al demonstrated a close relationship between increased compression depth and increased short-term survival.⁽⁸⁾

In theory, it is not possible for a vehicle to drive smoothly at a high speed in the midst of heavy traffic or on an uneven road. In such situations, the inertia from changes in speed inevitably produces instability, making it difficult for CPR performers to balance themselves, thus adversely affecting the depth of chest compressions. Even a moving stretcher can have such an adverse effect.⁽⁹⁾ In cases of such instability, those performing chest compressions are unable to control the direction, magnitude and even the point of applied force.

During chest compression, cardiac pumping is the dominant mechanism for generating forward blood flow,⁽¹⁰⁾ though blood flow also results from intrathoracic pressure fluctuation.⁽¹¹⁾ The depth of compression directly determines the extent of compressed cardiac and intrathoracic pressure fluctuations. By enabling the paramedic and the manikin to remain in relatively constant positions, our proposed device ensures that the applied force on the chest has an adequate magnitude and perpendicular direction under moving conditions, ensuring that the compression achieves the standard depth of > 5 cm, based on the 2010 American Heart Association guidelines for CPR.⁽¹²⁾

Our current experiment evaluated the proposed novel device based on its ability to enhance the quality of chest compressions, using the reference value of > 5 cm for adequate

depth as the standard to be compared against. Chest compression frequencies in both the experimental and control groups reached the standard of > 100 compressions/min. In the control group, the number of compressions per simulation was 1266.60, but the percentage of chest compressions that achieved adequate depth was only 50% (Table II). This low percentage confirms present speculations that the quality of chest compressions is relatively substandard during transport,⁽¹³⁾ and that the survival rates of patients with cardiac arrest who are given CPR while transported to a hospital remain poor.^(14,15) In the experimental group, the number of compressions per simulation was 1330.75 and the percentage of chest compressions achieving adequate depth significantly increased by 22% ($p < 0.0001$), as compared to the control group, to 72%. Hence, the experiment demonstrated the ability of the device to improve the quality of chest compressions.

This experiment simulated real-life CPR. The ambulance driver was a pre-hospital care staff, and the paramedics were skilfully trained and adhered to the 2010 American Heart Association guidelines for CPR.⁽¹²⁾ The microcomputer connected to the manikin was able to accurately measure the percentage of chest compressions that achieved adequate depth. With regard to practical application, our proposed novel device has a number of advantages such as simple fabrication, low cost, sturdiness, durability and ease of use. Furthermore, it does not require a power supply for use.

Although the present study has many strengths, it is not without limitations. One limitation is that the same paramedics may have been involved in both the experimental and control groups because of our randomisation process (refer to Appendix). Therefore, they could not be blinded to the presence of the device. Thus, if they recognised the device and realised the purpose of the experiment, the positive effect of the device might have been exaggerated, resulting in a false-positive result. Other limitations include the possible inconvenience of the device to paramedics during defibrillation. Also, the microcomputer used was not able to measure the complete relaxation of the compressions and hands-off fraction.

In conclusion, our proposed novel device may increase the percentage of chest compressions that achieve adequate depth during CPR in a moving environment. It may also improve the quality of chest compressions by allowing for continuous chest compressions. However, a large randomised

experiment is required to affirm the positive effect of the device on actual patients experiencing cardiac arrest.

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APPENDIX

Randomisation process

Step 1: A table consisting of 41 rows and 9 columns was created.

Step 2: Sequence numbers 1 to 40 were assigned to the 40 simulations and filled the first column of the table. Eight alphabets from A to H were each assigned to the eight paramedics and filled the first row of the table. The blank spaces in the table were then filled in with random numbers. The two alphabets corresponding to the largest and smallest random numbers in each row represented the paramedics participating in the simulation.

Note: A total of 40 simulations were randomly and equally divided into the experimental and control groups.

Step 3: Two copies of the table was printed. One copy was cut into 40 parts (according to the row labels) and placed into 40 light-tight envelopes. Each envelope contained a note with the family names of two paramedics and information about either the experimental or control group. The second copy of the table was opened after the experiment to check whether the first copy was maliciously modified.