2023 45th Annual International Conference of the IEEE Engineering in Medicine & Biology Society (EMBC) | 979-8-3503-2447-1/23/$31.00 ©2023 IEEE | DOI: 10.1109/EMBC40787.2023.10340167

High-Quality Chest Compression for Cardiopulmonary Resuscitation Using Newly-Designed Automatic Device*

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***Abstract*—High-quality chest compression during cardiopulmonary resuscitation (CPR) can remarkably improve survival rate and reduce the risk of secondary injury. In this study, a newly-designed automatic chest compression device was applied on an animal model and the effects of chest compression were examined in comparison of manual compression and machine compression by a commercialized device. Three pigs (weight:30±2 kg) were used for the experiment. A LUCAS2 CPR machine and the newly-designed CPR device were used for automatic compression treatment. Compression pressure and chest displacement were collected in the process of CPR. Regarding the statistical distribution of compression depths, the new CPR device showed a mean of the depths at 1.64 inches, which was greater than that of manual (mean = 1.21 inches) and of LUCAS2 (mean = 1.18 inches). In addition, the new CPR device showed a standard deviation (SD) of compression depths at 0.07 inches, which was lower than that of manual (SD = 0.15 inches) and of LUCAS2 (SD = 0.25 inches). These results suggested that the new CPR device performed higher compression depths with lower compression variability, indicating enforced compression and better stability. This study provided a preliminarily outcomes validating the new CPR device, which may play a role in high-quality chest compression for the first aid in emergency.**

***Clinical Relevance*— This study established an animal model to validate a newly-designed automatic device for CPR. Comparing with manual chest compression and automatic compression using LUCAS2, the new device showed greater compression depths and better stability, which may provide more effective CPR treatment for clinical usage.**

I. INTRODUCTION

Chest compression plays a key role in cardiopulmonary resuscitation (CPR) for a variety of emergency events [1]. High-quality chest compression, such as higher compression depths, more stable compression or labor-free continuous compression can effectively improve cardiovascular perfusion and survival rate and reduce risk of second injury. Conventional chest compression requires a compression frequency greater than 100 times/min and a compression depth at least 2 inches for each trial [2]. However, due to the limited power and endurance, lack of experience, unprofessional operation and environmental disturbance, the quality of manual chest compression is rather difficult to guarantee, leading to unsatisfactory effects and even second injuries to patients. Therefore, to perform chest compression using automatic device rather than manual operation for CPR has become an urgent demand in emergency medicine.

Automatic CPR devices can be driven by electrical and pneumatic power. Electrical CPR devices, such as LUCAS2, and pneumatic devices, such as Autopluse, have been used in the out-of-hospital and in-hospital emergency treatment [3]. Such automatic devices can improve the stability of mechanical parameters during the chest compression phase [4, 5]. These devices have been validated in many clinical trials and have demonstrated that these automated CPR devices can achieve better quality of chest compressions than manual CPR [6]. However, pneumatic devices must rely on heavy gas sources during use, and the effect of electric devices must rely on the power of motor, which would be influenced by the body type. With this purpose, we have designed a new automatic compression device for CPR. This device is driven by electrical power and all the mechanical parameters can be online adjusted and recorded to ensure the stability of the trapezoidal press wave. However, it is still unknow the functioning performance of this newly-designed device in comparison of the LUCAS2 or manual compression.

This study aimed investigate the functioning performance of the newly-designed automatic CPR device. An animal model was established to examine the quality of chest compression during CPR, comparing with manual and LUCAS2 compressions. We hypothesized that the new CPR device had higher compression depths with more stable functioning than the manual and LUCAS2 CPR device. This study may provide preliminary results for validating the new CPR device for clinical emergency treatment.

II. METHODS

A. Characteristics of Newly-Designed CPR Device

A newly-designed automatic device for implementing standard chest compression parameters had been developed. The new chest compression device was powered by a 48 V power supply with a servo motor driven filament rod for compression operation. The new device has a compression frequency of 100 times/min and a compression depth of 2 inches. The parts required for this device were designed using SolidWorks and fabricated using 3D printing technology. The press waveform used in this device is trapezoidal wave, including four components, and the time of each phase was set to 150 ms [7]:

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* This research was supported by the Key Research & Development Programs of Guangdong Province (2020B0909020004), National Key Research and Development Program (2020YFC1512701), Foundation of Clinical Research Center of Shandong University (2021SDUCRCD005) and Interdisciplinary Young Researcher Groups Program of Shandong University (2020QNQT004).

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- Pressing period: During this period, the press rod continued to press the chest to the maximum depth. The actual time of this phase was 162±15 ms.
- Retention period: During this period, the press rod reached the maximum press depth and held for a period of time, the actual time of this stage was 138±15 ms.
- Release period: In this stage, the press rod bounced back to the starting position of the press rod. The actual time of this stage was 162±15 ms.
- Waiting period: In this stage, no compression operation is performed and the chest is waiting for full rebound. The actual time of this stage was 138±15 ms.

The device is controlled by Arduino and has a pressure sensor and a displacement sensor inside this device to record data in real time and communicate with the computer through the serial port. The new CPR device and the waveform were shown in Fig 1. The waveform of the new device was compared with the waveform of previous animal experiment on the mathematical model of computer and obtained a better result of blood flow. In order to ensure the stability of the compression process, this study set up every three compressions to calibrate the compression position, while using the incremental control method to control the compression depth. After the preliminary experimental test, the compression depth error was less than ±1 mm under no-load condition, less than ±2 mm under CPR simulator condition, and the compression frequency error was less than ±3 times/minute, which met the requirements of animal experiments.

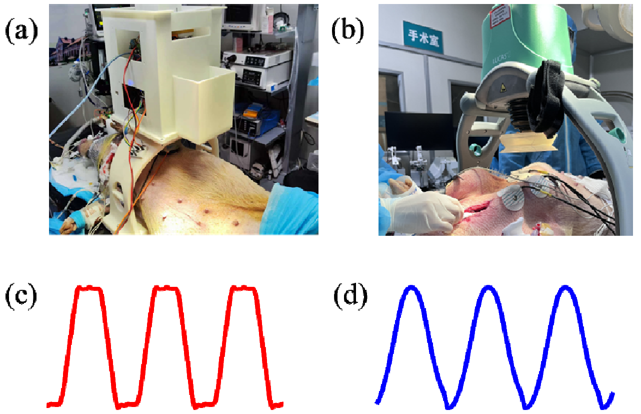

Figure 1. Chest compression devices. (a) the newly-designed automatic device. (b) LUCAS2 CPR device. (c) the waveform of newly-designed CPR device. (d) the waveform of LUCAS2 CPR device.

B. Measuring Devices

In this study, a FASTRAK-based data measurement system was designed. The system contains a total of one base coordinate device and four loci sensors, which can collect and record in real time and display the position and inclination angle of the four loci relative to the base coordinates on the software side. In this study, one of the loci was selected and combined with a pressure sensor to collect pressure-displacement data during chest compressions in real time and transfer it to a computer. And the data acquisition device was shown in Fig 2.

In this study, the data measurement point during chest compressions was selected to be the left side of the sternum of the experimental animal, and the pressure sensor and displacement acquisition device were placed at this location, with the surface of the acquisition device wrapped by a soft foam material, which did not damage the epidermal tissue of the experimental animal during chest compressions. The overall sampling frequency of the FASTRAK system used in this study was 120 Hz, and the sampling frequency of a single point was 30 Hz. The range of the pressure transducer used for pressure acquisition during chest compression was 1000 N, and the pressure sampling frequency was 120 Hz.

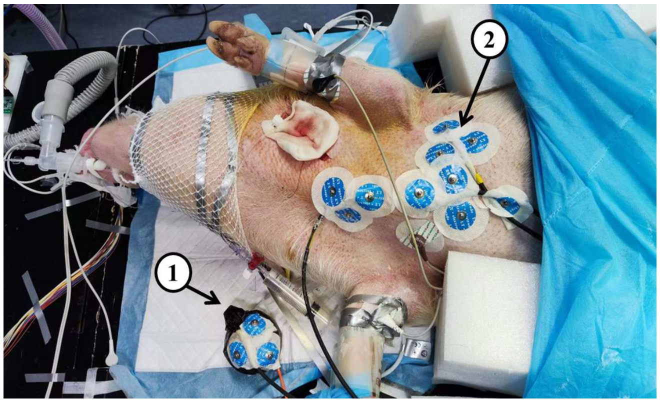

Figure 2. Location of data acquisition device. ①: the locations of electrodes for the compression force and depth data acquisition. ②: the location of compression during CPR.

C. Data Acquisition

In this study, we mainly collected real-time compression data from the device, including compression numerical data inside the compression device, pressure and displacement of the experimental animal at the left side of the chest at the compression position. The data in this study were collected from three healthy Bama pigs weighing 30±2 kg. The experimental procedures were approved by the Institutional Review Board of Shandong University (KYLL-2020(KS)-340) and were in accordance with the Declaration of Helsinki.

Data on the displacement of the compression device during chest compressions using the LUCAS2 CPR device were also collected in this study. Real-time depth data and pressure data of manual chest compressions performed by professional therapists were also collected in this study[8]. The compression location for recording data in this study was set to the left side of the sternum of the experimental animal, where the displacement sensor and pressure sensor were placed. During chest compressions, the pressure-position acquisition device was placed at the end of the compression bar of the new device and fixed by special parts. Also, in order to collect compression depth data from the LUCAS2 device, the data collection site was fixed at the suction cup position of the device in this study.

III. RESULTS

In this study, the data acquisition during chest compressions were processed and the continuous waveforms were segmented to obtain the data of pressure, depth and frequency. The press parameters were fitted by Gaussian, and the results (best-fit values) were shown in the tables.

A. *Depth of Chest Compression*

As the results showed in Table 1 and Fig 3. In terms of compression depth, the maximum compression depth of the new device in this study was 2.03 inches, the minimum compression depth was 0.88 inches. The standard deviation (SD) of the press depth of new device (0.07 inches) was lower than that of manual press (0.15 inches) and LUCAS2 (0.25 inches), and the mean of the press depth of new device (1.64 inches) was largest. The new CPR device showed a mean of the depths at 1.64 inches, which was greater than that of manual (mean = 1.21 inches) and of LUCAS2 (mean = 1.18 inches). The new CPR device showed a SD of compression depths at 0.07 inches, which was lower than that of manual (SD = 0.15 inches) and of LUCAS2 (SD = 0.25 inches).

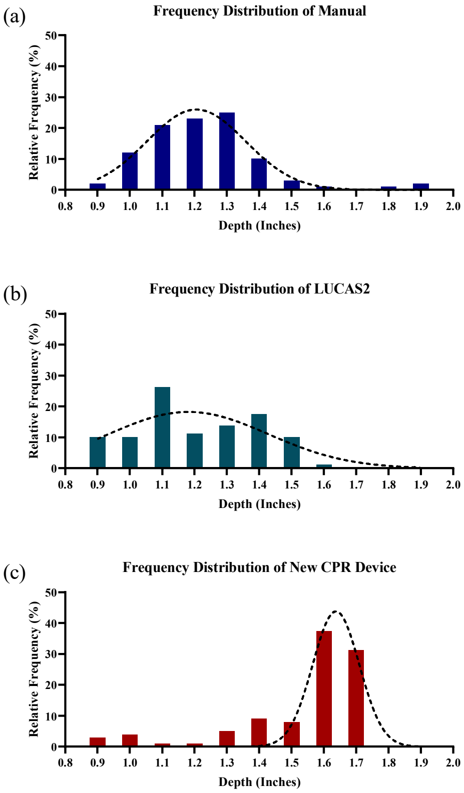

Figure 3. Frequency distribution of the depth in three chest compressions. Automatics is the newly-designed automatic device. (a) frequency distribution of depth of manual chest compression. (b) frequency distribution of depth of LUCAS2. (c) frequency distribution of depth of the new CPR device.

TABLE I. DEPTH DISTRIBUTION

Classification	**Amplitude (%)**	**Mean (inches)**	**SD (inches)**
Manual	25.99	1.21	0.15
LUCAS2	18.25	1.18	0.25
New Device	43.78	1.64	0.07

SD is standard deviation, Mean is arithmetical mean

B. *Frequency of Chest Compression*

In this study, the compression frequency was calculated for the three compression cases by processing the displacement signal of the compression position. Results were shown in Table 2 and Fig 4.

Among them, the stability of the compression frequency of the chest compression operation using the new device was higher than that of the manual chest compressions performed by professional therapists. The new CPR device showed a mean of the frequency at 91.46 times/min, which was lower than that of manual (mean = 142.40 times/min) and of LUCAS2 (mean = 121.10 times/min, Fig 4b). The new CPR device showed a SD of compression frequency at 6.29 times/min, which was lower than that of manual (SD = 6.69 times/min) and of LUCAS2 (SD = 6.87 times/min).

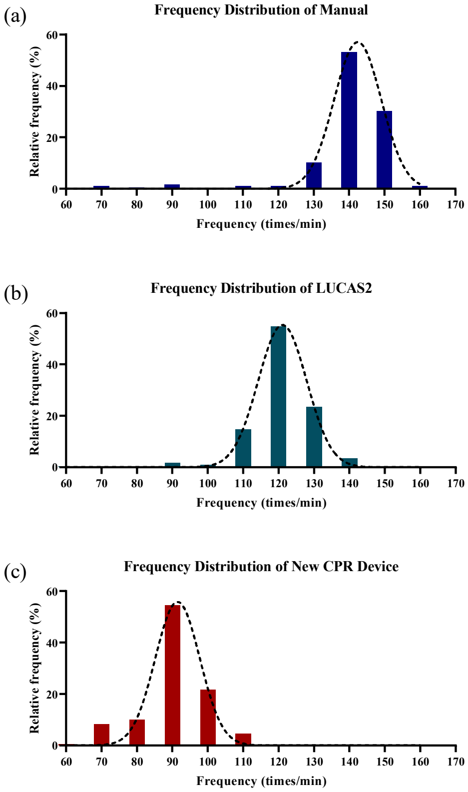

Figure 4. Frequency distribution of the frequencies in three chest compressions. (a) frequency distribution of frequency of manual chest compression. (b) frequency distribution of frequency of LUCAS2. (c) frequency distribution of frequency of the new CPR device.

TABLE II. FREQUENCY DISTRIBUTION

Classification	**Amplitude (%)**	**Mean (times/min)**	**SD (times/min)**
Manual	57.07	142.40	6.69
LUCAS2	55.31	121.10	6.87
New Device	55.84	91.46	6.29

SD is standard deviation, Mean is arithmetical mean

C. *Force of Chest Compression*

In this study, the SD of the press force of the new device at 9.66 N, which is lower than that of manual press (SD = 24.00 N). Results were shown in Table 3 and Fig 5. The new CPR device showed a mean of the frequency at 99.03 N, which was lower than that of manual (mean = 138.80 N).

IV. DISCUSSION

This study aimed to investigate the effects of the

TABLE III. FORCE DISTRIBUTION

Classification	**Amplitude (%)**	**Mean (N)**	**SD (N)**
Manual	20.38	138.80	24.00
New Device	59.66	99.03	9.66

SD is standard deviation, Mean is arithmetical mean

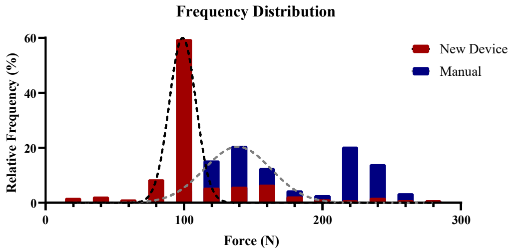

Figure 5. Frequency distribution of new CPR device and manual compression

newly-designed automatic CPR device which was applied on an animal model and the effects of chest compression which were examined in comparison of manual compression and machine compression by LUCAS2 CPR device.

Results showed that the statistical distribution of compression depths of the new device was more stable than that of manual and LUCAS2. It is noteworthy that most of compression depth data was concentrated in 1.64 inches, which is the largest mean among these three kinds of chest compression. The values of mean of chest compression of the new device closer to 2 inches, indicate more compression [2, 9]. This finding would suggest that chest compression with stable trapezoidal press waveform produced by the new device is conducive to maintaining stability of the press parameters. It is undeniable that the data error caused by the shaking of the device and the left-sided compression position will also affect the final statistical results.

Previous studies have shown that the frequency of chest compressions with automated devices is more stable compared to manual compressions [10]. By contrast, according to the results of the mean frequency of the three kinds of chest compression, the new device was closest to the frequency of 100 times/min, more stable and more accurate than that of manual and LUCAS2. In addition, the frequency of new device was lower than 100 times/min, but at full speed, the new device could perform close to 120 times/min. To ensure waveform stability, the new device was set to perform waveform calibration every three compressions, which significantly affected the press frequency. Some previous studies have showed that the compression frequency of LUCAS2 was nearly standard frequency, the actual frequency of the new device might be lower than the standard compression frequency.

Some previous studies used the pressure of chest compression to evaluate the quality of chest compression and calculate the relevant parameters rather than depth. Results of pressure further showed that the new device has a lower SD and mean than those of manual. This indicated that the stability of pressure of the new device was better than that of manual, and the decreased press accuracy reflected by the greater SD. The result was different from the result of depth data, these changes could be resultant from the position of the compression and the offset of the acquisition device. In this study, the data of blood flow was also collected. It was worth noting that the results of blood flow of the new device were better than those of others, which might be related to the parameters setting of the chest compression and the difference between waveforms.

The experimental results showed that the new device had the greatest compression depth and was the closest to the standard human compression frequency among all types, and the depth values were evenly distributed, which tentatively proved that newly-designed automatic device was effective in use. To prevent damage, the pressure data of the LUACS2 device were not recorded in this study. It is noteworthy to consider that the new device was designed with reference to the physiological dimensions of the CPR simulator, which has important role in the results of animal experiments, and it is also an aspect we need to improve in the subsequent study.

V. CONCLUSION

This study investigated the effects of the newly-designed automatic device for CPR on the animal model. Results showed that the parameters of new device were more similar to standard chest compressions and more stable distribution than those of manual and LUCAS2 chest compressions. This study provided a preliminarily outcomes validating the new CPR device, which may play a role in high-quality chest compression for the first aid in emergency.

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