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Short paper

Kinetics of manual and automated mechanical chest compressions

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Abstract

Aim: Early onset of adequate chest compression is mandatory for cardiopulmonary resuscitation (CPR) following cardiac arrest. Transmission of forces from chest strain to the heart may be variable between manual and mechanical chest compressions. Furthermore, automated mechanical chest devices can deliver an active decompression, thus improving the venous return to the heart. This pilot study investigated the kinetics of cardiac deformation during these two CPR methods.

Methods: Transesophageal echocardiographic analysis of the right ventricular wall behind the sternum during CPR was assessed during manual and mechanical chest compression in adult patients admitted to the emergency department for out-of-hospital cardiac arrest.

Results: 9 patients had manual and 11 mechanical chest compression. Mechanical chest compression was characterized by greater right ventricular lateral wall displacement [with a median (IQR) of 3.7 (3.12−4.27) vs. 2.53 (2.27−2.6) cm, $p < 0.0001$], and lower rising time [123 (102−169) vs. 187 (164−215) ms, $p = 0.002$], relaxing time [109 (102−127) vs. 211 (133−252) ms, $p = 0.0003$], compression rate [100.6 (99.6−102.2) vs. 131.9 (125.4−151.4) bpm, $p < 0.0001$], with compression-decompression time ratio of [1.04 (0.86−1.1) vs. 0.86 (0.78−0.96), $p = 0.046$].

Conclusion: Mechanical compared to manual chest compression delivered a more rapid compression and decompression of the cardiac structures at an adequate rate, with broader inward-outward movement of the ventricular walls suggesting greater emptying and filling of the ventricles. Transesophageal echocardiography may be a useful tool to assess the adequacy of chest compression without CPR interruption.

Keywords: Cardiac arrest, Cardiopulmonary resuscitation, Transesophageal echocardiography, External cardiac massage

Introduction

Cardiac arrest, despite its resource consumption, is still an event characterized by poor outcome. Early delivery of adequate cardiopulmonary resuscitation (CPR) plays a crucial role in the chain of survival. Deep compressions, complete-chest recoil, and appropriate rate are mandatory during CPR and directly influence both survival rate and neurologic outcomes.[1–3] Sudden and complete chest recoil generates negative intrathoracic pressure enhancing shift of blood from the venous compartment towards the right atrium and ultimately raising the cardiac preload.[4] Although trained teams usually perform CPR, high-quality chest compressions are variably achieved in real-life settings[5–7] due to rescuer fatigue, chest compression interruptions, inadequate compression depth and incomplete chest recoil.[4] Automated mechanical chest compression devices can guarantee a standardized depth and rate of compressions. Moreover, piston devices may ensure an active decompression phase strengthening the negative intrathoracic pressure and therefore increasing the amount of blood returning to the heart, which has been considered a critical determinant of survival after cardiac arrest.[8–10] Even though these encouraging theoretical premises, the use of mechanical

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devices has not been associated with better outcome in clinical trials.[11–13]

The effect of chest compressions on the cardiac chambers during cardiac arrest can be evaluated through transesophageal echocardiography (TEE) with no interruption of CPR. The inward and outward movements of the ventricular walls are essential preconditions for ventricular filling, blood ejection into the circulatory system, and can be measured by TEE during CPR.

We conducted this clinical pilot study with the aim of measuring the kinetics of automated and manual chest compression on the ventricular walls.

Methods

This retrospective cohort study was conducted on patients consecutively admitted between July 2015 and June 2018 to the emergency department of the Luigi Sacco Hospital in Milan, a referral center for extracorporeal life support, with criteria for extracorporeal cardiopulmonary resuscitation (ECPR) following refractory out-of-hospital cardiac arrest. The publication of data was authorized by the Institutional Ethical Committee (Comitato Etico Milano Area 1, ASST Fatebenefratelli Sacco, approved on 20th June 2018).

All patients with out-of-hospital witnessed cardiac arrest, age between 18 and 75 years, time from the event to CPR start ("no flow time") <6 min, absence of significant comorbidities or terminal illness, unsuccessful 20 min advanced cardiac life support treatment and expected event to hospital arrival (event-to-door) time <65 min were carried to the Emergency Department of our hospital to perform ECPR. On the patient arrival, a fast-focused two-dimensional TEE exam was performed, with no CPR interruption, by an ICU physician (EC) expert in echocardiography. The multiplane transesophageal probe (Philips X7-2 t TEE transducer on Philips Epiq 7 ultrasound system, Philips Healthcare, Andover, MA) was introduced into the esophagus, and the heart and ascending aorta were briefly examined to search for possible causes of the cardiac arrest and to rule out aortic dissection. Chest compression was continued during the introduction of the probe and the examination. Images and video clips were stored digitally and analyzed off-line (Philips QLAB, Philips Healthcare, Andover, MA).

Echographic measurement

After the correct visualization of the four-chamber midesophageal view, the displacement of the right ventricular lateral free wall was sampled by ultrasound M mode (Fig. 1), and a clip acquired during CPR maneuvers was stored and analyzed offline.

For this study, we considered the following variables of the compression-decompression cycle (Fig. 2): rising time, relaxing time, compression time, decompression time expressed in absolute value and percentage of the cycle time, and right ventricular lateral wall shift.

Statistics

The normality distribution of variables was checked with D'Agostino –Pearson test. Comparison of demographic and baseline clinical parameters was performed by Student's *t*-test for unpaired samples for variables normally distributed, and the Mann–Whitney rank-sum

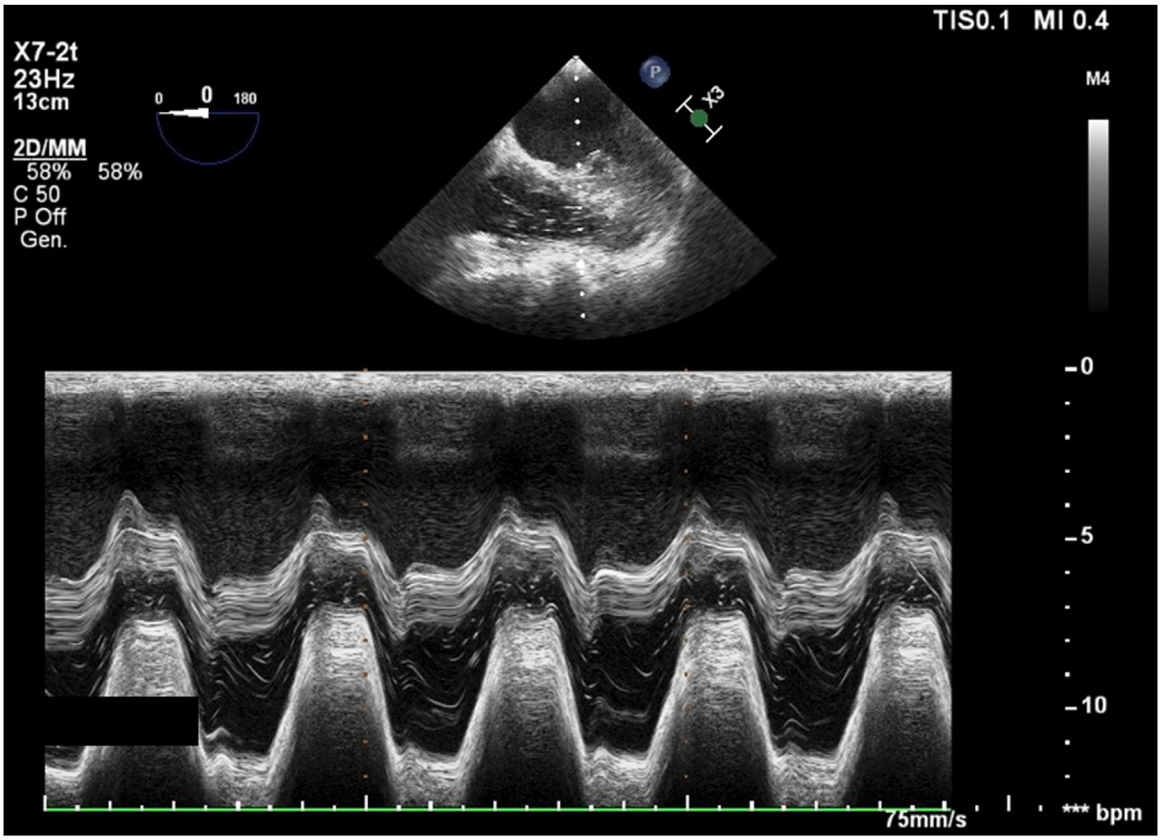

Fig. 1 – Midesophageal four-chamber view at 0° with monodimensional (M mode) sampling of the lateral free wall of the right ventricle just behind the sternum.

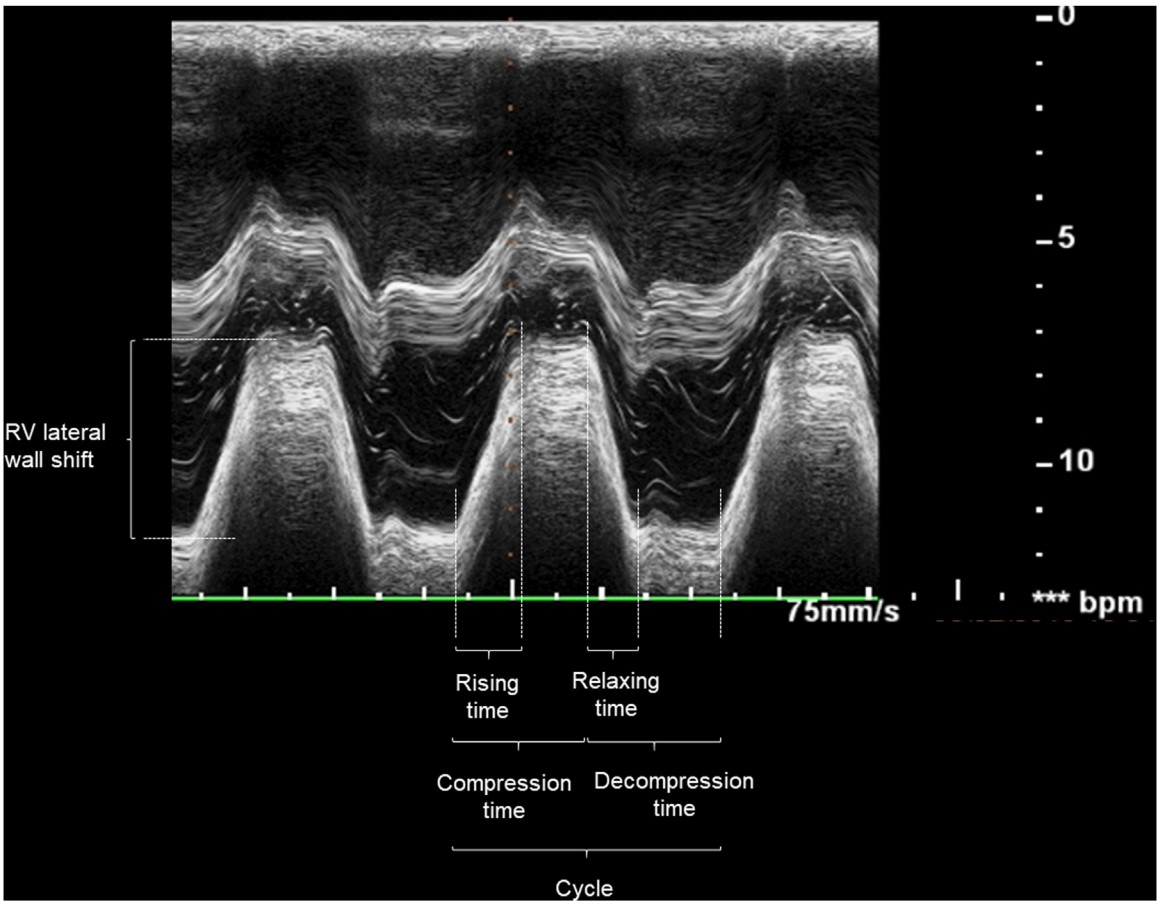

Fig. 2 – M mode echocardiographic midesophageal sampling of the lateral wall of the right ventricle. Each chest compression cycle was divided into its components: *Rising time*, time from the beginning of chest compression to the maximal ventricular wall displacement; *Compression time*, time from the start of chest compression to the outward displacement of ventricular wall; *Relaxing time*, time occurred o ventricular wall to complete the outward displacement; *Decompression time*, time from the beginning of outward ventricular wall displacement until next compression. *Vertical arrow* on the left side shows the right ventricular (RV) lateral wall displacement.

Table 1 – Demographic characteristics and echocardiographic finding of the studied subjects.

	Manual (n = 9)	Mechanical (n = 11)	p
Age (years)	56 (47–62)	52 (43–60)	0.39
Weight (kg)	80 (72.5–105)	80 (70–86.2)	0.75
BMI	26 (24.2–32.8)	26.7 (24.1–30.6)	0.9
Male/Female (n)	8/1	10/1	1
No flow (min)	0 (0–2)	2.5 (0–5)	0.08
RV lateral wall shift (cm)	2.53 (2.27–2.6)	3.7 (3.12–4.27)	<0.0001
Rising time (ms)	187 (164–215)	123 (102–169)	0.002
Relaxing time (ms)	211 (133–252)	109 (102–127)	0.0003
Compression speed ($cm\,s^{-1}$)	14.8 (12.3–17.6)	25.1 (19.9–36.5)	0.001
Decompression speed ($cm\,s^{-1}$)	14.7 (11.4–16.7)	28.9 (25.1–36.9)	<0.0001
Compression time (ms)	208 (186–214)	298 (279–313)	<0.0001
Decompression time (ms)	258 (205–263)	289 (283–325)	0.0001
Rising phase (%)	46.6 (34.8–49.6)	20.2 (17.3–29.5)	<0.0001
Compression phase (%)	46.3 (43.8–49.1)	51 (46.2–52.2)	0.055
Decompression phase (%)	53.8 (50.8–56.1)	48.9 (47.7–53.7)	0.052
Cycle (ms)	450 (397–478)	596 (587–602)	<0.0001
Comp/decomp ratio	0.86 (0.78–0.96)	1.04 (0.86–1.1)	0.046
Compression rate (bpm)	131.9 (125.4–151.4)	100.6 (99.6–102.2)	<0.0001

For definitions of compression-decompression intervals see the Fig. 2. Intervals are shown as absolute value (ms) and as percentage (%) of the length of compression-decompression cycle.

test for variables not normally distributed. Data are shown as median (IQR). Statistical significance was defined as $p < 0.05$ for the two-tail test. Analysis was performed using Graphpad Prism 5 (GraphPad Software, San Diego, CA) for Windows.

Results

Sixty-seven patients were consecutively admitted to the Emergency Department for non-traumatic out-of-hospital refractory cardiac arrest with indication to ECPR. Automated mechanical chest compression device (LUCAS 2; Jolife AB, Lund, Sweden) was used in 41 patients, and manual chest compression was performed in 26 patients. 25 patients were in cardiogenic shock after the return of spontaneous circulation at the time to hospital arrival, two patients had aortic root dissection and one patient cardiac tamponade and were not included in the study. Complete echocardiographic data, with mono and bidimensional midesophageal four-chamber views of adequate quality, were available in 11 patients with mechanical compressions and 9 patients with manual compressions and were analyzed. Advanced cardiac life support was performed in all cases by the physicians of the emergency medical system according to the current guidelines.[14] The presumed cause of arrest was unknown; none of the patients had a history of pre-existing cardiac disease.

The main results are shown in Table 1. There was no difference in demographic data and body mass index between patients with manual and mechanical chest compressions.

Mechanical chest compression was characterized by greater right ventricular lateral wall inward displacement, compression and decompression speed, compression and decompression time, cycle time, and lower rising time, relaxing time, and compression rate. The proportion of rising time within each cycle was significantly higher in manual than in mechanical chest compression, lasting almost for the entire compression phase, thus characterizing a sinusoidal compression-decompression pattern (Fig. 3).

Discussion

This study found that in a real-life scenario, on selected patients with witnessed out-of-hospital cardiac arrest candidate for ECPR, mechanical chest compressions was superior to manual chest compression in terms of compression rate, degree of heart compression, compression rising, and relaxation promptness.

There is evidence that both depth and rate of chest compressions affects the outcome of cardiac arrest.[15] The European Resuscitation Council Guidelines for Resuscitation recommend that compression depth be at least 5 cm but not greater than 6 cm, and rates between 100 and 120 compressions per min.[15] The highest survival rate was found linked to compressions between 40.3 and 55.3 mm (with a peak at 45.6 mm) depth after adjustment for confounders.[16] Maximal benefit is seen in the range of 100−120 compressions per min, above or below which survival decline.[17] At higher compression rates, the quality of chest compressions declines probably because rate and depth are inversely related.[17]

Furthermore, faster rates reduce the venous return and cardiac filling because of short decompression time for chest recoil, hence forward blood flow accordingly diminishes.[4] Although most of the above are strong recommendations, their level of evidence is generally low, and many studies led to contrasting results.[18] Moreover, some authors have found poor compliance with the recommended targets resulting in a wide variability in CPR quality.[5–7] Furthermore, energy transfer from chest deformation to the internal structure, and ultimately to the ventricles, is affected also by the body characteristics which are variable between subjects. The cardiac pump theory assumes that compression of the heart between the sternum and the vertebral column generates the pressure needed to squeeze blood from the right ventricle into the pulmonary artery and from the left ventricle into the aorta. The amount of chest compression transferred to ventricular chambers can be measured by TEE without CPR interruption. The inward and outward movements of the ventricular walls suggest filling and emptying ventricles. In our patients, the shift of right ventricular lateral wall, which is just behind the sternum, was greater with mechanical compression. During chest recoil and rib cage expansion, a negative intrathoracic pressure is generated, lowering the right atrial pressure, which increases venous return to the right cardiac chambers.[4] The active decompression achieved by mechanical device shifts the right ventricular lateral wall leftward (towards the initial “end-diastolic” position) with a very rapid slope, suggesting fast and full chest recoil. Therefore, the active decompression phase may increase the amount of blood return to the heart. In our patients, the right ventricular wall shift was faster both

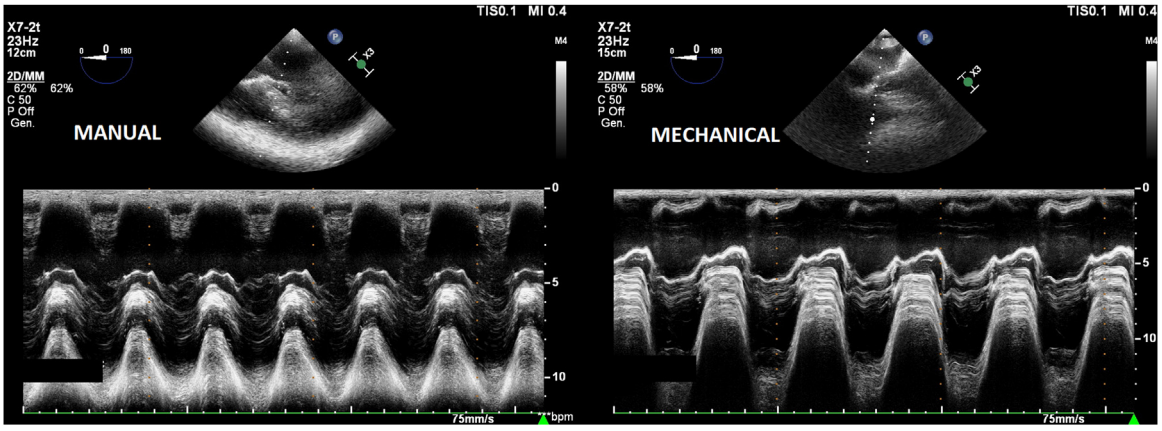

Fig. 3 – M mode sampling of the RV lateral wall just behind the sternum during manual chest compression (*left panel*) and after beginning of automated mechanical chest compression (*right panel*) in the same subject. Automated mechanical chest compression determined the transition from a sinusoidal to a squared pattern.

during compression and decompression with mechanical than with manual chest compression. Furthermore, the decompression period was longer with mechanical compression, thus potentially promoting ventricular preload.

Although in this exploring study, the mechanic of heart compression-decompression was better from a physiologic point of view with mechanical than manual chest compression, they resulted in similar survival rates in clinical studies.[11–13] Positioning the mechanical devices temporarily interrupts CPR with decline of cerebral perfusion pressure. Thereby the current recommendations do not support or refute the routine use of mechanical CPR devices[19,20] while remaining a reasonable alternative to manual chest compressions when high-quality manual chest compressions are not feasible or dangerous for the provider or during preparation for extracorporeal ECPR.

In conclusion, in patients with out-of-hospital cardiac arrest selected for ECPR, transesophageal echocardiography may help to assess the quality of chest compression without interruption of CPR, and automated mechanical chest compression resulted in a more favorable kinetics of heart compression than manual chest compressions.

Conflict of interest

We wish to confirm that there are no known conflicts of interest associated with this publication and there has been no significant financial support for this work that could have influenced its outcome.

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