

# AUTOMATED CARDIO PULMONARY RESUSCITATION

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## Abstract

Cardio Pulmonary Resuscitation (CPR) has saved the lives of countless patients in cardiac arrest. It generates a small but critical amount of blood flow to the heart and brain to preserve its functioning. CPR procedure demands successive, uniform and quality chest compressions administered to the subject until help arrives. Achieving this through manual technique demands a lot of energy and multiple trained medical personnel. To overcome this bottleneck, we have designed an electro-mechanical device that is intended to deliver the best quality compressions and the best quality life-saving care. Our device works in three modes- (15:2), (30:2), and continuous mode and delivers 120 compressions per minute producing a compression depth of 2 inches. When tested with a load cell, the device delivered a force of 22 pounds (10 kg). This prototype was built at a low cost and is also planned to be scaled up to a commercial, fully working, portable CPR device.

**Keywords:** Con

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## INTRODUCTION

Cardiopulmonary resuscitation (CPR) is a lifesaving technique useful in many emergencies, including a cardiac arrest or near drowning, in which the subject's breathing or heartbeat has stopped. CPR can keep oxygenated blood flowing to the brain and other vital organs until more definitive medical treatment can restore a normal heart rhythm. When the heart stops, lack of oxygenated blood can cause brain damage in only a few minutes- A person may die within eight to 10 minutes of cardiac arrest [9]. Keeping the blood flow active, even partially, extends the opportunity for a successful resuscitation once trained medical staffs arrive on site. CPR must be performed within four to six minutes after cessation of breathing to prevent brain damage or death. CPR consists of rescue breathing, which delivers oxygen to the victim's lungs, and external chest compressions, which help circulate blood through the heart to vital organs.

**Table I: Difference between Cardiac Arrest and Cardiac Attack**

Cardiac arrest	Cardiac attack
Occurs suddenly. It is triggered by an electrical malfunctioning of the heart causing an irregular heartbeat (arrhythmia). The heart cannot pump blood to the brain, lungs and other organs and seconds later, the person loses consciousness. Death occurs within minutes if the victim does not receive treatment. Cardiac arrest is an ELECTRICAL problem.	Occurs when a blocked artery prevents oxygen-rich blood from reaching a section of the heart. If the blocked artery is not reopened quickly, the part of the heart begins to die. The longer a person goes without treatment, the greater the damage. Cardiac attack is a CIRCULATION problem.

## MANUAL CPR PROCEDURE

In first aid, 'ABC' stands for airway, breathing, and circulation. The recovery position helps minimize further injury [5].

- Airway: The airway must be clear. Choking, which results from the obstruction of airways, can be fatal.

## METHODS OF CARDIO PULMONARY RESUSCITATION

### a. Compressions with rescue breaths

A universal compression to ventilation ratio of 30:2 is recommended for adults. With children, considering 2 trained rescuers are present, a ratio of 15:2 is preferred [11].

### b. Compression only

For adults with cardiac arrest, compression-only (hands-only or cardio-cerebral resuscitation) CPR which involves chest compressions without artificial ventilation is recommended for the untrained rescuer [13].

CPR procedure must be done only in the case of cardiac arrests, which is usually confused with cardiac attacks. Table I explains how cardiac arrests differ from cardiac attacks.

- Breathing: Once the airways are confirmed to be clear, determining whether the person can breathe, and, if necessary, providing rescue breathing is an important step.
- Circulation: If the person is not breathing, the first aider should go straight for chest compressions and rescue breathing. The chest compressions will promote circulation. In some cases, an extra D which stands for Defibrillation or deadly bleeding might be added.
- Deadly bleeding or defibrillation: Some organizations consider dressing severe wounds or defibrillation a separate fourth stage, while others include this as part of the circulation step.

CPR technique differs for infants, children, and adolescents [3] where 'adult' includes children aged 8 years and older. Table II depicts the differences in the procedure.

**Table II: Difference between Infant, Child and Adult CPR**

Parameter	Infants	Child	Adult
Age	28 days to 1 year	1 to 8 years	Greater than 8 years
Hand position	Two fingers over the lower half of sternum	One hand over the lower half of sternum	One hand placed over the lower half of sternum and

			other hand placed on top
Compression rate	100 per minute	100 per minute	100 to 120 per minute
Compression to ventilation ratio	5:1	5:1	15:2

**A. Performing CPR on an infant**

The rescuer opens the airway using a gentle head tilt/chin lift, delivers gentle breaths over the infant’s mouth and nose so that the infant’s chest rises with each breath [4]. Chest compressions are delivered by placing two fingers of one hand over the lower half of the infant’s sternum and pressing down about one half inch to one inch. Compression rate is 100 per minute, giving five chest compressions followed by one rescue breath in successive cycles [4].

**B. Performing CPR on a child aged one to eight**

The compression rate is the same-five compressions and one rescue breath. Rescue breaths are delivered using a mouth-to-mouth seal[4]. Chest compressions are delivered by placing the heel of one hand over the lower half of the sternum and depressing about one to one and one half inches per compression [4].

**C. Performing CPR on a child aged eight and older**

Two hands are used for compressions, with the heel of one hand on the lower half of the sternum and the heel of the other hand on top of that hand [4]. 15:2 compression technique is used with compression rate of 80 to 100 per minute and depth of about one and one half to two inches per compression. Rescue breaths are delivered with a mouth-to-mouth seal [4].

**D. In-hospital CPR**

In the hospital setting, ventilation is usually performed with a bag-valve-mask (BVM) device. If the patient is not intubated, CPR is done by one provider performing chest compressions, while the second provider provides breaths with BVM ventilation [2]. The ratio of compressions to breaths is 15 :2 . Once a patient is intubated, chest compressions are performed continuously, while rescue breaths are given independently via the BVM at a rate of 10 per minute [2].

**NEED FOR AUTOMATION OF CPR**

The Cardio Pulmonary Resuscitation procedure a.) demands a lot of energy [1] and effort. Possibilities of significant loss in stamina of the bystander results in deterioration of compression quality. This may reduce the survival rates of the subject with cardiac arrest [2]. b.) The bystander must be trained, before he or she can perform CPR to subjects. This scenario cannot be expected in every case and in cases pertaining to rural areas. c.)

The CPR procedure must be stopped once there is a Return of Spontaneous Circulation (ROSC) [1]. Automation makes sensing ROSC easier through pulse sensors. d.) Automation provides medical professionals time and freedom to focus on other patient parameters before they get to the hospital.

**A. Parameters to be fulfilled during CPR**

The CPR procedure must fulfill the following requirements

1. The chest compressions must produce at least 2 inches of compression depth in the subject’s chest [10].
2. The compression rates must be at least 100 per minute and a maximum of 120 per minute [10].
3. The compressions must be uninterrupted and the ventilation must be given at proper intervals (in the case of 15:2 or 30:2 compressions to ventilation ratio)[10].

In order to compress the chest wall for a depth of 2 inches, a force of 100 to 125 pounds (45 to 56 kg) is required to be applied on the chest wall of the subject with cardiac arrest [10].

**EXISTING MECHANICAL CPR DEVICES**

There are a few existing mechanical CPR devices in the international market. The development of this device has not yet begun in full fledge in India.

**1) AutoPulse Resuscitation System from ZOLL Medical Corporation (North America)**

It is a battery operated CPR system producing 100 compressions per minute [6]. It has a built in stretcher that permits the transport of the subject around sharp corners, stairways and into the ambulance [6].

**2) LUCAS version 3.1 from Stryker(Sweden)**

Adjustable depths, adjustable compression rates, adjustable operation times [7]. It transmits reports wirelessly to e-mail address [7]. The compression rate is around 110 to 120 and the depth is around 1.8 to 2 inches and its piston and suction cup setup ensures user comfort [7].

**3) Life-Stat and Thumper from Michigan Instruments (Michigan)**

It provides Chest compressions at rates of 100 or 120 per minute (based on its versions) [8]. Has Adjustable chest compression of 3.2 inches (0 to 8cm) [8]. It accommodates patients with sternum heights up to 14.5 in, chest widths up to 22 in [8].

**PROPOSED METHOD**

The mechanical design of our device prototype was done in order to achieve the parameters that the CPR procedure requires. Our prototype achieves a compression rate of around 120 compressions per minute (i.e.) two compression cycles per second and produces a compression depth of around 2 inches. Our prototype was built to perform CPR only in adults and the operation modes can be selected between three different modes- a.) 15:2 operation b.) 30:2 operation c.) Continuous compression. The mechanical setup is a unique arrangement that converts the rotational motion produced by the motor into a linear, single axis motion. Our prototype uses a NEMA 23 stepper motor and the motor is driven using a DM 542 driver. We are also experimenting with other motor options including high torque DC motors and other stepper motors. The prototype operation is controlled by a micro-controller Arduino Uno. The pulse of the subject is being constantly monitored for the ROSC. The basal frame is fortified and rigid to provide firm ground and support for the subject undergoing CPR. A pin locking system enables the adjustment of the height of the suction cup with respect to the patient’s chest. The rescue breaths in between the compressions are currently given manually using a Bag Valve Mask (BVM) and the ventilation is to be automated in the further versions of the prototype.

a. Design of our Prototype

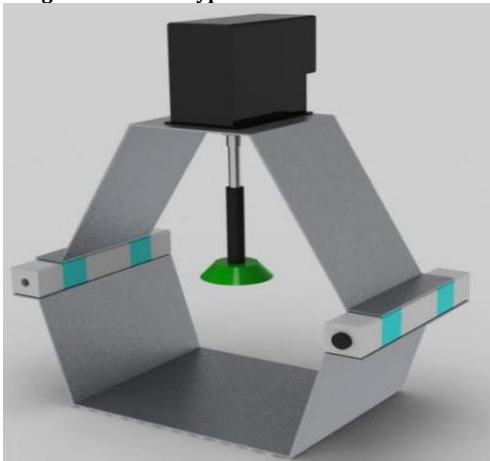


Fig. 1: Isometric view of our prototype designed using Solid Works. The shaft produces the up-down motion.

OBSERVATION

The compression rate was achieved through the micro-stepping driver. The prototype was tested for load delivery using a 30 kg load cell. During operation of the device prototype, the load delivered by the shaft was recorded by the signal conditioner of the load cell at every instant. The values obtained are tabulated below.

Table III: Readings taken from Load Cell

Time(sec)	Load(kg)		
	Test 1	Test 2	Test 3
0	0	0	0
0.2	6.9	8	7.5
0.25	9.6	10	11
0.4	7	6	6
0.5	2	1	2
0.6	5	6	4
0.75	10.1	9.8	10.5
0.8	7	8	8
1	1	1	1.3
1.2	7	5.9	6
1.25	10	10.6	11
1.4	6.3	6	7
1.5	2	2.5	0.8
1.6	6	6	6
1.75	9.8	10	10.4
1.8	7	7.5	7.4
2	0.5	1	2

These readings were taken and a graph was plotted for the load delivered vs. time for each test trial.

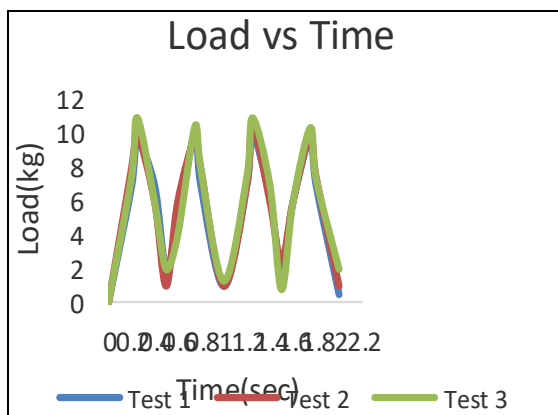


Fig. 2: Graph representing load vs. time when tested using load cell. The graph is represented here for a duration of 2 seconds. Since the compression rate is 120 per minute, we obtained 2 peaks of maximum load delivered in 1 second. The same waveform will be repeated for every second of the compression delivery.

The procedure of recording the load delivered was repeated for three different trial runs and the graph obtained was consistent in every trial. Thus the repeatability of our device was addressed. Statistical tests like the T-Test, and the ANOVA test were also performed to check for significant differences. We performed T-Test on the data taking two Test data at a time and the ANOVA test on all the three data values simultaneously. The p values obtained during T-Test for each set of tests were 0.47, 0.65, and 0.30 for Test 1 and Test 2, Test 2 and Test 3, Test 1 and Test 3 respectively and they were higher than the p-value of null hypothesis which was 5% (0.05). The observations of the ANOVA test are given below.

Table IV: Anova: Single Factor

SUMMARY				
Groups	Count	Sum	Average	Variance
Test 1	17	97.2	5.717647	11.75029
Test 2	17	99.3	5.841176	12.54257
Test 3	17	100.9	5.935294	13.74243

ANOVA						
Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.405098	2	0.202549	0.015976	0.984156	3.190727
Within Groups	608.5647	48	12.67843			
Total	608.9698	50				

It can be inferred from the above data that the F value of the data, which is 0.015976 is way lesser than the Fcritical value of 3.190727. Also the p-value, which is 0.984156, is higher than the null hypothesis p-value of 0.05. Thus the null hypothesis cannot be eliminated. All these inferences from both the tests prove that the sets of data are not significantly different and are close to each other. Thus the ANOVA test reassures the repeatability and the reliability of the device output.

CONCLUSION

Our prototype achieves a compression rate of around 120 compressions per minute. With the target force around 100-125 pounds, our prototype has achieved a force of 22 pounds (10 kg) and we predict to achieve the entire target force in further versions of the prototype. The output was shown to be reliable and the repeatability was also ensured.

Studies show that mechanical CPR was associated with an increased rate of ROSC and was advantageous over manual CPR [1]. Our device setup automates the procedure of CPR for the same reason and ensures increased survival rates and CPR quality. This prototype was designed to be at proper functioning at a cost of INR 20,000 per unit and we predict a commercial product with improvements in design and aesthetics can be produced at a cost of INR 50,000 per unit.

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