Journal Computational Simulation 8[19]1-7: e60819107

Article

Advances in CPR: Design and Validation of the *RescueBeat* System for Compression and Ventilation

Avances en RCP: Diseño y validación del sistema *RescueBeat* para compresión y ventilación

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CONAHCYT classification:

Area: Medicine and Health Sciences
Field: Medical Sciences
Discipline: Clinical Sciences
Subdiscipline: Emergency medicine

https://doi.org/10.35429/JCS.2024.8.19.6.1.7

History of the article:
Received: September 08, 2024
Accepted: December 30, 2024

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Abstract

Advances in CPR: design and validation of the *rescuebeat* System for compression and ventilation

Objectives	Methodology	Contribution
Create an intuitive and accessible device for people with no prior knowledge of first aid, to provide effective CPR by minimizing the response time between compression and ventilation.	Applied research, with a mixed approach and explanatory management. The design of the RescueBeat system is developed with the methodology of Pahl and Beitz (2007), programming and calculations based on vital body operations.	It considers a technological contribution in the area of mechatronics; It has a direct impact on the emergency area of the health area.

Cardiopulmonary Reanimation CPR, corporeal compression and ventilation, Emergency

Resumen

Avances en RCP: diseño y validación del sistema Rescuebeat para compresión y ventilación

Objectives	Methodology	Contribution
Crear un dispositivo intuitivo y accesible para personas sin conocimientos previos de primeros auxilios, con la finalidad de brindar RCP efectiva al minimizar el tiempo de respuesta entre compresión y ventilación.	Investigación aplicada, con enfoque mixto y manejo explicativo. El diseño del sistema RescueBeat, es gestado con la metodología Pahl y Beitz (2007), programación y cálculos en función de operaciones vitales corpóreas.	Considera una aportación tecnológica en el área de la mecatrónica; tiene un impacto directo en el área de las emergencias del área de la salud.

Reanimación cardiopulmorar RCP, compresiones y ventilación corpóreas, emergencias

Citation: Martínez-Torres, Rosa Elia, Mendoza-Razo, Juan Arturo, Padrón-Vázquez, Alejandro and Espinosa Juárez, Cid Tonatiuh. Advances in CPR: Design and Validation of the *RescueBeat* System for Compression and Ventilation. Journal Computational Simulation. 8[19]-1-7: e60819107.

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Introduction

Cardiovascular diseases are one of the main threats to health, being the number one cause of death worldwide, and it is estimated that this event will continue to increase in the coming decades. The prevention and treatment of this type of diseases is based on the progress and technological advance of science and also on the prompt response of the emergency in the area of health. The aim of this article is to prioritise the study of cardiorespiratory arrests by presenting a technological development that provides cardiopulmonary resuscitation (CPR) (Dávila, 2019).

The practice of CPR involves procedures that aim to perform the work of the heart when it stops working, in addition to bringing blood to the body, which can reduce the mortality rate. For correct resuscitation, factors such as the amount and frequency of compressions and the necessary ventilations are considered (Zuluaga and Agudelo, 2020).

A paradigm in the implementation of these techniques holds that the success rate is low or null, however, recent studies and techniques, allow to know and study the functions of the body and the conditions that can be presented, allowing to integrate areas of science to propose solutions (Zuluaga and Agudelo, 2020).

Engineering has had a beneficial impact on the area of medicine, creating devices with countless applications for the care of diseases. The design and development of technological tools focuses theory towards experimentation with disruptive technologies (Serna, 2022).

This paper presents the methodological stage of a research, which concludes with a technological development in prototype format using the principles of CPR; called RescueBeat, this development promotes the prevention of human errors that commonly occur in stressful situations, as well as the decrease in effectiveness that can be caused by fatigue during compressions (Serna, 2022).

The aim of RescueBeat is therefore to reduce mortality caused by the simultaneous arrest of cardiac and respiratory function.

The methodology used in this research combines the design approach of Pahl and Beitz (2007), with the expertise of healthcare professionals, and utilised tools such as a programming development platform, electrical design simulation software and computer-aided design.

Creating a device that is easy to use, intuitive and accessible to people without prior knowledge of first aid, leads to a particular design that meets the operations sought: compressions and ventilation; the development presented achieves the objective of being able to be manipulated easily by anyone, and opens lines of research and development to continue contributing to this project for the benefit of health in emergency situations.

Literary bases

Performing correct CPR involves knowing the corresponding procedures and techniques, which is why the American Heart Association (AHA) mentions the characteristics that should exist when providing this assistance, seeking to increase the victim's chances of survival (AHA, 2021).

The CPR procedure in adults consists of placing the base of the hand on the centre of the chest, specifically on the sternum, supported by the other hand. Compressions should be performed with the aim of sinking the area by 4 to 5 centimetres and at a rate of 100-120 compressions per minute. Ventilations are recommended for a high chance of success (AHA, 2021).

Standard compressions can be performed where the minimum or maximum rate mentioned above is met, while respecting the chest to return to its initial position. Due to the effort required to meet this condition, the so-called 30:2 method was established, where 30 compressions and 2 ventilations are performed with each ventilation lasting approximately 1 second each. As a priority, compressions should not be interrupted for more than 10 seconds (Pansky and Gest, 2015).

Knowledge of human anatomy is the basis for applying chest compressions to the thorax, as it acts as a mechanical pumping mechanism and is essential for lung ventilation.

ISSN 2523-6865
RENIECYT-CONAHCYT: 1702902

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Composed of the thoracic vertebrae, 12 pairs of ribs and the sternum, it forms a cavity that expands and contracts with a determined rhythm, which causes the muscular action that allows the flow of air into the lungs - respiratory function - and also has a protective role for vital organs: heart and large blood vessels (Pansky and Gest, 2015).

Methodology and development

A design methodology based on the principles of Pahl and Beitz (2007) is implemented. It starts with a thorough clarification of the task, identifying key product needs and functions. Various materials are explored, assessing technical and economic feasibility. Computer-aided design (CAD) tools, rapid prototyping and programming development software were used to realise the design. Each stage of the process included a trial and error system, aiming for the final prototype to meet the established requirements.

Starting from the identification of the problem to be solved, and the information related to the required anatomical operations, an analysis of the actions to be performed by RescueBeat was carried out, which was translated into a function diagram that clearly organises the priority of each task as well as visualising a basic alternative solution for each one of them, where the operational needs of the person who will manipulate it, as well as those who will be assisted, can be satisfied (Figure 1).

Box 1

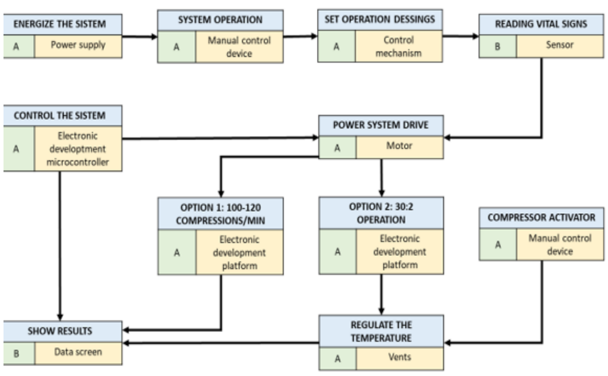

Figure 1
Functional Diagram

Own Elaboration

Based on this activity, an analysis was carried out to identify parameters that represent advantages and disadvantages, and the different materials and tools explored to meet the basic operational needs are presented in table 1, which shows two of the total elements evaluated as examples

Box 2

Table 1
Identification and ranking table of selection criteria

Energising the system		
Option	**Advantages.**	**Disadvantages**
Battery bank CD	Portable	Duration Accessible Cost Efficiency
Source CA	Efficiency Cost Duration	Laptop Accessible
Operate the system		
Option	**Advantages**	**Disadvantages**
Switch	Simplicity Space Maintenance	Duration Cost
Button	Simplicity Cost Space Maintenance	Duration
Sensor	Maintenance Simplicity	Duration Cost Space

Own elaboration

With the information obtained, the activity of evaluating the options explored is considered, where a value is assigned on a Likert-type scale with levels from 1 to 3, where 1: not useful, 2: may become useful with some adjustments, 3: useful. Based on the comparison criteria for each of the systems, table 2 is created, which for the purposes of this article, is subject to the first two elements analysed.

Box 3

Table 2
Proposed options appraisal table

Energising the system						
Material	Portable	Acces	Efic	Durac	Cost	Total
Battery CD	3	1	2	2	2	10
AC source	1	2	3	2	3	11
Operate the system						
Material	Simp	Manten	Esp	Durac	Costo	Total
Switch	3	3	3	1	1	11
Button	3	3	3	2	3	14
Sensor	3	3	2	2	2	12

Own Elaboration

ISSN 2523-6865
RENIECYT-CONAHCYT: 1702902

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Finally, the highest totals were extracted and a list is created and recorded in table 3:

Box 4

Table 3
Selection of elements

Function to be fulfilled	Option chosen:	Score:
Energise the system	AC source	11
Powering the system	Button	14
Set system configuration	Button	14
Read vital signs	Pulse sensor	13
Actuating the power system	Stepper motor	13
Controlling the system	Arduino	14
Operation option 1 and option 2	Arduino	13
Operate compressor	Solenoid valve	12
Regulating the temperature	35 litre compressor	14
Display data	Display 16x2 with Ic2 module	12
Extra: Prototype housing	Wood	13

Own Elaboration

Once the optimal elements were selected, the development of the device was started by making computer aided drawings (CAD) using SolidWorks software as a useful resource. In order to have a clearer idea of the approximate dimensions of the system.

Figure 2 shows the model of the housing made in SolidWorks, in which the approximate size and the spaces designated for each of the elements can be appreciated.

Box 5

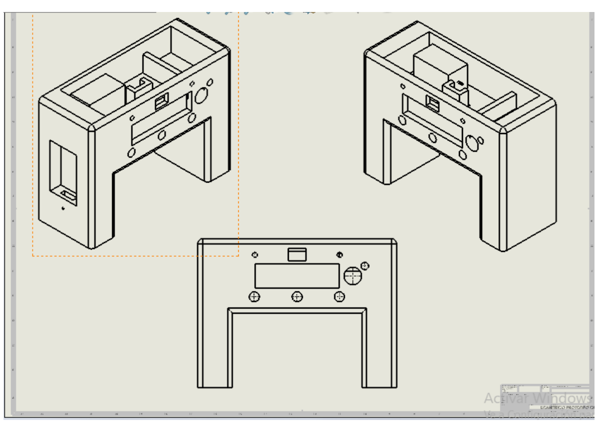

Figure 2
Base design of the RescueBeat
Own Elaboration

Simultaneously, programming was carried out to automate the desired functions, using software with a development board - microcontroller - which allows the entire system to be governed: basic aspects of information input and output, optimal development of functions. This programming design uses a basic C++ language, allowing a clear understanding of its operation and ease of manipulation in reference to the 30:2 compression-ventilation (figure 3).

Box 6

```
#include <Stepper.h>
#include <LiquidCrystal_I2C.h>
#include <Wire.h>
#include <Adafruit_GFX.h>
#include <Adafruit_SSD1306.h>
#include <SPI.h>

// Definición de constantes
int CICLOSDECOMPRESION=3;
const int boton1 = 2;
const int boton2 = 4;
const int boton3 = 13;
int red = 3;
int blue = 5;
int buffer = 6;
                    /*const int stepsPerRevolution = 300;
                    const int pin1 = 8;
                    const int pin2 = 9;
                    const int pin3 = 10;
                    const int pin4 = 11;*/
const int PUL = 8;  // Pin para la señal de pulso
const int DIR = 9;  // Pin de dirección del motor
const int EN = 10;   // Pin Enable
int i=0;
int j=0;
const int PASOSPORREVOLUCION = 4000;
const int VELOCIDAD = 1200;  // Tiempo de espera entre pasos (micro
int rele = 12;
```

Figure 3
RescueBeat programming code
Own Development

The electrical connection diagram (Figure 4) shows the microcontroller board at the centre of the circuit, including the pulse sensors, the operating buttons, the motor controller, the 16x12 i2c lcd display, and the relay responsible for opening and closing the compressor opening and closing valve.

Box 7

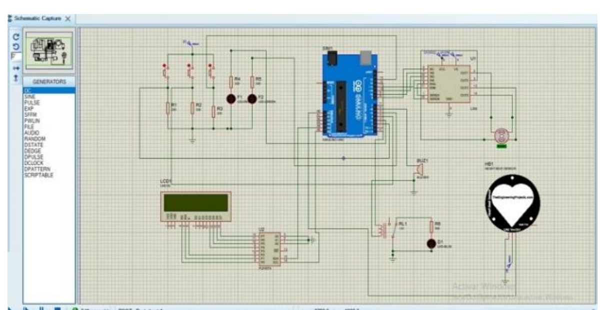

Figure 4
Electrical diagram simulated in Proteus
Own Elaboration

ISSN 2523-6865
RENIECYT-CONAHCYT: 1702902

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Some of the calculations based on literature that are indispensable in relation to compressions and ventilation are shown:

Equation for pressure calculation

Referred to as Pascal's principle, it establishes that any change in pressure at one point of an enclosed fluid is transmitted in its entirety and without decrease to all points of the fluid. In the mechanics of materials it is used when a material is subjected to loads and is expressed by the following formula, where P is pressure and A is area.

$$P = \frac{F}{A} \quad (1)$$

Equation for area calculation

Allows to calculate the surface of different plane figures with applications in different areas.

$$A = B * h \quad (2)$$

Development of force calculation

Considering for simplicity the sternum as a rectangle with the following dimensions:

$$L = (10 + 5 + 3)cm = 18\text{cm}$$

$$B = 6cm$$

Where:
L= Length in metres (m)
B= Base in metres (m)
Calculating the area of the rectangle where:

$$A = \frac{18cm*6cm}{10000}$$

We obtain from Equation 2 that the area of the sternum is:

$$A = 10.8x10^{-3}\ m^2$$

With the data obtained from the previous study on the average thrust force, we take the highest impact force of 227N and substitute it into equation 1.

Where:
P: Pressure measured in Pascals (Pa).
F: Force in units of Newtons (N)
A: Area measured in square metres (m^2)

With the data obtained and applying the formula we obtain that:

$$A = 10.8x10^{-3}m^2$$

$$F\_aproximada = 227N$$

$$P = \frac{227N}{10.8x10^{-3}\ m^2} = 21.01\ KPa$$

L he ideal pressure for resuscitation is not fixed, but depends on the person applying it, as these characteristics vary according to each individual. Factors such as age, physical training and lifestyle directly influence the amount of force that can be safely and effectively applied, therefore, the value mentioned is only a starting point for calculation (Caeiro, González and Guede, 2013).

Considering that the maximum pressure applied to the cortical bone is 215 MPa, and the approximate pressure that can be applied when performing chest compressions is 21.01 KPa, it is evident that a stress that exceeds the capabilities of the cortical bone is not performed, thus avoiding a fracture.

Results

From the construction and testing of the developed CPR mechanism device, it was demonstrated that it is possible to implement a compression and ventilation system that provides effectiveness and safety. The prototype achieved a compression rate of 100 compressions per minute and a ventilation rate of 12 breaths per minute, which is within the parameters recommended by the American Heart Association for CPR.

In addition, the ventilation system was verified to be capable of providing an adequate volume of air for artificial respiration, suggesting that the prototype is effective in providing respiratory support in emergency situations.

Box 8

Figure 5a, b
RescueBeat, technological development
Own Elaboration

Conclusions

This technological development has demonstrated the feasibility of an innovative CPR mechanism that combines compression and ventilation. The results suggest that this system can be a valuable tool in emergency medical care, especially in situations where fast and effective response is crucial.

The research also highlights the importance of innovation and the development of technologies that improve emergency medical care. In the future, it is possible that technological systems may become a standard tool in medical care, which could significantly improve outcomes for patients suffering cardiac arrest.

Ultimately, it demonstrates the importance of research and development in improving emergency medical care, and highlights the need to continue to innovate and develop life-saving technological devices to achieve a better quality of life as a society, also highlighting the right to health.

Declaration

Conflict of interest

The authors declare no interest conflict. They have no known competing financial interests or personal relationships that could have appeared to influence the article reported in this article.

Author contribution

The specific contribution of authors a and b focuses on the scientific and technical direction of the research project, assignment of methodologies and tools, as well as inter-institutional management for dissemination and publication; On the other hand, authors c and d, build the prototype presented based on proposed elements.

Availability of data and materials

The data obtained from this research are accessible through the technical report that belongs to the Technological Institute of San Luis Potosí, in the persons of the authors who intervene in it.

Funding

There is no funding for the manufacture of the prototype or its dissemination. The authors assume this responsibility.

Acknowledgements

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Abbreviations

CPR – Cardiopulmonary resuscitation.

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