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Development and validation of a low-cost simulator for the acquisition of basic CPR skills

Desarrollo y validación de un simulador de bajo costo para la adquisición de destrezas básicas en RCP

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Summary

Introduction: Knowing how to perform quality Cardiopulmonary Resuscitation (CPR) can double or triple the chances of contributing to the survival of a person who has suffered sudden cardiac arrest. The purpose of this project was to develop, under expert parameters and suitability assessment by the end user, a low-cost electro-mechanical simulator that allows the development of basic skills for CPR training for future physicians and/or the general population that needs training for basic and advanced management of cardiac arrest. **Methods:** The work was developed in two stages. The first stage corresponds to the design and implementation of the simulator, where the activities carried out to build the prototype are described. The second stage shows the activities executed during the validation process of the simulator. **Results:** A prototype was implemented that meets the essential characteristics of interactive simulators and is also low-cost. Regarding its validation, the results obtained support its development and effectiveness. **Conclusion:** The prototype of the interactive simulator developed allows training with interactive practices that help correct errors in real time, improve the applied technique and gain confidence. CPR is an essential skill that can have a significant and positive impact on the life of a person in an emergency situation. It is an invaluable tool that can make the difference between life and death. By learning CPR, you gain the peace of mind of knowing that you are prepared to face a critical situation. In addition, it fosters a culture of prevention and first aid in the community.

Keywords: Medical Education, Simulation, CPR, Feedback

Abstract

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1. Introduction

Globally, more people die each year from cardiovascular disease than from any other cause, primarily from ischemic heart disease. More than three-quarters of these deaths occur in low- and middle-income countries, where cases continue to rise (1). Cardiopulmonary resuscitation, also known as CPR, is a procedure designed to revive people who have stopped breathing or whose heart has stopped beating. Essentially, this technique combines chest compressions with artificial ventilation to maintain blood flow and oxygen flow to the brain. Correct CPR can mean the difference between gaining time until an ambulance arrives and administering more specific treatment, or death.

The American Heart Association (AHA) recommends using audio-visual feedback devices during CPR training for real-time optimization of the effectiveness of maneuvers. Studies report a 25% increase in survival from arrest with acoustic and visual feedback of compression rate and depth (2). When CPR training is conducted following AHA guidelines, chest compressions should be delivered at a rate of 100 to 120 per minute and with a minimum depth of 5-6 centimeters. To meet the new training requirements, feedback devices must be able to, at a minimum, measure and provide real-time feedback, both auditory and visual, on compression rate and depth. This will allow students to correct or validate their skills performance immediately during training.

Due to the high cost of interactive, feedback simulators, coupled with their lack of availability in the local market, the need to generate local developments arises. The Faculty of Engineering takes on this challenge by carrying out this project, led by teachers and students. The purpose of this project was to develop, under expert parameters and suitability assessment by the end user, a low-cost electro-mechanical simulator that allows the development of basic skills for training in cardiopulmonary resuscitation (CPR) for future doctors and/or the general population that needs training for basic and advanced management of cardiac arrest.

2. Methods

The methodology used for the development of this work is divided into two well-defined stages, the first corresponds to the design and implementation of the simulator and the second to the validation process of the same.

2.1 Stage 1: Design and implementation of the simulator

The first objective proposed in the project was to design and implement an interactive medical simulator for cardiopulmonary resuscitation using low-cost technologies and processes, with the aim of making it accessible to health centers and educational institutions in the country . To achieve this, it was necessary to first conduct a survey of the main characteristics of the simulators on the market, in order to determine, together with collaborators specializing in medical simulation, the functional requirements and conditions to be considered in the design. Then, the functionality of the simulators was defined, based on the resuscitation maneuvers required, the available sensing capacity and the way in which the practitioner receives feedback on the maneuvers. To do this, the guidelines, restrictions and regulations regarding international recommendations had to be taken into account. Once the characteristics of the simulator were defined, work was done on multiple aspects simultaneously, including: the mechanical structure; possible techniques for molding the mannequin with human features and testing of materials; the data acquisition system, sensors and actuators; and the data communication system, among others. In the developed prototype, all the information generated by the sensors is collected in a microprocessor embedded in the dummy itself, which allows the implementation of the control and response procedures for each practice session. Real-time analysis algorithms were developed that allow the detection of the correct execution of the resuscitation procedures. This aspect constitutes one of the most relevant contributions of the project from a scientific point of view. In addition to the dummy's own actuators, which allow indicating whether the maneuvers were performed correctly, a feedback system was developed with a user interface that allows the recording and reporting of the maneuvers supplied by means of a computer, tablet or cell phone . The schedule of activities carried out for the development and implementation of the prototype is detailed below:

a) **Study and analysis of the characteristics of commercial simulators:** Activities and meetings were held with medical simulation specialists to determine the characteristics and conditions of a CPR simulator and the basic parameters of the maneuvers to be implemented. The parameters defined for interaction with the practitioner are: body and hand positioning, depth (5 to 6 cm) and frequency of compressions (100 to 120 times per minute). Figures 1 and 2 show the position of the body and hands.

b) **Functional definitions of the simulator:** Based on the analyses carried out in activity a), the functional characteristics that the simulator should have were defined. It was ensured that they complied with national and international standards and recommendations for the application of CPR maneuvers. Figures 1 and 2 show the position of the body and hands to correctly perform the maneuvers.

c) **Design and manufacture of the human-like dummy:** The physical prototype of the dummy that serves as the patient to be resuscitated was designed and implemented. The aim was to obtain characteristics similar to a human being, such as size, hard and soft parts, possible movements, etc. In this instance, parts were manufactured using 3D printing technology, through the use of semi-rigid and soft

materials. Figures 3, 4, 5 and 6 show the manufacturing process of the synthetic skin for the simulator's torso, which was made with composite materials.

d) **Design and implementation of the structural arrangement:** Because it is mainly composed of semi-rigid and soft materials, the dummy required mechanical parts that provide mechanical rigidity and, at the same time, allow it to imitate the real movements of the human body. The mechanical resistance of the thorax was emulated with a set of springs (fig. 7 and 8). For its design, the existing bibliography was analyzed and the value of the force that the practitioner must apply to the thorax was obtained (40 Kgf. for a 70 Kg adult) (9). In addition, the resistance provided by a commercial simulator was measured; the value obtained for a 6 cm compression was 38 Kgf. (fig. 9 and 10). In addition, the sensors, actuators and the computer system that controls them were incorporated into this structure to obtain the interactive response of the simulator.

e) **Electronic instrumentation:** The selection of sensors and actuators (Fig. 11) incorporated into the simulator was carried out with criteria of robustness and reliability, so that they tolerate the performance of repetitive and very intense maneuvers. At this stage, the circuits for conditioning the signals involved and their subsequent sampling and digitalization were also designed. **Development of embedded software:** The control software of the microcontroller platform was implemented with the capacity to acquire the variables associated with the resuscitation maneuvers, run real-time analysis algorithms to detect the correct execution of the maneuvers and control the actuators to notify the operator, audibly and/or visually, if they are outside the margins established by the AHA. In addition, the transmission of the generated data to an external computer monitoring system was incorporated. A diagram of the system's operation is shown in Fig. 12.

f) **Development of software for the monitoring device:** An application was developed to be installed on a mobile device, such as a tablet, notebook or cell phone. It allows monitoring of the maneuvers performed, graphically displaying the monitored variables in real time, storing the data generated and analyzing the records in deferred time.

g) **Integration and validation of the complete system:** Once the previous stages were completed, the developed parts were integrated and the necessary tests were carried out to validate the functioning of the prototype simulator as a whole. The tests included testing the prototype for the entire set of manoeuvres, executed correctly and incorrectly, under different environmental conditions (temperature, humidity, surfaces, etc.).

Figures 1 and 2. Position of the hands and body to perform the maneuvers.

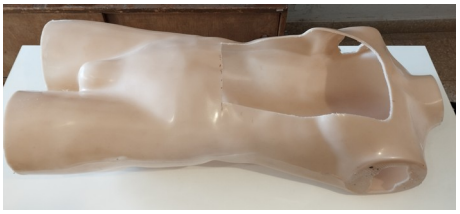


Figure 3. Commercial manequin used as a structure for our simulator.

Figure 4. Cast for the synthetic skin.

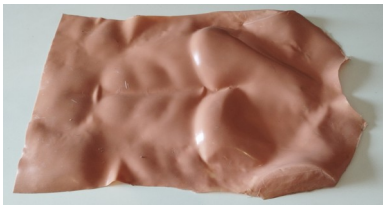


Figure 5. Synthetic skin.

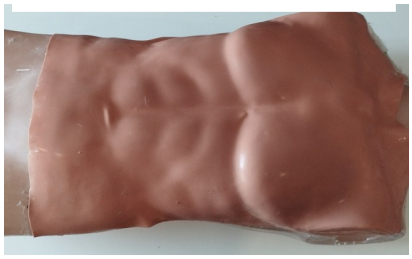
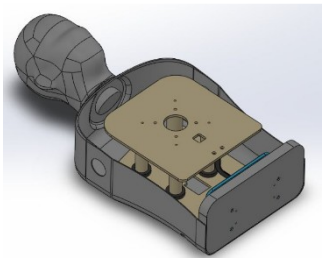


Figure 6. Skin inserted on the structure.



Figures 7 and 8. Mechanic system of resistance to compression (springs).

Figures 9 and 10. Measure of the compression in a commercial simulator.

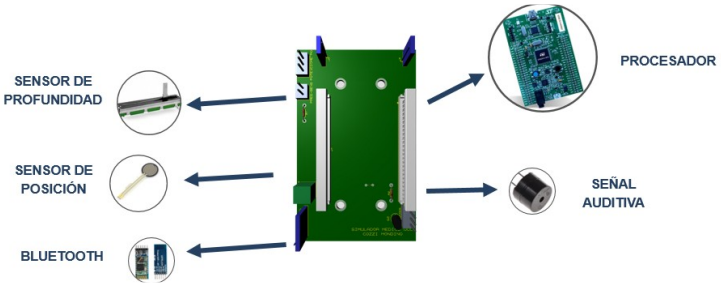


Figure 11. Sensors and actuators.

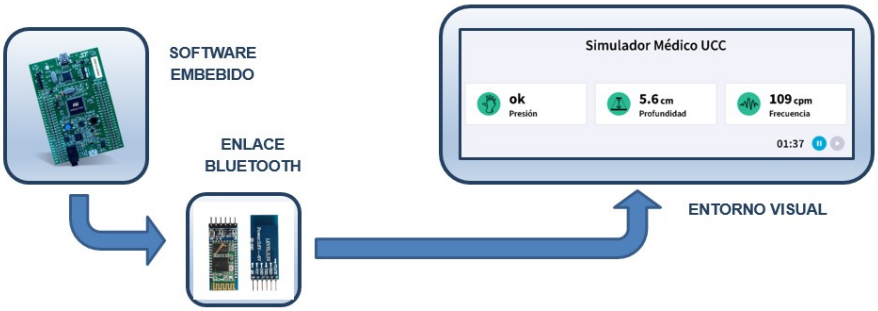


Figure 12. Diagram of the system

2.2 Stage 2: Simulator validation process

The validation process was carried out by students, teachers and health personnel, and is very important to ensure that the prototype CPR simulator meets the specifications and requirements necessary for effective and realistic training. After the implementation of the simulator, the validation process carried out by experts allowed the prototype to be adjusted and confirmed that it meets the conditions of an interactive CPR. The systematic actions carried out to carry out this validation are detailed below:

a) **Selection of people involved in the validation:** Teachers and health personnel were recruited for the validation. In addition, in order to conduct a randomized study, health sciences students who already had basic CPR training participated.

b) **Review of specifications:** The reviews were carried out by teachers and health personnel from the San José simulation center, who verified that the adopted specifications (hand position, depth and frequency of compressions) complied with International Standards.

c) **Analysis of the simulator's physical structure:** The analysis of the structure assessed whether the torso mimicked human anatomy, including a chest with simulated ribs, an area for chest compressions, and a sternum. In addition, the skin was made of a material that simulated the texture and elasticity of human skin, allowing for a more realistic training experience. The mechanism of the system that simulates the resistance of the human body was analyzed, allowing the practitioner to feel like he or she is performing compressions on a real person. The experts verified the operation of the sensors and devices that indicate whether the compressions are being performed with the correct depth and rhythm, as well as the position of the hands.

Figure 13. Commercial simulator, without feedback.

d) **Randomized study of simulator use:** The randomized study of simulator use was carried out with students from the Faculty of Health Sciences, who had already had CPR practices at some stage of their career. The participation of the students was voluntary, signing a consent to participate in the research activity. For this process they were divided into two groups, being able to perform CPR maneuvers for two minutes, one group used a non-interactive commercial simulator (fig. 13) and the

other, the developed prototype. The data monitored were; hand position, depth and frequency of the maneuvers.

e) **Validation activity:** Students from the Faculty of Health Sciences participated in the validation activity. They were invited to participate voluntarily. The inclusion criteria were that they had received CPR training at some point during their studies and that they had voluntarily agreed to participate and signed the consent form. The validation process was carried out as follows: the participants were divided into 2 groups at random, to whom the importance and objectives of the activity were previously explained. Each student was assigned a random number, independent of the group in which they were participating. Group A was asked to perform 2 minutes of CPR on a standard commercial model chest simulator, this group acting as a control or reference group. Group B also performed two minutes of CPR, but with the prototype simulator designed by the Faculty of Engineering, having real-time feedback on hand placement, compression frequency and depth. Finally, the members of both groups in random order performed maneuvers for two minutes in an interactive CPR simulator "CAE Ares - Medical Simulator © " (fig. 14) (10). The maneuvers were monitored by a "blind" observer (who does not know to which group each student belongs), completing a form where the position of the hands, the average frequency of the compressions and their depth were recorded.

Figura 14. CAE Ares - Medical Simulator, de alta fidelidad.

f) **Data analysis:** Finally, a statistical analysis was performed, with the aim of validating whether the training carried out with the prototype for this study improves the performance of the students with respect to a standard non-interactive commercial simulator.

Ethical considerations: Student participation was voluntary and anonymous. Current international (Helsinki 2013) and national legislation (ANMAT "Guide to good clinical practices in health research", Provincial Law 9694 of the province of Córdoba and Law 25.326 on Habeas Data enacted on October 30, 2000) was respected. Data were recorded in accordance with article 8, safeguarding personal data and professional secrecy. This study is WHO Category I: Study without risk.

3. Results

a) Hand position: Based on the results obtained in the validation activity, the correct hand position was first analyzed to allow for high-quality CPR according to AHA standards. 69% of group A positioned their hands correctly, while in group B the percentage rose to 93%.

b) Compression rate: The AHA recommends that chest compression rate be set between 100 and 120 compressions per minute to achieve good myocardial perfusion.

The average compression rate during the 2-minute maneuver was measured in the trial, as shown in Table 1. Figure 1 describes the results obtained by the participants in each group. It is highlighted that 66% of group A performed the maneuvers in the recommended frequency range, while group B achieved 89% of correct frequencies.

Table 1. Data on the frequency of compressions performed during two minutes.

Frequency of maneuvers (per minute)			
Group A		**Group B**	
Event	**Frequency**	**Event**	**Frequency**
1	105	1	112
2	126	2	125
3	126	3	118
4	115	4	120
5	110	5	110
6	115	6	113
7	93	7	106
8	108	8	115
9	111	9	117
10	108	10	111
11	82	11	109
12	100	12	100
13	109	13	106
14	100	14	104
15	116	15	118
16	114	-	-
Average	**109.13**	**Average**	**112.27**
Deviation	**10.35**	**Deviation**	**6.49**

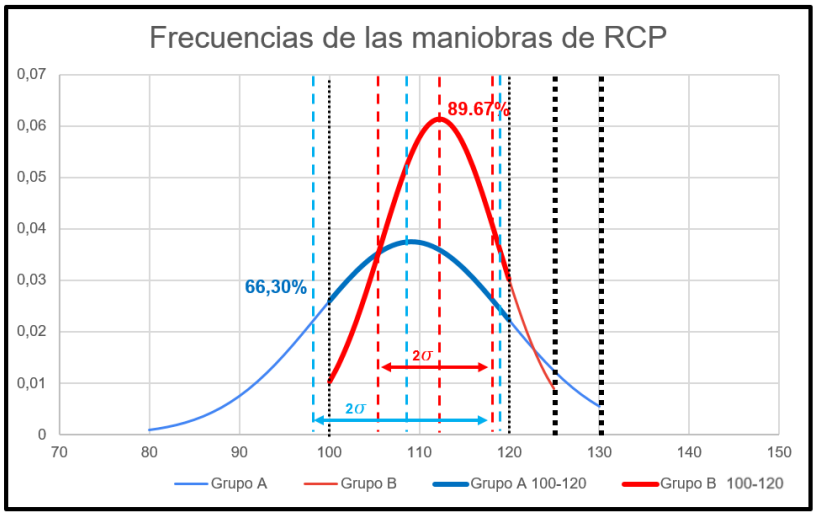


Figura 1. Media y desviación estándar de los datos de la frecuencia de las compresiones realizadas durante dos minutos.

c) Compression depth

Regarding compression depth, the guidelines indicate that it should be between 5-6 cm. This test analyzes the average depth reached by each participant when performing the CPR maneuver. 20% of group A managed to work within the correct compression depth range, while group B did so in 44% of cases. In addition, it is important to note that the

deviation in group B from the expected values is relatively low, in contrast to the deviation in group A, which shows a slight tendency to work at a lower depth (figure 2).

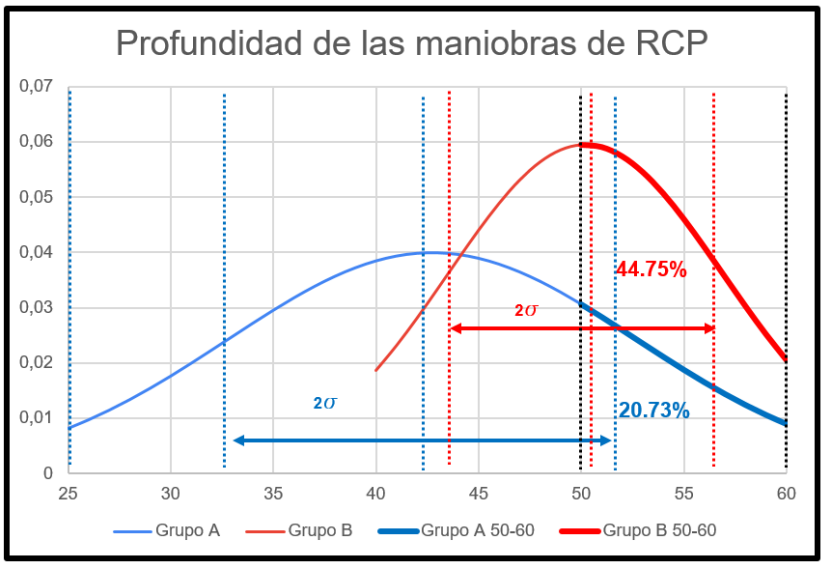


Figura 2. Media y desviación estándar de los datos de las compresiones.

4. Discussion

The importance of training future health professionals and the general population in cardiopulmonary resuscitation lies in the fact that it is a vital technique for saving lives in medical emergency situations (1). CPR provides chest compressions that help pump blood from the heart to vital organs in the body, including the brain. This supplies oxygen to the tissues and prevents brain and other organ damage that could occur from lack of oxygen. If these maneuvers, specifically compressions, are not performed correctly, the success rate in resuscitation decreases dramatically (2).

To increase the survival rate, training using interactive devices with real-time feedback allows for timely and appropriate CPR that can double or triple the chances of survival for a person who has suffered cardiac arrest outside the hospital (3). CPR training not only provides practical skills, but also increases people's confidence to act in emergency situations (4). When training in CPR, it is necessary that the equipment to be used is not only validated by expert opinion, but also by comparative, randomized studies and analyzed in reference to other commercial equipment with and without feedback. This allows us to ensure that the training given with this equipment complies with the regulations and recommendations of the AHA and other international associations (5). In the case of our prototype, not only did it obtain the consensus of the experts, but our validation study made a conclusive difference regarding the benefits of using this simulator compared to the non-interactive one.

In terms of cost, the construction of a prototype can cost up to 4 times less than a commercial simulator with similar characteristics. But its advantage is not only economic, it is also important to consider the availability, the purchase management times and the possibilities of importing the equipment found on the market. Finally, it is worth highlighting in favor of our prototype, the availability of a local technical service and low-cost spare parts, developed by 3D printing (6-8).

5. Conclusions

- We have described the construction of a low-cost CPR simulator.
- In the analysis of the results, it can be observed that the group that carried out the training with a simulator with real-time feedback has performed correct CPR maneuvers in a higher percentage than those performed by the control group.
- This comparison allows us to conclude that the interactive simulator has managed to meet the expectations of the objectives, allowing for faster and more accurate learning of CPR maneuvers.
- Further comparative studies with different populations and a larger number of participants are needed to confirm the preliminary results of this study.

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Author contributions: Juan Luis Castagnola and Diego German Freille conceptualized the idea, methodology, data validation, data curation, writing and preparation of the research design stages, review and final editing of the document. María del Rosario Barello, Paola Senatore and María Delfina Vélez Ibarra participated in the implementation of the prototype, data validation, review and final editing of the document.

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