33rd Annual International Conference of the IEEE EMBS
Boston, Massachusetts USA, August 30 - September 3, 2011

Development of a patient simulator for teaching and evaluation of the basic cardio-pulmonary reanimation protocol

C. Villagómez[1], F. Suarez[1], S. Gómez[1], A. Dávila[2], A. Vega-Gonzalez[3,4], J. Gómez-González[4].
[1]Laboratorio de Ingeniería Biomédica, Facultad de Ingeniería, UNAM, México
[2]Centro de Enseñanza y Certificación de Aptitudes Médicas. Facultad de Medicina, UNAM, México
[3]Departamento de Ingenierías Química, Electrónica y Biomédica, DCI, Universidad de Guanajuato, México
[4]Departamento de Control y Robótica, Facultad de Ingeniería, UNAM, México;
juan@dctrl.fi-b.unam.mx

Abstract. Providing appropriate cardio-pulmonary reanimation after cardio-pulmonary arrest is paramount for survival. An effective and low-cost approach to learn and practice the cardio-pulmonary reanimation is through a computerized life-size patient simulator. The present work describes the development of a patient simulator for the Centre of Education and Certification of Medical Aptitudes (CECAM) from the UNAM's Faculty of Medicine. This patient simulator has many new and innovative features, such real-time feedback to the medical student, which improves the whole teaching/learning experience.

Keywords: cardio-pulmonary reanimation, patient simulator, simulator

I. Introduction

DEATH of patients due to a wrong-administered medical procedure in the US was about one hundred thousands per year in 1999 [1] [2]. This number was larger than deaths due to car accidents, AIDS or breast cancer. An approach to reduce this figure is through the use of computerized patient simulators with different electronic systems embedded to simulate different physiological and pathological conditions. These patient simulators help to expose medical students to diverse life-threaten scenarios with the aims of teaching and evaluation.

Currently the Faculty of Medicine of the National Autonomous University of Mexico (UNAM), has a Centre of Education and Certification of Medical Aptitudes (CECAM). The CECAM has a few patient simulators and it uses them for teaching and evaluating medical procedures without the need of having an actual scenario that can be a life-threaten situation for a real patient.

The training with patient simulators also has the advantage of repeatability, thus the medical instructor can reproduce the same scenario as many times as need and can show the medical procedure in detail. Furthermore, the medical student has a real-time feedback of his/her actions on the medical procedure being administered. The feedback to the student has been shown to improve the learning process up to 74% [3].

One medical protocol of major significance is the cardio-pulmonary reanimation (CPR). This procedure is the most important determinant of survival after cardiopulmonary arrest in and outside the hospital [4]. Delaying CPR after cardiac arrest results in poor outcome, because for every minute without CPR, survival chance decreases by 7% to 10% [5].

There are two CPR protocols, the basic and advance one. The later involves access to all resources within the hospital, whilst the basic one relies only on human intervention. The CECAM taught the basic protocol on an old patient simulator. This patient simulator allows the student to practice the basic-traditional procedure for cardio-pulmonary reanimation. It complies with an old version of the approved CPR protocol by the American Heart Association (AHA). This patient simulator only provides a led-bar display to indicate the amount of force being administered on each chest compression. It lacks of any other kind of feedback to the student.

The current patient simulator at the CECAM has worn out but more importantly it is out-of- date. It has an obsolete AHA's CPR protocol and the instructor must operate the breathing and pulse by hand (in case the procedure was applied correctly). These drawbacks lead to a new design for the basic CPR, with new features such as: an updated CPR protocol [6], a variety of interactive scenarios, a better feedback to the student/instructor, and a logger to record all actions during the procedure.

II. Methods

The developed full-body patient simulator consists of three systems, which give flexibility to its operation and service. These systems are as follows:

- Sensing system: It allows measuring the intensity for each chest compression and artificial respiration. It also measures the permeability of the airway.
- Processing system: It quantifies and evaluates all the actions performed on the patient simulator by the student. It also computes the vital signs and shows them to the instructor. The instructor, then, can decide the course of the session in real-time. It also sends the feedback information to the storage and display System.
- Storage and display system: It saves all the actions and results in a database. It also shows all the information

and sequence of events on a web page, so the student can review his/her performance.

The patient simulator has a remote control, which allows changing parameters such as response time for each step of the basic CPR protocol [6], modifying the scenario by activated/deactivated: permeable airway, audible feedback, pulse, respiration, counters of artificial respiration and compressions, air volume. Thus it allows total control of the patient simulator.

III. DESIGN AND IMPLEMENTATION

The design and implementation of the systems was based on the recommendations of the AHA's protocol for CPR and the guidelines for feedback physicians' clinical performance [3,6]. The current AHA´s protocol for the basic CPR, recommends 30 chest compressions at a rate of at least 100 per minute and two artificial respirations per duty cycle.

A. Sensing system

1) Chest compression.

The patient simulator has a hollow heart model made of rubber silicone, which is normally full extended. When there is compression in the thorax, the heart model is compressed and its internal pressure rises. This internal pressure is measured through the use of a pressure sensor (MPX family). The system was calibrated by applying a set of chest compressions with different amount of force (low, medium, high and appropriate force). This was done with the help of experts on CPR. The values were transformed into mmHg units to be reported on the screen and to be use on the physiological model. Thus the obtained value is proportional to the displacement of the thorax (fig. 1).

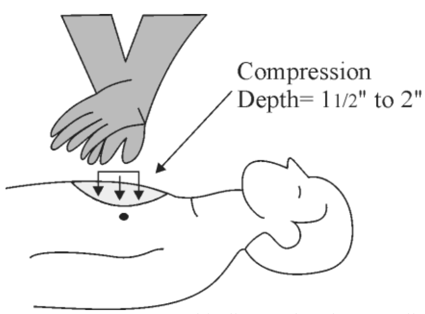


Fig. 1. The AHA's CPR protocol indicates that thorax's displacement must be one and a half or two inches.

The calibration was done with the help of nine physicians, who are experts on CPR. Each expert reproduced the CPR protocol at different times to give a total of 150 chest compressions. All these values, together with the values of the chest displacement, were used to calculate the mean values and range for each category of chest compression (low, medium, high and appropriate).

2) Artificial respiration.

The quantification of air flow is very important when applying artificial respiration. To measure the air flow, a sensor of variable resistance was used (Fig. 2). This sensor is able to change the resistance due to the presence of a small-movable flipper which also helps to get a uniform flow.

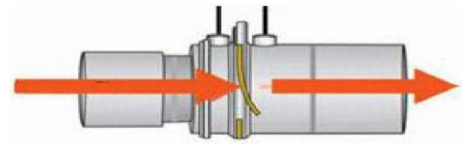


Fig. 2. The air flow is measured using a sensor membrane. This can quantify the amount of air that is provided with every breath

The sensor is basically a differential pressure sensor which signal feed a conditioning circuit and then it goes to the CPU, where it is processed to report the volume breathed by the student.

It is important to mention that the AHA recommends 500ml of air on each artificial respiration [6]. With this in mind, a similar sensor was used at the lungs. This helps to calculate the input volume and report this value as feedback to the student and instructor. Figure 3 shows the measurements performed for this sensor with the aim to calibrate the system.

3) Permeability of the airway.

The sensing of the airway was done with two sensors. The first one uses a set of potentiometers to determine the horizontal position of the head and the manoeuvre of hyperextension. The second sensor uses a magnetic sensor to check the presence of an object obstructing the airway (designed specifically to the airway).

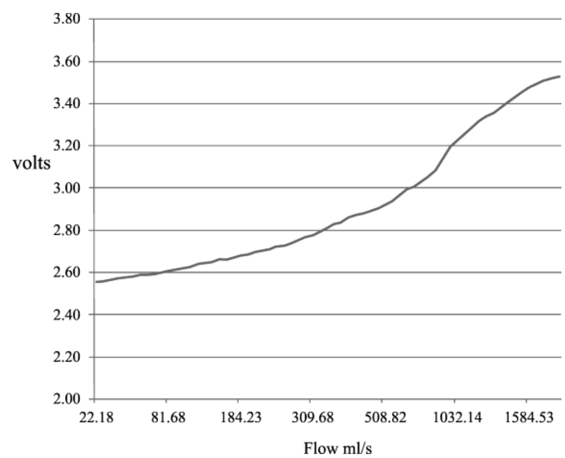


Fig. 3 Average of five measurements of the flow sensor. The volume was controlled to cover the range showed. This curve was used to calibrate the sensor and to report the volume provided in each breath.

These sensors help to check the CPR protocol, which indicates that the first step is to accommodate the head and verify for any obstruction in the airway.

In addition the signals were digitized and send to the CPU through the USB bus. The speed is fast enough that the system operates in real-time. All the information feeds the equations, which represent the physiological model to calculate blood pressure and Oxygen saturation.

B. Processing system.

The CPU gets the information every 6 ms and processes it, using a physiological model which is described by differential equations [7, 8, 9].

The equations describing this model can be separated in two sections, cardiovascular and respiratory. The cardiovascular section encompasses pressures and flows for the following compartments: abdominal aorta (AA), thoracic aorta (Ao), carotid artery (car), jugular artery (jug), cava vein (IVC), superior cava vein and right heart (RH), and administered chest compression (P). All these compartments have compliance (C) and resistance (R) as shown in fig. 4. For more details on the physiological model see ref [7].

In this work, all the measurements of chest compression were performed on the right-hand side of the heart, therefore only this side was considered in the model (see nomenclature on table 1).

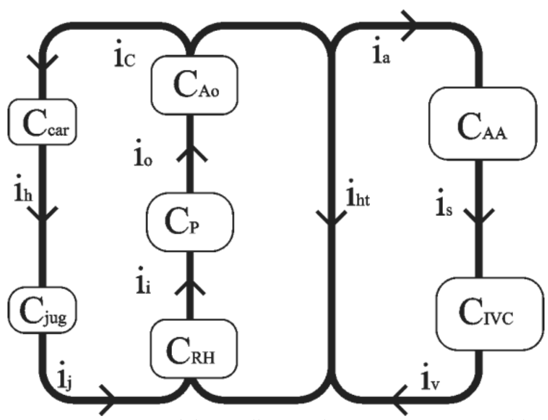


Fig. 4. Arrangement of the cardiovascular compartments used in the physiological model. Modified from [7]

The respiratory section calculates the CO_2 in the alveolar space using as a parameter the oxygen volume. By using a constant metabolism model the oxygen consumption and CO_2 production can be simplified [7].

C. Storage and display system

1) Storage

All acquired information on the patient simulator is transmitted wireless (Wi-Fi, if not available, it has a local database as a backup) to a central computer where the information is stored in a database. The database is separated into two tables, as follows:

- Model parameters: This table contains all physiological data, such as; blood pressure, partial concentration of oxygen, CO_2 and PH in arterial blood. All these values according to the actions and times performed by the user.
- Response times: This table contains all the sequence of actions (compressions and artificial respiration) during the CPR protocol.

2) Display

The graphical user interface, written in JAVA, is stored in the WEB server. The user can access this application at any time.

The graphical user interface consists of three frames:

a) A time line. This shows all the events performed during the CPR (fig. 5 a).

b) The physiological parameters. The changes of patient simulator's physiological parameters are shown on this frame in real-time.

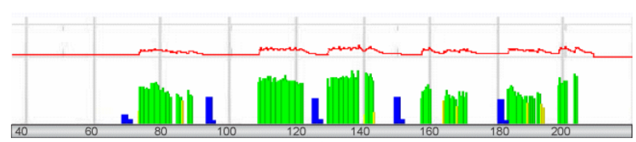
c) A practical guide. This section shows all the information related to the CPR protocol and contains text and images for a better understanding of the procedure. (fig. 5 b).

TABLE 1
SUBSCRIPTS AND VARIABLES

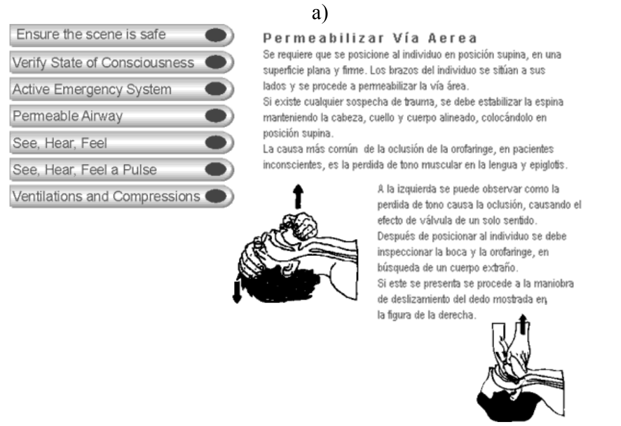
Subscript		Variables	
AA	*Abdominal aorta*	**C**	*Compliance, L/mm Hg or mL/mm Hg*
Ao	*Thoracic aorta*	**i**	*Flow or current between compartments, [L/s]*
a	*Aorta at level of diaphragm*	**P**	*Instantaneous pressure in a compartment, mm Hg*
C, car	*Carotid*	**R**	*Resistance, mm Hg/(L/s)*
h	*Head*	**ΔP**	*Pressure increment, mm Hg, during time Δt*
J, jug	*Jugular*	**Δt**	*Time increment, s*
IVC	*Inferior vena cava*		
RH	*Right heart and superior vena cava*		
ht	Heart		
P	Pump		

Adapted from [7].

In summary, the graphical user-friendly interface shows all the information in real-time and it allows the student to check his/her progress. The student can review this information as many times as he/she wants, thus improving



a)



b)

Fig. 5. Graphic interface, a) Plot of compressions and breaths in relation to time, where students can observe the volume and pressure of air, as well as, the frequency of each chest compression. b) The interface provides information on all the basic CPR protocol. As an example the figure shows the information on how to locate an obstruction by a foreign body in the airway.

his/her learning experience.

IV. DISCUSSION

The aim of this study was to develop a new full-body patient simulator for the basic CPR protocol. The new design has new features not found in commercial models, such as sensor in the airways, which can detect any obstruction (fig 6) and modify the response of the simulator accordingly, real-time feedback for the instructor, ability to change the physiological parameters through a remote control, a logger to store all actions and responses, a very realistic human physiological emulation of the pulse and respiration, an audible feedback to keep track of the correct rhythm of compressions and artificial respiration manoeuvres and capability to operates in two modes, automatic and manual.

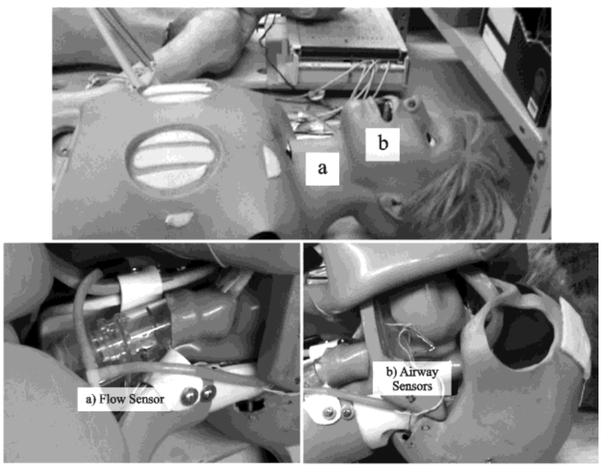


Fig. 6. Full-body patient simulator. The figure shows the final appearance of the patient simulator (top) and some of the sensors such as the flow sensor (a), and the airway sensor (b).

The patient simulator was designed to be easily updated or modified which gives it a great flexibility. First instructors' impressions indicate a substantial improvement on the patient simulator, which give them more freedom to focus on other aspects of the CPR protocol, such as environmental factors, student's biomechanics and behaviour.

The patient simulator allows a full coverage of the basic CPR protocol and helps to evaluate all aspects in detail. Furthermore the evaluation of the basic CPR protocol can be improved if the training sessions are video-taped and analysed off-line.

V. CONCLUSSION

The patient simulator allowed a formal assessment and feedback on physician performance on the basic CPR protocol. This promotes an active involvement in the process. All the amount of information reported, the timing and amount of feedback, and other information, such as practical guidelines, are important for improvement of the learning and teaching experience. The first impressions of the students and instructors were that the new design helped to accelerate the learning. However, the independent contributions of these innovations have not been well documented. Therefore it is recommended a follow-up study of feedback effects in learning.

The features of this design cannot be found on any commercial simulators for basic CPR. This has been proven to be very attractive to other schools of medicine. In fact, two other local universities have shown interest to reproduce this patient simulator.

ACKNOWLEDGMENT

We would like to thank to UNAM-DGAPA project PE104009, CONACyT 49740 and CECAM.

REFERENCES

[1] Amitai Ziv, MD, MHA. "Simulation based medical education-from vision to reality". Educ. méd. v.10 n.3 Barcelona sep. 2007.

[2] Kohn, L.T., Corrigan, J.M. & Donaldson, "To Err is Human: Building a Safer Health System", M.S. (Eds) (1999) Washington, DC, National Academy Press.

[3] Veloski J, Boex JR, Grasberger MJ, Evans A, Wolfson DB., "Systematic review of the literature on assessment, feedback and physicians"' clinical performance: BEME Guide No. 7. Med Teach. 2006 Mar, 28(2):117-128.

[4] Ali B., Zafari A. M., "Narrative review: Cardiopulmonary resuscitation and emergency cardiovascular care", Review of the current guidelines. Ann Intern Med 2007; 147:171–179

[5] Larsen M., Eisenberg M., Cummins R., Hallstrom A., "Predicting survival from out-of-hospital cardiac arrest: A graphic model", Annals of Emergency Medicine, Volume 22, Issue 11, November 1993, Pages 1652-1658, ISSN 0196-0644, DOI: 10.1016/S0196-0644(05)81302-2.

[6] Lippincott Williams & Wilkins, "Adult Basic Life Support 2005" American Heart Association Guidelines for Cardiopulmonary Resuscitation and Emergency Cardiovascular Care, Circulation by the American Heart Association , 2005; pp. 2-10.

[7] Babbs C., "CPR techniques that combine chest and abdominal compression and decompression. Hemodynamics insights form a spreadsheet model". Circulation 1999;100;2146-2152.

[8] Milhorn H., Benton R., Ross R., Guyton A., "A Mathematical Model of the Human Respiratory Control System", Biophysical Journal, Volume 5, Issue 1, January 1965, Pages 27-46, ISSN 0006-3495, DOI: 10.1016/S0006-3495(65)86701-7.

[9] Tehrani F.T.. "Mathematical Analysis and computer simulation of the respiratory system of a new born infant", IEEE Transactions on Biomedical Engineering, 1993;Vol 40, No 5.