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CPR SIMULATOR PROTOTYPE FOR NEONATES

Supervisor:
Prof. Oscar Caceres

Prof. Alessandro Rizzo

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Candidate:

Miloš Morača

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SUMMARY

This integrative project describes the development of a prototype to carry out practices of Cardiopulmonary Resuscitation of neonates or young infants by medical science students and anyone interested in acquiring skills in this activity.

Currently there are different types of models to carry out this task. However, it was decided to design an own system in order to have an accessible prototype to be able to add sensors and interfaces in such a way that when carrying out the CPR practices more realism, fidelity, practical application is obtained and it allows to carry out a posteriori the evaluation process that can be used as feedback to the user. In addition, greater accessibility from the economic point of view.

This project, therefore, seeks to develop a training and learning system for the user that will have different stages considered necessary to optimize the learning of the procedure.

I sought to proceed with the elements and possibilities that are within our reach, due to the impossibility of accessing the GRSI laboratory motivated by the Covid pandemic19, I carried out a prototype that is the most faithful.

After starting this project, it was carried out the development of a 3D model of the torso of an infant between 2 and 6 months, which will be prototyped at a later stage, once it is possible to access the GRSI laboratory at Universitad Nacional de Cordoba.

The resulting model was designed to house the system of sensors that will perform a real-time diagnosis of the user's performance. Therefore, the model has the appropriate spaces for each component of the system, such as its sensors, wiring, power supply, boards and displays.

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To my family, for accompanying and supporting me in all circumstances, for teaching the principles and values that make us people and professionals, and who are a fundamental pillar in our lives.

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CHAPTER 1
INTRODUCTION

Cardiorespiratory arrest (CRA) in children is usually a terminal episode of respiratory failure or shock. Both conditions usually present an initial compensated phase, from which the child rapidly deteriorates to a phase of decompensation followed by respiratory or cardiorespiratory arrest. Prolonged hypoxia in both cases involves multiple organs, including the central nervous system.

Fortunately, CRP in the child is a rare event. The estimated incidence of out-of-hospital CRA in paediatric age is 8-20 cases/100,000 children, and that of in-hospital CRA is approximately 100 times higher (2-6% of children admitted to intensive care units).

Rapid and effective CPR is associated with early recovery of circulatory function and survival without neurological damage. Only 2-10% of children with out-of-hospital CPR survive, and most with severe neurological sequelae.

Taking this into consideration, it can be noticed the importance of an adequate training, not only of a health professional, but of any person, in order to increase the survival rate in out-of-hospital CRPs. In fact, it is vital to start CPR in the first three minutes after cardiorespiratory arrest, otherwise the probability of the child suffering sequelae is very high. Death can occur in as little as 4 or 6 minutes.

In this project I sought to create a prototype that would be a guide in the learning and implementation of CPR, focusing mainly on cardiac massage (frequency and pressure) and that would allow accessibility in terms of economics by the institutions related to this practice.

The objective was then to make a model that allows its seriousness at a lower cost using local production methods complemented by rapid prototyping technologies such as FDM process (Fused Wire Arrangement or 3D printing), in turn using Arduino microcontrollers and different software for obtaining and processing data.

This avoids the use of injection matrices for the manufacture of CPR simulators and expensive electronic elements, allowing production on demand according to the particular needs of each institution.

Cardiac emergencies threaten life. Heart attacks and strokes are the greatest cause of illness and death in America. Every day in homes, parks and workplaces someone has a heart attack or goes into cardiac arrest. Performing CPR immediately after a person has a heart attack or stroke can greatly increase the likelihood that he or she will survive (Jimenez Murillo, 2015).

1. OBJECTIVES

1.1. General

To design a training system to allow the teaching of CPR, focused on the compression of the chest of a baby-like doll that is suitable to house an integrated system of sensors and controllers, which facilitate a feedback of the user's performance, without compromising the quality of the simulation, for the teaching and practice of medical science students and the general public.

The aim was to make a low-cost design that can be made available to institutions that need it.

1.2. Specific Objectives

A series of specific objectives were planned, which from March onwards had to be reformulated when the restrictions due to the COVID19

The objectives set at the beginning were:

- Analyze the requirements that a training system in CPR techniques should fulfill for a manikin with similar characteristics to a newborn or a few months old baby
- Identify the necessary dimensions to use for the development of the model based on anthropometric percentiles, medical studies and research.
- Design and model in design software (SolidWorks) the 3D model with all the features required to meet the objectives proposed by the team.

1.3. Important clarifications on objectives:

Due to the pandemic and the resulting quarantine, it was impossible for us to have access to the GRSI's laboratory.

It was not possible to access the GRSI lab's 3D printers to print the first prototype as a result the entire project could not be implemented physically leaving only computer designs and software programming. To compensate for this, the complete printing and rendering process of the finished project was computer simulated.

2. BACKGROUND

Next, it is shown an analysis of what is known as "state of the art" where different models of already existing mannequins were studied, from which different aspects were taken as reference such as: dimensions, materials, systems, and operations, among others.

2.1.1. Mannequins instrumented to apply the CPR technique

Mannequins usually consist of a head and torso. The latter is usually made of a plastic that is not very flexible, to simulate the consistency of the human chest. In addition, they have bags that imitate the lungs, so that when the practitioner blows, you can see that the chest of the dummy rises and then contracts. Because the technique used is different for adults, infants, and children, there are generally two or more types of mannequins, depending on the manufacturer.

Usually this type of simple mannequin, include a bag to be transferred to different places, since its main purpose is to be portable.

Most do not include real-time feedback to the student and trainer. However, there are more advanced manikins, which include a panel in which the student is given feedback on his/her performance, and some of them contain a box with sensors, simulating heartbeats, heartbeats, and reactions to defibrillation, since they need to be applied in stages subsequent to basic CPR. One disadvantage is that their cost is very high.

2.1.2. Basic Buddy CPR Training Manikin (model LF03694)

It has an articulated head, which is used to free the airways, and it also has a plastic structure, which is covered with a material that resembles the consistency of the human body. Finally, in the area where compressions are performed, it has a foam cylinder internally, which complements the resistance offered by the body to perform chest compressions.

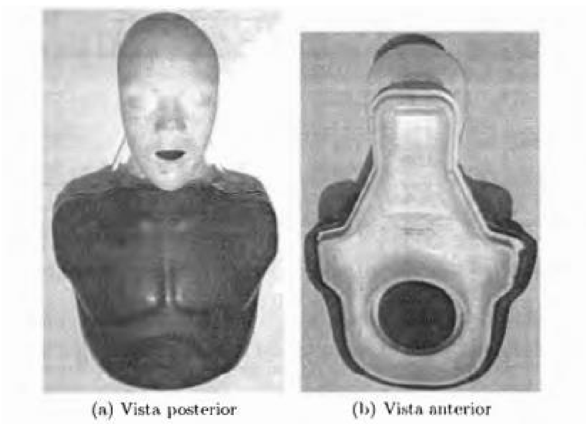

Figure 1 CPR Basic Buddy Manikin

The materials with which the dummy is constructed simulate the resistance of the human chest. The dummy consists of three parts: a rigid plastic base, a foam rubber and a rubber cover. This last one is the one that gives the resistance of the sternum and the ribs in a person.

The rigid plastic serves only as the base of the dummy; this structure is where the cover is attached. In the center of the base there is an opening in which a foam rubber is placed that delimits the zone of compression.

As mentioned before, the foam has its place inside the opening of the base and its only function is to delimit the compression zone.

Something important to highlight about this material is that it does not affect the resistance of the chest when performing compressions.

The cover (picture 2) which has a hollow cylinder which serves to cover the foam. The cover is the fundamental part of the dummy since it simulates the resistance of the human chest. It also has the strategic points of the technique highlighted to facilitate the location of the compression zone.

Figure 2 Basic Buddy dummy cover

Price $15,000 [1]

2.1.3. Code Blue® III Newborn 2 Advanced Life Support Training Simulator [2]

This simulator has the following characteristics:

- Wireless communication
- Built-in rechargeable battery
- Available with an OMNI 2 or UNI control tablet
- Programmable crying
- Realistic airway with tongue, visible vocal cords, trachea and esophagus
- Supports oral and nasal intubation via an endotracheal tube and other standard medical devices
- Unilateral elevation of the thorax with intubation of the right main trunk
- (CPR) Chest compression and ventilation performance sensors
- Realistic chest cavity and backward motion.
- Compressions generate palpable pulses
- Bilateral lung expansion and realistic chest rise during bag-valve-mask ventilation (BVM)
- The internal rechargeable air tank provides spontaneous (automatic) chest rise and pulses after resuscitation for up to 60 seconds.
- Connect real electrodes to conductive skin sites and monitor the ECG with real medical equipment
- Palpable umbilical, brachial and radial pulse
- Programmable heart and lung sounds
- Intravenous access for drug infusion

This product has all the necessary elements for simulation in the treatment of newborns, being one of the most complete devices on the market that I could find. In Argentina, however, I could not find distributors of the product, so I can only know the cost in the U.S. market, understanding that it may vary in our country due to import costs and tax costs.

Figure 3 Maniquí Code Blue® III Newborn with OMNI® 2 Advanced Life Support Training Simulator

Estimated price: USD$4900 [3]

2.1.4. Little Baby QCPR (Laerdal) [4]

2.1.4. Little Baby QCPR (Laerdal) is a realistic and affordable Basic Life Support (BLS) manikin for pediatrics. Through the gamification of learning and objective information, Little Baby QCPR improves the quality of training, student interest and efficiency in the classroom].

Figure 4 Little Baby QCPR

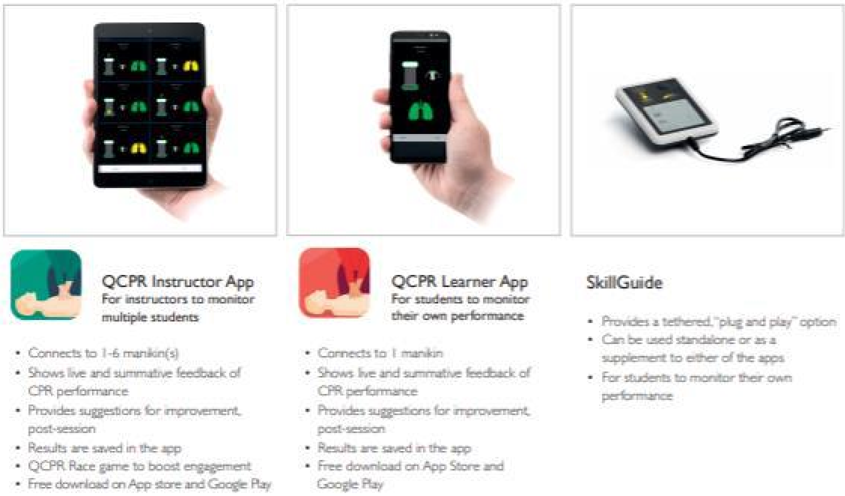

Figure 5 Feedback Options

The Little Baby QCPR allows:

- Real-time feedback on compressions and ventilations, to identify course compliance and provide personalized quality improvement suggestions
- Post-event performance report including CPR scores and tips for improvement
- Details on compression release, depth and frequency, hand placement, ventilation volume, number of compressions and ventilation cycles.
- Choking training with sound

Little Baby QCPR also includes features such as:

- Head tilt with open/blocked airway
- Visible chest rise in vents
- Visible landmarks: nipples, ribs, breast tip
- Limbs with realistic movement

Estimated price Usd $400 [5]

2.1.5. HeartiSense Premium Kit.

Figure 6 HeartiSense Premium kit

Applications and sensor kits that can be connected to any adult or child manikin that does not currently have a CPR feedback function

- Can be used on any type of adult or child CPR manikin to allow monitoring and feedback that meets the requirements of the AHA CPR feedback device
- The dual Bluetooth control unit allows instructors to control, monitor and document training while the student monitors his/her CPR performance.
- The application includes a metronome to help students practice with the correct compression rate
- Includes lay responder and health care provider modes to customize training for a specific group
- Allows for accurate and effective training and evaluation
- Works with CPR trainers from all manufacturers
- Provides real-time feedback and a realistic interface
- Perform compressions, ventilations or both
- Digitally stores all training and evaluation data
- Each package includes premium compression pad, control module, breathing module, breathing module holder punch (A, B), punch guide, battery (1.5V AA), Quick User Guide, sponge (for Prestan® dummy) and Heartisense ™ for student and instructor applications
- Estimated price: US $448.75 [6]

3. STATE OF THE ART

It was decided to make, after knowing some of the existing simulators, an analysis of the state of the art. Although our dummy to be developed is that of a newborn baby, it is essential to know how the questions were solved in an adult dummy to take it as a reference and try to transfer it to our case. The simulators previously seen, are completely based on the fundamentals of the CPR technique and have two key factors: one is the similarity between the resistance offered by the material used in the simulator with respect to the human body, and on the other hand I have the immediate feedback, both of which are in accordance with our objectives. This second factor mentioned is very helpful for the student because it allows him to correct on the fly and at the end of each cycle gives him a global feedback on the aspects evaluated, and on the other hand the existing similarity with reality also covers many aspects to carry out a teaching of greater fidelity to reality.

CHAPTER 2
THEORETICAL FRAMEWORK

1. BASIC CONCEPTS

This integrative work was destined, as its name indicates, to design and test a prototype so that interested people could carry out training and practices of cardiopulmonary resuscitation applied to neonates and infants up to 1 year of age.

Therefore, first and foremost, it is convenient to start analyzing the nomenclature to make some definitions clear:

- Neonate: I am going to define a neonate to a child in the period immediately after birth.
- Infant: An infant goes from birth to one year of age.
- Child: A child goes from one year of age to puberty.
- Adolescent: Finally, an adolescent is a child who is past puberty.

Some key characteristics about infants:

1. Relatively large head compared to body.
2. Occiput (back and bottom of the head) prominent, this leads to a tendency in supine flexing, which generates an obstruction of the airways.
3. Small face and mouth with a relatively large tongue, which in case of reaching an unconscious state, generates a risk of airway obstruction.

1.1. Cardiorespiratory arrest

Cardiorespiratory arrest, hereinafter CRP, is understood as the generally unexpected and potentially reversible interruption of breathing and mechanical activity of the heart.

In pediatrics, most cardiac arrests are the result of shock, progressive respiratory failure, or a combination of both. Less frequently, pediatric cardiac arrests occur without warning signs, such as sudden collapse from an arrhythmia, ventricular fibrillation, or ventricular tachycardia.

Neonates and infants with CRP are identified by the presence of the following three key clinical signs:

1. Unconsciousness.
2. Apnea or agonal breathing (gasping).
3. Absence of pulse or vital signs (not moving, not breathing, not coughing).

Unlike the adult, generally, it does not occur unexpectedly, but can usually be predicted. This is so because the cause that most often leads to CRP in the child is respiratory failure, which usually sets in gradually. In contrast, in adults, CRP is more often the result of cardiovascular failure, which tends to precipitate abruptly and is therefore less predictable.

The most frequent causes of CRP in children are summarized in Table 2.1. In general, CRP in the child is usually of respiratory cause and occurs more frequently in infants, the main causes being: sudden infant death syndrome (SIDS), congenital malformations, complications of prematurity and acute respiratory disease. In the child over 1 year, the most frequent cause of CRP is severe trauma, usually secondary to a motor vehicle accident, followed by cardiovascular disease and cancer. CRP of cardiac origin is observed almost exclusively in children with congenital heart disease, especially in the postoperative period of cardiac surgery.

The identification of clinical signs specific to respiratory and/or cardiovascular failure allows, on the one hand, the early detection of patients at risk of presenting CRP and, on the other hand, the implementation of specific therapeutic measures to prevent their presentation. In this sense, the prevention of CRP should be a priority objective, implementing both specific training plans for health professionals and health education measures for the general population and, especially, for parents/caregivers of children with chronic diseases.

It should be remembered that when a disease precipitates a situation of respiratory or cardiovascular failure, there is usually an initial physiological compensation response, with which the body sets in motion a series of mechanisms that aim to preserve the distribution of oxygen and nutrients, especially to the vital organs. It is in this compensation phase, when it is more convenient to detect the child at risk.

2. VITAL ORGANS OF THE NEWBORN:

To fully understand the importance of CRP, it is important to understand how it affects cardiorespiratory arrest and the consequent lack of blood supply to the various vital organs.

2.1. Brain

It is an organ that centralizes the activity of the nervous system and exists in most animals. The brain is located inside the skull and constitutes the most voluminous and known part of the brain. It is located in the upper anterior part of the cranial cavity and is present in all vertebrates.

Inside the skull, the brain floats in a transparent liquid, called cerebrospinal fluid, which fulfills protective functions, both physical and immunological.

Global ischemic brain injury has become the main obstacle to functional recovery for many patients who survive both circulatory arrest and the very delicate subsequent period. The knowledge of the physiopathological and functional mechanisms involved in the post-ischemic process, together with the applied therapeutics, has a great influence on the final result of the patient resuscitated from a circulatory arrest in the operating room.

The brain is an organ that depends almost exclusively on aerobic metabolism, that is, on the supply of oxygen. The brain is able to tolerate only short periods of ischemia and anoxia, due to its great metabolic demands, which are essential for maintaining the cell structure, the ionic concentration gradients between the interior and exterior of the neuron and for performing the organic function for which it is intended.

An indirect indicator of this situation is that, although the brain represents only 2% of the body weight of an adult, it receives 15% of the total cardiac output, uses 20% of the oxygen consumed by the whole body and consumes an amount of ATP equivalent to 20% of that produced by the whole body.

The average CBF (Cerebral Blood Flow) of an adult person without arterial lesions is about 50 ml/100 g of tissue/ minute. The white substance is less irrigated, as it requires approximately 20 to 25 ml/100 g/min, while the gray substance needs between 60 and 80 ml/100 g/min.

In a person with no previous injury of his brain vessels, synaptic transmission between nerve cells ceases when the blood flow in the brain decreases to half or one third of the normal FSC, i.e. when it reaches 18 to 25 ml/100 g/min. This occurs despite the fact that the reserves of adenosine triphosphate (ATP) in the brain cells are still sufficient. Neuronal death occurs when the ion transport mechanisms start to fail, when the FSC reaches values close to 10-15 ml/100 g/min.

I have already pointed out that no closed cardiac chest massage technique can even approach the perfusion achieved during normal circulation or the circulatory response achieved by open chest CPR or cardiopulmonary bypass. It has been argued that during external cardiac massage, cerebral perfusion pressure (CPP) at best barely reaches 40 mmHg of the 80 mmHg required for proper nerve cell irrigation. Therefore, even during resuscitation, nerve damage of different magnitude will be installed, depending on the time spent in the recovery of the spontaneous and effective heartbeat.

The same happens when the heart rate falls below 30 beats per minute or when oxygenated blood does not reach the brain for 10 to 15 seconds.

When any of the above situations occurs, the neuronal electrical failure begins to set in. At this point, which we can call the first threshold of cerebral ischemia, an electrical silence is observed in the EEG and clinical manifestations appear, especially loss of consciousness, which are still potentially reversible. As we see, the process of cerebral ischemia begins before serious or irreversible neurological injuries appear.

The definitive magnitude of the damage to the nerve structures (primary neuronal injury) will be related to the time during which this abnormal situation persists; although it also depends on a series of phenomena that come into play once the appropriate supply of oxygen to the nerve cell is restored. This stage, which includes what has been called secondary neuronal injury, occurs minutes or even days after the recovery of spontaneous cerebral circulation.

It is important to know that the secondary neuronal lesion is not a consequence of the initial ischemia itself, but a product of the events subsequent to the re-perfusion (that is, to the reinstallation of the cerebral circulation). In this phenomenon, the alterations of the cerebral microcirculation and the putting in circulation of diverse neurotoxic compounds of the cellular disintegration of the ischemic stage play a key role.

Although the purpose of cardiorespiratory resuscitation after circulatory arrest is to re-establish the flow of oxygenated blood to the brain as quickly as possible, this is often not easily achieved, as a result of the installation of phenomena subsequent to the re-establishment of spontaneous circulation.

Therefore, it is very common that even after a successful recovery from circulatory arrest or equivalent hemodynamic situations (severe hypotensions, extreme bradycardias) certain nervous disorders are inevitable, with persistence of different degrees of CNS depression.

2.2. Heart

It is the main organ of the circulatory system, in charge of keeping the blood of the whole body circulating and, thus, providing oxygen to all tissues.

It has a conical shape, somewhat flattened from front to back. There is an apex or vertex, a base, an anterosuperior face, which is the sternocostal face, and a postero-inferior face, which is the diaphragmatic face that rests on the muscle of the same name. It has a thick left edge that some authors consider as a left face; it has a thinner right edge.

In regard to anatomy, the heart is located in the lower part of the medial mediastinum, between the second and fifth intercostal space, left, and is located obliquely: about two thirds to the left of the median plane and one third to the right.

The heart muscle is divided into four chambers or heart chambers, two upper atria or atria and two lower chambers or ventricles. The atria receive the blood from the venous system, pass it to the ventricles, and from there it goes into the arterial circulation.

The main function of the cardiovascular system is to supply blood to the body's tissues in an adequate manner with each of the needs and situations. This supply depends on the heart's ability to act as a pump, on the regulation of peripheral resistance and on the ability of each territory to locally regulate the flow of blood. None of these factors is constant throughout the day, since the periods of rest and activity, as well as the metabolic needs of the different organs and tissues determine blood perfusion.

It is therefore necessary that there be regulation to ensure that variations in cardiac and vascular activity allow a distribution of cardiac output according to the needs of different organs and tissues. Such regulation is exercised at the cardiac, vascular and renal levels through the combined actions of the central and peripheral nervous systems, as well as by various humoral systems and agents.

The pumping capacity of the heart is a function of the beats per minute (heart rate) and the volume of blood ejected per beat (systolic volume). The heart rate and the systolic volume are regulated by nerves of the autonomic nervous system and by mechanisms intrinsic to the cardiovascular system.

The cardiac output is the volume of blood pumped per minute by each ventricle. The average resting heart rate in a newborn is 140 beats per minute; the average systolic volume (the volume of blood pumped per beat by each ventricle) is 5 to 8 mL per beat. The product of these two variables gives an average cardiac output of 700 mL (0.7 L) per minute.

Because the cardiac output of the right ventricle is normally the same as that of the left ventricle, the lungs receive the full cardiac output, while other organs share the right ventricular output. In order for this to occur, the pulmonary circulation must have low resistance, low pressure and high blood flow compared to the systemic circulation.

The heart has an internal electrical system that controls the rhythm of the heartbeat. Thanks to this, it works like a syncitium.

The heart muscle is myogenic. This means that, unlike skeletal muscle, which needs a conscious or reflex stimulus, the heart muscle is self-exciting. Rhythmic contractions occur spontaneously, just as their frequency can be affected by nervous or hormonal influences, such as physical exercise or the perception of danger.

The sequence of the contractions is produced by the depolarization (inversion of the electrical polarity of the membrane due to the passage of active ions through it) of the sinus node or Keith-Flack node (nodus sinuatrialis), located on the upper wall of the right atrium. The electrical current produced, of the order of microamperes, is transmitted along the atria and passes to the ventricles through the atrioventricular node (AV or Aschoff-Tawara node) located at the junction between the two ventricles, formed by specialized fibers. The AV node serves to filter out the overly fast activity of the atria. From the AV node, the current is transmitted to the His bundle, which distributes it to the two ventricles, ending up as the Purkinje network.

Its normal rate of contraction is in the order of 60 to 100 times per minute in adults and 140 times per minute in neonates, this pulse decreasing as age increases.

Certain problems can cause abnormal heart rhythms called arrhythmias. There are many types of arrhythmias. During an arrhythmia, the heart may beat too slow, too fast, or stop beating. When the heart develops an arrhythmia where it stops beating, a sudden cardiac arrest occurs. This is different from a heart attack (infarct), in which the heart usually continues to beat but blood flow to the organ is blocked.

There are many possible causes of cardiac arrest. These include coronary heart disease, physical stress, and some genetic conditions. But sometimes it is not possible to know the cause.

The most common mechanism of cardiac arrest, as a result of a heart attack, is a very serious arrhythmia called ventricular fibrillation. This arrhythmia can occur as a result of the sudden lack of oxygen caused by the occlusion of a coronary artery. Ventricular fibrillation generates a chaos in the electrical activity of the heart that becomes mechanically inefficient, and as a consequence, the heart stops pumping blood effectively.

If not treated immediately, sudden cardiac arrest can lead to death. With proper and prompt medical care, you can survive.

Performing cardiopulmonary resuscitation (CPR), using a defibrillator or even performing chest compressions can improve the chance of survival until emergency personnel arrive.

It is important to remember that sudden cardiac arrest is different from a heart attack, which occurs when blood flow to a part of the heart is blocked. However, sometimes a heart attack can trigger an electrical disturbance that leads to sudden cardiac arrest.

2.3. Lungs

The lungs are anatomical structures belonging to the respiratory system, located in the rib cage, on both sides of the mediastinum.

Due to the space occupied by the heart, the right lung is larger than its left counterpart. They have three faces; mediastinal, costal and diaphragmatic, they are irrigated by the bronchial arteries and the pulmonary arteries carry blood for oxygenation.

They are protected by the ribs and separated from each other by the mediastinum. They are covered by a double membrane called the pleura, between both pleura a cavity is formed (pleural cavity) which is occupied by a thin layer of serous fluid.

The lungs are the organs in which the exchange of oxygen from the inspired air takes place and carbon dioxide is released, which passes into the exhaled air from the blood. This exchange is produced by simple diffusion of the gases thanks to the difference in partial pressures of oxygen and carbon dioxide between the blood and the alveoli.

The main structures of the lungs are the bronchi, bronchioles and alveoli. The alveoli are the microscopic sacs lined with blood vessels in which the exchange of oxygen and carbon dioxide gases takes place; they are said to be the functional unit of the lung.

The interruption of the pulmonary gas exchange for more than 5 minutes can irreversibly damage some vital organs, especially the brain. This is almost always followed by cardiac arrest unless respiratory function is quickly restored. However, intensive ventilation can have negative hemodynamic consequences, particularly in the period nearing arrest and in other circumstances where cardiac output is low. In most cases, the ultimate goal is to restore adequate ventilation and oxygenation without compromising cardiovascular status.

Respiratory arrest (and the deterioration of breathing that can progress to respiratory arrest) may be caused by

- Airway obstruction
- Decreased respiratory effort
- Weakness of the respiratory muscles

3. AIRWAYS

Usually the airways are compromised by obstructions in:

- Upper airways
- The lower airways

Infants under 3 months breathe through their nose, and therefore a nasal blockage can lead to an obstruction of the upper airway. At any age, loss of muscle tone in cases of reduced consciousness can cause an upper airway obstruction by moving the back of the tongue into the oropharynx. Other causes of upper airway obstruction include blood, mucus, vomiting, or foreign body; vocal cord spasm or edema; and tracheal pharyngeal inflammation (e.g., epiglottis), tumors, and trauma. Patients with congenital developmental disorders often have abnormal upper airways that become more easily blocked.

Obstruction of the lower airways may be due to aspiration, bronchospasm, airspace occupancy diseases (e.g., pneumonia, pulmonary edema, pulmonary hemorrhage), or drowning.

4. DECREASE IN RESPIRATORY EFFORT

The decrease in respiratory effort reflects an alteration in the CNS due to one of the following causes:

1. Disorder of the central nervous system
2. Adverse drug effect
3. Metabolic alterations

CNS diseases affecting the brain stem (e.g., stroke, infections, tumors) can cause hypoventilation. Diseases that increase intracranial pressure cause hyperventilation at first, but then hypoventilation occurs if there is compression of the brain stem.

CNS depression due to severe hypoglycemia or hypotension can eventually compromise respiratory effort.

5. WEAKNESS OF THE RESPIRATORY MUSCLES

This weakness can be caused by:

- Neuromuscular conditions
- Fatigue

Neuromuscular causes include spinal cord injury, neuromuscular diseases (myasthenia gravis, botulism [5], poliomyelitis, Guillain-Barré syndrome [6]) and neuromuscular blocking drugs.

Respiratory muscle fatigue may occur if patients breathe at a minute rate that exceeds 70% of their maximum voluntary ventilation for long periods (e.g., due to severe metabolic acidosis or hypoxemia).

6. IMMINENT RESPIRATORY ARREST

Infants, especially if they are under 3 months old, may have sudden apnea without warning due to massive infection, metabolic condition, or respiratory fatigue. Patients with asthma or other chronic lung diseases may develop hypercarbia and fatigue after prolonged periods of respiratory distress and suddenly become obnoxious and apneic without warning, despite adequate oxygen saturation.

7. DIFFERENCES BETWEEN NEONATES AND ADULTS

The main differences are that the physiognomy of the thorax, that of a newborn has thinner walls and its ribs are formed mostly by cartilage tissue of greater elasticity unlike an adult in which the percentage of cartilage decreases substantially giving the skeleton greater rigidity and strength. Therefore, a strong compression in the thorax of an infant or young child will produce a greater deviation of the chest wall towards the vital thoracic organs, such as the heart and lungs.

With this in mind we must perform the maneuvers with less force to obtain similar results to those obtained with adults and avoid damaging underlying organs and obtaining the expected results.

At birth, the baby's heart is halfway between the top of the skull and the pubic symphysis. The major axis of the heart is directed horizontally, with its base in the fourth intercostal space and its vertex to the midclavicular line. These relationships are maintained until the fourth year approximately, and later the heart moves gradually downward, due to the elongation of the thorax, until it is placed in the fifth intercostal space with its apex within the medioclavicular line. Until the first year, the width (or length) of the heart is no more than 55% of the width of the chest taken at the xiphoid line (imaginary line extending from the xiphoid appendix of the sternum). After the first year, the width of the heart is a little less than 50% of the width of the chest.

At birth, the chest is circular, but as the baby grows, the transverse diameter becomes larger than the anterior-posterior dimension, giving the chest an elliptical appearance. At birth, the circumference of the chest is about half an inch smaller than the head. At one year, the chest is equal to or greater than the circumference of the head slightly; after one year, the chest becomes progressively larger than the head.

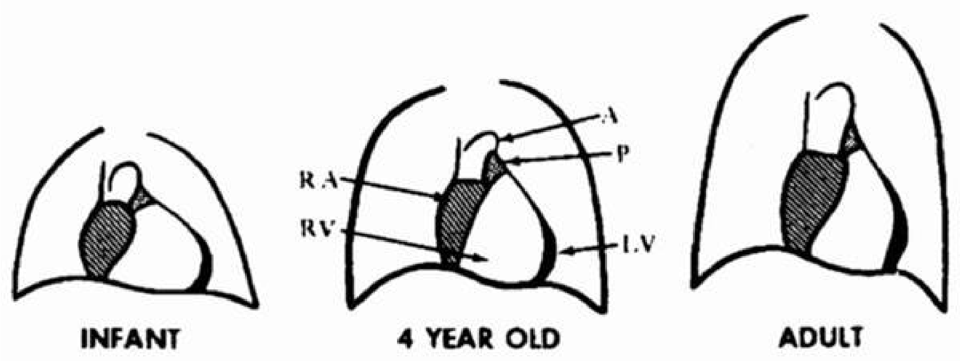

Figure 7 Differences in chest size with respect to age

Another difference that is observed is related to physiology, since the heart of a newborn baby beats at a frequency of 100 to 120 ppm considerably higher than that of an adult that goes from 70/85 bpm. Therefore, in neonates we must perform compressions with a greater frequency than those performed in adults.

Before cardiac arrest, bradycardia in children with dyspnea is considered a sign of imminent cardiac arrest. Neonates, infants, and young children are more likely to have bradycardia due to hypoxemia, while older children tend to have a tachycardia. In an infant or child with a heart rate < 60/min and signs of poor perfusion that do not improve with respiratory support, chest compression maneuvers should be initiated. Rarely, bradycardia secondary to heart block is seen.

Although the need for cardiac compressions is less than 1% of newborns, knowledge of this technique is important and can be life-threatening if not performed properly.

Babies and children are not miniature adults. Their anatomy differs from that of adults in several aspects that must be taken into account in the proper design of neonatal and infant CPR simulation systems.

8. TRANSITION FROM INTRAUTERINE TO NEONATAL LIFE

Within the cardiac physiology and the cardiovascular system in the pediatric age it is very important to know the bases of the fetal circulation and the changes that take place in the birth to understand many of the pathologies that can arise in the neonatal period.

In the fetus the ventricles constitute a parallel circuit as opposed to the serial circuit in the newborn. Oxygenated blood reaches the heart from the placenta through the umbilical vein that flows into the inferior vena cava through the venous duct. From the inferior vena cava, the blood reaches the right atrium, almost all of which is directed to the left atrium through the foramen ovale. From the left atrium it passes into the left ventricle and the aortic artery that carries the blood to all the fetal organs. It is collected and returned to the placenta through the iliac arteries from where the two umbilical arteries exit.

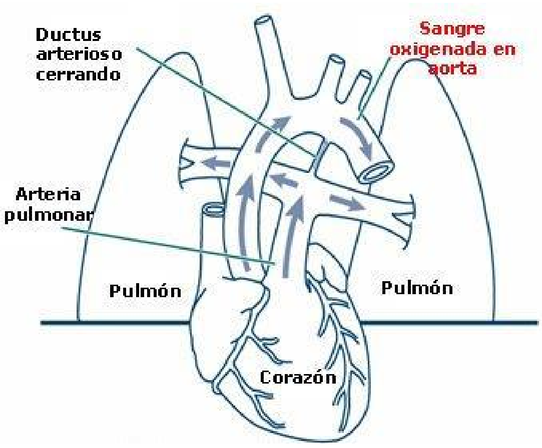

Figure 8 Fetal circulation physiology

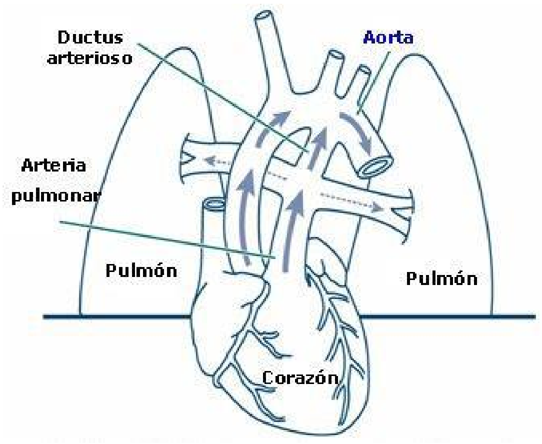

Figure 9 Circulation physiology of a newborn

The blood coming from the upper chamber passes through the tricuspid valve into the right ventricle and from there it is expelled from the heart through the pulmonary arteries. This blood does not reach the lungs because they are in a situation of vasoconstriction; it passes through the ductus arteriosus to the descending aorta.

At birth, the first thing that occurs is a decrease in pulmonary pressures due to the mechanical expansion of the lungs and the arterial elevation of the partial pressure of oxygen as a result of the newborn's breathing, the absorption of the intra-alveolar fluid begins, oxygen enters and the arterioles relax.

By clamping the umbilical cord, low pressure placental circulation is eliminated, thus increasing systemic vascular resistance. The blood from the right atrium flows to the right ventricle and the lungs because it has less resistance at this level. With all this process during the first days of life, the vessels and orifices of the fetal circulation are closed: the ductus venosus, the foramen ovale and the ductus arteriosus.

After birth, the newborn depends on its lungs as the only source of oxygen; the fluid of the lungs must be absorbed from the alveoli. Pulmonary vasodilation occurs, increasing blood flow to the alveoli so that oxygen can be diffused.

9. NEONATAL CARDIOPULMONAR RESUSCITATION

I proceeded to differentiate two basic types of cardiopulmonary resuscitation based on the public to which the training is directed, in the case that they are parents or people from the general public (in this case of lesser difficulty) and another oriented to health professionals where greater preponderance will be given to training in positive pressure ventilation and the use of different techniques based on the patient's condition

In both cases, both basic and advanced resuscitation seek to provide adequate practical training in the criteria and skills required to provide potential students of this course the necessary skills to provide proper CPR in newborns and infants.

9.1. Basic Cardiopulmonary Resuscitation

The following sequences of actions ensure maximum survival after a PCR. According to the online course of pediatric CPR (Argentine Society of Pediatrics) [7]

1. Prevention of Cardiorespiratory Arrest
2. Early and quality CPR
3. Warning to emergencies
4. Advanced life support
5. Post-PCR care

To carry out CPR I will use the following sequence, this sequence allows us to reduce the delay when starting CPR.

1. Compressions
2. airway opening
3. Good ventilation

The order of these actions allows to reduce the reaction times, since it begins with an action, which everyone can perform and emphasizing the importance of this action. The opening of the airway and the provision of ventilation can produce significant delays in the maneuver.

The sequence for performing basic resuscitation is:

1. Initial evaluation of the response
2. Call for help
3. Cardiac Massage
4. Secure the airway
5. Achive good ventilation

1. Initial evaluation of the response:

During the initial assessment of the response we must control simultaneously the response and breathing, at this time the rescuer must place the patient in a safe place, on a rigid surface. Secondly, it must be determined whether or not the patient is conscious by means of some gentle stimulation. And finally, evaluate breathing, color paleness, cyanosis, and spontaneous movements. If the child does not respond to the stimuli and does not respond, CPR should be initiated with the CAB sequence.

2. Call for help:

If there is only one person performing the resuscitation you should shout for help or if possible by phone.

3. Cardiac Massage:

Before talking about cardiac massage, we want to clarify that for both basic and advanced resuscitation, the technique for carrying out the massage itself is the same, then different procedures change when it comes to measuring the heart rate or other variables, but the way in which the massage is carried out does not vary.

Before starting with cardiac massage, it is important to carry out an evaluation of the circulation, evaluate position, frequency, relationship between compressions and ventilations.

- In infants and newborns, the brachial or femoral pulse should be checked. This process should not take more than 10 seconds. If you do not perceive it or you are not sure, you should start compressions.
- If the pulse is present but spontaneous breathing is absent, the victim should be ventilated until ventilation is recovered. The pulse should also be checked every two minutes, and it should not take more than 10 seconds to perform this task. If the pulse is not present or is less than 60 bpm, cardiac massage should be initiated.

The cardiac massage consists of rhythmic compressions of the sternum that compress the heart against the spine, increase the intrathoracic pressure, and circulate the blood to the rest of the body. These are performed at a depth of approximately one third of the anteroposterior diameter of the thorax, that is, approximately 3.5 to 4 cm. These compressions should be strong and fast, with a minimum frequency of 100 compressions/minute and a maximum frequency of 120 compressions/minute, always allowing the thorax to return to its normal position.

There are different techniques to carry out the massages: [8]

1. Place the thumbs (side by side in the case of a full-term newborn or one on top of the other if preterm) on the lower third of the sternum, below the intermamillary line, and the rest of the fingers hugging the chest.
2. Another way is to compress at the same point with two fingers placed perpendicularly to the sternum. This technique may be more useful in the case of a single rescuer.

Figure 10 Different cardiac massage techniques

In both techniques explained, the massage should be performed on the lower third of the sternum, two fingers approximately above the xiphoid appendix. It is preferable to locate the area by going from the bottom to the top, following the costal ridge to the xiphoid appendix, since the intermammary line as a reference line can lead to compression in an inadequate area.

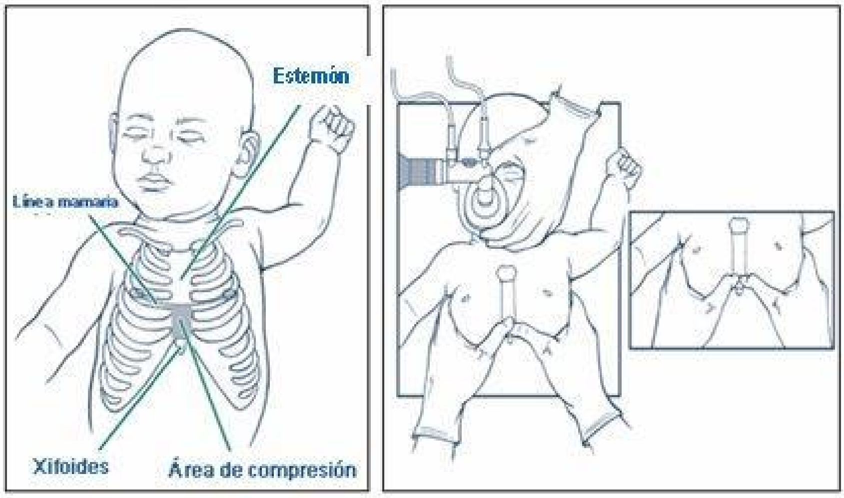

Figure 11 Area where pressure should be applied during heart massage

[9] During CPR, cardiac massage should always be accompanied by positive pressure ventilation. Coordination increases effectiveness. Available evidence supports that the ratio of cardiac massage to ventilation should remain 3:1 for newborns in the delivery room.

120 compressions should be performed every 60 seconds. Each event will occur in approximately half a second, with exhalation occurring during the first compression after each ventilation. It is also important to know that the chest should be allowed to relax completely at each compression to improve blood flow to the heart.

The current measure to document adequate progress during neonatal resuscitation is to evaluate the heart rate response.

It is important to minimize interruptions in heart compressions during resuscitation. The chest should be allowed to relax properly after each compression, improving blood flow to the heart.

4. Secure the airway:

To overcome the obstruction, the head must be placed in the extension position and the shawl raised (sniffing position).

This maneuver is done by following a series of steps.

1. Place one hand on the forehead and gently tilt the head back. The head will be in a medium line and slightly extended.
2. With the other hand under the chin, raise the chin, avoiding compressing the soft parts.
3. Remove any foreign objects visible in the mouth.
4. The proper position should align the external auditory meatus with the shoulder.

5. Good ventilation:

Ventilation should be mouth-to-mouth with or without barrier protection.

Breaths should last one second each, and hyperventilation should be avoided in order to prevent gastric distension and aspiration.

9.2. Advanced Cardiopulmonary Resuscitation

The normal transition explained in section 2.4 occurs in a few minutes, but the entire process can be completed in hours or days. Studies show that RNs need more than 10 minutes to achieve greater than 90% saturation. Lung fluid may require several hours to be completely absorbed. Functional ductus closure occurs within 24 to 48 hours. Complete relaxation of the lungs may take months.

This is a period in which the RN can present difficulties that alter the adaptation and for that reason present immediate cardiorespiratory pathology.

The mechanisms that could affect this period are: ineffective ventilation, systemic hypotension due to bleeding and hypoxia, pulmonary vasoconstriction with the consequent persistent pulmonary hypertension of the newborn, etc.

When a normal transition does not take place, the oxygen supply from the lungs decreases, the pulmonary arterioles remain contracted and pulmonary blood flow is compromised. The most important problem is the loss of gas exchange and the focus of neonatal resuscitation must be on effective ventilation to allow the lungs to expand. This is the most important principle of neonatal resuscitation.

Signs and symptoms that the newborn may have when the transition stage is compromised include

- Central respiratory depression.
- Muscle hypotonia.
- Bradycardia or Tachycardia.
- Tachypnea.
- Cyanosis.
- Hypotension.

There are studies that have shown that the lack of respiratory effort is the first sign that an RN has presented some perinatal problem. Perinatal hypoxia may lead to an initial period of rapid breathing followed by a period of primary apnea. During this period, a stimulation maneuver (those recommended) will lead to the resumption of breathing.

If cardiorespiratory involvement continues, this will lead to secondary apnea, in which stimulation will not restart breathing. This is characterized by absence of breathing, bradycardia, and hypotension. To reverse this process, positive pressure ventilation should be started as soon as possible, and then the degree of perinatal involvement will be assessed as more advanced resuscitation maneuvers are required.

9.2.1. Initial Assessment

In the first seconds after birth, it is important to define whether the RN requires any resuscitation maneuvers. For this purpose, a rapid assessment of the following three characteristics should be carried out:

- Is it a term gestation?
- Does the RN cry or breathe?
- Does it have good muscle tone?

If the answer to these questions is YES, ideally the RN should remain with its mother as soon as it is born, establishing the first skin-to-skin contact.

Let's briefly look at the reasons why these three questions are chosen to make the initial decision:

a. Is it a term gestation?

There is a greater risk of needing resuscitation in premature RNs, due to the immaturity of their organs and systems. For this reason, it is recommended that preterm (PTN) infants (less than 37 weeks) be evaluated and receive the initial steps in a site with a safe heat source. It should be noted that some late preemies (34-36 weeks) may receive initial care with their mother as long as we remain vigilant in monitoring their vital signs and maintaining their temperature.

b. Does the RN cry or breathe?

The presence of breathing is evident through the visualization of the chest. The child is expected in the first few seconds of breathing to expand the chest in a rhythmic and sustained manner. A loud cry also expresses respiratory adequacy. Care should be taken not to misinterpret ineffective breathing effort (panting, shortness of breath, gasping*), which may be an expression of respiratory and/or neurological depression.

c. Do you have good muscle tone?

In the RNT the right tone is expressed with limbs in flexion and active mobility.

Approximately 60 seconds ("the golden minute") are assigned to complete the initial steps, re-evaluate and begin ventilation if necessary.

Returning to the sequence, if the RN is full-term and vigorous, it does not need resuscitation and should not be separated from the mother.

The RN should be dried, placed in skin-to-skin contact with the mother and covered with a dry compress or towel to maintain the temperature. Breathing, muscle tone and color should be observed continuously. In these RNs, one should wait at least 1 minute to perform the umbilical cord ligation, and the baby can be placed on the mother, without this altering the benefits of this practice. There is insufficient evidence to recommend a time for cord ligation in RNs that require resuscitation maneuvers.

If this is not the case, the initial steps should be taken.

9.2.2. Initial Steps

The initial steps of resuscitation consist of

- Providing warmth and helping to maintain a normal temperature
- Dry the RN and remove any wet pads or towels.
- Place the head in a "sniffing" position (slight neck extension) to open the airway.
- Only if necessary, clear the airway by suctioning through a rubber bulb or suction catheter. Mouth and nose cleaning with a cloth, towel or compress can also be used.
- Stimulate breathing.

9.2.3. Temperature control

Postnatal temperature in the normal range in non-asphyxiated RN is a predictor of morbidity and mortality at all gestational ages. Body temperature should be recorded as an indicator of quality of care. It is recommended to maintain body temperature between 36.5 and 37.5 C. The aim is to achieve normothermia and avoid both hypothermia and iatrogenic hyperthermia.

9.2.4. Clearing the airway

The first step is to place the RN in a position that contributes to the opening of the airway. The RN should be positioned with the head towards the operator, in dorsal decubitus and with a slight extension of the neck ("sniffing" position) that allows the alignment of the posterior pharynx, the larynx and the trachea. Care must be taken to avoid hyperextension and flexion of the neck, positions that obstruct the airway. The need for airway aspiration is then assessed. [10]

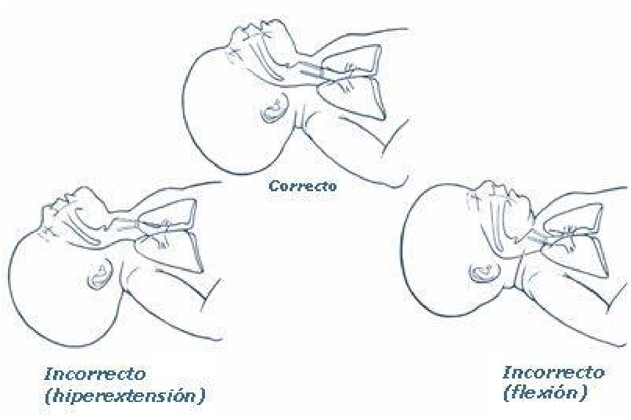

Figure 12 Newborn in sniffing position

9.2.5. Intubation and tracheal suction

Current evidence is insufficient to recommend intubation and tracheal suctioning in these RNs. There are small controlled studies that have not shown benefit from routine intubation and suctioning practice. Therefore, the recommendation not to routinely intubate is maintained, with an emphasis on prioritizing ventilation. In any case, there are patients who may require intubation to clear the airway, but that will be the decision of the professional in charge.

In general, the positioning of the RN, the drying of its body, and the eventual aspiration of secretions are sufficient stimulation for the beginning of effective breathing. If this is not the case, a complementary tactile stimulation of short duration can contribute to this.

The most suitable methods for carrying out complementary tactile stimulation are

- Slapping or gentle tapping on the soles of the feet.
- Gently rubbing the back.

9.2.6. Re-evaluation of the initial steps

After performing the stabilization maneuvers, the RN is assessed again. The decision to advance beyond the initial steps is determined by the simultaneous evaluation of two vital signs:

- Breathing: Chest movement, frequency, depth and symmetry of breathing must be evaluated, as well as alterations in the breathing pattern.
- Heart rate (greater or less than 100 bpm): Heart rate is the primary vital sign for assessing the effectiveness of resuscitation. It should be greater than 100 bpm. The fastest way to check the heart rate of RN is through palpation of the umbilical pulse. Assessment of the HR should be done intermittently by auscultation of the precordial beat. It is recommended to count the beats in 6 seconds and multiply that value by 10 to estimate the bpm.

Then we proceed to analyze the following possibilities:

1. If there is apnea or the heart rate is less than 100, the newborn's breathing should be assisted by providing positive pressure ventilation with bag and mask for 30 seconds; then, evaluate again.
2. If the newborn does not respond to positive pressure mask ventilation or the heart rate is < 60 beats/minute, the newborn should undergo endotracheal intubation.
3. If the child is adequately ventilated and the heart rate remains < 60 beats/minute, chest compressions should be given.
4. If severe bradycardia persists while the infant is adequately ventilated and chest compressions have been given for 1 minute, the umbilical vein should be catheterized or an intraosseous needle placed to deliver intravascular epinephrine as soon as possible.

9.2.7. Non-invasive positive pressure ventilation

Non-invasive positive pressure ventilation is a form of mechanical ventilatory support applied through a face or nasal mask, without the use of an endotracheal tube or other invasive airway devices.

In many cases, NIPPV can avoid the need for endotracheal intubation (ET), with the risks that it entails.

There are 2 types of NIPPV: a) continuous positive airway pressure (CPAP), and b) bilevel positive airway pressure (BiPAP). Continuous positive airway pressure applies uniform support pressure during inspiration and expiration. Bilevel positive airway pressure is similar to CPAP, but alternates between different levels of pressure on inspiration and expiration.

If the child is in an out-of-hospital situation, in which no artificial respirators are available, mouth-to-mouth resuscitation is performed. To do so, we will kneel down next to the child's head and follow the following steps:

- Open the airways.
- Cover the child's nose.
- Breathe in deeply.
- Place our lips around the child's mouth (if the child is less than one year old, we can cover the mouth and nose at the same time so that it is completely sealed).
- Make 5 uniform rescue breaths (blows) until you can see that the child's chest rises. Remove the mouth to take in air and observe that the chest comes down again. Between each breath, we must maintain the position of the head and hands, but we must remove the mouth to facilitate breathing.

Figure 13 Mouth-to-mouth ventilation procedure [11]

The effectiveness of ventilation is judged primarily by the rapid improvement in heart rate. If the heart rate does not increase within 15 seconds, the mask should be adjusted to ensure a good seal, check the position of the head, mouth, and chin to ensure that the airway is open, aspirate the mouth and airway, and assess the elevation of the chest wall. Airway pressure should be increased to ensure that the chest wall is elevated properly.

9.2.8. Invasive mechanical ventilation

Invasive mechanical ventilation is the procedure of artificial respiration, by which a ventilator is connected to the patient through an endotracheal tube (intubation) or a tracheotomy in order to replace the ventilatory function.

Intubation is a technique that consists of introducing a tube through the patient's nose (nasotracheal) or mouth (orotracheal) until it reaches the trachea, in order to keep the airway open and assist the patient in the ventilation process.

Pediatric patients, given that they are in a stage of growth and anatomical-physiological change, have a series of special characteristics that make a specific evaluation of each child necessary before proceeding with intubation. Depending on their characteristics, the materials to be chosen and the way in which the procedure is to be performed will vary.

We take into account that we are going to use this method when neonatal cardiac arrest is predominantly due to asphyxia, so providing ventilation continues to be the focus of resuscitation.

Intubated children require a series of care during and after intubation in order to achieve adequate ventilation, avoid accidental extubations and airway injuries. [12]

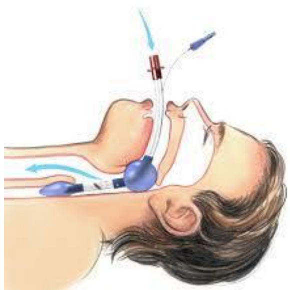

Figure 14 Endotracheal intubation

9.2.8.1. Medicines

The use of medications during neonatal resuscitation is rare. Bradycardia in the newborn is usually the result of poor pulmonary adaptation or deep hypoxemia; establishing adequate ventilation is the most important part of correcting it. However, if the heart rate persists below 60 bpm, despite adequate ventilation with 100% oxygen (preferably with orotracheal intubation) and chest compressions, administration of epinephrine, volume, or both is indicated. In any case, we will not go into detail on this subject since it will remain, if necessary, at the discretion of a professional to administer medication.

9.2.8.2. Post-resuscitation care

Newborns who required resuscitation maneuvers are at risk for deterioration after their vital signs return to normal. Once ventilation and/or circulation is assured, the patient should be maintained or transferred to a site where continuous monitoring is in place and care can be anticipated.

10. MANNEQUIN MATERIALS

The second main objective of this project was to find material that could be printed in 3D and make a perfect replica of the newborn baby's torso when CPR is performed.

As we will see later on, the dummy will be subdivided into two parts, an upper and a lower one, in order to obtain a detachable model with easy access to its internal electronic circuits. In the upper part of the dummy, the material should have the ability to compress to the same depth as the baby's body when force is applied and be elastic so it can return to its previous shape.

In addition, in the lower part of the dummy, the material should be hard and resistant, so that it can withstand the force applied to the upper part, as well as store the different electronic components that I am going to use (microcontroller, sensor, plates, etc).

This research is mainly aimed at finding a flexible material for subsequent printing and placement on the top of the dummy. In the lower part of the dummy from the beginning it was considered to use Polylactic Acid or more commonly known as PLA. This was considered in this way due to several characteristics of this material which did not make us doubt our decision:

- It is currently widely used due to its affordable price and also because it is accompanied by a printing technique such as FDM (explained below), which is the most widespread technique in Argentina today because the printers needed are the most economical and with a wide range of application possibilities, it provides excellent results.
- It is manufactured from 100% renewable resources, such as corn, beet, wheat and other products rich in starch.

- It is resistant to moisture and grease.
- PLA can be formulated to be rigid or flexible and can be co-polymerized with other materials. It has the mechanical characteristics to withstand the small force that will take place on the top of the dummy, which is a force of approximately 2 N.
- Its flammability is too low.
- Its degradation product, lactic acid, is non-toxic and totally incompatible, because it is produced by living beings.

With this in mind, I proceed to carry out the research to choose the material to be placed on the top of the dummy.

To start the research, the first thing to be investigated is the density of the human body and tissues for later analysis.

The table shows the densities of the human organs and body parts.

Tissue	Comparison				
	Material	Infill (%)	Error (%)	Material Density (g/cm³)	Tissue Density (g/cm³)
Blood	PETG	100	1	1,057	1,060
Liver	PVA	100	1	1,050	1,050
Brain	PVA	100	1	1,050	1,050
Muscle	PVA	100	1	1,050	1,050
Fat	Copper	80	1	0,95	0,947
Teeth	Tungsten	60	5	2,624	2,750
Cortical Bone	-	-	-	-	1,920
Marrow Bone	Aluminum	100	1	0,980	0,987

Table 1 Densities of the different parts of the human body

The density of almost all human tissues is about 1 g/cm3, so the material should have a similar density.

To find the ideal material, and without any physical tests (due to the closure of laboratories because of the COVID pandemic), extensive research was done and a company, Prestan Products of Cleveland located in Ohio (United States) that manufactures human manikins for CPR teaching was contacted. This allowed to obtain more empirical and experience-based information, which led to a more complete investigation.

Based on this research, the best results were obtained with the materials of the family of thermoplastic elastomers (TPE).

The main reason for this choice is their good ability to return to the initial position after the force is applied and their density which is also around 1 g/cm3.

Prestan Products, provided the information that they have made many tests regarding the best compressible and printable material and that the best performance and characteristics were always presented by the materials of the Thermoplastic Elastomers (TPE) family.

The table shows some of the thermoplastic elastomers with their densities along with some other characteristics.

Property	TPV (EPDM) fully cured	TPS (SEBS)	NBR/ PVC	TPC (COPE)	TPU	CR	NBR	EPDM
Density, g/cm^3	0.89 - 0.98	0.90 - 1.2	~1.4	~1.18	~1.1	~1.4	~1.2	~1.2
Typical Hardness, Shore	35A-50D	25A-90A	60A-90A	90A-80D	60A-60D	50A-90A	40A-90A	40A-90A
Typical Service Temperature, °C (°F)	-60/+135 (-76/+275)	-45/+110 (-49/+230)	-30/+95 (-22/+203)	-40/+150 (-40/+302)	-40/+120 (-40/+248)	-40/+120 (-40/+248)	-40/+130 (-40/+266)	-40/+135 (-40/+275)
Compression Set	●	△	X	△	△	○	○	●
Processability	TP	TP	TP	TP	TP	TSR	TSR	TSR
Recycling	Yes	Yes	Yes	Yes	Yes	No	No	No
Weathering/Ozone	●	△	○	○	○	○	○	●
Chemical Resistance	●	○	○	●	△	○	○	●
Oil Resistance	△	X	○	○	○	○	○●	X

Table 2 Comparative table of the different thermoplastic elastomers

It can be noticed that the densities of almost all TPE are around 1 g/cm3 and that it is very similar to the density of human tissue; and together with the ability to return to its initial shape, TPE represents the perfect material with which the baby's torso will replicate when CPR is performed.

10.1. Characteristics of TPE

Thermoplastic Elastomers (TPE), sometimes referred to as thermoplastic rubbers, are a class of copolymers or a physical mixture of polymers (usually a plastic and a rubber) consisting of materials with both thermoplastic and elastomeric properties. Thermoplastics are relatively easy to use in manufacturing, for example, by injection molding. Thermoplastic elastomers show the typical advantages of rubber and plastic materials. The advantage of using thermoplastic elastomers is their ability to stretch and virtually return to their original shape, which gives them a longer life and better physical properties than other materials.

TPE became a commercial reality when thermoplastic polyurethane polymers became available in the 1950s. During the 1960s, styrene block copolymer became available, and in the 1970s, a wide range of TPE became available.

To qualify as a thermoplastic elastomer, a material must have these three essential characteristics:

- Ability to stretch and, by removing stress, return to something similar to its original shape.
- Processable as a high temperature melt.
- Absence of significant creep.

10.2. Types of TPE

There are seven generic classes of commercial TPE (designations according to ISO 18064):

1. Styrene block copolymers, TPS (TPE-S)
2. Thermoplastic polyolefin elastomers, TPO (TPE-o)
3. Vulcanized thermoplastics, TPV (TPE-v or TPV)
4. Thermoplastic Polyurethanes, TPU
5. Thermoplastic Copolyester, TPC (TPE-E)
6. Thermoplastic polyamides, TPA (TPE-A)
7. Unclassified thermoplastic elastomers, TPZ

10.3. Advantages

Depending on the environment, TPE has excellent thermal properties and material stability when exposed to a wide range of temperatures and non-polar materials. TPE consumes less energy to produce, can be easily colored with most colorants and allows for economical quality control. TPE requires little or no preparation without the addition of reinforcing agents, stabilizers or curing systems. Therefore, there are no variations between batches in the weighting and measuring components, resulting in better consistency in both raw materials and manufactured items. TPE materials have the potential to be recyclable since they can be molded, extruded and reused as plastics, but have elastic properties typical of rubbers that are not recyclable due to their thermosetting characteristics. They can also be shredded and converted into 3D printing filaments with a RecycleBot.

10.4. Manufacturing

The two most important manufacturing methods for TPE are extrusion and injection molding. TPE can now be printed in 3D and has proven to be economically advantageous for manufacturing products through distributed manufacturing. Manufacturing by injection molding is extremely fast and very economical. Both the equipment and methods normally used for extrusion or injection molding of a conventional thermoplastic are generally suitable for TPE. TPE can also be processed by blow molding, fusion calendering, [6] thermoforming and heat welding.

10.5. Applications

TPE are used when conventional elastomers cannot provide the range of physical properties needed in the product. In 2014, the world market for TPE reached a volume of approximately 16.7 billion US dollars.

11. 3D PRINTING

3D printing, also called addition manufacturing, is a set of processes that produce objects through the addition of material in layers that correspond to the successive cross sections of a 3D model.

Some methods use melting or softening the material to produce the layers, for example, selective laser sintering (SLS) and molten deposition modeling (FDM), while others deposit liquid materials that are solidified with different technologies.

These SLS and FDM technologies are the most widely used worldwide as both the materials (in the case of polymers) and the machines themselves are relatively inexpensive.

11.1. Fused Deposition Modeling (FDM)

Molten deposition modeling (MDF) is a manufacturing process used for prototype modeling and small-scale production.

This technology uses an additive function, depositing the material in layers until the part is formed. A plastic or metal filament, which is initially stored in rolls (coils), is introduced into a nozzle. The nozzle is above the melting temperature of the filament material and can move in three electronically controlled axes. The nozzle is normally moved by stepper motors or servo motors. Generally the nozzle is moved by a stepper motor that moves vertically (Z), while the movement in the other two dimensions, in horizontal (x and y), is made by the object itself deposited on the initial platform, which is the one with two other stepper motors (one in each dimension). There are several possible combinations of nozzle, platform and motors. The piece is built with fine threads of the material that solidify shortly after leaving the nozzle depending on the ambient temperature.

The secret of FDM's accuracy and precision is the coordination of material feed and printer extrusion head movement. Both are constantly changing to produce a flat yarn of material that measures from 0.20 mm to 0.97 mm wide and as thin as 0.13 mm high. Part accuracy or tolerance is as high as 0.08 mm. [13]

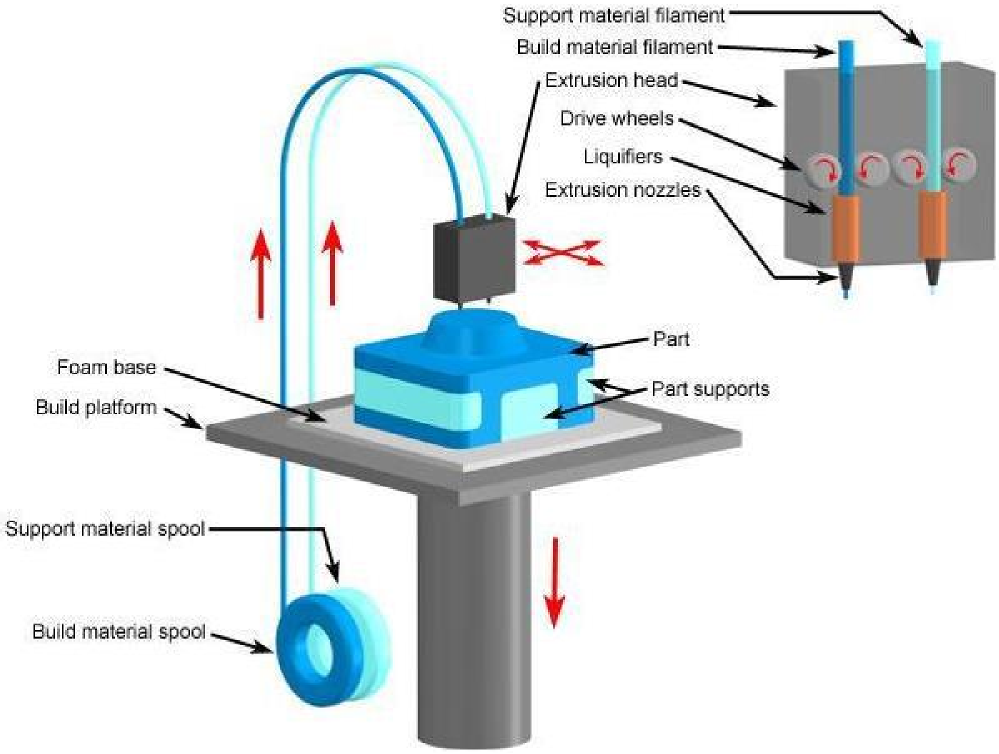

Figure 15 Working principle of FDM technology

11.2. Selective Laser Sintering (SLS)

SLS (Selective Laser Sintering) is an additive manufacturing method. It creates parts in an additive way by sintering fine particles of polymer powder to fuse them locally. Your plastic part will be created layer by layer, according to your 3D model.

During the 3D printing process, the SLS machine preheats the bulk powder material in the powder bed slightly below its melting point, to enable the laser to raise the temperature of the selected regions to the melting point.

A roller will apply a layer of polymer powder, then the laser will sinter the powder according to the 3D file and the construction platform will lower before applying a new layer of powder. The process will be repeated until the desired part is created.

CHAPTER 3
MATERIALS AND METHODS

1. CHOICE OF THE MATERIAL TO BE USED

There are several factors that we had to take into account when choosing the material to use. One of them is that we needed two roles of materials to carry out the 3D printing of the designed mannequin. It had to have elastic characteristics in its front half that would allow it to depress properly when the correct pressure is applied. At the same time, rigidity was required in its back part, since a structuring component must be involved that not only maintains the shape of the dummy, but also supports the electronic components, which need support and fixation to function properly.

In addition, I took into consideration the wear to which these materials will be subjected, the friction between components, the contact with the user, the dynamic loads on the parts. Also the constant hygiene that will be applied to the simulator, will require the use of surfaces suitable to resist cleaning chemicals, as well as dirt such as perspiration and the natural oils generated by human skin.

Taking all these factors into account, I chosed the material that I considered optimal for project.

Next, I will make an in-depth analysis of the material chosen to carry out the printing of the model, which is known as thermoplastic polyurethane (TPU).

Of all the types of TPE mentioned before, thermoplastic polyurethane (TPU) proved to be the best due to its density and structure along with its wide use in 3D printing, in this area it is known as Flex and has an approximate price of $3500. I believe it is the ideal material to carry out the project, because as I will explain below, it has very good characteristics in its various aspects, whether aesthetic, mechanical and structural.

TPU can be 3D printed with several technologies to achieve specific properties. FDM (Fused Deposition Modeling) printers can melt and extrude TPU filaments to create flexible parts such as cases, seals, gloves, among others.

Being flexible, TPU material can cause some difficulties during printing, such as clogging, nozzle clogging and deformation. However, with good calibration and adjustments, it offers a wide variety of possibilities.

In addition to being harder and, as a result, easier to work with, TPU also has better resistance to abrasion and low temperatures and shrinks much less than the softer TPE. Although these two filaments tend to have very different applications. On average, TPU filaments are printed at a high temperature of approximately 245°C (473°F).

Depending on the Shore hardness of the mixture (shore hardness is a scale of measurement of the elastic hardness of materials, determined from the elastic reaction of the material when an object is dropped on it) and whether or not it has additives, the TPU filament may require different configurations.

1.1. General properties

Thermoplastic polyurethane (TPU) is a fully thermoplastic elastomer. Like all thermoplastic elastomers, TPU is elastic and melt processable, and its other properties include transparency and resistance to oil, grease and abrasion.

But more than any other thermoplastic elastomer, TPU can provide a considerable number of combinations of physical properties, making it an extremely flexible material, adaptable for many uses.

1.2. Advantages of TPU:

1. Latex-free: Many products that come into contact with the skin, including clothing or sporting goods, contain latex, a naturally occurring rubber. It can cause allergies and skin irritation (also called hypersensitivity).
2. It does not contain agents such as mercaptobenzothiazole, thiuram and carbamate (which can be found in latex and cause skin irritation) or latex proteins (which are absorbed by the skin from latex). TPU rubber is synthetic, so it has nothing to do with latex.
3. It is biodegradable: most thermoplastic polyurethane compositions are not biodegradable. However, modern chemical companies offer blends with organic building blocks in molecule chains that can degrade in soil in 3 to 5 years. Although these compounds are generally referred to as biodegradable TPU to differentiate them from normal TPU (which is not biodegradable);;.
4. High resistance to abrasion, wear, oil and radiation.
5. High elasticity.
6. Transparency.
7. Strength.
8. Good tactile properties.
9. Easily colorable.
10. Versatility of compounds and properties.
11. Can be sterilized.
12. High elasticity throughout the hardness range.
13. Excellent resistance to impacts and low temperatures.
14. Good flexibility over a wide temperature range.

1.3. Disadvantages of TPU

1. Requires special manufacturing conditions in all methods.
2. Some grades have short life cycles.
3. The cost of the material is higher compared to some analogues (such as PVC).
4. Requires control of the amount of water before processing.
5. Transparent TPU turns yellow irreversibly.

1.4. Structure

By varying the ratio, structure and molecular weight of the reaction compounds, a huge variety of different TPUs can be produced. This allows urethane chemists to tailor the polymer structure to the desired final material properties. For example, a higher ratio of hard to soft segments will result in a stiffer TPU, while the reverse is also true.

Hard segments have high interchain interaction due to hydrogen bonds between the urethane or urea groups. The hydrogen bonding associations within the hard segments of TPUs act as reinforcing filler for the soft matrix.

The soft segments consist of flexible, linear and long polyester chains, depending on the application, interconnecting two hard segments.

For example, wet environments generally require a polyester-based TPU, while oil and hydrocarbon resistance often calls for a polyester-based TPU. For even greater utility, the molecular weight, ratio and chemical type of the hard and soft segments can be varied.

Numerous studies in the literature show that many factors influence the final properties of the TPU, i.e.: the polymerization process used during synthesis, the processing method and thermal history of the polymer, the chemical structure, the solubility parameter, the molecular weight, the glass temperature of the polyol, the volume fraction of HS and SS in the copolymer, the intermolecular interaction between the hard SS, the characteristics of the raw materials used.

1.5. Processing

TPU can be processed by extrusion, injection molding, blow molding and compression molding equipment.

It can be vacuum formed or solution coated and is well suited for a wide variety of manufacturing methodologies.

TPU can be easily sterilized, welded, processed, colored, painted, printed, die-cut and cut.

1.6. Mechanical Properties

In the following, the different mechanical properties of TPU in its different aspects are explained.

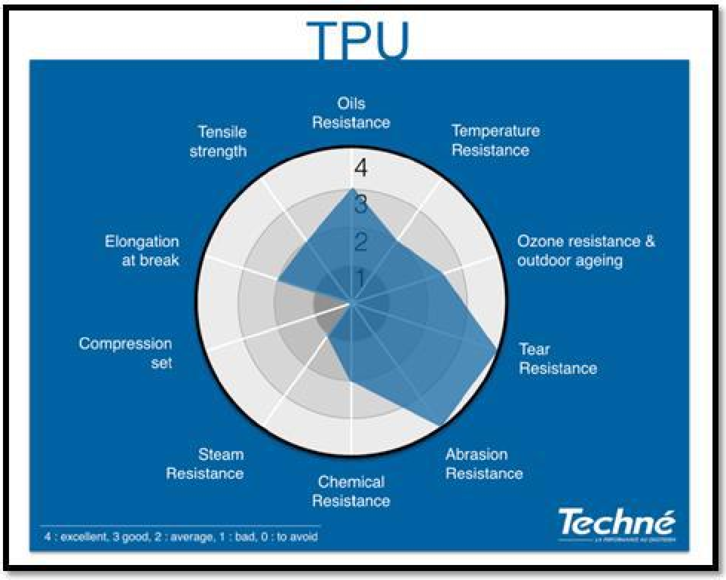

Figure 16 Mechanical properties of TPU

1.6.1. Hardness

Thermoplastic elastomers are measured in Shore A and Shore D according to ISO 868. Shore hardness is a measure of the resistance of a material to penetration by a needle under a defined spring force. It is determined as a number from 0 to 100 on the A or D scale. The higher the number, the greater the hardness. The letter A is used for flexible types and the letter D for rigid types. However, the ranges overlap, both are related by an exponential curve. [20]

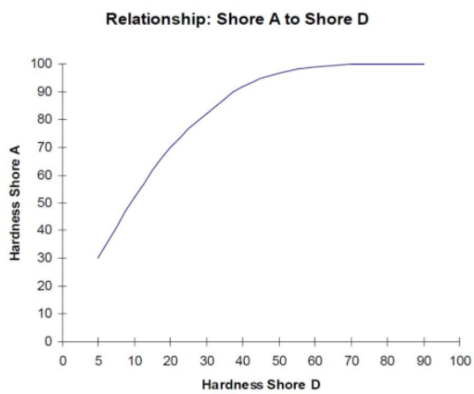

Figure 17 Ratio between Shore hardness A and D

As we can see in Figure 17, approximately 40 Shore D corresponds to 90 Shore A.

Thermoplastic polyurethane is supplied with a surface hardness from 35 Shore A, 70 Shore A up to 74 Shore D. A further distinction between grades is made by the use of flame-retardant additives, malleating agents (for low-adhesion surfaces), or plasticizer (for even higher flexibility, especially reduced flexural moduli and partial flame retardancy).

1.6.2. Abrasion

While TPU abrasion values according to ISO 4649-A are hardness dependent, the harder versions withstand the typical insulation abrasion test for an extremely long period of time.

The abrasion resistance of materials is generally determined by measuring the weight loss of a sample in a standardized wear test as shown in the table below:

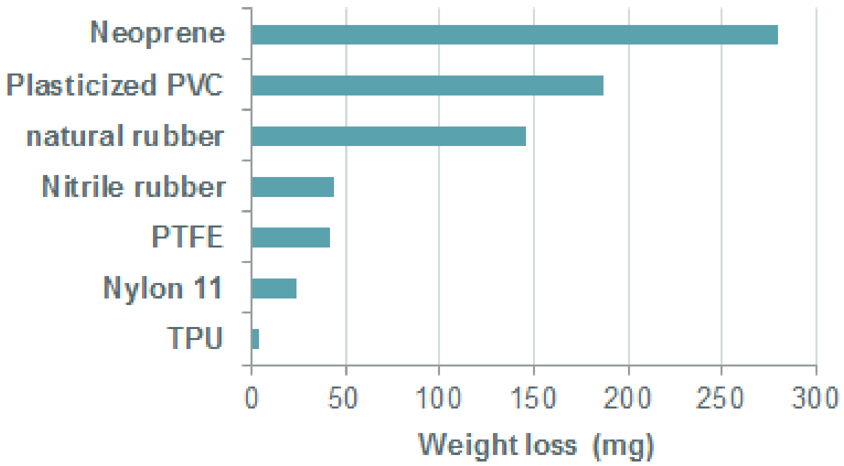

Figure 18 Results of the wear test on a sample of TPU and PVC.

The comparative results of such a test, as shown in Image 18, clearly show the superior abrasion resistance of TPU compared to other materials, such as PVC and rubbers.

1.6.3. Weathering and ozone resistance

Weathering behavior can be measured according to ISO 4892-2, Part A, using injection molded test plates with a thickness of 2 mm. Due to the chemical structure, TPU in general shows very good resistance to ozone. The selected grades were stored for 72 hours at 40 °C (104 °F) with an ozone concentration of 200 pphm and a stress of 20 percent. All grades remained free of cracks.

1.6.4. UV resistance

Aliphatic TPUs guarantee color fastness in their esthetic parts. They show superior stability to ultraviolet radiation and thus superior color stability, while maintaining good mechanical properties.

1.7. Applications.

- TPU is used in fused filament deposition (FFD) 3D printing. The absence of deformation and the fact that no priming is needed make it ideal for filament 3D printers when objects need to be flexible and elastic. The fact that TPU is a thermoplastic allows those filaments to be re-melted by the 3D printer's "extrusion" head and then cooled back into the solid elastic part.
- TPU powders are also used for other 3D printing processes, such as LASER Sintering (SLS TPU) and 3D inkjet printing (TPU powder bed). SLS printers can also use TPU-based powders to sinter flexible parts.
- FDM printers can melt and extrude TPU filaments to create flexible parts such as housings, seals, gloves, among others. Being flexible, TPU material can cause some difficulties during printing, such as clogging, nozzle clogging and deformation. However, with good calibration and adjustments, it offers a wide variety of possibilities.

1.8. Sanitary applications

Thermoplastic polyurethane (TPU) is well known and specified in the medical industry for advanced medical and sanitary products due to its high performance characteristics. Due to its excellent mechanical properties, durability and resistance to oils and chemicals, TPU is very suitable for medical applications.

Since TPU contains no plasticizers, it also offers the medical industry an environmentally friendly replacement for PVC without sacrificing flexibility.

Some examples of TPU medical applications include devices used for diagnostics, anesthesia and artificial respiration, as well as healthcare mattresses, dental materials, compression stockings, medical instrument cables, gel shoe orthoses and wound dressings.

1.9. Other medical benefits of TPU

Many products that come into contact with your skin, including clothing or sporting goods, contain latex, a naturally occurring rubber. It can cause allergies and skin irritation (also called hypersensitivity), which makes some people wonder whether TPU may also contain latex.

TPU is a thermoplastic polyurethane and has no agents such as mercaptobenzothiazole, thiuram and carbamate (which are found in latex and cause skin irritation) or latex proteins (which the skin absorbs from latex).

2. METHOD OF DESIGN AND DEVELOPMENT OF THE MANNEQUIN

To carry out the design and development of the mannequin, as it is important that, in every project, there should be interdisciplinary work and interconnection of different areas as the main source of intertwining ideas, knowledge and experience, I had the help of a group of advanced students of industrial design who suggested us to carry out the procedure following the following instances:

1. Search for approximate dimensions
2. Obtaining scans (DICOM images).
3. Transfer of images to STL format.
4. Use of DICOM images for section tracing.
5. Clean pass of the shape
6. Final shape
7. Sum of components
8. Proposal of materials
9. Prototyping

2.1. Search for approximate dimensions

To start the development of the modeling, I began with a background search on the dimensions available in anthropometric tables [21].

After observing that the perimeter established in most of the tables was 35 cm +/- 2 cm, a formal search for proportions and approximate measurements was started, since this was the only accurate measure of the dimensions. Measurements referring to textiles for newborns were used to corroborate the proportions and I proceeded to start the modeling and a list of possible sections for the development of the model was made, as we can see in the following images.

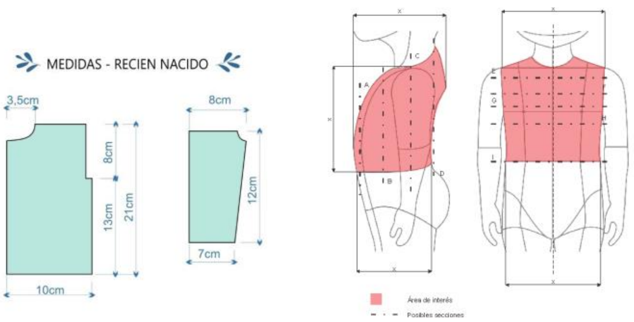

Figure 19 Approximate measurements obtained in the first instance.

2.2. Obtaining DICOM format images

Thanks to the collaboration of the OULTON Institute and its support in the projects of our university, I was able to obtain DICOM images obtained from the diagnostic imaging method called Nuclear Magnetic Resonance, performed in infants of different ages, with the objective of being able to work with these images, in order to have greater certainty and precision when taking measurements.

By using these images it was proposed to obtain a file transportable to a three-dimensional format, because the DICOM format is a format difficult to manipulate. As its name indicates (Digital Imaging and Communication On Medicine) it is a standard for the transmission of medical images and data between hardware for medical purposes. The protocol includes the definition of a file format, a network communication protocol based on TCP/IP.

These files are composed of a succession of images, in this case 125, which when combined give rise to a 3D model.

In order to view the images and work with them, I used the ITK-SNAP program, which allowed us to obtain transversal, longitudinal and posterior sections in different areas of the scan. I was able to observe here that the study performed on the infant only had information on the thoracic section of the neonate, and lacked information on the abdominal part.

Through a system of axes, as shown in Figure 20, it is possible to move and obtain the necessary slices. However, our main objective with this file was to convert it to STL format, where it would then be exported from the reading application, that is, from ITK-SNAP to SolidWorks, which will allow us to adapt it to our objectives: the elaboration of a CPR model that contemplates the design premises proposed.

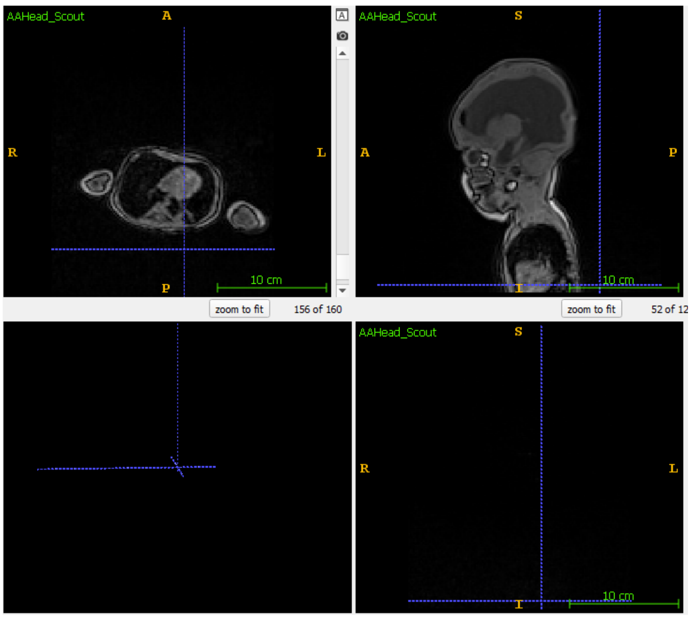

Figure 20 Image processed in ITK-SNAP

2.3. From DICOM to STL format

By means of a combination of programs (Blender, Rhino and Meshmixer) it was possible to convert the DICOM file to STL, in order to import it into a 3D program, SolidWorks. The Blender, Rhino and Meshmixer programs were used because of their file conversion capabilities, which allows the scan to be exported in its entirety. These aforementioned programs use the succession of images (principle by which DICOM files are conformed) for the transformation of images into 3D solid files.

Our objective at this point was to use the STL file to make different cuts in the model and obtain the most relevant sections to then form a solid with the exact measurements.

However, I had the inconvenience that the STL format was imported as a figure, i.e. a non-editable format and not workable as a solid or surface, so it was useless to continue with this imported file.

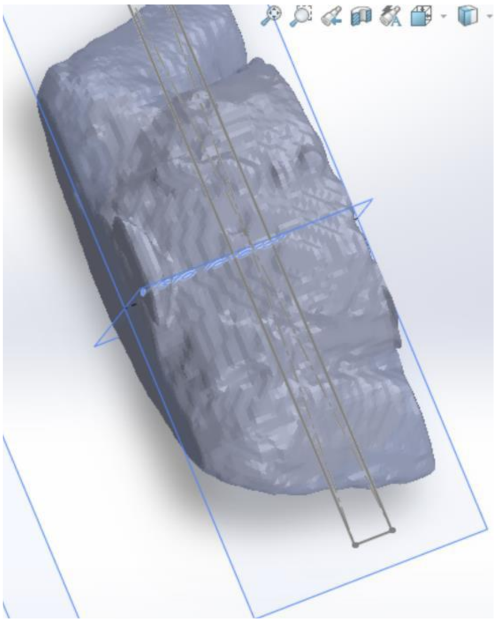

Figure 21 STL file imported as figure

As we can see in the image 21, the finishing was of very poor quality, with undefined parameters, not measurable in terms of dimensions and since it was not a 3D solid, the intervention in it was very limited, not allowing the use of cuts and sections to visualize and develop the model, that is why I proceeded to face the problem in a different way.

At this point, I was faced with a new problem and therefore I proceeded to search for possible alternatives for the development of the model. I still had the possibility of implementing the sections obtained in the ITK-SNAP program, a procedure that will be explained below.

2.4. Use of DICOM images to sketch sections

What I did in this instance was: I took the images of the most relevant sections obtained from the DICOM file (obtained in ITK-SNAP) and proceeded to import them into SolidWorks. Then they were scaled and adjusted with respect to the previously known proportions, finally they were traced, being used as a reference for the parameters of the sketches necessary to define the shape of the resulting solid. This can be seen in the following image.

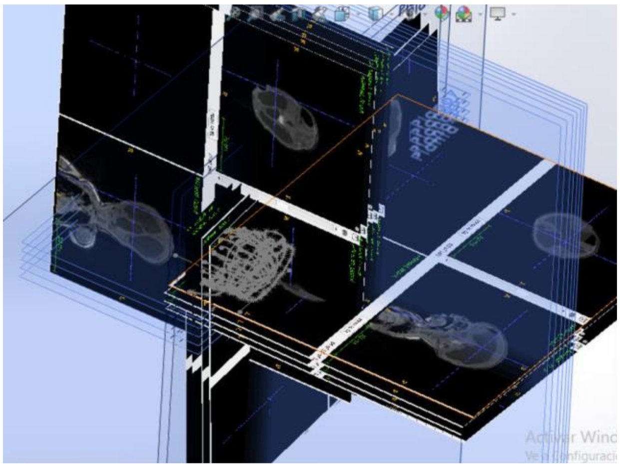

Figure 22 SolidWorks procedure for tracing relevant sections

The method or operation used in the Solid Works program is the overlay, which consists in the use of the so-called sketches. Sketches are 2D drawings defined within a plane in a Cartesian space. For a better understanding of the development process, I will quote IRAM 4507 Standard, which defines a section as the figure resulting from the intersection of several planes with the body or part. The more sections are defined, the more precise the shape is, but in this case the sections, being precedents of an organic body with undefined limits, were not sufficiently accurate or parameterizable manually.

Therefore, sketches were made, each one representing a specific section of the volume.

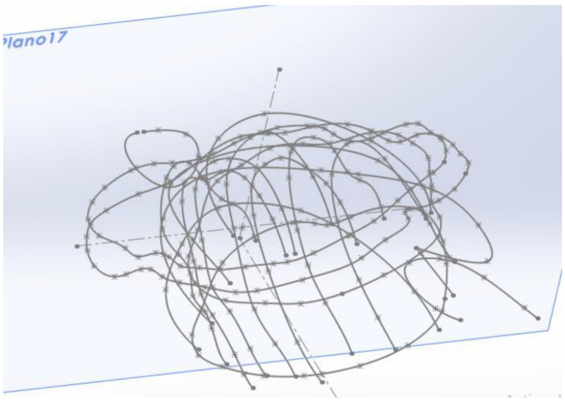

Figure 23 Point interpolation in Spline

These were related and overlaid to form a surface defined by these faces. The sections used can be either vertical or horizontal in order to define the final shape as well as possible.

For the reproduction of the sections, the Spline tool was used in the first instance.

As we can see in image 23, the Spline tool, what it does is to interpolate the shape between points and they are very useful for modeling free forms with smooth and continuous transitions. However, this is a tool that does not have parameters and therefore is a good way to, as the design progresses, lose or deviate from the parameters that were originally agreed upon. For this reason I obtained a model that was quite deficient in shape, which will make printing and therefore the reproduction of the model difficult, so it was decided to approach the development of the 3D model in another way.

2.5. Obtaining a model of proportions

Images of models available on the Internet were used and the shape was reproduced to maintain the proportions. The images previously obtained from the DICOM file were used as a scale reference, in order to achieve a configuration and dimensions that would be more faithful to reality.

The sections obtained in the DICOM images were thus complemented with images of available models in the necessary views (frontal, lateral, superior, etc.) for subsequent reproduction.

These neonatal or infant views were fundamental in the development of the model since they were used to adjust possible imperfections or lack of information in the previous sections.

As previously mentioned, a DICOM file, having its purpose in a medical field, and being corresponding to a human body, does not have a correct delimitation of the sections that were considered of importance; that is why this complementation of information and dimensions arrived at a good result in terms of dimensions and real aspects of a neonate.

Through this process it was possible to obtain a solid with a more consistent and simplified shape for a CPR simulator.

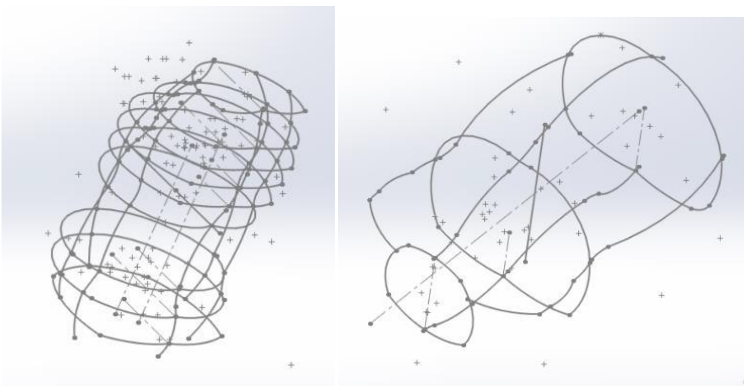

Figure 24 Proportion model obtained

As shown in image 24, the model in question does not have extreme details, but it does have clear references to the different parts of the torso such as the sternum and pectorals, which are points of interaction with the user. In addition, a simpler shape facilitates 3D printing, lowering costs and increasing the production speed of the simulators.

2.6. Final form

Once an approximate shape of the model was obtained in terms of proportions, finishes and dimensions, it was decided to add details to it in order to obtain a more reliable design.

Taking into account that the main objective of the project is to develop a simulator for the RCP, it was decided to simplify the model generating a more organic shape and not so defined in its totality, it was decided to work with greater detail in those sectors more relevant with respect to our objectives, thus reducing possible conflicts when carrying out the 3D printing, in turn reducing costs. We can say that we are looking for a model with a lower level of detail, but adequate to our needs.

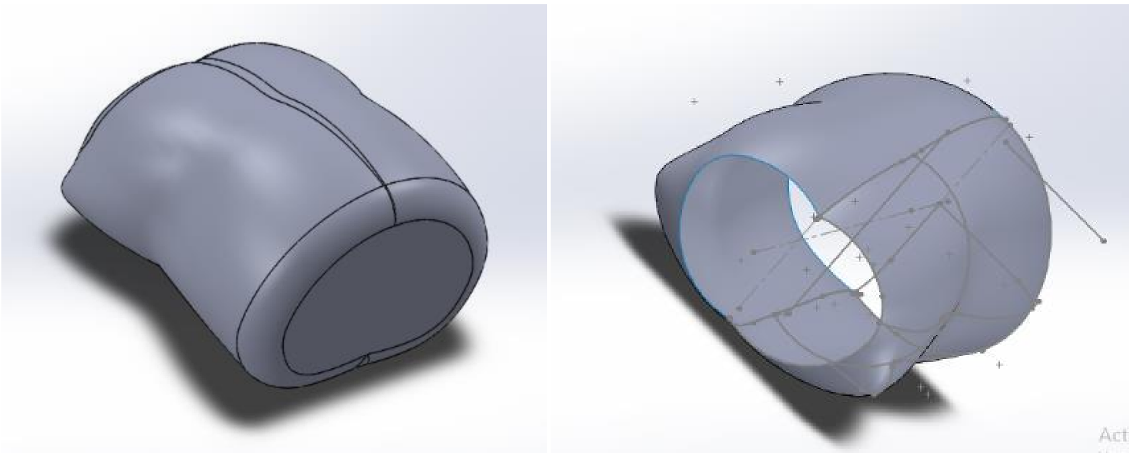

Figure 25 Outer surface of the torso not closed and then closed and with rounded edges.

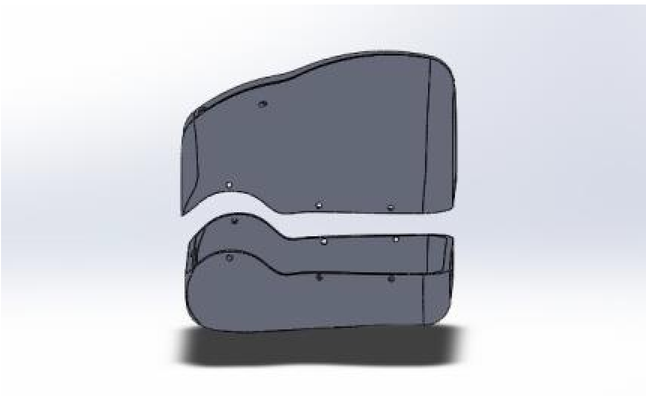

Figure 26 Division in the lower and upper part of the model

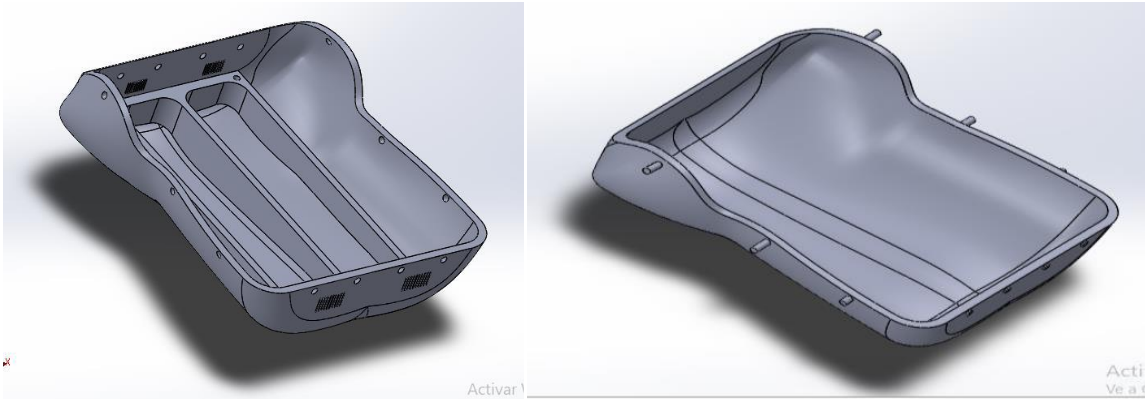

Figure 27 Lower part of the model, with and without structural reinforcement (lower part)

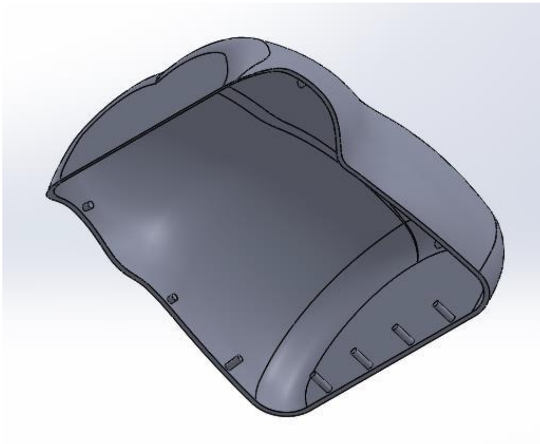

Figure 28 Upper casing

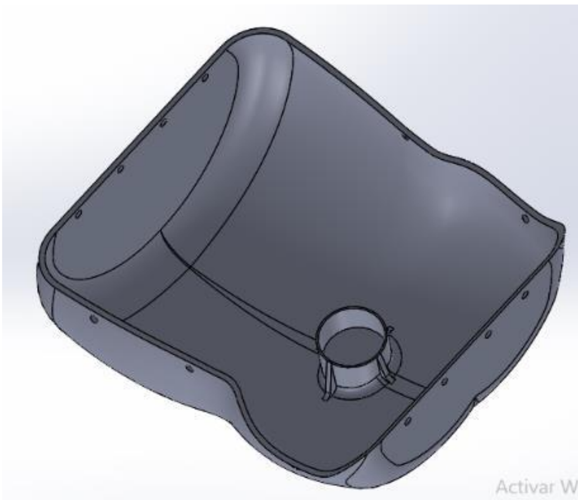

Figure 29 Cylinder reserved for spring inlet (upper part)

With the outer surface of the torso completely defined as shown in image 25, the ends are closed and the final roundings are made.

The volume was subdivided into two halves. One upper and one lower. These were divided with a surface in reference to a horizontal plane with changes in height present in the shoulders, this part of the sides of the torso, leaving the pectorals and abdomen, on the one hand, in the upper part, and the back in the lower piece, this can be seen in image 26. The dividing surface was projected once defined and then once the solid was cut in its entirety, the splitting tool was used to obtain the two halves. Both could be 3D printed, but with materials with different characteristics.

The upper piece, must have elastic characteristics since it is necessary that it can collapse or depress when the user applies force on the sternum. That force will have to be counteracted by an element with elastic characteristics, since when the pressure is removed the depression generated has to return to its original state simulating the reaction of an organic human torso. For this purpose, a spring with a resistance of 3 kg or 29.4 N was selected. This resistance is estimated by specialists in the area of neonatal resuscitation, who also mentioned that this pressure varies depending on each patient and it is the experience of the person and the physical build of the treated subject that really determines the pressure exerted, however, these parameters were the most indicated, until a prototype is taken to field tests and can be adjusted according to the consideration of specialists in the area.

The professionals consulted indicated that it is preferable that the resistance be greater than the real one, so that the user develops a greater muscle memory when assisting with CPR for long periods of time. There are other possibilities besides the use of a spring that can be considered in the future continuation of the project.

In image 28, we can observe the behavior, or ribbed cylinder that allows the upper casing to receive the spring which in turn is supported by the lower piece with a guide system similar to the upper one in order to be compressed in an adequate manner and avoid displacements.

The lower part, image 27, was designed as a rigid structuring component to maintain the integrity of the simulator and function as a base for all mechanical and electronic components, but it also has formal characteristics that simulate the back of an infant, since one of the CPR compression methods requires the user to place his hands on the child's back. In the internal part of the lower part there are a series of ribs that can be seen in the image that give greater rigidity to the piece, also these generate a flat surface to place the internal components properly, to access them and avoid damage by incorrect movements or blows. A removable plate was proposed, which makes it possible to remove all the mechanical and electronic elements at the same time for their assembly and future maintenance. Extending the useful life of the system, it would also be possible to exchange housings quickly in case they are not in use conditions, taking advantage of the modularity of the component system.

The upper and lower pieces are linked in such a way that the upper piece (elastic laminar) is superimposed on the lower piece (rigid structuring). The upper piece advances on the surface of the lower piece to leave a margin, which allows it to be fixed. Initially, it was considered to use a press-fit between them, but the tension generated during the activity deactivates or damages the joint. Then, the use of a hook system was considered, printed on the lower casing itself, which would fix the upper piece by means of perforations aligned with the hooks. Finally, the use of hooks was ruled out, as the 3D printing would likely fail with use, and it was decided to use threaded fasteners to secure the two pieces together.

To achieve the overlap between the pieces in the 3D modeling the already cut surfaces were selected and given a thickness, the lower piece projected its thickness internally, while the upper piece externally, allowing the upper piece to overlap over the other, then the upper piece was extended over the other by approximately 1 cm to be able to fix them in a through way.

Once the housings were twinned, the necessary perforations were made in the two housings, to be able to insert a through screw between the two pieces, as shown in image 26, 3 perforations can be seen on the side of the torso and 4 on the base, these were arranged so that the screws fix the sectors where more deformations will be present.

Other interventions made on the casings were the perforations and housing of the indicator LEDs for the user, as well as USB connectors were included for the connection via cable of the Arduino board with a notebook or Tablet, charging port for the batteries as can be seen and a button panel to use the different modes of the system, placing the 3 LEDs in the upper center of the torso. Also in the upper piece, nipples of the neonate were incorporated, as a reference to facilitate the location of the sternum by the user.

In the lower part, in addition to the perforations for the screws and the reinforcement ribs for fixing the component plate, grid-shaped cuts were incorporated in the upper and lower faces to allow the sound of the speaking component to be correctly perceived from the outside, in addition to taking advantage of the resonance generated by the torso itself, amplifying the sounds in a more comprehensive way.

2.7. Characterization of the spring

The spring as a mechanical element keeps the shells in their original shape avoiding a permanent collapse, it is contained by two 3D printed structures, as we said before (upper and lower part of the dummy).

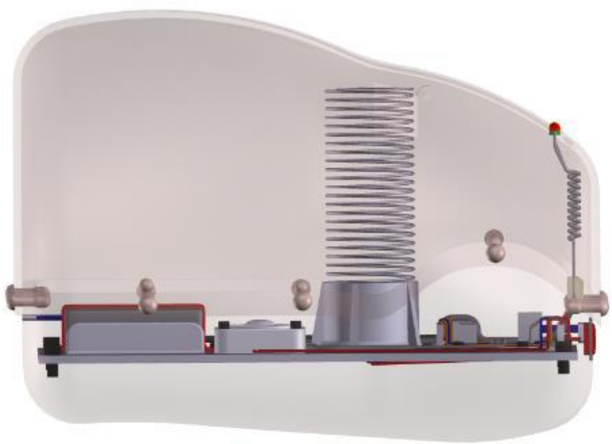

Figure 30 Lateral view of the spring with respect to the dummy

As we can see in image 30, these structures prevent the spring from slipping out while working, and provide parallel surfaces for the sensor to work in reference to.

The characteristics of the spring are within the following parameters: the minimum inner diameter, or ID, is 31.5 to 32 mm since it must be able to accommodate the proximity sensor. The outside diameter, OD, has more tolerance, but is also limited by the other nearby components including the space occupied by the printed base that receives this component. The lengths are determined by the space available between the upper housing and the component board. The installed length Li is 100mm. Considering that the spring has no preload, the operating length is 60 mm if we consider that the depression to reach the sternum is 40 mm. The force applied on the infant sternum that could be recorded in tests carried out at the GRSI Laboratory before the start of quarantine, estimate a range of forces required to perform the compressions of between 1.5kg to 3 kg or 29.4 N.

Attached in Annex N°9 is the study and calculations performed in the GRSI laboratory on springs applied to CPR, including the requirements for a spring used in neonatal manikins. In order for this spring to be implemented in the designed manikin, it should only have a longer length, adding 2cm to the length of the manikin.

Clarification: The calculations and estimations have a theoretical character, it is included in future works the task of making a print of the first prototype and taking it to perform tests with different health professionals, due to the fact that the material that will be used for the external part of the manikin is used by companies that have at this moment commercialization of similar manikins.

We understand that the adjustments to be made once the physical prototyping has been carried out will only affect the spring, which can be modified to meet the requirements of the health professionals who perform the different tests. In order to achieve the best representation of the mechanical behavior of the resistance of the model with respect to a neonate.

2.8. Removable plate

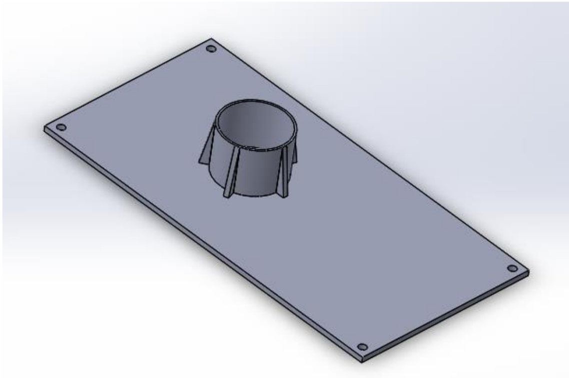

Figure 31 Detachable, electronic components mounting plate

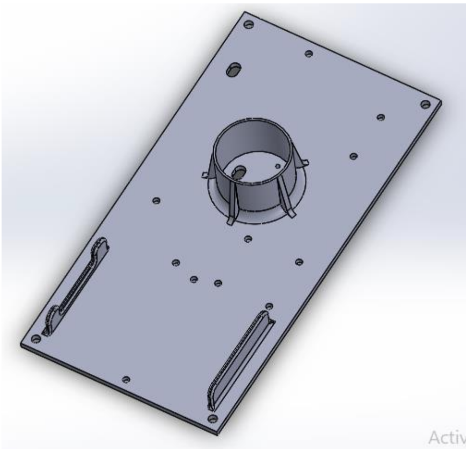

Figure 32 Component mounting holes and spring support are shown.

The plate to which the electronic components are screwed, image 31, can vary in material. A fast manufacturing option is the use of laser cutting, as it is popularly known or laser beam cutting (LBC) is a thermal cutting process that uses highly localized melting or vaporization to cut laminar elements, in this case mdf pieces that would allow cutting the plates with all its perforations in a single operation, then the elements could be screwed with common wood screws, or use nuts inserted from the back side of the plate. the base of the spring will be 3d printed and then added to it.

Another option for manufacturing the plate is to print it completely with 3D printing, which would increase costs and manufacturing times plus metal inserts or nuts of different diameters would have to be added to it.

An approximate wall thickness was established, in order to have an internal volume of the object where the sensors and systems necessary for the operation of the simulator will be located. Cataloging the components according to type and function, they were placed in the internal space and their optimal location was determined in order to facilitate the connection of the necessary cables. This will be explained in more detail in the next chapter.

3. 3D PRINTING PROPOSAL

There are two widespread technologies for 3D printing, FDM and SLS.

In proposing the use of FDM instead of SLS, FDM has some advantages, it is less expensive and secondly, it is usually faster to produce TPU parts with filaments instead of powder.

In contrast, 3D printing with TPU filaments using FDM will result in a dimensionally less accurate part, with visible print layers that cannot be smoothed. In addition, since TPU is a soft material, particularly when compared to ABS and PLA thermoplastics, TPU filaments can flex in the extruder mechanism, resulting in filament winding and extruder clogging.

However, the softness of the material is what makes layer-to-layer adhesion in TPU prints strong and durable.

I selected the FDM technique as the printing method, since in our work the economic aspect is very important for it to be viable and, as mentioned previously in the theoretical framework, the difference in costs between one technique and the other is substantial. Using this technique because it is widely used allows us to generate different models since it is not difficult nowadays to find printers that use this technology.

Once the file was finished, I proceeded to perform a printing simulation, it should be noted that the program used for this purpose is Cura Maker and the printer to be used tentatively is the Wanhao Duplicator 9 model.

3.1. Model loading and print simulation.

The Cura Maker program was chosen for printing the 3D model.

The model will be divided into two large printing blocks, on the one hand the upper and on the other hand the lower housing.

The printing parameters that are necessary to put into the program are mentioned below:

- Printing temperature: the recommended extrusion temperature range is between 225-250° C, depending on the type of 3D printer and the TPU filament available. However, keep in mind that printing at higher temperatures will allow the filament to melt faster and flow more easily from a nozzle.
- Speed: TPUs typically print best at slower speeds. It is good practice to set half the average speed (15 mm/s - 20 mm/s) to ensure high quality prints.
    - Extrusion Multiplier: The extrusion multiplier is the 3D printer setting that allows you to control the amount of filament coming out of the nozzle or simply the extrusion flow rate. Since TPU filaments can be improperly extruded during the printing process, improper bonding of layers and perimeters occurs. One way to solve this problem is to increase your extrusion multiplier slightly.
    - Retraction: retraction is the mechanism in a 3D printer, which pulls the filament back into the extruder as a means of preventing the filament from melting. This feature is very useful with rigid filaments such as PLA and ABS, however, with TPU filaments, retraction can be a challenge and can cause clogging. Therefore, it is highly recommended to disable retraction to avoid stretching and compression of the flexible filament in the nozzle.

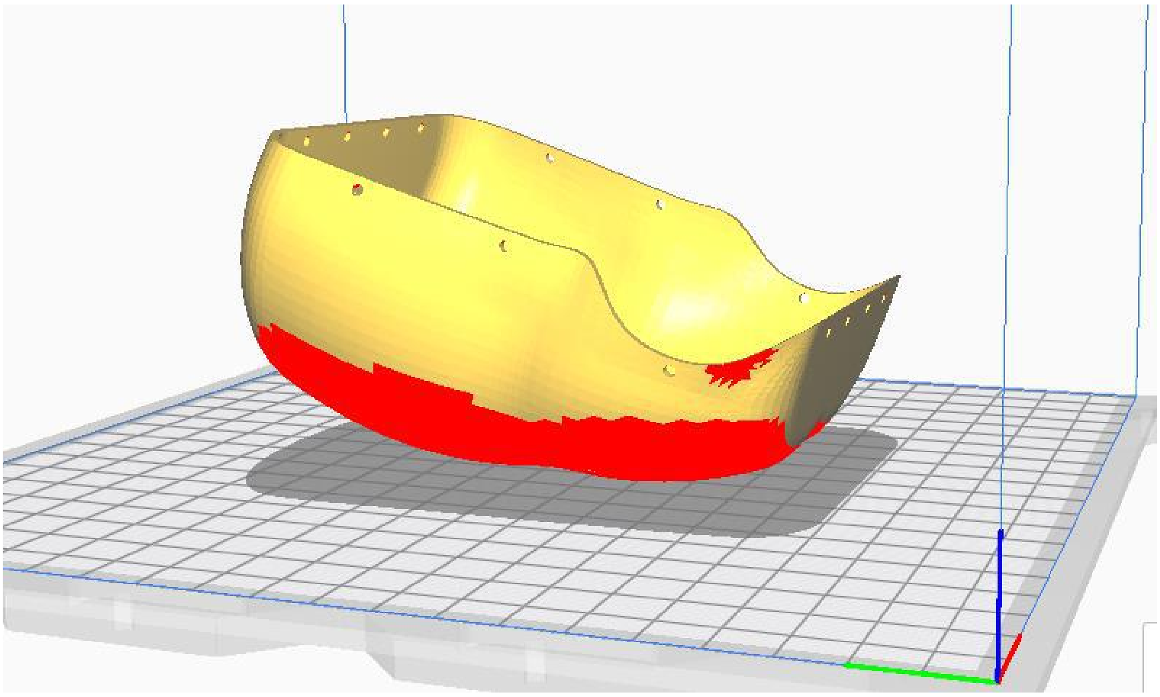

Figure 33 Housing during simulation on printer bed

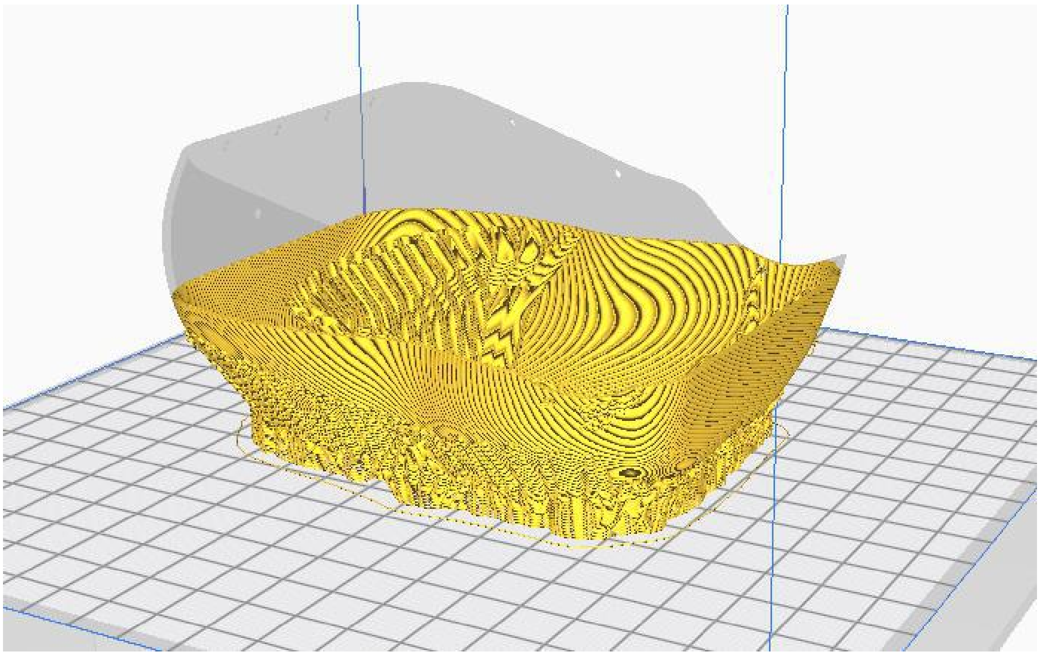

Figure 34 Simulation of layers, for FDM method

The area highlighted in red is where the printing supports for the part will be presented, the program detects where the part will need reinforcements.

At the beginning of the project, it was determined that the technology to be used would be 3D printing by FDM (fused material deposition), that is why all the design development of the model in all its stages was carried out as to be approached with this technology; that is why all the necessary considerations were taken into account so that at the prototyping stage it could be printed in the most optimized way.

Aspects such as the use of pronounced radii, support on the largest possible surface on the printing bed and avoidance of sharp edges (which are initiators of failures) were taken into account.

Figure 35 shows a first approximation of how the part would be supported on the bed. Figures 36 and 37 refer to the upper part of the model for CPR. Figure 34 shows the progressive succession of layers that characterizes FDM 3D printing.

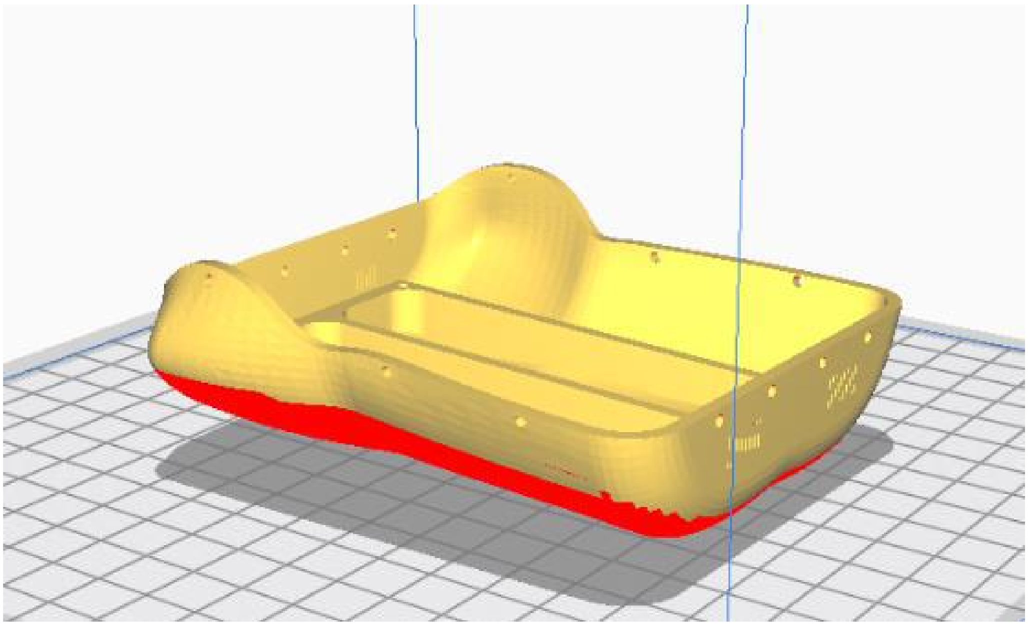

Figure 35 Simulation of bottom part printing with reinforcements

In image 35, we have the second printing block, the lower part of the model. The bipartition line was placed in such a way, bordering what would be the shoulder of the model, so that in this way the efforts when exerting pressure when doing the PCR are divided correctly and do not collapse the model.

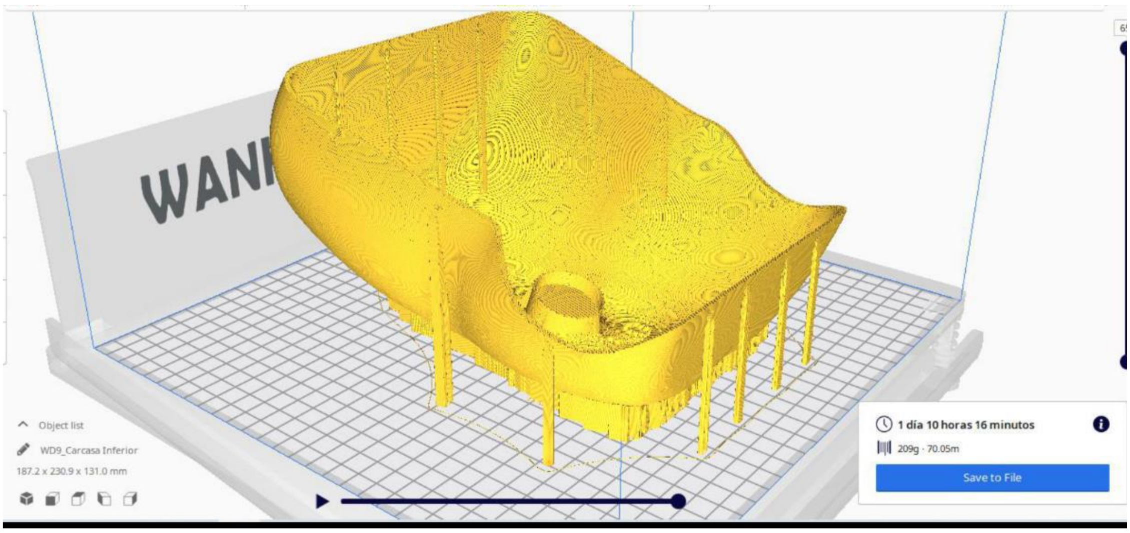

Figure 36 Last step prior to printing the upper casing

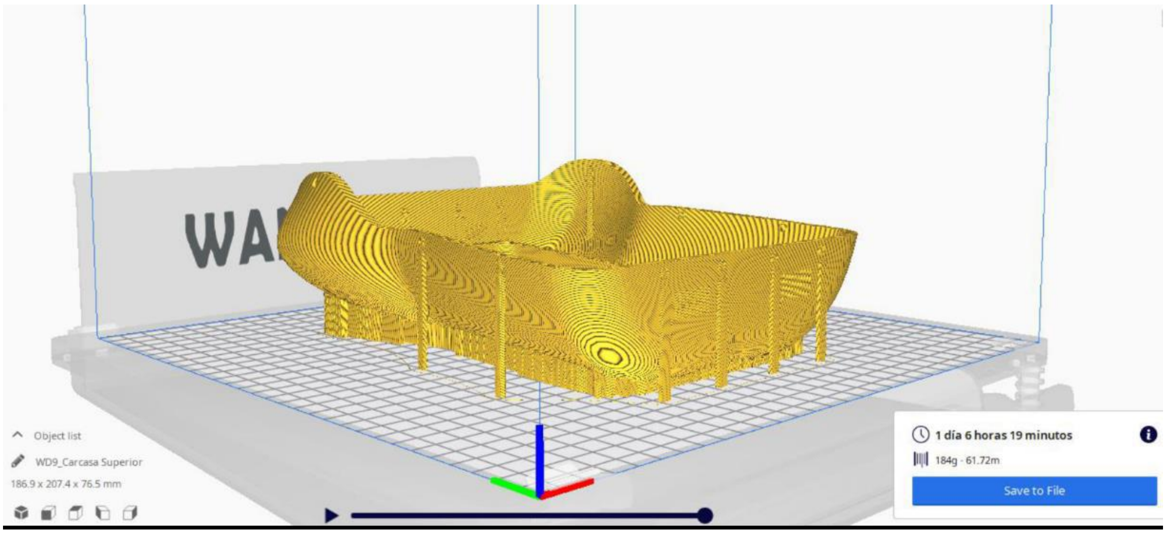

Figure 37 Last step prior to printing the lower casing

Finally, an estimate was requested to carry out the printing since I do not have my own 3-D printer and relevant data was obtained, such as the printing time for each casing and the necessary amount of material needed for each one of them. Image 36 shows the estimated time needed to print the upper shell of the mannequin (1 day 10hs 16 minutes) and the amount of material needed (209gr), in the same way, Image 37 shows the time needed to print the lower shell of the mannequin (1 day 6hs 19 minutes) and the amount of material needed (184gr).

The estimated cost of printing both shells in the market as of October 2020 is around $7000.

CHAPTER 4
RESULTS AND DISCUSSION

In this chapter I will show the results obtained in this project. By way of clarification, I would like to mention that due to the isolation measures proposed because of covid-19, I found restricted our access to the laboratories, contact and visits with different health professionals, faculty professionals and professionals from different areas, so the reliability tests, calibration, among others, were carried out with elements present in our homes, as well as the consultations that had to be carried out virtually, not being able to take advantage of 100% of these possibilities, which would have been of great help and are a fundamental part of a project.

1. FINAL DESIGN

Next, we proceed to show images and explanations about the finished model. I will proceed to explain from the outside to the inside of the mannequin for convenience reasons

1.1. External housing of the manikin

Figure 38 External view of the dummy

In image 38 we can see the mannequin model in its final design.

It is important to mention that in order not to make the design work more complex, we chose to focus only on the functional part of the mannequin (torso) without adding the head, arms or legs, since including them does not provide us with a contribution from the functionality point of view. However, it is possible that for the user to feel a greater empathy and connection with the mannequin when performing the maneuvers, it is advisable to add these parts in order to obtain a better user experience, so this task is included in future works.

In these views we can appreciate the leds that make the visual guide function for the user training. In addition, we can observe the folds corresponding to the medial line of the neonate (vertical line corresponding to the medial junction of the pectorals) and also the xipho-sternal line (transverse line of the mannequin corresponding to the location of the xiphoid process of the sternum). Both lines are important when locating the exact point where cardiac massage is to be performed.

Figure 39 Rear view of the mannequin

In image 39 we can see the back of the manikin, in which the folds corresponding to the spine of the neonate can be observed. In this part we can also observe, on both sides, the axillary folds, which are very useful when performing the technique of chest compressions with two hands, since when manipulating the baby with both hands and performing the compressions with the fingers on the anterior part of the baby, these folds are very comfortable and provide greater ergonomics to the model.

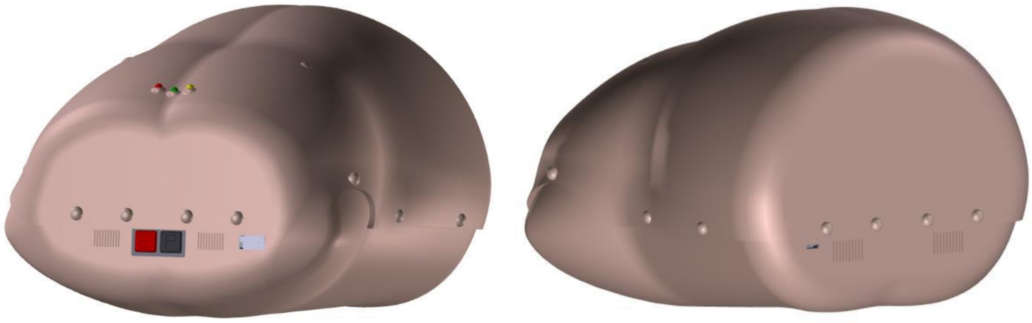

Figure 40 View of mannequin covers

In image 40, we can see the upper and lower part of the dummy housing. Here we can see, in the first (upper) image, the buttons corresponding to the two processes previously explained in addition to the space corresponding to the USB connection for the Arduino UNO microcontroller. The red button corresponds to the practice process (for convenience it is the first one) and the blue button corresponds to the evaluation process.

In the second image, we can see the lower part of the dummy's housing, which has the space corresponding to the micro USB input to connect the battery of the electronic circuit.

1.2. Internal components

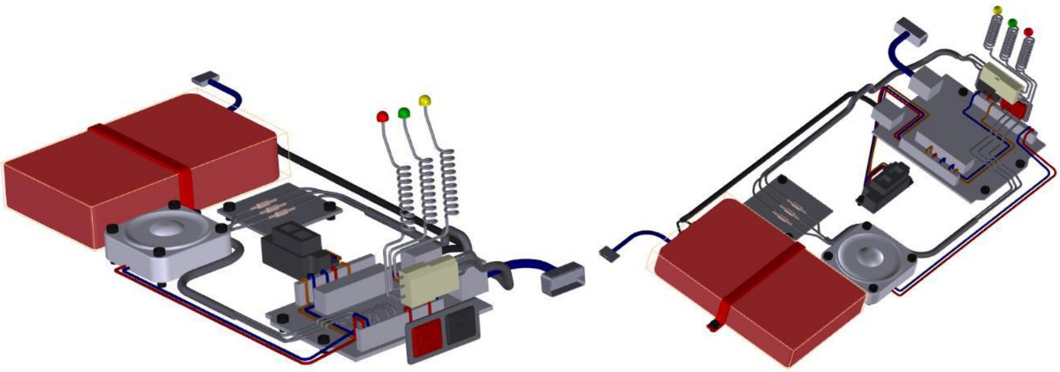

Figure 41 Final circuit layout inside the dummy

In the image 41 we can observe the electronic circuit that is mounted inside the dummy, more specifically in its lower part. It is mounted on a removable board which will be shown below.

The circuit as I explained above is made up of, in the middle of it, the SHARP infrared sensor, the speaker located at the bottom of the sensor, which is connected to a plate on which are a set of resistors. Then at the top we can see the Arduino Uno microcontroller, from which arise the three LEDs, corresponding to the visual guide, connected with a tab which allows the connection and disconnection of the three at the same time, to simplify and we do not have to be connecting one by one when disassembling the dummy. We can also see the LEDs connected by telephone cables, which are stretchable and allow a perfect opening of the housing. From the Arduino Uno also comes a female USB cable, which will have its respective place in the housing, so that it can be connected in case of possible software changes. Something that I have not mentioned before, and can be seen in the red image, is the battery of the complete circuit, I decided to make a space for it inside the circuit and also add a micro USB female cable, which also has its respective space in the housing, which serves to charge the battery when necessary.

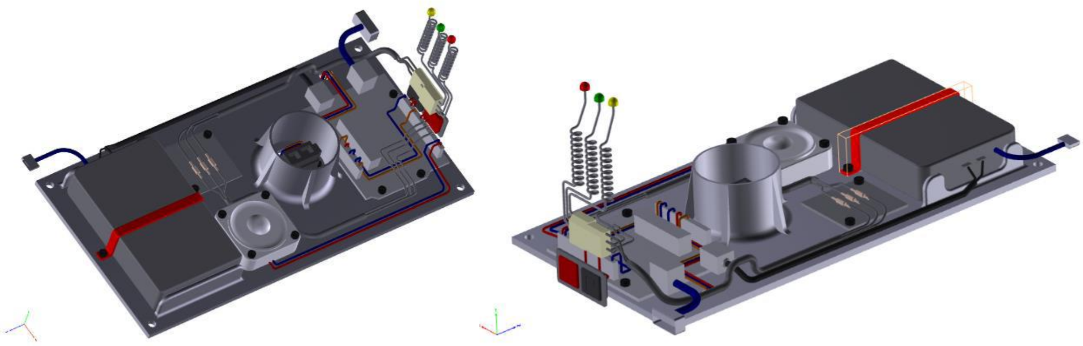

Figure 42 Circuit on removable board

In the image 42 we can observe the electronic circuit explained recently, but this time mounted on the previously mentioned board. This plate is intended to keep the electronic circuit in place and gives us the benefit of being removable for when it is necessary to work more comfortably on the electronic components or even make exchanges of modules in case something breaks down, in turn this plate is screwed to the bottom of the dummy, by means of four Allen screws.

Each element is attached to the removable plate by Allen type screws and metal fasteners.

Detail of elements:

- Speaker: 4 Allen screws
- Electronic board: 2 Allen type screws diagonally across
- Battery: 2 Allen screws and a metal fastener.
- SHARP distance sensor: 2 Allen screws diagonally.
- Arduino board: 3 Allen screws.

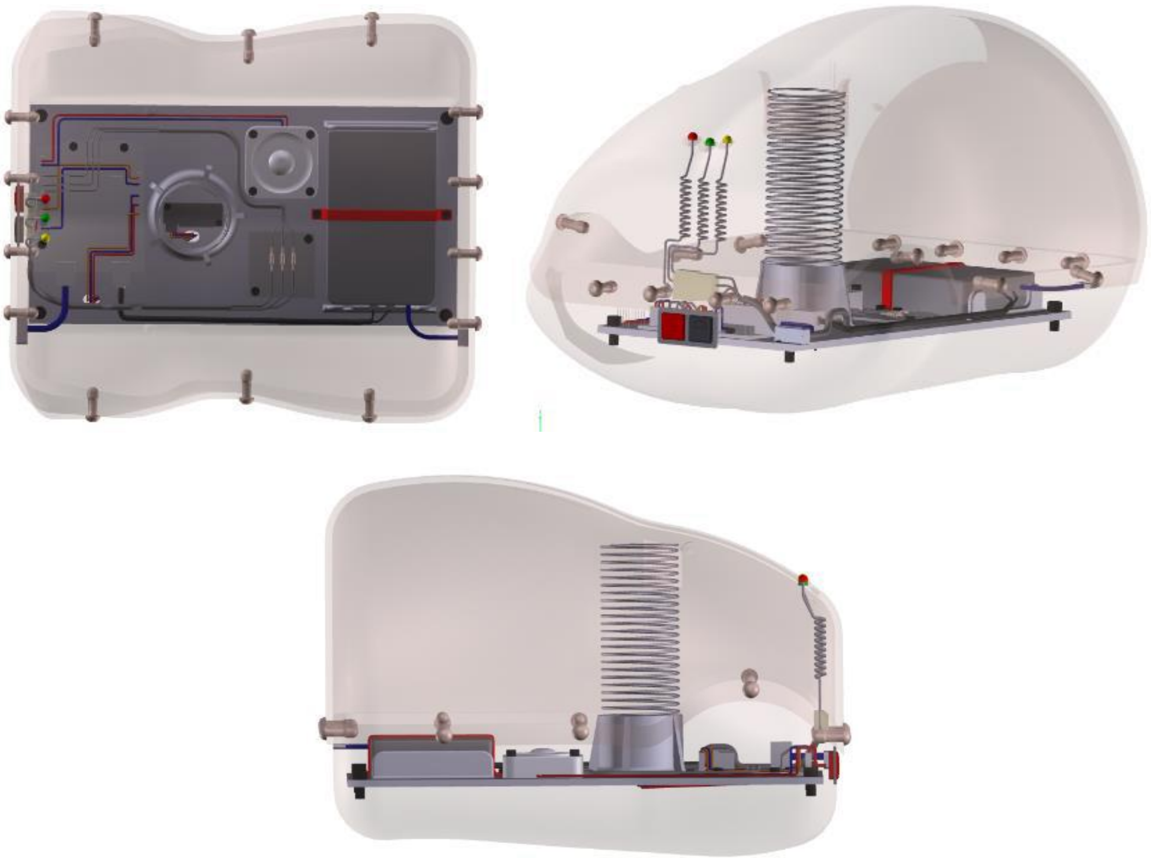

Figure 43 View through the dummy

Figure 43 shows the board and the electronic circuit mounted inside the dummy. This allows us to locate spatially how these elements will be placed inside the dummy.

In the last image we can also see the spring attached to the board and making contact with the upper part. In the center of the spring is located the SHARP infrared sensor, which takes the data corresponding to the distance of the previous toras, as explained above.

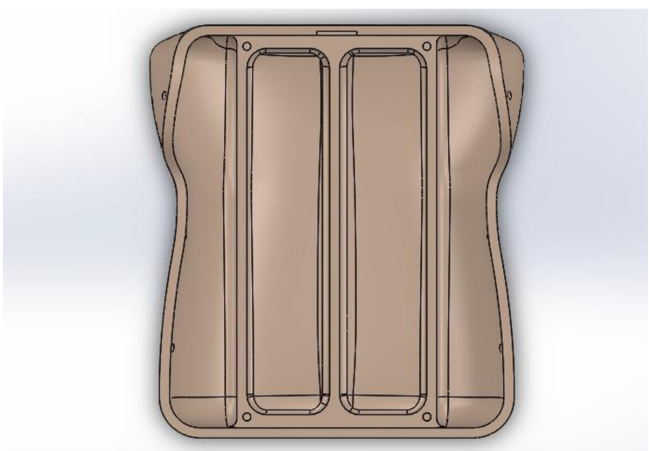

Figure 44 Internal face of posterior thorax with reinforcements

In image 44 we can observe the internal face of the posterior thorax of the dummy, where the plate is mounted together with the electronic circuit as previously mentioned. Here we can see the four holes where the Allen screws are inserted to adjust the plate.

Figure 45 Internal aspect of the upper thorax

In image 45 we can see the inner side of the anterior thorax of the dummy. In this area the spring is inserted in the medial part. This insertion zone was designed to be flat and not to follow the external contours of the dummy. This is so that the sensor can take an accurate measurement from a flat surface, which increases the census accuracy, as well as allowing a better insertion zone for the spring.

1.3. Exploded view of the finished mannequin model

The following is an exploded view of the complete model, since this way we can clearly show the components of the model, in an exploded view and where each of the components are numbered.

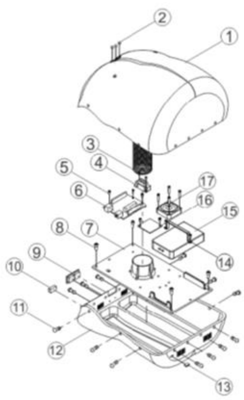

Figure 46 Exploded View

Inside the upper and lower housings of the dummy, we have the electronic components that work in a systemic way. As mentioned above, the electronic and mechanical components will be incorporated as a modular assembly, which can be removed or inserted inside the torso. To achieve this, most of the components were placed in a laminar piece in the form of a plate (it can be made of laser-cut wood or 3D printed), piece (7) of the image 46 that includes perforations and protrusions, to fix the necessary components, so that they can be screwed or fixed to it. In turn, the plate is screwed to the lower part of the torso (12) by means of Allen screws, part number (11). The lower part (12) being 3d printed, probably needs plastic threaded metal inserts, to have a thread and a secure attachment to the structure by the plate.

The electronic elements, fixed to the board are: the Arduino Uno microcontroller (6), the board where the resistors and other necessary electronic components are connected (17), battery (15), speaker (16) and finally the SHARP infrared distance sensor (4) which is located inside the spring.

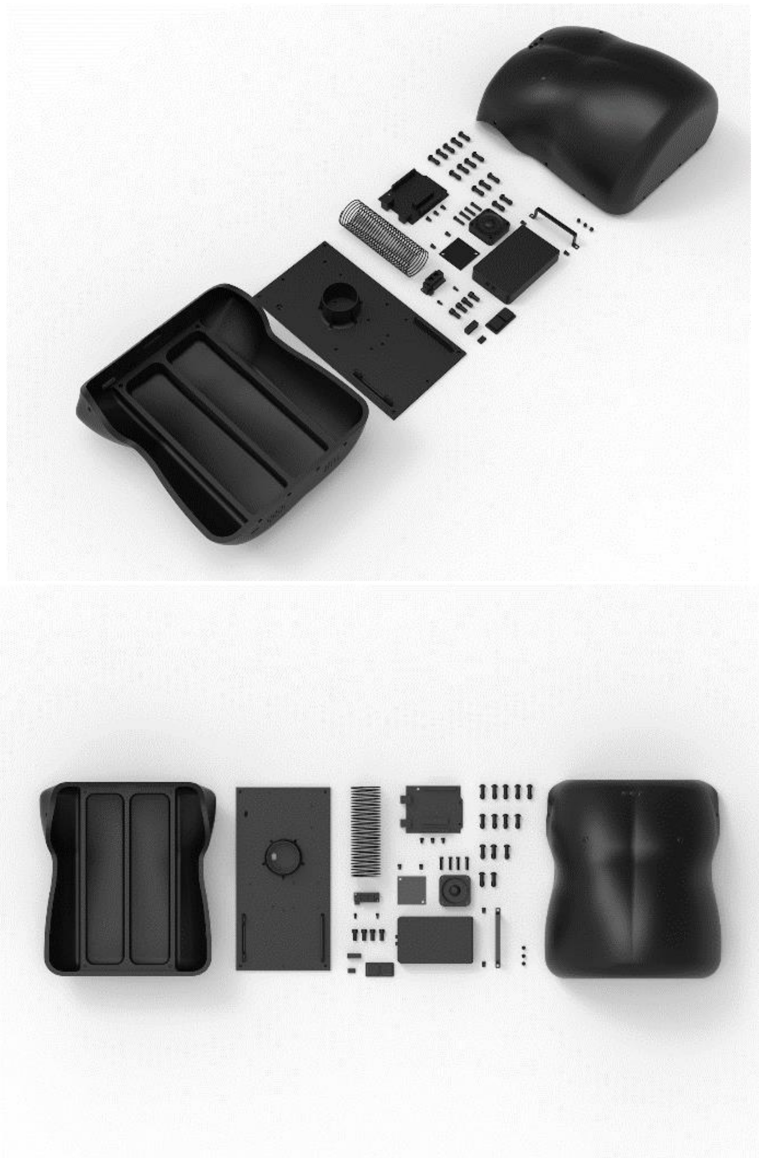

Figure 47 Presentation of finished mannequin components

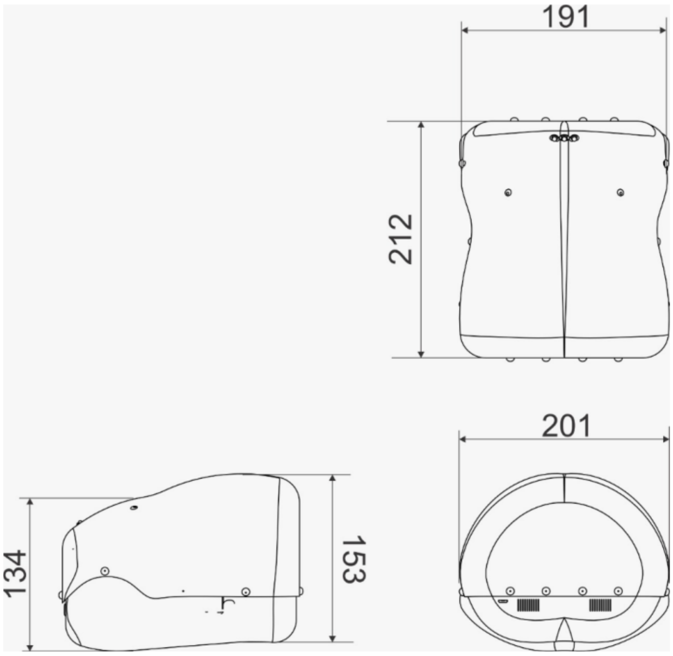

Figure 48 Final external dimensions of the dummy

CHAPTER 5
CONCLUSION

After carrying out this project, I were able to design and model of the manikin, which meets the objectives set from the beginning.

Although, due to different accessibility restrictions, as a consequence of the current pandemic, I was not able to realize the ideas in a tangible way because I could not access to laboratories, 3D printing stores, however I believe that I managed to solve these problems, sometimes exceeding expectations, using the elements present in homes and taking advantage of the different online technologies that have emerged due to this global situation, applying ingenuity and practicality, thus developing the main skill of an engineer.

Although I could not reach the physical implementation of the finished model, I was able to achieve a final design that included all the details that the real model should have, taking care of details that at first I did not believe possible to attend and I was even able to propose the printing method and even the materials to be used.

Also, considering the general objective of this project, I always took into account the manipulation of low cost elements like the materials to be used for the printing of the manikin, that are elements of very accessible cost, thus making an economical final prototype, facilitating its accessibility to any center in which the learning of the neonatal CPR technique is of interest.

1. FUTURE WORK

I were able to achieve encouraging results in terms of effectiveness and reliability of our results, it would be interesting that, in future works, after lifting the restrictions, I could continue with the correct validation of the results obtained and the practical implementation of the same and thus take advantage of the maximum potential of this work.

Some objectives to be achieved in the future are:

- Addition of head, feet and arms to the design, in order to achieve a more realistic model that allows greater empathy and better user experience.
- Carry out the implementation of the model, in order to realize the 3D printing, with the proposed materials and also integrate the necessary electronic and mechanical components.

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