Preservation of cardiopulmonary blocks: A real and interactive biomaterial for teaching and learning lung plethysmography and mechanical ventilation

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Abstract— *The introduction of biomaterials to thoracic training has an important impact on human health and has significant economic benefits. We present a real, reusable and low-cost biomaterial that is a useful tool in teaching and learning training programs for lung* plethysmography *and mechanical ventilation procedures. At the end of non-cardiopulmonary-related research studies, five cardiopulmonary blocks were harvested from rabbits (3), a dog (1) and a cat (1). Cardiopulmonary blocks were preserved with McCormick's solution and impregnated with glycerin-phenic acid. Subsequently, the cardiopulmonary blocks were connected to a volume ventilator to ensure good lung compliance and that there was no leakage. An acrylic plethysmograph was designed, and cardiopulmonary blocks were placed* through *an endotracheal tube and connected to a ventilator. Lungs were insufflated under four different inspiratory pressures (10, 12, 14 and 16 cmH₂O), and respiratory parameters were calculated. Although it was necessary to significantly increase the inspired tidal volume and the compliance decreased (ANOVA + Student's t: p<0.05) compared to the values required for blowing non-preserved cardiopulmonary blocks, all the preserved cardiopulmonary blocks maintained their structural integrity, and the lungs were shown to be elastic pieces with smooth texture, along with distension and insufflation capacities. This biomaterial was shown to be functional and reusable for the teaching and learning of lung plethysmography and mechanical ventilation practices.*

Keywords— Cardiopulmonary Block, Preservation, Biomaterial, Plethysmography, *Education.*

I.   INTRODUCTION

A comprehensive understanding of respiratory mechanics is pivotal for the accurate diagnosis and treatment of lung disease, adequate application of artificial or assisted ventilation systems and for analyses of environmental effects. It is difficult to obtain an understanding of lung mechanics due to the complex and dynamic nature of pressure-volume relationships of the respiratory system. This is largely attributable to the fact that respiratory mechanics are governed by the mechanics of both the lung and chest wall; the direct visualization of pressure-volume relations can be expected to accelerate and enhance our understanding of respiratory mechanics and considerably increase student motivation to learn about this complex system.[1] Developing real and reusable models for teaching and learning ventilation procedures that mimic respiratory mechanics is essential for the training of clinicians in all the pulmonary specialties and for addressing both ethical and economic issues. A variety of simulation procedures[1] and virtual respiratory models[2] have been developed as tools for teaching. We designed an acrylic box that simulates proper chest function, where pressure differences made it possible to generate the movements that occur during spontaneous respiration or as a result of assisted ventilation. Additionally, we developed training programs to teach surgical skills to human and veterinary medical university students based on cryopreservation[3-4] and lyophilization[5] methods and obtained excellent results. However, neither of these techniques was useful for tissue preservation that was necessary to obtain a reusable biomaterial. It has been reported that treatment with McCormick solution[6] and impregnation with glycerin-phenic acid[7] are useful methods for anatomically maintaining different organs.

The aim of this study was to show the feasibility of using a real, reusable and low-cost biomaterial as a tool for teaching and learning training programs on mechanical ventilation using a homemade acrylic box as a thorax simulator.

II.   EXPERIMENTAL DETAILS

2.1   Procurement and Preservation of Biomaterials

Using normal surgical techniques, we harvested five cardiopulmonary blocks from three rabbits (n=3), one dog (n=1) and one cat (n=1), regardless of sex and age. The animals were euthanized with intravenous administration of an excess of pentobarbital (Anestesal, Pfizer, Mexico) and potassium chloride (PISA, Jalisco, Mexico) at the conclusion of non-related cardiopulmonary research studies that were revised and approved by the ethical committee of the Instituto Nacional de Enfermedades Respiratorias "Ismael Cosio Villegas" (INER). The study was conducted under Technical Specifications for the Care and Use of Laboratory Animals of the Mexican Official Norm (NOM-062-ZOO-1999)[8] and the Guide for the Care and Use of Laboratory Animals of the United States of America.[9] Immediately after harvesting, the cardiopulmonary blocks were washed for 3h using a hose connected at one end to running water and the other to the trachea. Subsequently, the cardiopulmonary blocks were perfused through the trachea and entirely covered, with McCormick's solution (To prepare 40 liters of the McCormick fixative solution: potassium phosphate dibasic anhydrous (26.4 g), dibasic sodium phosphate anhydrous (100g), ascorbic acid (68g) and salt of Prague (340 g) dissolved in 36 liters of distilled water, added with 4 liters of formalin 10%), and they were stored during 60 days at room temperature in a perfectly sealed polypropylene container. Lungs were covered with a blanket in order to prevent floating in the solution. Subsequently, the cardiopulmonary blocks were impregnated with a glycerin-10% phenic acid solution for 30 to 60 days. Then, the cardiopulmonary blocks were connected to a volume ventilator (Harvard Apparatus, USA) to ensure good lung compliance and that there was no leakage.

2.2 Design and Operation of the Plethysmograph

Based on the dimensions of the largest cardiopulmonary blocks (rabbits), an acrylic plethysmograph (height 20 cm, diameter 12 cm, thickness of acrylic sheet 0.6 mm, volume 2,200 ml) was designed. Three ¼-inch holes were made on the cover of the box (16x16 cm). In one of the holes, an extension tube was connected to a suction pump; a sphygmomanometer was introduced through the second hole. The third hole was used to connect the cardiopulmonary block (Figure 1).
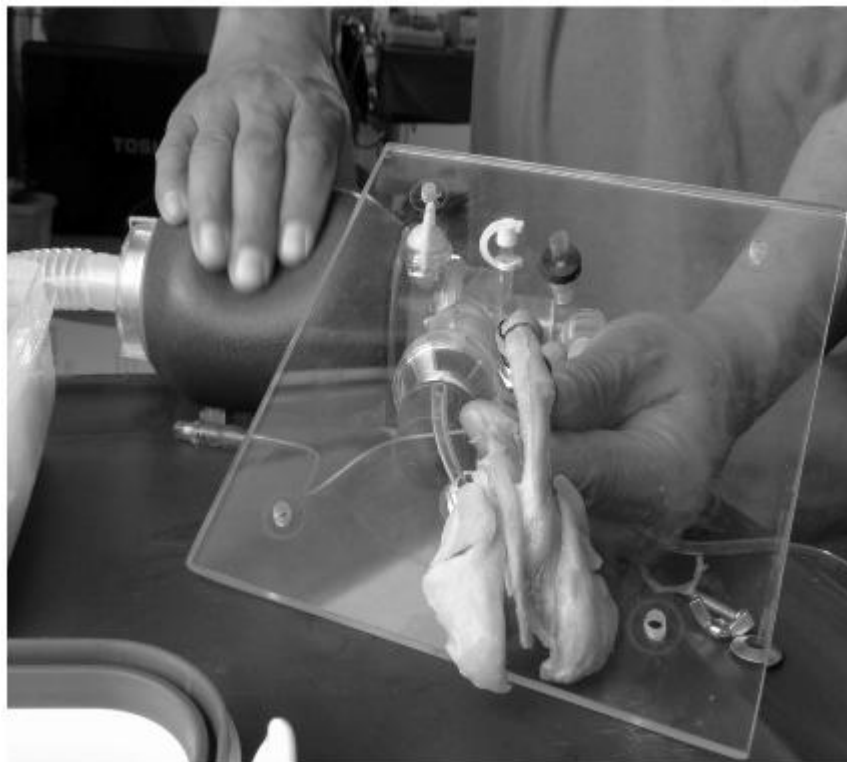

FIGURE 1: AN ACRYLIC PLETHYSMOGRAPH WAS DESIGNED. THREE ¼-inch HOLES WERE MADE ON THE COVER OF THE BOX. ONE OF THE HOLES WAS USED TO CONNECT THE PRESERVED CARDIOPULMONARY BLOCK.

2.3 Teaching and learning Interactions

The cardiopulmonary blocks were removed from the storage box. One hour prior to implementing the teaching and learning program, both lungs were massaged with smooth and steady motions. Then, the blocks were placed inside the acrylic box and connected *through* an endotracheal tube (4F) to a ventilator (Viasys Respiratory Care, AVEATM 16050) (Figure 2). Subsequently, the lungs were insufflated under four different inspiratory pressures (10, 12, 14 and 16 cmH$_2$O), and the

compliance ratio (C20/C), inspired tidal volume (Vti), airway resistance (Raw) and percentage of leakage were obtained for each of the inspiratory pressures.

FIGURE 2: TO IMPLEMENTING THE TEACHING AND LEARNING PROGRAM, THE BLOCKS WERE PLACED INSIDE THE ACRYLIC BOX AND CONNECTED *THROUGH* AN ENDOTRACHEAL TUBE TO A VENTILATOR. THE LUNGS WERE INSUFFLATED UNDER FOUR DIFFERENT INSPIRATORY PRESSURES (10, 12, 14 and 16 cmH$_2$O), AND THE COMPLIANCE RATIO (C20/C), INSPIRED TIDAL VOLUME (Vti), AIRWAY RESISTANCE (RAW) AND PERCENTAGE OF LEAKAGE WERE OBTAINED FOR EACH OF THE INSPIRATORY PRESSURES.

III.   RESULTS

After preservation, all five cardiopulmonary blocks maintained their structural integrity and shape. Mean values ± standard deviation of six measurements of compliance ratios (C20/C), inspired tidal volumes (Vti), airway resistance (Raw) and percentages of leakage were obtained using one preserved cardiopulmonary block from a rabbit at 10, 12, 14 and 16 cmH$_2$O of maximal inspiratory pressure (MIP). Additionally, all the measurements were obtained from one unpreserved cardiopulmonary block from a rabbit under the same conditions; these data are shown in Table 1.

TABLE 1

MEAN VALUES ± STANDARD DEVIATION OF SIX MEASUREMENTS OF COMPLIANCE ratio (C20/C), TIDAL VOLUME INSPIRED (Vti), AIRWAY RESISTANCE (RAW) AND PERCENTAGE OF LEAK WERE OBTAINED WITH ONE PRESERVED CARDIOPULMONARY BLOCK (RABBIT) AT 10, 12, 14 and 16 cmH$_2$O OF MAXIMAL INSPIRATORY PRESSURE (MIP) VERSUS MEASUREMENTS OBTAINED FROM ONE CONTROL NON-PRESERVED CARDIOPULMONARY BLOCK OF RABBIT . *ANOVA AND T-STUDENT (P<0.05).

MIP (cmH$_2$O)	10	12	14	16
C20/C Ratio	2.29±0.08 *1.06±0.01**	2.44±0.13 *0.98±0.08**	2.37±0.09 *1.01±0.07**	3.05±0.60 *3.49±0.00**
Vti/kg (ml/kg)	10.05±2.35 *14.80±0.00**	15.75±0.95 *15.10±0.00**	7.65±1.15 *16.05±0.05**	9.85±1.45 *16.60±0.00**
Raw (cmH2O/L/s)	51.10±2.10 *222.00±0.00**	46.65±1.95 *230.50±84.50**	77.25±5.55 *240.00±44.00**	86.90±20.10 *240.00±44.00**
Leak (%)	19.50±5.50 *70.00±0.00**	17.00±2.00 *74.00±7.00**	17.00±0.00 *74.50±8.50**	11.50±4.50 *68.50±8.50**

The mean values ± standard deviations of compliance ratios (C20/C) using one preserved cardiopulmonary block from a rabbit obtained at 10, 12, 14 and 16 cmH$_2$O of maximal inspiratory pressure were 1.06±0.08, 0.98±0.08, 1.01±0.07 and 1.49±0.00, respectively. These values were significantly lower (ANOVA+Tukey: $p<0.05$) than the mean values ± standard deviations of compliance ratios (C20/C) obtained from an un-preserved cardiopulmonary block from a rabbit (2.29±0.08, 2.44±0.13, 2.37±0.09 and 3.05±0.60 at 10, 12, 14 and 16 cmH$_2$O of maximal inspiratory pressure, respectively).

The mean values ± standard deviations of inspired tidal volumes (Tvi) using a preserved cardiopulmonary block from a rabbit obtained at 10, 12, 14 and 16 cmH$_2$O of maximal inspiratory pressure were 14.80±0.00, 15.10±0.00, 16.05±0.05 and 16.60±0.00, respectively. These values were significantly higher (ANOVA+Tukey: $p<0.05$) than the mean values ± standard deviations of Tvi obtained using an un-preserved cardiopulmonary block from a rabbit (10.05±2.35, 15.75±0.95, 7.65±1.15 and 9.85±1.45 at 10, 12, 14 and 16 cmH$_2$O of maximal inspiratory pressure, respectively).

The mean values ± standard deviations for airway resistance (Raw) using a preserved cardiopulmonary block from a rabbit obtained at 10, 12, 14 and 16 cmH$_2$O of maximal inspiratory pressure were 222.00±0.00, 230.50±84.50, 240.00±44.00 and 240.00±44.00, respectively. These values were significantly higher (ANOVA+Tukey: $p<0.05$) than the mean values ± standard deviations of Raw obtained using an un-preserved cardiopulmonary block from a rabbit (51.10±2.10, 46.65±1.95, 77.25±5.55 and 86.90±20.10 at 10, 12, 14 and 16 cmH$_2$O of maximal inspiratory pressure, respectively).

The mean values ± standard deviations of leakage (%) using a preserved cardiopulmonary block from a rabbit obtained at 10, 12, 14 and 16 cmH$_2$O of maximal inspiratory pressure were 70.00±0.00, 74.00±7.00, 74.50±8.50 and 68.50±8.50, respectively. These values were significantly higher (ANOVA+Tukey: $p<0.05$) than mean ± standard deviation values of leakage (%) obtained using an un-preserved cardiopulmonary block from a rabbit (19.50±5.50, 7.00±2.00, 17.00±0.00 and 11.50±4.50 at 10, 12, 14 and 16 cmH$_2$O of maximal inspiratory pressure, respectively).

IV. DISCUSSION

Although the total preparation time cardiopulmonary blocks varies between 90 - 120 days, the preservation of the cardiopulmonary blocks with McCormick's solution and glycerin-phenic acid treatment allows obtaining reusable, malleable, non-toxic and non-infectious pieces in which there will not be development of fungi and bacteria due to phenic acid. This technique of preservation is a good alternative for fixing and preserving anatomical specimens and also reduces the use of formaldehyde at lowering the risk of poisoning, in addition to the ingredients are readily available and to be inexpensive.

Learning how to use the mechanical ventilation system is important because oxygenation of blood in the lungs is essential for an organism's metabolism. Movements of the rib cage, diaphragm and lungs, also known as "inspiration and expiration", have been studied and researched for decades through various pilot studies, as reported by Dr. Hutchinson in 1846[10] and by Dr. Kuebler in 2007[1]. Based on this model, different devices have been created with the aim of teaching respiratory mechanics. Dr. Wolfgang Kuebler[1] reported the development of a tool for studying changes in ventilation pressure and further modifications of the chest and lungs in patients with pneumothorax. This design was useful for teaching concepts regarding respiratory mechanism but had some degree of complexity and was had high costs. Based on this background and with a clear idea of how to present respiratory mechanics for the purpose of teaching these concepts to new students and physicians, an acrylic box that simulates the thorax was developed. This box had three different openings that allowed connections to a vacuum (negative pressure), oxygen measurement device and a volume ventilator, and was able to simulate inhalation and exhalation from the lungs using preserved and reusable cardiopulmonary blocks of rabbits, dogs and cats. As mentioned above, one of the holes of the artificial thorax was used to cause negative pressure between the lung surface and the inside of the acrylic box. The pressure difference between the environment and the negative pressure causes the air entering the alveolus to "inspire". Exhalation results when the intra-alveolar pressure is greater than the external pressure; thus, "breathing" is an involuntary movement that is caused by pressure differences where inhalation and exhalation is created by pressure differences of the environment and the alveolus. These changes in transpulmonary pressure are induced by the chest wall, or the "acrylic box", and in humans this pressure is caused by muscles, resulting in the development of inspiration. These data clearly demonstrate an understanding that breathing (airflow) is an involuntary movement of the chest. The chest retracts the lung and the thorax expands, and these differences cause negative pressure in the pleural cavity. Another important concept to be learned is the resistance of the airways. A cross section at the level of the respiratory and transitional zones of the airway shows that the diameter in this area is much greater than that of a cross-section of the trachea. Thus, it is obvious that the air enters airways of a child through a larger hole and therefore slows down. In lung disease, different areas of parenchyma do not slow down airflow; in instances of bronchial asthma, COPD is accelerated. Another important concept that students must understand is the role of surfactant. This substance is a lipoprotein produced by alveolar

type 2 cells. The purpose of the surfactant is to cause surface tension and to prevent the alveoli from collapsing. In different conditions, and particularly in lungs that have been prepared for implantation for research or therapeutic purposes, this surfactant undergoes changes and does not fulfill its main function: to prevent the alveoli from collapsing. Compliance and elasticity are also important pulmonary activities. Compliance is the ability of lungs to enlarge, and elasticity is their ability to return to their original size. Compliance and the surfactant have important implications for respiratory mechanics. For example, lesions that cause pulmonary fibrosis (hardening) decrease compliance and causes changes in the surfactant. In COPD and pulmonary emphysema, multiple alveolar walls are broken and "holes" are created. This increases the amount of air that enters the lungs, and the withdrawal of parenchyma is increased. This in turn increases transpulmonary pressure, significantly decreasing distensibility and therefore, elasticity, and causes both fibrosis and changes in respiratory mechanics, i.e., respiratory distress patterns in emphysema patients. The use of the acrylic box and the preserved cardiopulmonary blocks is simple and very low in cost. It is also useful for teaching units related to chest trauma, which occurs relatively frequently in incidents of violence and motor vehicle accidents. For example, pneumothorax, when air exits the parenchymal lung and enters the pleural cavity, leads to a significant decrease in compliance and results in respiratory failure. Additionally, hemothorax, when blood accumulates in the pleural cavity, prevents normal compliance and elasticity. It is also possible to use the model to teach ribcage disorders (paradoxical breathing, diaphragmatic paralysis) that eventually cause disorders such as pneumothorax, hemothorax, and respiratory failure. Finally, the study of these measures of the lung mechanics of the control group compared to lungs preserved between 30 and 60 days with McCormick and glycerin solutions resulted in the following findings: Compliance was lower in the lungs that were preserved for 2 months. Additionally, volume, resistance and escape were higher in lungs that were preserved. These observations can be attributed to the fact that unpreserved lungs maintain their complete architecture, while the partially preserved lungs lose their anatomical constitutions. Although the total preparation time cardiopulmonary blocks varies between 60 and 120 days, the treatment of the cardiopulmonary blocks McCormick's solution and impregnated with glycerin-phenic acid allows obtaining malleable, non-toxic and non-infectious pieces in which there will be no growth fungi and bacteria due to phenic acid. This is a good alternative for fixing and preserving anatomical specimens and also reduces the use of formaldehyde at lowering the risk of poisoning in addition to the ingredients are readily available and to be inexpensive.

V.   CONCLUSION

Cardiopulmonary blocks treated with McCormick solution and impregnated with glycerin-phenic acid were shown to maintain their structural integrity. Lungs are elastic pieces of tissue that have smooth texture with distension and insufflation capabilities. Preserved cardiopulmonary blocks are functional and reusable biomaterials that can be used for pulmonary mechanical ventilation programs. Pressure differences in the thorax (acrylic plethysmograph) were able to generate differences in suction pressure, helping students understand the mechanism of spontaneous breathing and artificial ventilation.

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