Fabrication of a Nursing Manikin Overlay for Simulation of Chest Drainage Management

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Abstract—Medical manikins are a type of patient simulator used to train medical staff. The benefits of using a medical manikin simulator include the suspension of disbelief, simultaneous team and individual learning, allowable failure, personalized scenarios, frequent repetition and a focus on the needs of the learner rather than the patient. Unfortunately, one of the limitations of medical manikins is that they cannot simulate every problem that medical staff comes across. The SimMan (Laerdal) manikins do not have the ability to simulate when excess air or fluid is in the pleural space of the lung or thorax, the drainage of which must be managed by nurses. These three symptoms are called a pneumothorax, pleural effusion and excess thoracic blood, respectively. The purpose of this research was to create an overlay for the SimMan manikin to simulate a pneumothorax, pleural effusion or excess of thoracic blood for nurses to learn and practice responsibilities during chest drainage. The process began by obtaining a scan of a manikin from the Milwaukee School of Engineering nursing department. Simultaneously developed, a pneumothorax, pleural effusion and excess thoracic blood simulator became the basis for the layout of the overlay. Beginning with the computer scan, a mold of the overlay was shaped using computer automated design programs. This mold was customized to accommodate all necessary components and ports of the simulator. The mold was printed using a stereolithography (SLA) machine and created by layering silicone to make the housing for the simulator. The overlay resulting from this research is currently being used to train nursing students at the Milwaukee School of Engineering.

Keywords—medical manikin, simulation, chest drainage

I. INTRODUCTION

Respiration is the exchange of gas from the air outside to the cells inside of a living organism. In humans respiration is alternated between inspiration and expiration. The lungs and the heart are vital organs that participate in respiration. Inside the lungs, gas is exchanged through the blood gas barrier via the alveoli and the heart transports the oxygen and waste to and from the lungs to the rest of the cells in the body [1].

The pleural space is in between the visceral pleura (a membrane on the outside of both lungs) and the parietal pleura (on the inside of the chest wall). The pleural space holds about 2-10mL of fluid [2] and is constantly under negative pressure (-4cmH₂O during expiration and -8cmH₂O during inspiration [1]). The negative pressure in the pleural space allows for the lungs to expand as the chest cavity expands [1].

The mediastinum is the space in between the two lungs that encompasses the heart (and pericardium surrounding the
Excess air can enter the pleural space (pneumothorax) if there is a hole in the lungs due to a puncture wound. The excess air causes the pleural space to be under positive pressure so the lung cannot expand properly without the assistance of mechanical ventilation (collapsed lung). A large amount of excess air in the pleural space (tension pneumothorax) can cause a mediastinal shift which places too much pressure on the heart such that the ventricles cannot fully expand and pump enough blood to the entire body [5].

Excess fluid, including blood (hemothorax) or mucus (empyema), can enter the pleural space due to a blocked artery that causes a rupture in the lung, cancer, wounds to the chest or infection in the lungs. This excess fluid also causes collapsed lungs due to positive pressure [6]. Excess blood can enter the thorax from chest wounds such as fractured ribs, trauma wounds or a diaphragmatic rupture [6]. Excess fluid in the thorax also causes pressure on the heart that reduces cardiac output [1]. Chest drainage is used to reset the negative pressure in the pleural space. Chest drainage for the mediastinum allows blood to flow around the heart instead of stagnating [5]. Nurses in a hospital commonly come across patients who have chest drains.

Chest drainage systems have evolved from a three bottle system to units that encompass three key features: a collection chamber, an air leak monitor and a suction monitor. The collection chamber includes units of measurement to observe the amount of fluid in the chamber. The air leak monitor includes colored fluid where the gas bubbles through to easily observe the bubbles. The suction control differs for each chest drainage system. A wet seal drainage system uses water to control the amount of suction on the patient; the amount of suction is determined by the water volume in the chamber. A dry seal drainage system uses a relief valve that responds to changes in the patient to provide a constant suction on the patient; the amount of suction is controlled by a dial [7].

Nurses’ responsibilities with chest drainage include monitoring the rate, color and consistency of fluid collecting in the drainage unit, the amount of suction on the patient, vital signs of the patient, re-dressing the insertion site and replacing the drainage system if it is leaky or full [1].

These responsibilities of the nurses could be daunting without proper training. Medical simulations are an effective way to train nurses in an environment that promotes individual and team problem based learning simultaneously. It has been found that nurses who go through simulation trainings become more confident and competent from simulations, leading to a higher level of performance than nurses that do not have simulation training [7].

At the Milwaukee School of Engineering Nursing Department there are two SimMan® manikins (Classic and Essential) that are used for medical simulations. These two medical manikins do not have pneumothorax, pleural effusion or excess thoracic blood simulation available for the nursing students to learn about their responsibilities with chest drainage. One of the obstacles with chest drainage simulation is the limitation of the simulators. A pneumothorax simulator is available and compatible with the SimMan® manikin but the simulator must be inserted into the manikin. The pneumothorax simulator is only for the insertion of a needle for a thoracentesis (insertion of a needle to evacuate fluid), not a chest drainage [8]. Other simulators are similar in the fact that the learning focus is the insertion of a needle. This is a skill specific to physicians. Nurses do not have this responsibility. Another obstacle is the cost of the medical manikins and other simulators, while technology may improve rapidly; it may be a challenge for institutions to afford new models [9].

The purpose of this research is to create a manikin overlay that will house the pneumothorax, pleural effusion or excess thoracic blood simulator as to supplement the pre-existing SimMan® manikin in the nursing department or a human model.

II. METHODOLOGY

Specifications to be achieved by the medical manikin overlay were: the overlay must be safe to use on a human model or manikin model without compromising the normal function or warranty of the manikin, and it must be realistic in drainage and overall appearance and incorporate part of the pneumothorax, pleural effusion or excess thoracic blood simulator. To meet all of these specifications the pneumothorax, pleural effusion and thoracic bleeding simulator was designed first so that the dimensions of the simulator would be considered in the design of the overlay.

The pneumothorax, pleural effusion and excess thoracic blood simulator consisted of many components. Reservoir bags that were able to hold 1L of liquid or air were encased in a pressure bag that filled with air. The air was pressurized using an air pump. The air pump was controlled electronically by a pressure switch that allowed the pump to be switched on and off when the pressure within the bags was outside of the operating range. The reservoirs were pressurized on the bags so air and fluid were able to flow throughout the system even though the bags were at or below the plane of the overlay. The fluid flow in the system was regulated by electronic, adjustable valves that the user could open and close with a remote control. Separate one-way valves prevented the fluid and air from flowing back into the reservoirs. The liquid and air from the reservoirs were initially mixed for the pleural effusion simulator by combining in a single tube using a Y-connector. The liquid and air in the pleural space simulator was mixed further by flowing through a small perforated tube inserted into the main tube inside of the overlay. Liquid from the reservoirs was allowed to flow through a separate tube for the mediastinum simulator (there was no need for mixing since there was only liquid). The fluid was then separated into two tubes for the mediastinum drainage ports. All drainage ports for both the pleural and mediastinal drainage were 32F (10.7 mm inner diameter) drainage tubes. The two mediastinal drainage tubes were then connected using a Y-connector. The
drainage tubing was attached to the chest drainage unit (one for mediastinum and one for pleural space) by a larger, more flexible tube (0.5 in diameter). The simulation of the subcutaneous emphysema was made by adding water-filled polymer spheres to a tightly sealed plastic pocket.

A Handy SCAN 700™ (Creaform) was used to scan the manikin once with markings for placement with the chest drainage tubes and once without the tubes. The scan without the tube placement was used to create the overlay using the scan with the tube placement as reference. The scan was processed using VX elements then the scan was transferred to the computer program Geomagic® Freeform® (Geomagic) (see Fig. 3 and Fig. 4).

![Fig. 3. Front side view of the manikin chest from the original scan in Geomagic® Freeform®.](image)

![Fig. 4. Back side view of the manikin chest from the original scan in Geomagic® Freeform®.](image)

The scan was cleaned up using the add and smooth clay features, and by using a simple boolean subtraction operation a mold of the overlay was made. The mold was then exported to Magics (Materialise) so that material was taken out of the mold for cost efficiency while still maintaining structural support with ribbing in both the x and y directions on the bottom of the mold (see Figure 5 and Fig. 6). The file was then sent to the Rapid Prototyping Center at the Milwaukee School of Engineering to be printed using the stereolithography (SLA) machine, iPro™ 8000 (3D Systems) with Accura® 25 Plastic (3D Systems). After the mold was processed at the Rapid Prototyping Center the mold was water sanded down to the desired smoothness (1500 grit).

![Fig. 5. Top, left view of the final mold design in Magics.](image)

![Fig. 6. Bottom, left view of the final mold design in Magics.](image)

Skin pigmented Dragon Skin Silicone® (Smooth-On, Inc) was painted into the mold cavity. Aluminum wire mesh covered the chest to provide structural support. Hollow 10mm polypropylene balls were added on top of the mesh and between the silicone layers as to reduce the weight of the overlay. The entire simulator was not fitted into the overlay. The components that were incorporated into the overlay were the tubes that connected to both reservoirs, and a pocket that simulated subcutaneous emphysema. These components were added then the silicone was painted over the parts, encasing them into the overlay. The dimensions of the mixing chamber for the pleural space simulator and tube for mediastinum simulator were used to make cavities in the overlay. Cavities were preferred for ease of changing the chambers if need be. Slits were cut in the correct positions for pleural space and mediastinum drainage. The tubing was also sutured into place adding to the realism of the overlay. Slits were also cut in the overlay for the back strap (Wolfpack Gear) to be connected so that the overlay may be worn by a human model (see Fig. 7 and 8).
Fig. 7 shows the front side view of the final overlay version, A and B are locations for the pleural space and mediastinal space tube insertions respectively and C is the location for the subcutaneous emphysema.

Fig. 8 shows the back side view of the final overlay version, A and B are the locations for the mediastinal and pleural space tubes to connect to the simulator respectively.

III. DISCUSSION

Success was measured by the number of specifications set before the project started that were met at the end of the project. The specifications that were met at the end were the realism of the air and liquid flow, tidalizing and tube placement. Realism of the overlay was determined by matching the flow rates of the liquid and air and the change in volume of tidalizing to the observations of chest drainage patients at the Froedtert Hospital located in Milwaukee, Wisconsin and knowledge of Mr. Richard Gillard, R.N., of Froedtert Hospital. The flow in the simulator was able to range from 5 mL/hour to 100 mL/hour representing the normal and high fluid flow observed in chest drainage. The simulator was able to have a range of tidalizing volume change between 0.80 mL and 4.0 mL. The instructor is also able to release 50 mL in an instant to simulate if the impact of patient movement. The tubes were placed using information from literature and confirmation from Dr. Jane Paige of the Milwaukee School of Engineering Nursing Department. The simulator also runs within the desired simulation time of up to 20 minutes.

IV. FUTURE DIRECTIONS

Success of the manikin overlay may be measured by nursing educators by rating its realism of the following components: skin (and subcutaneous emphysema), respiration (and tidalizing in the tubing), fluid flow in tubes, air bubbling in chest drainage unit, tube insertion placement and sutured tubing. Suggestions from instructors and students may be used to further improve the overlay in its realism and practicality.

Success of the manikin overlay may also be measured by its education value in the nursing department at the Milwaukee School of Engineering. A study may be made with two groups, one group will learn chest drainage in a classroom setting (control) while the other group will learn chest drainage in a simulation setting with the manikin overlay. Similar to a previous study [10] nursing students will be judged on their confidence, competency and skill with chest drainage by their evaluators after going through the program.

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