Power of computer simulation with 3D printed models for training acute care nurse practitioners

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Abstract

This paper presents the development of a 3D simulation combined with 3D printed models in the training of acute care nurse practitioners. The simulation/animation shows the placement of four Zephyr endobronchial valves in the bronchi airways of the right lung. A CT (computed tomography) scan was obtained from a patient with severe emphysema. 3DSlicer was used to separately segment the chest (including ribs, spine, sternum, clavicle and scapula), lungs, trachea and Zephyr valves. The chest provided a frame for the placement of the lungs, trachea and valves. The 3DSlicer data files for the segments were saved in a folder and placed on the MEDNET (Model Exchange and Development of Nursing and Engineering Technologies) website for faculty and students to download and to run on their personal computers. The segments can be viewed in any combination, zoomed and rotated in the simulation. Fusion360 was used to remove part of the lung exteriors to view into the lungs to observe the differences in the bronchi airways. Models of the segments were 3D printed to augment the simulation based learning experiences (SBLEs) for nurse practitioner training. The 3D simulation and the STL (stereolithography) files of the chest, lungs, bronchi and Zephyr valves were also included in the folder and placed in the MEDNET.

Keywords: Zephyr valves, emphysema, computer simulation, acute care training.

1. Introduction

Simulation is defined as "the process by which we are trying to achieve results approximating clinical practice as closely as possible" (Koukourikos et al., 2021). More recently simulation in healthcare has been defined as a method to train and assess learners in a safe and controlled environment that attempts to present the patient authentically (Issenberg et al., 2008). Simulation can be used to demonstrate evidenced-based practice procedures thereby making the information more memorable and understandable to students (Koukourikos et al., 2021). Low fidelity simulators are static and lack realism, whereas high fidelity simulators combine body manikins with computers to produce physical signs, such as human patient simulators.

Computer simulation software is readily available for medical image analysis, visualization and animation of various medical applications. Several of these applications are patient specific, pre-surgery planning, post-surgery patient consultation, 3D renderings of specific body parts, anatomical whole-body CT segmentations, augmented reality, virtual reality and medical training. A specific example is a 3D printed model for airway evaluation and in a pre-

anesthesia plan (Han et al., 2015).

Endobronchial stenting was added to the evidenced-based treatment guidelines for COPD in 2020. The Zephyr endobronchial system is a device to treat patients with severe chronic obstruction pulmonary disease (COPD) and severe emphysema (COPD Foundation, 2018). The Food and Drug Administration (FDA) approved the use of the Zephyr valves in 2018.

When a person breathes, air passes through the trachea and into the lungs. In severe cases of COPD and emphysema, a person experiences hyperinflation where air becomes trapped in the lungs. As a result, air is prevented from entering the lungs on inspiration and causes shortness of breath. The Zephyr endobronchial stent blocks off the damaged parts of the lungs that contribute to hyperinflation and reroutes the air to the healthy parts of the lung. Trapped air can then escape as the person breathes out as the stent acts as a one-way valve. This causes less pressure on the diaphragm which leads to improved breathing (Iavarone, 2022).

A bronchoscope with a camera is used to place the Zephyr valves in the airways of the lungs (Figure 1). Multiple valves may be inserted. Figure 2 is a photo of the Zephyr valve (Pulmonx, 2023). The diameter of the valve ranges from 5.2-8.0mm and the length ranges from 4.0-8.0mm.

Figure 1. Installation of Zephyr valve (Pulmonx, 2023).

A study by Dransfield et al., (2020) and Criner et al., (2010) of 190 patients concluded that patients with severe hyperinflated emphysema achieved lung volume reductions with Zephyr valves and experienced improvement in multidimensional scores for breathlessness, activity and psychosocial parameters up to twelve months.
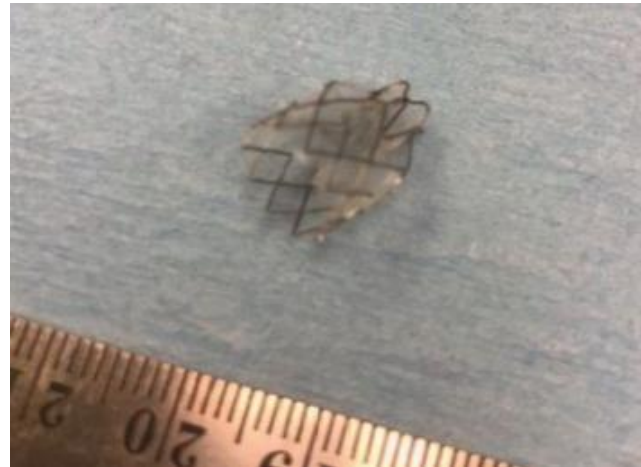

Figure 2. Zephyr valve.

Oliveria et al., (2014) conducted a study of 198 patients treated with Zephyr valves over a ten-year period. The study demonstrated endoscopic lung volume reduction with Zephyr valves was a safe procedure with favorable outcomes at long term follow-up.

A study by Sciurba et al., (2010) included 321 patients, 220 patients were assigned to receive the endobronchial valves (EBV group) and 101 received standard medical care (control group). At six months there was an increase of 4.3% in the FEV1 (forced expiratory volume in one second) in the EBV group as compared to a 2.5% decrease in the control group. Therefore, there was a mean difference of 6.8% in the FEV1 (p=0.005). In conclusion the endobronchial valve treatment for advanced emphysema induced modest improvements in lung function, exercise tolerance, and symptoms. The risks of EBV implantation outweigh the risks of the procedure which include COPD exacerbation, pneumonia, pneumo-or hemothorax, and hemoptysis after implantation.

The objective of this project was two-fold: 1) development of a computer simulation/animation model of the Zephyr valves installed in the bronchi airways and 2) 3D print models of the Zephyr valves, lungs and trachea to augment the simulation. The goal was to utilize the simulation, along with the many related 3D printed models, into the acute care training of nurse practitioners in the College of Nursing (CON) at the University of Alabama in Huntsville (UAH). By allowing the students to see the simulation and touch the 3D printed endobronchial valves, they develop a better understanding of evidenced-based practice and can assimilate the current practice guidelines used to treat COPD and emphysema.

2. Materials and Methods

A CT (computed tomography) scan was obtained from a sixty-five-year-old female with severe emphysema. The patient underwent the placement of three one-way Zephyr valves to accomplish total occlusion of the right upper lobe (RUL) of the right lung. Several days later a fourth valve was installed in the right middle lobe (RML) of the right lung. The CT scan was performed without contrast and was reconstructed with a slice thickness of 2.50mm.

The trachea is a healthy adult is about 11.5cm long and 2.5cm in diameter and divides into two main bronchi. The right bronchus divides into three smaller secondary lobar bronchi (right upper lobe, right middle lobe and right lower lobe) and the smaller left bronchus into two small secondary lobar bronchi (left upper lobe and left lower lobe). The secondary bronchi continue to branch to form tertiary bronchi which further divide into tertiary bronchioles. Segmental bronchi continue branching until the sixth generation of bronchi called bronchioles.

The scope of work consisted of the following four phases:

*Phase1: Segment selected structures from the CT scan, consisting of the following tasks:

1. Anonymize the patient data.
2. Use 3DSlicer to segment:
    A. Chest including ribs, spine, sternum, clavicles (collar bones) and scapulae (shoulder bones).
    B. Right and left lungs.
    C. Trachea and bronchi airways.
    D. Four Zephyr valves.
3. Download STL files and use 3DBuilder to review STL files.

*Phase2: Develop 3D simulation of segmented models consisting of the following tasks:

1. Download models in NRRD (nearly raw raster data) format.
2. Use 3DSlicer Save option to save the entire scene, all data, visualization and processing settings.
3. Create folder containing the following files from the Save option:
    A.3DSlicer scene, format .MRML (medical reality markup language).
    B. 3DSlicer, format .NRRD.
    C. 3DSlicer segmentation, format .SEG.NRRD.
4. Provide folder of the files to nursing students.

*Phase3: 3D print models of lungs, trachea and Zephyr valves, consisting of the following tasks:

1. Download STL files from 3DSlicer into PrusaSlicer for the Prusa printer or Chitubox for the Elegoo Saturn2 resin printer.
2. Use PrusaSlicer or Chitubox to clean up models, add support structures and create G-code for the appropriate printer.
3. Transfer G-code to appropriate 3D printer and print models.

*Phase4: 3D print lung interior consisting of the following tasks:

1. Download STL file of lungs from 3DSlicer into AutoDesk Fusion360.
2. Use Fusion360 to remove outside sides of lungs.
3. Use Fusion360 to clean up model, add support structures and create G-code for Elegoo Saturn2 resin printer.
4. Transfer G-code to resin 3D printer and print model of lungs.

Table 1 summarized the parameters in 3DSlicer (3DSlicer, 2022) for segmenting the structures. The lungs and trachea models were segmented using the Paint and Grow from Seeds options in the 3DSlicer Segment Editor. By selecting an image in each of the three planes (axial, coronal and sagittal planes) in the CT only a minimal of "leakage" occurred in the lung's segmentation. The trachea was segmented by selecting three images only in the axial plane.

The chest and Zephyr valves were segmented using the Threshold option in the 3DSlicer Segment Editor. The chest consisted of bones and the valves of a titanium mesh. The Threshold range of -1024 to 3071 is like the Hounsfield Unit (HU) which makes up the gray scale in medical CT images.

Dense bones and metals absorb much of the radiation while soft tissue (muscle, fat and organs) allow more of the x-rays to pass through them. As a result, bones appear white on the x-ray (HU >100), soft tissue shows up shades of grey (HU <100) and air shows up black (HU= -1000).

Table 1. 3DSlicer parameters.

Structure	Segmentation Option	Scissors Option	Smoothing Algorithm
Chest	Threshold=324	Yes	Fill in holes 8.0mm
Lungs	Paint and grow from seeds	Minimal	None
Trachea	Paint and grow from seeds	Minimal	None
Zephyr valves	Threshold=184	Yes	None

3. Results and Discussion

The folder created in Phase2 allowed students to easily download the necessary files for the simulation. The 3DSlicer Scene program can be considered an auto-run program. Therefore, by clicking on this program all the necessary files are automatically loaded. The 3DSlicer screen in Figure 3 will then

appear. Selecting the 3D-Only icon from the tool bar will create a full screen of the 3D model. The user can then rotate and enlarge the model using the cursor. The user can also return to the Four-Up icon in the tool bar and click on Segment Editor in the modules option.

There is an eye icon to the left of the text for each segment. Clicking on an eye will either remove or restore the selected segment. For example, clicking on the chest, lungs, and trachea eyes will remove these segments, leaving only the Zephyr valves on the screen. Clicking on the 3D-Only icon will then enlarge the screen to zoom and rotate the valves.
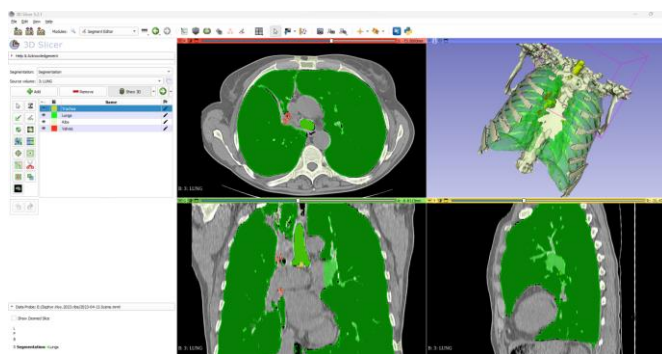
Figure 3. 3DSlicer display.

Figure 4 shows the assembly of the four segments (chest, lungs, trachea and Zephyr valves) from the 3D simulation. Figure 5 shows only the chest segment which served as the frame for the lungs and Zephyr valves. Figure 6 shows the segments after the removal of the chest. A unique feature of 3DSlicer is the opacity setting which was set at 20% for the lungs. As a result, the bronchi airways are visible in the lungs.
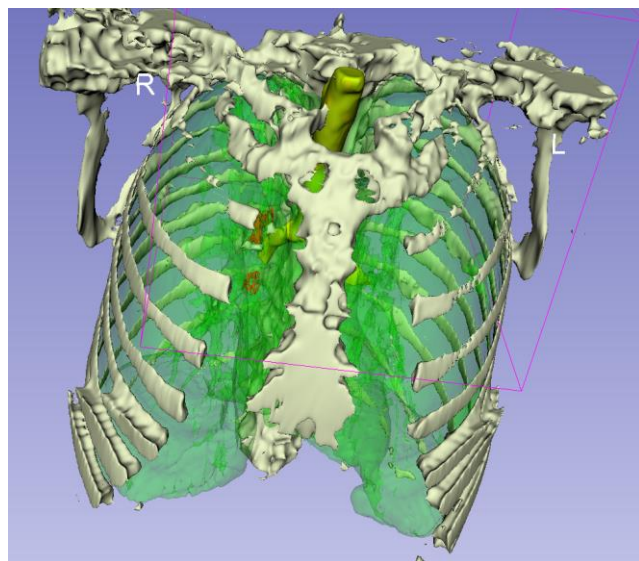
Figure 7 is the 3D animation of only the trachea and Zephyr valves. The 3DSlicer segmentation of the trachea extended to the Zephyr valves. It appears that 3DSlicer stopped the segmentation at the valves. The Paint and Grow from Seeds options require a continuation of the structure segmentation.

Figure 8 is the 3D animation of the four Zephyr valves. The bottom valve was installed in the right middle lobe of the right lung. The top valve is actually the cluster of three valves in the right upper lobe of the right lung and was printed as one structure although they are three different overlapping valves.
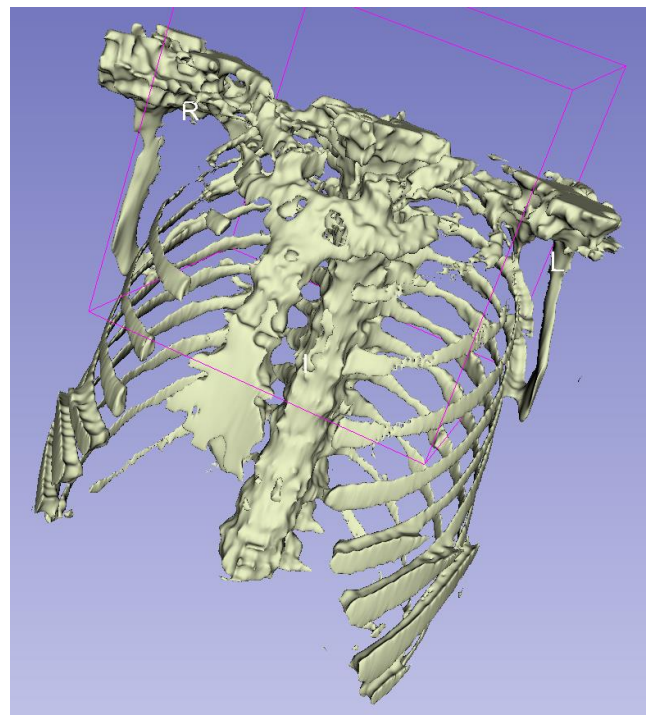

Figure 5. 3D animation of only chest segment.

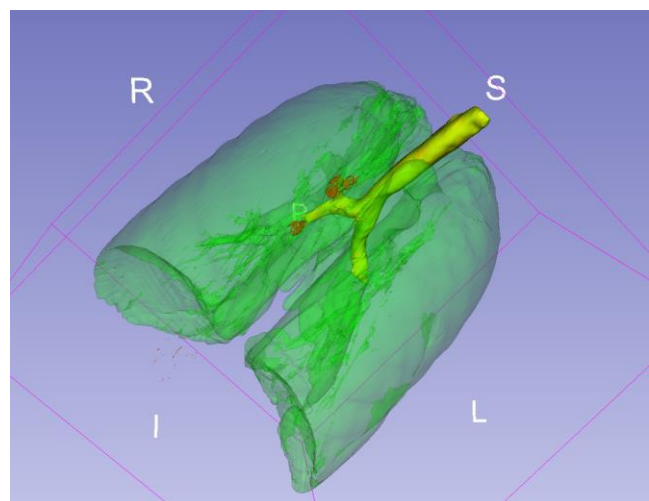**Figure 4**. 3D animation of all four segments.

Figure 6. 3D animation with the chest removed.

The Zephyr valves were printed on an Elegoo Saturn2 resin printer using a photopolymer resin (Figure 9). Resin printing yields high accuracy and detail and produces parts with smooth surfaces and fine features.

3D printed models were only printed of the trachea, Zephyr valves and the lungs. The STL (stereolithography) file of the chest was not 3D printed and instead was only used to add more detail in the 3D simulation.
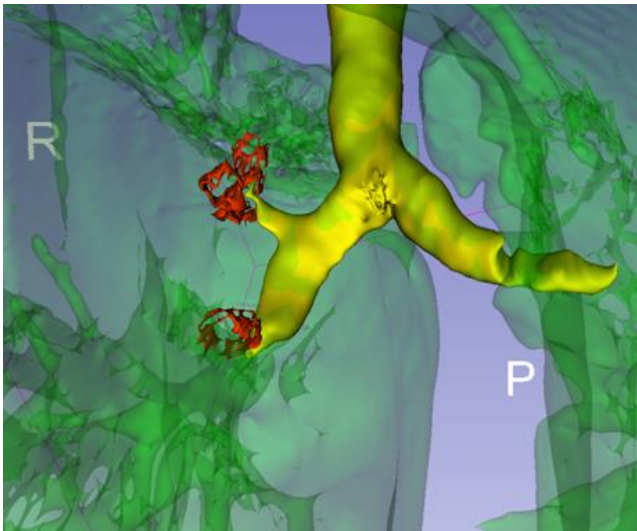

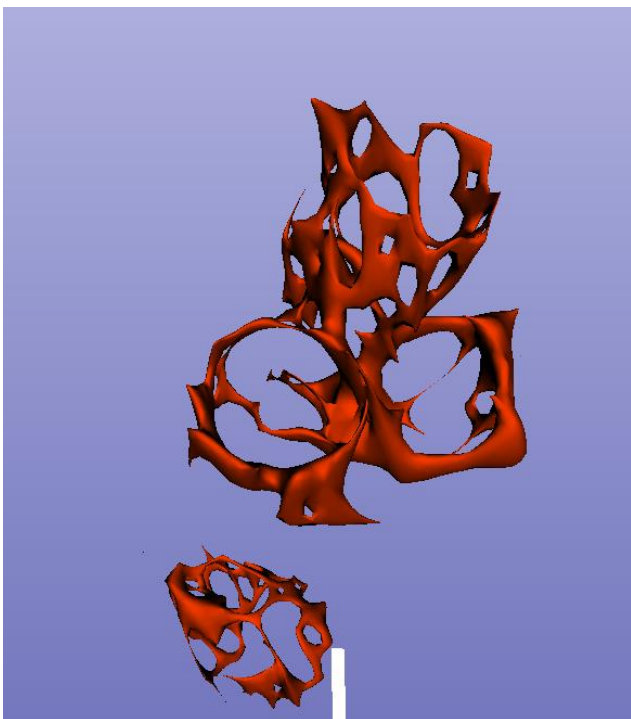**Figure 7.** 3D animation of trachea and Zephyr valves.

Figure 8. 3D animation of Zephyr valves.

Figure 10 is the Fusion360 model of the lungs with no opacity. Using Fusion360 the exterior sides of the

lungs were removed to expose the bronchial airways, like the simulation in Figure 6. Figure 11 shows the inside of the lungs.

Figure 12 is the 3DSlicer view looking at the right lung from the inside with the Zephyr valves. The smoothing algorithm was applied to only the lungs. Since the valves are not connected to the bronchi, the lung and bronchi must be printed and attached separately.
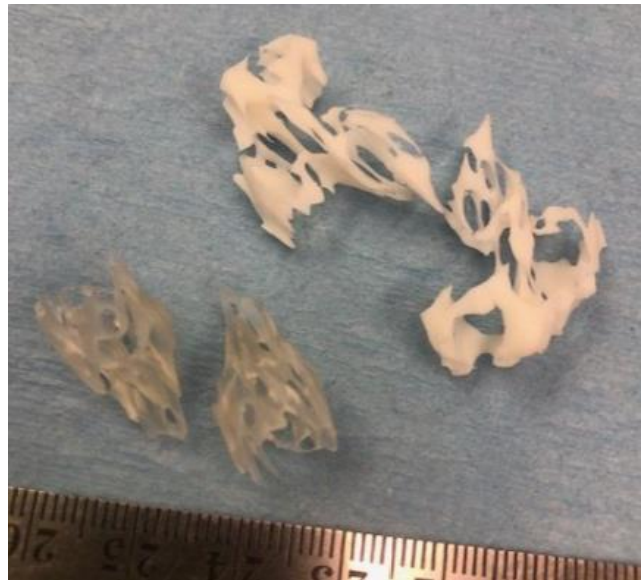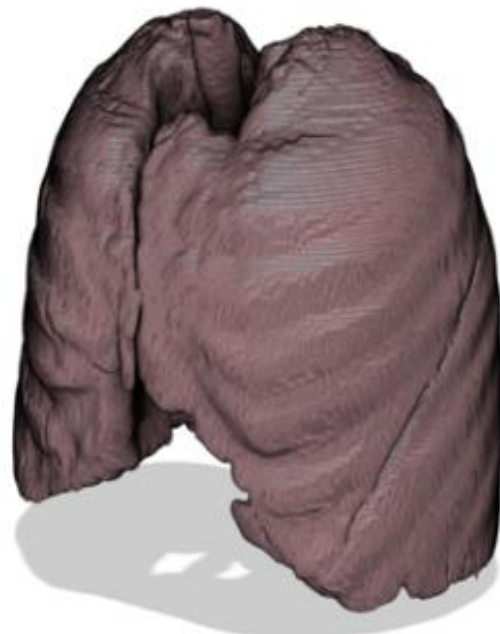

Figure 9. 3D printed models of Zephyr valves.

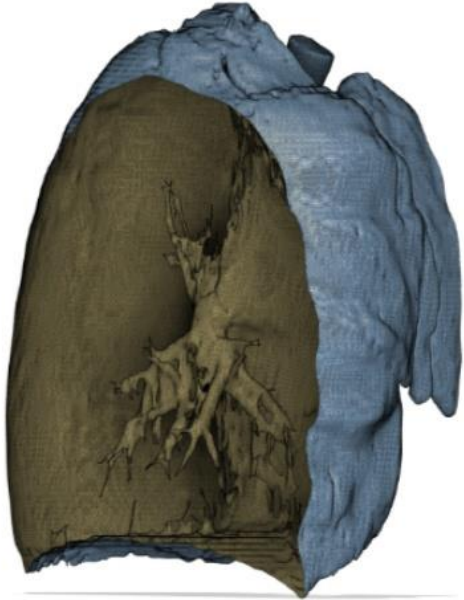**Figure 10.** Fusion360 model of lungs.

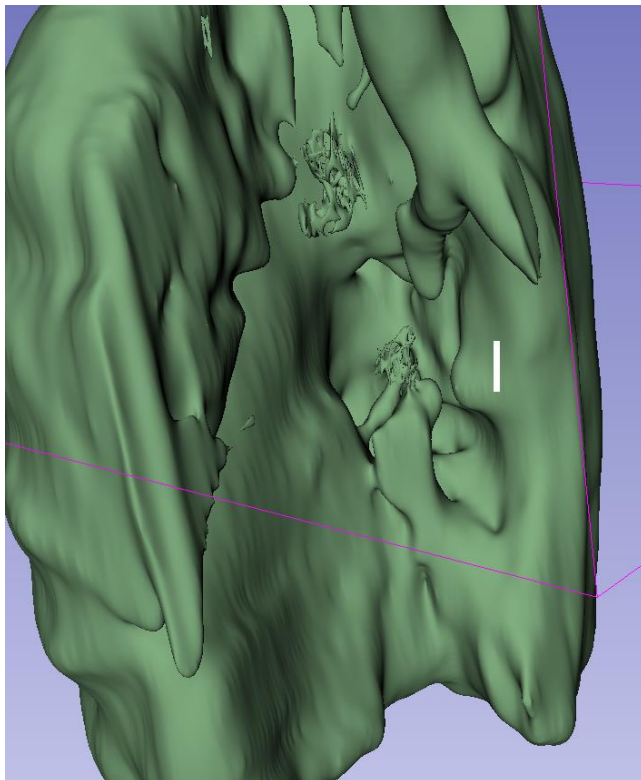**Figure 11**. Inside of right lung from Fusion360.

Figure 12.   Close up of inside of right lung from 3DSlicer.

The 3D simulation in Phase2 has been placed on the MEDNET (Model Exchange and Development of Nursing and Engineering Technologies) website that is maintained by the Systems Management and Production Center (SMAP) at the University of Alabama in Huntsville (UAH). SMAP is collaborating with the College of Nursing (CoN) in developing and producing models and simulators/trainers to enhance nursing education and classroom training.

The full benefits of the simulation are still being evaluated. However, research has shown the link between simulation and retainment of knowledge. Being able to use multiple modalities of teaching makes the information more memorable, allowing students to retain information listed in the evidence-based guidelines. Simulation also helps students understand when, who, and to whom they should refer patients because they develop a better understanding of the procedure. One example of dissemination of the simulation included the nursing faculty sharing the simulation for the medical faculty at a regional teaching hospital. The hospital is a location where the Zephyr valves are being inserted.

Another benefit is the use of the simulation by the nursing faculty as a teaching tool where graduate nursing students can download the simulation to view and manipulate the models. The students have access to the models and simulation/animation at anytime of the day allowing them to direct their learning.

The STL files of the following models from patients with various medical conditions are also on MEDNET and augment the Zephyr valve computer simulation:

- Compression fractures at L1 and T12 vertebrae (from MRI of 78 year old female).
- Kyphoplasty repair to compression fractures (from MRI of 78 year old female).
- Two year follow-up at L1 and T12 showing bone spurs (from CT of 80 year old female).
- Collapsed/punctured lung and healed lung after six weeks (from CT of 16 year old male) (Figure 13).

In addition, the following STL files of various organs and bones from a CT scan of an eighty year old female are also on MEDNET:

- Spine and spine segments (cervical, thoracic and lumbar vertebrae).
- Skull and various cross sections of the skull.
- Heart/aorta/spine assembly (Figure 14).
- Kidneys/aorta/spine assembly.
- Organs, including lungs, heart, liver, stomach, spleen and kidneys.
- Whole body skeleton (Figure 15).

The STL files are available for downloading by faculty and students. The files can be viewed with 3DBuilder which is available on computers with Windows10 or newer.   Many of the STL files have been 3D printed and used by the teaching faculty.

Several models from Embodi3D are also being used by the teaching faculty. Embodi3D was established by Dr. Michael Itagaki, a practicing interventional

radiologist in Seattle, WA (Hanna, 2016). Embodi3D is a library of 20,000+ printable anatomical models (in STL format) that have been generated from real medical scans and uploaded by users throughout the world. Most of the models are free.

Figure 13. Collapsed lung/healed lung.

Figure 14. Heart/aorta/spine assembly.

Figure 15. Whole body model segmented from CT scan.

4. Conclusions

The Save option in 3DSlicer allows the user to save a partial segmentation and can then be restored later to continue the segmentation. However, the Save option can also save a completed segmentation, provided that the user defined all the necessary parameters. In this study the chest, lungs, trachea and four Zephyr valve segmentations were combined into one folder and saved.

The Save option will save all the segmentations, along with an auto-run program; therefore, a novice (such as a nursing student), can easily load and execute the simulation with one click. 3DSlicer version 5.2.0, or newer, must be loaded before executing the simulation.

In summary the following conclusions are made:

- The 3DSlicer features of zooming and rotating were directly transferrable to the 3D simulation.
- The segmented lung model included in detail the bronchi tree. With Fusion360 the outside layer of the lung model could be peeled back, providing the ability to look inside the lung.
- The MEDNET website provides easy access for faculty and students to download and execute the simulation on their computers.

One area for further investigation is to add the lungs with the sides removed to the simulation. The challenge is that Fusion360 is proprietary. A possible solution is to record the animation and have students access the simulation/animation through MEDNET.

Simulation based learning experiences (SBLEs) are an array of structured activities that represent actual or potential situations in education and practice. These activities allow nursing students to develop or enhance their knowledge, skills, and attitudes, or to analyze and respond to realistic situations in a simulated environment. SBLEs occur in a simulation laboratory where students come for a given amount of time to engage in activities specifically designed around a set of learning objectives. These activities are developed into simulation cases with realistic patient scenarios.

The College of Nursing has developed over one hundred SBLEs. Each simulated clinical experience is documented and placed in a binder with specific objectives, a set up sheet and pictures for standardized repetition. The simulation in this paper will be added into selected SBLEs in the College of Nursing.

Many of the nursing programs in Alabama are on campuses with 3D printing capabilities. Therefore, these technology departments can download the STL files and 3D print the models. Presently, there has been minimal downloading of the STL files. The nursing programs must be informed of the 3D printed models and request that the technology departments 3D printed the models. The UAH Systems Management and Production Center has just begun informing and working with the nursing programs on the usage of MEDNET. The nursing faculty has requested simulation and modeling of congenital defects such as Patent Foramen Ovale, and Tetralogy of Fallot.

The power of animation, combined with color, zooming in and out and rotating medical structures, are invaluable additions to the teaching of acute care nurse practitioners. The simulations, animations and models allow students to bridge the knowledge gaps between the current guidelines and newest treatment options for specific disease processes. Providing this technology for students to download encourages them to direct their learning and to continue to be lifelong learners. This safe realism is one of the greatest benefits of simulation.

Acknowledgements

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