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Development of Simulator for Training Nursing Students: A 3D Printed Model of Arteries and Veins Rising from Heart

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Abstract

This paper presents the development of a simulator showing the arteries and veins rising from a human heart for use in training nursing students. The simulator included 3D printed models of the heart, rib cage, left lung, clavicles and scapulas. Silicone rubber o-ring cord was used to simulate sixteen arteries and twelve veins. 3D printed models of the brachiocephalic and the left subclavian trunks were attached to the aortic arch for inserting the arteries. Simulation based learning experiences (SBLEs) are an array of structured activities that represent actual or potential situations in education and practice. These activities allow students to develop and enhance their knowledge and skills, or to analyze and respond to realistic situations in a simulated environment. The College of Nursing has developed over one hundred SBLEs. This simulator is being integrated into the appropriate SBLEs and provides an opportunity for nursing students to study human anatomy and the location and size of arteries and veins from and to the heart. The simulator provides nursing students hands on training to touch and feel organs and to trace arteries and veins. The goal is for the simulator to become part of a blended or multimodal approach in human anatomy and physiology training for nursing students.

Keywords: Simulator, 3D printed model, student nurse training.

1. Introduction

Human anatomy and physiology are considered a cornerstone of health related professional care education. These courses assist in building a foundation in human structure and function and serve as a pre-requisite for nursing courses and clinicals (McVicar, etal, 2014).

Human cadavers are perceived as the standard for teaching students (Washmuth, etal, 2020). However, human cadavers are expensive, requiring embalming, storage and special transportation. In recent years human cadavers are being replaced by a variety of innovative teaching technologies. One of these technologies is 3D virtual human cadavers such as the Anatomage Table (Narnaware and Neumeier, 2021) and a second is the synthetic cadaver (SynDaver, 2022).

These innovative teaching technologies are very expensive, ranging up to $100,000. In addition, there are the recurring costs of maintenance, refurbishment and replacement parts.

Emerging evidence is now showing a trend toward the use of multiple innovative technologies combined with visual aids in nursing education (Rutty etal, 2019). These include website/online learning, videos and multimedia, podcasts, virtual patients, gamification, computer simulation and medical image scans (Estai, 2016).

There are less expensive technologies to augment the teaching of human anatomy and physiology. One of these technologies is 3D printing. 3D printers are now available that can print high quality and to scale skeletons and organs. A good quality printer is available for less than $1000 and a 1.2kg reel of filament for under $30. An organ, such as a liver or lung, can be printed for less than $15.

This paper presents the development of a less expensive simulator showing the arteries and veins rising from and to a human heart for training nursing student. Most simulators ignore or only include a very small number of these vessels. This simulator includes 3D printed models of the heart, rib cage, clavicles (collarbones) and scapulas (shoulder bones). The arteries and veins rising from and to the heart are simulated using silicone rubber o-ring cord.

The goal is for the simulator to become part of a blended or multimodal approach in human anatomy training for nursing students in the College of Nursing's Simulation Based Learning Environments (SBLEs). Of special focus is location and diameters of the major vessels from and to the heart.

The Systems Management and Production (SMAP) Center at The University of Alabama (UAH) has been working closely with the College of Nursing (CoN) in developing simulators for nursing education. Typically a team is established for each project and consists of 1) a researcher from the SMAP Center who provides technical support and mentoring, 2) a faculty member from the College of Nursing who serves as the subject matter expert and 3) students, generally from science and engineering, who do the design and fabrication. The team meets throughout the project for feedback from the nursing faculty and to assure that the project goals are being satisfied.

One of the projects was a full scale model of the human body with major organs and arteries (Figure 1) (Lioce etal, 2021). This model had several problems. First, since the organs were rigid it was difficult to correctly locate many of the organs, resulting in voids between the organs. In the human body these voids do not exist since the organs are soft and fit close together. Second, it was difficult to correctly place many of the arteries around the organs that were in the interior of the rib cage. As a result the students had difficulty seeing many of the organs and arteries.

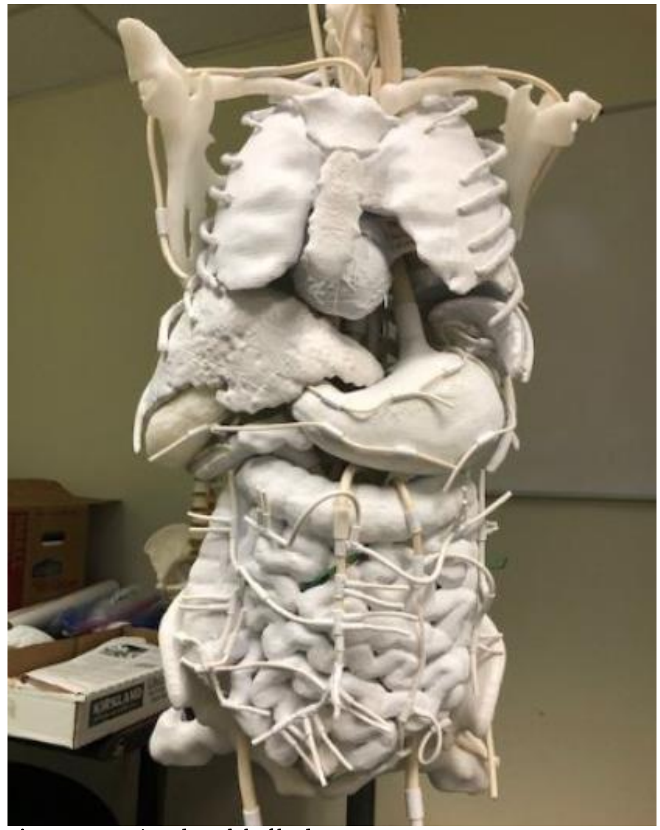
Figure 1. 3D printed model of body.

A solution to the problem was to develop specific simulators that were mounted on plywood where the organs could be spaced further apart and the arteries more visible. Table 1 summarizes the simulators that have been previously developed for the College of Nursing. Table 1 also lists the 3D printed organs and the number of arteries for each simulator. These simulators did not include veins.

As an example, Figure 2 is Simulator3 showing the arteries supplying blood from the aorta to the pancreas and duodenum. The simulators were placed on plywood. 3D printed blocks were glued to the plywood. The organs were then glued or fused to the blocks.

Feedback from the faculty in the College of Nursing was to add veins to the heart Simulator1. Therefore, another simulator, Simulator5, was developed showing the major arteries and veins rising from and to the heart.

Included in this paper are the development of Simulator5, the 3D printed structures in the simulator, a description of the arteries and veins rising from and to the heart, the assembly of the simulator and the addition of the simulator into the CoN Simulation Based Learning Experiences (SBLEs).

Table 1. Simulators.

Simulator	Number of arteries in simulator
1 Arteries supplying blood from heart to the lungs 3D printed models: Heart, lung, ribs. clavicle (collarbone)	24
2 Arteries supplying blood from aorta to liver, stomach, spleen, gallbladder and duodenum 3D printed models: Liver, stomach, spleen, gallbladder and duodenum	22
3 Arteries supplying blood from aorta to pancreas and duodenum 3D printed models: Liver, spleen, gallbladder, duodenum and pancreas	21
4 Arteries supplying blood from the superior mesenteric artery and the inferior mesenteric artery rising from the aorta to the intestines 3D printed models: Small intestines and large intestines	18

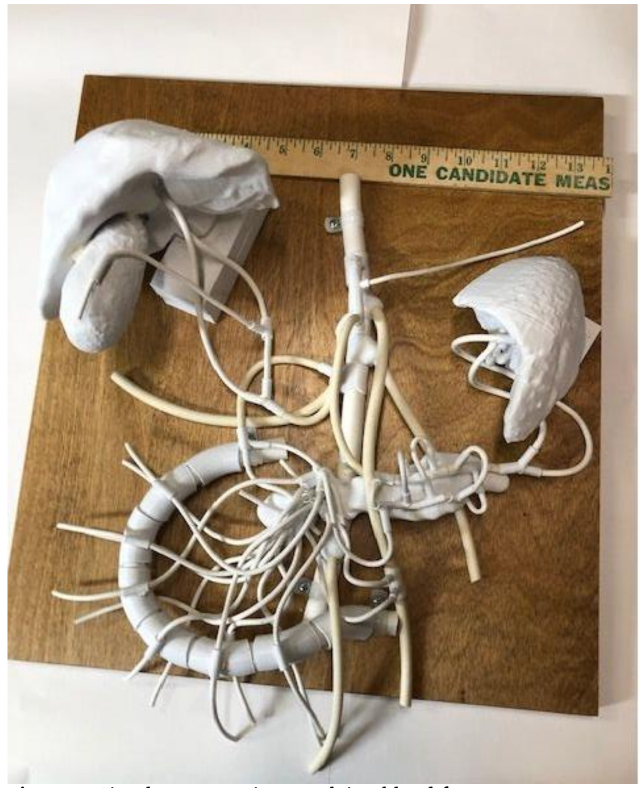

Figure 2. Simulator3 arteries supplying blood from aorta to pancreas and duodenum.

2. Methodology

Figure 3 is the schematic of the sixteen arteries and twelve veins in Simulator5. Table 2 lists the names of the arteries and veins, the diameter of each vessel from the literature and the corresponding diameter of the silicon rubber o-ring cord used to simulate each vessel. The numbers next to the vessel names in Figure 4 correspond to the artery and vein numbers in Table 2.

Veins are generally larger in diameter, carry more blood and have thinner walls in proportion to their lumen (channel in the blood vessel). Arteries are smaller, have thicker walls in proportion to their lumen and carry blood under higher pressure than veins (University of Deleware, 2022).

Silicone rubber o-ring cord was used to simulate the arteries and veins. These vessels were inserted into 3D printed sleeves which were fused to the models with a soldering iron. A 3D printed model of the brachiocephalic trunk was attached to the aortic arch for adding the right subclavian, right vertebral and right common carotid arteries. A 3D printed model of the left subclavian trunk was also attached to the aortic arch for adding the left brachial and left coronary artery. The left common carotid artery was attached directly to the aortic arch. The corresponding veins were also simulated with o-ring cord.

The ascending aorta and the left and right coronary arteries were included in the 3D printed model of the heart. The descending aorta was attached to the aortic arch rising from the heart model. The left and right pulmonary arteries were part of the heart model.

The inferior vena cava vein was inserted directly into the 3D printed heart model. The superior vena cava vein was part of the heart model. The right and left brachiocephalic veins were inserted in the superior vena cava vein. The right subclavian and right internal jugular veins rose from the right brachiocephalic vein. Likewise, the left subclavian and left internal jugular veins rose from the left brachiocephalic vein.

The arteries and veins from and to the heart to the lungs were included in the simulator. The pulmonary arteries carry deoxygenated blood from the heart to the lung. The superior and inferior pulmonary veins carry oxygenated blood from lung to the heart.

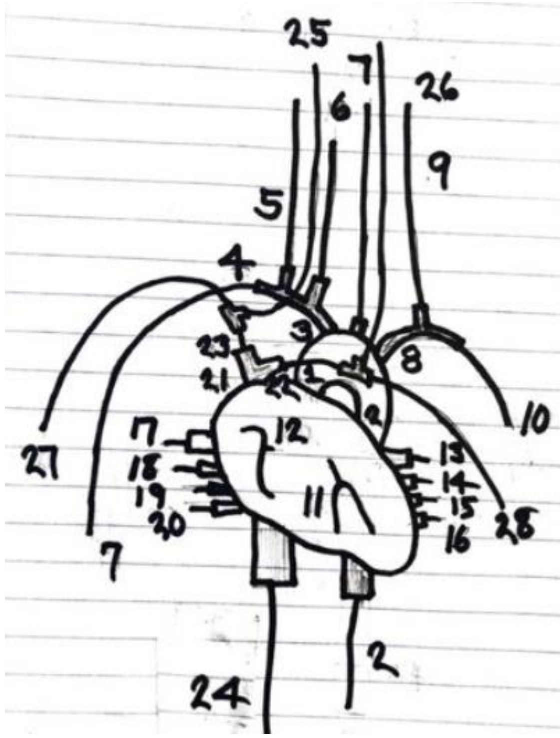

Figure 3. Schematic of arteries and veins in Simulator5.

Table 2. Parameters of arteries and veins in Simulator5.

Vessel	Diameter of vessel from literature (mm)	Diameter of o-ring cord in trainer (mm)
1 Ascending aorta artery	30.9+-4.1 (Hager etal, 2002)	19mm printed on heart model
2 Descending aorta artery at diaphragm	24.3+-3.5 (Hager etal, 2002)	20mm printed on heart model Inserted 14mm o-ring cord
3 Brachiocephalic trunk artery	12.1+-1.6 (Sheikh and Oliver, 2021)	8
4 Right subclavian artery	6.38 (Kaki etal, 2018)	5
5 Right vertebral artery	3-5 (Weerakkody and Gillard, 2021)	3
6 Right common carotid artery	4.3-7.7 (Limbu, 2006)	6
7 Left common carotid artery	4.3-7.7 (Limbu, 2006)	6
8 Left subclavian trunk	9-12 (Rigberg etal, 2006)	8
9 Left vertebral artery	3-5 (Weerakkody and Gillard 2021)	3
10 Left brachial artery	3.93+-0.49 (Tomiyama, 2015)	5
11 Left coronary artery	3D printed on heart model	-
12 Right coronary artery	3D printed on heart model	-
13 Left pulmonary artery	19.74+-2.35 (Gokoglan etal, 2014)	10
14 Left pulmonary (smaller) artery	-	5
15 Left superior pulmonary vein	9.6-10.5 (Kim, 2005)	5
16 Left inferior pulmonary vein	9.0-9.9 (Kim, 2005)	6
17 Right pulmonary artery	19.24+-2.43 (Gokoglan etal, 2014)	10
18 Right pulmonary (smaller) artery	-	5
19 Right superior pulmonary vein	12.3-13.1 (Kim 2005)	5
20 Right inferior pulmonary vein	11.4-12.4 (Kim,, 2005)	6
21 Superior vena cava vein	14-28 (Sonavane etal, 2015)	-
22 Left brachiocephalic vein	-	7
23 Right brachiocephalic vein	-	10
24 Inferior vena cava vein	12-17 (Mookadam, 2011)	16
25 Right internal jugular vein	14.8+-3.9 (Tennebein etal, 2006)	10
26 Left internal jugular vein	11.2+-3.6 (Tennebein etal, 2006)	8
27 Right subclavian vein	11.2+-3.6 (Tennebein etal, 2006)	10
28 Left subclavian vein	10-20 (Tennebein etal, 2006)	8

Table 3 lists the developers of the STL files for the models that were downloaded from Embodi3D which was established by Dr. Mike Itagaki, a practicing interventional radiologist. Embodi3D is a library of printable anatomical models generated from real medical scans and uploaded by users throughout the world. Most of the models are free or a minimal cost; however, the user is required to register.

Many of the STL files were modified before 3D printing. Also the files were segmented to only print selected portions. Various sleeves for the o-ring cord were designed and printed by students at the University of Alabama in Huntsville.

The 3D printed models were printed on the Prusa i3 MK3 printer with a PLA (polylactic acid) filament. The arteries and veins were simulated with various diameters of silicone rubber o-ring cord.

Table 3. Developers of the 3D printed models for Simulator5.

Model	Developer of 3D printed model
Heart	Embodi3D.com "Marco Vettorello, MD, Italy"
Left rib cage, spine, clavicles (collarbones) and scapulas (shoulder bones)	Embodi3D.com "Selami Ekinci, Turkey"
Left lung	Embodi3D.com "Selami Ekinci, Turkey"
Cervical spine segment	Embodi3D.com "Selami Ekinci, Turkey"
Brachiocephalic trunk	University of Alabama in Huntsville
Left subclavian trunk	University of Alabama in Huntsville
Variety of sleeves to insert o-ring cord	University of Alabama in Huntsville

3. Results and Discussion

Figure 4 is the 3D printed model of Simulator5. Figure 5 is a close-up of the simulator. The blue sleeves (darker sleeves) identify the veins. Figure 6 shows the arteries rising from the heart to the arms and neck. Figure 7 shows the veins from the arms and neck to the heart.

Figure 8 shows the arteries and veins from and to the heart to the lungs. Blue sleeves (darker sleeves) surround the two right pulmonary arteries. The two right pulmonary veins are also visible which carry oxygenated blood from the lungs to the heart. Note that in this instance the blue sleeves signify arteries and not veins.

Simulator5 includes 3D printed models of the heart, rib cage with a portion of the spine, cervical spine segment (C1-C7), left lung, clavicles (collarbone) and scapulas (shoulder bones). The trachea and esophagus were omitted.

Instruction manuals have been developed for each trainer for community colleges/technical schools in the state to fabricate the trainers for their nursing programs. The STL files are available from Embodi3D.com and the Systems Management and Production Center (SMAP). The SMAP Center provides most of the supplies to assemble the trainers such as the silicon rubber tubing, clamps and super glue. The community college/technical school must have a 3D printer such as the Prusa which is a relative inexpensive 3D printer.

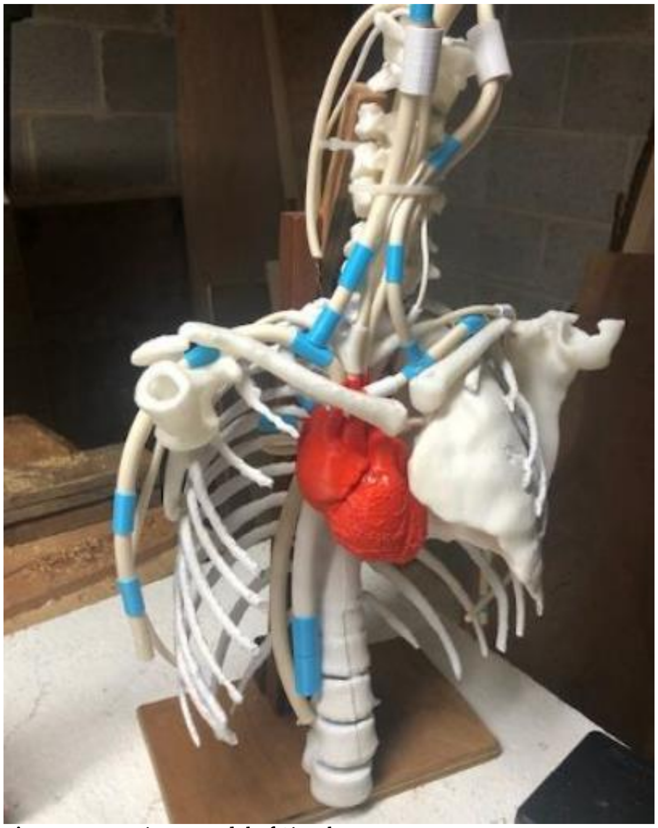

Figure 4. 3D printer model of Simulator5.

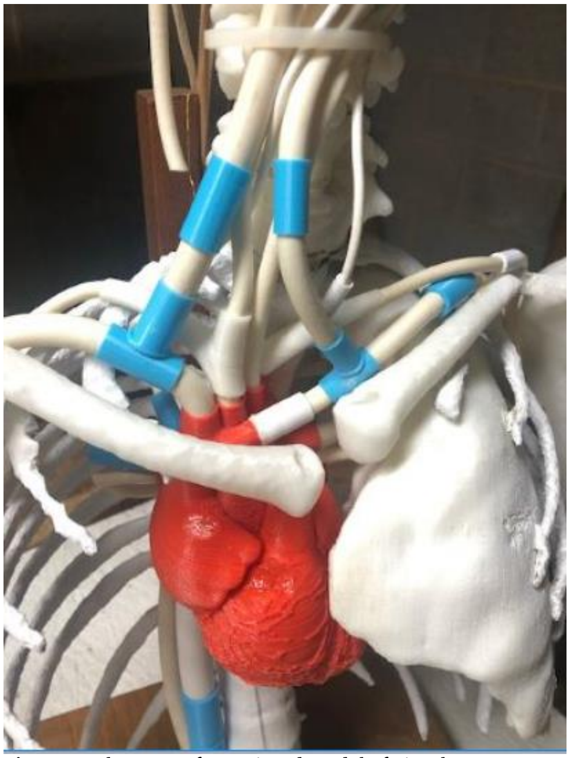

Figure 5. Close-up of 3D printed model of Simulator5.

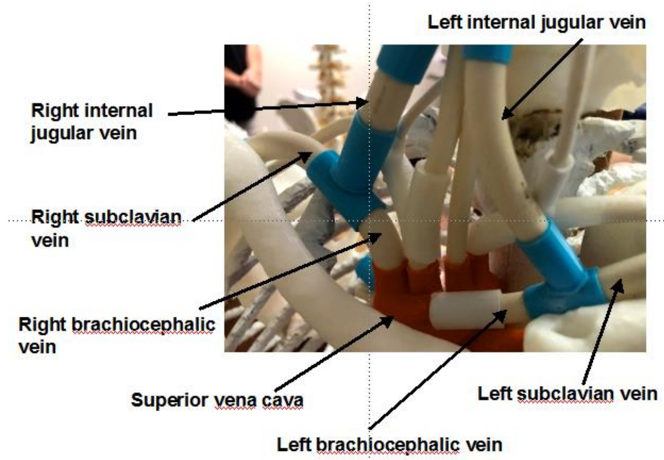

Figure 7. Veins rising from the arms and neck to the heart.

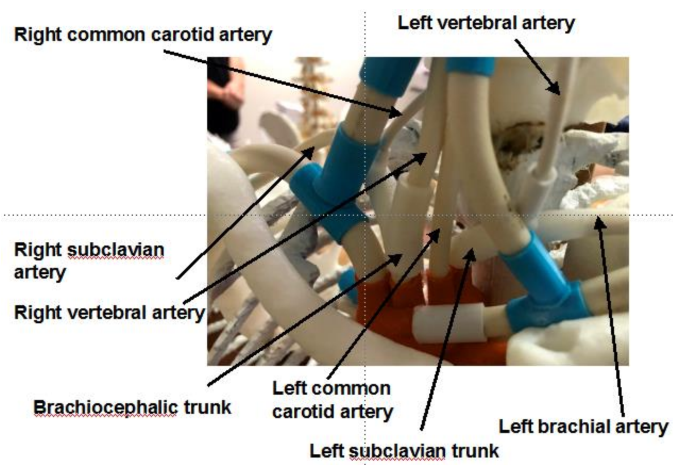

Figure 6. Arteries rising from heart to arms and neck.

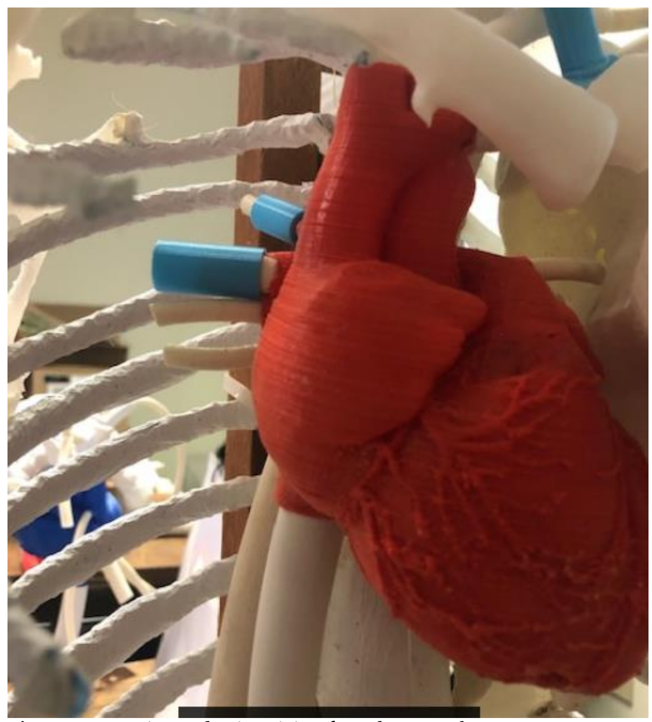

Figure 8. Arteries and veins rising from heart to lungs.

4. Conclusions

Simulator5 was relatively easy to fabricate. With the instruction manuals the simulator can also be readily duplicated. Community colleges/technical schools with 3D printer capability are duplicating the simulator for use in their nurse training programs.

The estimate cost of materials is $100. Approximately two reels of PLA filament ($50) was used to 3D print the various parts on a Prusa i3 MK3.

The silicone rubber o-ring cord, clamps and glue cost about $50. The Systems Management and Production Center (SMAP) has prepared kits for the community colleges/technical schools that include the necessary items, excluding the PLA filament. The community colleges can download the STL files from the SMAP Center website.

Simulation based learning experiences (SBLEs) are an array of structured activities that represent actual or potential situations in education and practice. These activities allow participants 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 nursing 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 in detail and placed in a binder with specific objectives, a detailed set up sheet and pictures for standardized repetition with multiple clinical groups.

Simulator5 is being integrated into the appropriate SBLEs and provides an opportunity for nursing students to study human anatomy and the location, name and size (diameter) of arteries and veins rising from and to the heart. With the o-ring cord students are able to trace the arteries from the heart and the veins returning to the heart.

The o-ring cord diameters correspond to the diameters of the arteries and veins. Consequently, students are able to visualize the actual size of the vessels and to contrast the differences in vessel diameters. One of the interesting student feedbacks has been regarding the large diameter of the aorta and the jugular veins.

The goal is for Simulator5 to become part of a blended or multimodal approach in human anatomy and physiology training for nursing students in the College of Nursing's SBLEs. Currently this multimodal approach consists of the following technologies: 1) 3D printed model of the human body as shown in Figure 1, 2) Simulator5 in Figure 2 and the other four simulators in Table 1, 3) 3DSlicer 3D computer simulation models of organs, and 4) a synthetic cadaver.

A spinoff of the UAH simulators (including Simulator5) has been a number of STL (stereolithography) files of the 3D printed models of many organs, including the heart, liver, lungs, stomach, spleen, pancreas, kidneys and bladder, which students can view on their own computer (and outside the classroom) in 3DBuilder which is available on any computer with Windows. The models can be viewed in 3D and rotated and enlarged.

In addition, the College of Nursing has recently purchased a synthetic cadaver SynDaver to assist in anatomy training. SynDaver is a replica of the human body, including skin with fatty tissue, tendons and ligaments, organs and bones. Figure 9 is a photo of SynDaver with the skin layers removed (SynDaver, 2022).

Figure 9. SynDaver with skin removed.

Acknowledgements

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