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Application of 3D printing in the development of training simulations for nursing students

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Abstract

This paper presents the application of 3D printing in the development of training simulations for nursing students. The simulations are a cricothyrotomy trainer, a vein finder, an onychectomy trainer, wrist splints and finger splints, a needle injection pad trainer and a suture pad trainer. Cricothyrotomy is a procedure in which an incision is made through the skin and cricothyroid membrane to establish a patient airway. The vein finder consists of a light that will penetrate skin, fatty tissue and oxygenated blood, but will not penetrate deoxygenated blood and will result in the veins showing up dark. Onychectomy is a surgical procedure in which part or all of a fingernail or toenail is removed. The wrist splints and finger splints were printed flat and then thermoformed to soften the material and custom fitted on the wrist. The needle injection pad trainer simulates tissue layers. The suture pad trainer is used to practice lancing and cleaning an abscess and stitching a wound. The nursing faculty were actively involved throughout the process. The simulations are being used to provide nursing students with hands-on experiences, allowing students to practice specific skills at a lower cost and to gain these skills in a safe learning environment.

Keywords: 3D printing, rapid prototyping, medical, nurse training, simulation

1. Introduction

In 1986 Chuck Hall was granted a patent for the first 3D printing technology, stereolithography (SLA). SLA 3D printers are based on photopolymerlization, using a laser to harden an ultraviolet sensitive resin layer by layer. The 3D printing process builds a 3D object from a computer-aided design (CAD) model by successively adding material layer by layer.

In the last several years the precision, repeatability and material selection have increased so that 3D printing is now considered viable as an industrial production technology, resulting in the term additive manufacturing.

At the present, the most commonly used 3D printing process is a material extrusion technique called fused deposition modeling (FDM), a special application of a plastic extrusion. FDM is widely used by hobbyists and consumer-oriented models and is also the least expensive technique. A variety of materials are used in fused deposition modeling including PLA (poly lactic acid) plastic, ABS (acrylonitrile butadiene styrene) plastic, thermoplastic, polycarbonate (PC), polycarbonate-

ABS composites (PC-ABS), Ultem 9085 thermoplastic and polyamide (nylon).

PLA plastic and ABS plastic are the two most used materials for fused deposition modeling. PLA is a vegetable based plastic which commonly uses cornstarch as a raw material. PLA is fully biodegradable thermoplastic polymer. Many different versions of PLA filaments have been developed such as aluminum PLA, PLA made with wood fibers and PLA with bronze particles. Materials used by other 3D printers are glass filled polyamide, epoxy resin, silver, titanium, steel, wax and photopolymers.

With the use of these various materials 3D printing has found many new applications. One of these new applications is in healthcare. Some examples in healthcare are invisible teeth straightening devices, prosthetic devices, surgical tools, occupational therapy devices and anatomical models. Custom patient specific anatomical models allow physicians to show patients a 3D representation of their own body and what needs medical attention. 3D printers can rapidly make medical equipment such as clamps, braces vacuum pumps and replacement parts at very low cost (Carfagno, 2019).

This paper presents the development of six 3D printed task trainers for use with skill and simulations for nursing students in the College of Nursing at the University of Alabama in Huntsville (UAH). Healthcare simulations are a proven method of training students by providing much needed hands-on experience and feedback thus allowing the students to practice specific skills in a safe setting.

2. Literature review

According to a 2014 study by Meehan-Andrews (Hatch and Shaw, 2019) nurses and nursing students found the most success in learning by a hands-on approach to receiving information. 3D printing allows students to visualize anatomy and physiological concepts based on more realistic structures rather than standardized models. Instructors are better able to demonstrate anatomical differences and give visual examples of disease progression. Furthermore, 3D printing facilitates training for procedures in simulated conditions without risk to a patient. This could increase confidence in a student before entering a clinical setting. The simulation of a specific and complex procedure provides a unique opportunity to determine the best strategy and to practice the steps to take.

A recent article in Docwire (2020) has compiled some of the top stories and research of 3D printing in the medical industry. Several of these top stories are: using living cells in a 3D printer to bioprint tissue structures, 3D printing ovaries for transplants and gold nanoparticle 3D printing in pharmaceutical industry.

An article in Medical Futurist (2017) has a list of 3D applications in medicine and healthcare. Several of the applications are finger splints, models of cancerous tumors to aid discovery of new anti-cancer drugs, organ models, plastic 3D printed implants, personalized braces, prosthetic parts and synthetic skins.

C. Huston (2013) studied the impact of seven emerging technology on nursing care: 1) genetics and genomics, 2) less invasive and more accurate tools for diagnostics and treatment, 3) 3D printing, 4) robotics, 5) biometrics, 6) electronic healthcare records (EHR), and 7) computerized physician/provider order entry (CPOE) and clinical decision support. For 3D printing Huston states that bio-printers using a bio-ink made of living cell mixtures can build a 3D structure of cells, layer by layer, to form human tissue and eventually human organs for replacement.

Lim et al. (2016) conducted a study to assess the effectiveness of 3D prints versus cadaveric materials for learning external cardiac anatomy. Following a pre-test to determine baseline external cardiac anatomy knowledge, participants were assigned to three groups who underwent self-directed learning sessions using 1) cadaveric materials, 2) 3D prints or 3) a combination of cadaveric materials/3D prints. Participants were then subjected to a post-test. The results suggested that the use of 3D prints may provide certain benefits to anatomy learning and supports their use and as a supplement to cadaver-based curriculums.

Chae et al. (2015) discussed the potential of 3D printing to become an essential office based tool in plastic surgery to assist in preoperative planning, patient and surgical trainee education and the development of intraoperative guidance tools and patient specific prosthetics in everyday surgical practice.

3. UAH College of Nursing

The UAH College of Nursing completed a major renovation and addition in 2015. The College offers RN-BSN, BSN, MSN, DNP and a new PhD degree in Nursing, as well as a Post Masters Family Nurse Practitioner Certificate, and a Graduate Certificate in Nursing Education. The fall 2019 enrollment was 1440 students with 846 undergraduate and 594 graduate students. 338 degrees were awarded in 2018-19.

The Learning & Technology Resources Center occupies over 10,600 sqft. The Center houses a fourteen bed hospital lab, a fourteen table assessment lab, four advanced practice provider clinical examination rooms, seven high-fidelity simulation laboratories, a four bed Obstetric/Pediatric laboratory, a telehealth room, pyxis medication room, and multiple debriefing rooms. Figure 1 is a photo of the sixteen-bed hospital laboratory that is equipped with a variety of human patient simulators (Moeller, et al. 2015).

Figure 1. Teaching hospital

The UAH Learning & Technology Center has developed over one hundred simulation training scenarios. Each simulated clinical experience is documented in detail and placed in a three-ring binder with specific clinical objectives, a detailed set up sheet and picture for standardized repetition with multiple clinical groups. The 3D printed units presented in this paper have been integrated into clinical training scenarios.

4. UAH 3D printing lab

The UAH 3D printer lab contains the following 3D printers:

- Prusa-i3 MK3S.
- Monoprice-MPS Mini.
- MakerBot-Replicator+.
- FlashForge-Creatorpro.

The material primarily used in the UAH 3D printer lab is PLA (polylactic acid) plastic filament. Another Lab material that offers flexibility, elasticity and high strength is TPU (thermoplastic polyurethane) filament.

5. Training simulations

The faculty and staff from the College of Nursing and the Systems Management and Production Center conducted a needs assessment that identified a number of potential task trainers. The focus of these collaborations between nursing and engineering was to provide skill training solutions to support cost prohibitive hands-on training for fine motor skill procedures.

The following training simulations were selected to 3D print:

- Cricothyrotomy trainer.
- Vein finder.
- Onychectomy trainer.
- Wrist splints/braces and finger splints.
- Needle injection pad trainer.
- Suture pad trainer.

A previous paper (Lioce, et al., 2020) discussed the following training simulations 1) a human brain, 2) a human heart, 3) a placenta and 4) a compression fracture.

A number of the digital design files was acquired from Thingiverse.com which is a website dedicated to the sharing of open source, user-created digital design files. Modifications were made to these design files. Each of the trainers is discussed in the following sections.

6. Cricothyrotomy Trainer

A cricothyrotomy is a surgical procedure where an incision is made through the skin and cricothyroid membrane to establish a patient airway during certain life threatening situations, such as an airway obstruction by a foreign body, angioedema, or massive facial trauma.

Figure 2 is a photograph of the 3D printed cricothyrotomy trainer. Three prototype 3D units were printed until the nurses found a unit with a good strength and texture. The housing unit was printed using a PLA filament. The insert was printed with TPU for flexibility. Eight units were produced in 2018 at a cost savings of $4000 and are still in use. The units are providing hands-on experience for students in flight nursing.

Figure 2. 3D printed cricothyrotomy trainer

7. Vein finder

The 3D printed vein finder consists of a battery powered circuit with a number of red LED's with the wavelength between 620-680 nm. Light at this wavelength will penetrate skin, fatty tissue and oxygenated blood. However, light at this wavelength will not penetrate deoxygenated blood which circulates through the veins and will result in the veins showing up dark.

The use of the 3D printed vein finder is as follows. The vein finder is used with patient's arm to aid in physical assessment and vein identification for patients who may be dehydrated or difficult sticks. The vein finder is placed on the skin near a typical IV site, the light illuminates the veins to identify the size and direction of the vein to improve success of first time IV insertion.

Figure 3 is a photograph of the 3D printed vein finder. The vein finder was printed using a PLA filament. This unit was the result of several high school internships collaborating with the College of Nursing and the SMAP center.

Figure 3. 3D printed vein finder

8. Onychectomy trainer

An onychectomy is a surgical procedure in which part or all of a fingernail or toenail is removed. It is often performed on the big toe to ward off ingrown toenail infections and is sometimes used as a method against severe toenail fungus. Figure 4 is a photograph of the 3D printed onychectomy trainer. The unit was printed using a PLA filament.

9. Wrist splints/braces and finger splints

3D printed wrist splint/braces were printed flat with open shapes and then thermoformed to soften the material and custom fit the brace on the wrist. The fit can be adjusted as needed after the initial forming. A number of finger splints were also 3D printed.

One of the biggest challenges in low-cost 3D printed prosthetic devices is the proper fit. If the loads on the device are not properly distributed across the skin, the brace can result in irritation, bruising or rashes.

Figure 4. 3D printed onychectomy trainer

Figure 5 is a photograph of several of the 3D printed wrist splint/braces and finger splints. The material is PLA filament. These units provide for quick splinting and bracing which allow for swelling and for quick applications in rural settings.

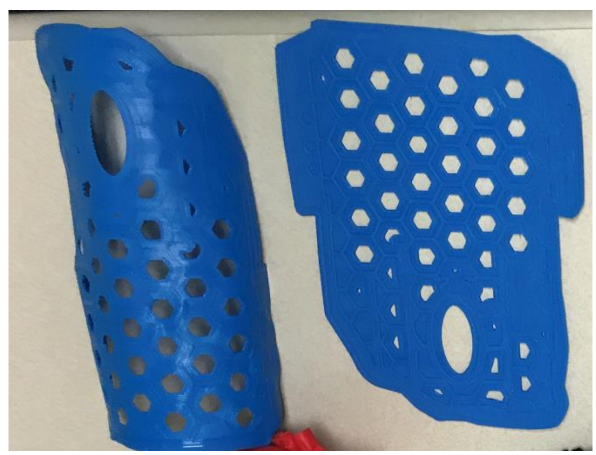

Figure 5. 3D printed wrist splints/braces and finger splints

10. Needle injection pad trainer

Lipton, et.al. (2019) have conducted a detailed analysis of solid freeform fabrication of soft tissue for needle injection. The authors determined that a two layer system was needed, a top layer to simulate the epidermis and a base layer to simulate the subcutaneous tissue. They also identified four key variables which control the needle puncture force and depth: Young's Modulus (stiffness) of the base layer, Young's Modulus of the top layer, thickness of the top layer and sharpness of the needle.

The 3D printed injection pad trainer consists of a pad for simulating injections (intradermal, intramuscular and subcutaneous injections). Trainers generally have multiple tissue layers representing epidermis, dermis, fat and muscle layers. Some trainers can attach to an arm or thigh.

Figure 6 is a photograph of the finished injection pad trainer. The three layers of the injection pad were made using Dragon Skin Fx for the external layer and a standard two-part silicon for the fat and muscle layers. Dragon Skin Fx-Pro is a soft and stable platinum silicone rubber for creating silicone makeup appliances and skin effects. Color effects can be achieved by adding silicone pigments.

A CAD program was used to design the base and holder of the pad. The base and holder was then 3D printed. The mold for the injection pad was then designed and 3D printed. The Dragon Skin Fx-Pro was then poured into the mold to the correct thickness of the skin layer. Once it had cured the skin layer was removed from the mold. The two-part silicone was mixed and then poured into the mold to the correct thickness of the fat layer. Once it had mostly cured the fat layer was removed from the mold. The process was repeated again with the two-part silicone for the muscle layer. All three layers were than correctly stacked back in the 3D printed base and holder.

Color pigmentation was added during the mixing process before pouring. Flesh tone skin pigment was added to the skin layers. Various darker pigments were also used for the skin layer to show different skin tones. The fat layer remained the clear silicone color. A red pigment was added to the muscle layer. The nursing faculty was actively involved in this process to represent the desired realism.

3D printing improved the longevity of the injection pad trainers, provided more trainers to expand the number of students who can practice and be validated by faculty on skills. The collaboration resulted in a better design of the trainer for more efficient drainage and airflow, making cleanup easier and the trainer more proficient. The current 3D printed unit is still having difficulties with intradermal injections. The unit leaks (spits out) the liquid.

11. Suture Pad Trainer

The suture pad trainer (See Figure 7) is similar in design and fabrication to the above injection pad trainer. The Dragon Skin Fx-Pro was then poured into a mold. After curing, dishwasher liquid pods were inserted into the voids (bumps). Then another layer (fat layer) of Dragon Skin Fx-Pro was poured. Tendons are embedded into this layer. The tendons are strips of PLA filament that have been flattened. After curing another layer (muscle layer) of Dragon Skin Fx-Pro is then poured.

Color pigmentation was added during the mixing process before pouring. A flesh tone skin pigment was added to the skin layer, a yellow pigment was added to the fat layer and a red pigment was added to the muscle layer. The nursing faculty was actively involved in this process to represent the desired realism.

Figure 6. 3D printed injection pad trainer

The abscess is a raised area in the skin layer where an infection has developed. The students have to practice lancing and cleaning the abscess (the dishwasher pod). The students practice on stitching the wound when a tendon is involved and on avoiding the tendons when making an incision.

Figure 7. 3D printed suture pad trainer

12. Conclusions

In summary the following conclusions are made:

- The 3D printed units are being used to provide nursing students with much needed hands-on experience, allowing the students to practice specific skills in a safe environment. Multiple units have been printed to allow nursing students practice these skills in team.
- All the 3D printed parts have been added to the hands-on training of nursing students at UAH. Duplicate units have been printed to allow teams of nursing students to simultaneously use the units.
- The nursing faculty was actively involved in the entire 3D printing process to assure the objects satisfied their training requirements. This collaboration assured desired texture, elasticity, density, strength, color and realism.
- The Thingiverse website is a design community for sharing user created digital design files for 3D printers. Several of the trainers were obtained through Thingiverse. The design files were modified to satisfy the nursing faculty training requirements.
- Through a number of versions of the 3D printed cricothyrotomy units it was possible to find a unit that the nursing faculty stated had the ideal strength and texture.
- The 3D printed onychectomy units have been a challenge to fabricate, requiring multiple versions and technologies including pattern making, mold making and material pouring. Simulating skin is still an ongoing problem.
- The wrist splints/braces and finger splints were relative easy to 3D print and have a number of training applications.
- 3D printing improved the longevity of the injection pad trainers and provided more trainers to expand the number of students who can practice and be validated by faculty on skills. The collaboration resulted in a better design of the trainer for more efficient drainage and airflow, making cleanup easier and the trainer more proficient.
- All the 3D training simulations were printed at a cost that was considerable less than purchasing similar items commercially. More importantly, with 3D printing it was possible to customize the units to satisfied nursing faculty training requirements. A problem still exists in liquid leakage.
- In addition to the lower cost, the 3D trainers could be printed rapidly.

The success to date in satisfying the nursing faculty requirements has lead to a number of other 3D printed projects. As a result of this relationship, the Systems Management and Production Center has installed a 3D printer in the College of Nursing for both faculty and student use.

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