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Achieving realism in women's health simulation with silicone rubber labia majora augmented with an anatomically correct uterus: An enhanced training experience for nursing students

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Abstract
This paper presents the development of 1) a realistic labia (majora and minora) overlay on a pelvic simulator and 2) a supporting realistic uterus trainer for enhanced training of nursing students in the College of Nursing at the University of Alabama in Huntsville. Dragon Skin silicone rubber with the addition of Slacker gave the material a flesh-like texture. The design goals of realism and anatomical correctness were met. The material costs for one labia assembly was $24, while the uterus with a cover was $46. Anatomical uterine models were used for enhanced classroom learning. The labia patches were used in clinical simulation to promote accurate, safe, and respectful perineal care and insertion of urinary catheters in maternity patients. Faculty noted enhanced student performance in the clinical setting after students used the labia patches in pre-clinical simulations and skills. The pelvic simulators with labia patch overlay were also used in a skills lab at a local hospital. The feedback consisted of 1) realistic density and feel, 2) durability with no signs of tearing or damage and 3) straps that secured the overlay with no sliding or movement. In summary, the flesh-like texture and anatomical correctness of the labial assembly greatly enhanced the realism of the pelvic exam simulator. Likewise, the flesh texture of the uterus provided a valuable supplement to the in-class training.

Keywords: pelvic exam simulator, labia majora, labia minora, uterus, 3D printing

1. Introduction

Physical examination is an essential component of patient care and instrumental in generating diagnostic cues (Mealie etal, 2022). Visual inspection is a vital first step in this process allowing healthcare providers to assess patients for pathology and to aid in the identification of landmarks before initiating palpation, auscultation, percussion, and clinical procedures. In women's health, visual inspection of the perineum is an important component of assessment. A pelvic examination includes an evaluation of the external and internal genitalia and the pelvic organs. Along with the visual inspection, a speculum exam is performed to evaluate the internal genitalia and collect a Pap smear (O'Laughlin etal, 2021).

Insertion of a urinary catheter is a common clinical procedure performed by trained clinicians to empty the bladder or to collect urine specimens through insertion of a soft and flexible catheter into the urethral meatus (Feneley etal, 2015). This clinical skill is introduced early in nursing clinical experiences to ensure mastery upon program completion. However, due to the inconsistent nature of clinical opportunities in the hospital setting, simulations reassure students of equitable clinical experiences and can enhance competence in a safe and controlled setting (Koukourikos etal, 2021). Specific to maternity nursing, students need to be aware of anatomical variances to the perineum and pelvic area due to trauma and physiologic changes during the intrapartum and postpartum settings. Failure to recognize these changes may impact a student's ability to identify landmarks for accurate and safe insertion of a urinary catheter. Additionally, poor insertion technique and management of a urinary catheter can contribute to CAUTIs: Catheter-associated Urinary Infections. CAUTIs are a leading cause of hospital-acquired infections. Failure to properly clean the perineum and areas proximal to the urethra contributes to the risk of causing CAUTIs (Chuang etal, 2021). Providing students standardized opportunities to visualize and accurately identify the labia majora, labia minora, clitoris, and urinary meatus in a simulated setting can promote clinical accuracy and safety in the skill of inserting urinary catheters and in delivering perineal care.

Simulation can be defined as "obtaining the essence of without the reality of." Enhanced reality is now being added to simulation. Healthcare simulations are becoming more real. As an example, nursing schools now have multi-bed hospital labs that are equipped with human patient simulators that can simulate various body functions. Wearable headsets can project a video in a student's field of view. The video combined with real visual images and cues seen in real patients can create a sense of realism. Silicone makeup appliances and skin effects are adding movie-grade effects in simulation trainers. A variety of realistic wounds such as bullet entry and exit, knife wounds, abrasions, and bruises can be simulated for nursing student training and mass casualty incident training.

Nursing student education has shifted from the traditional approach of lectures and teaching on patients in a clinical setting to a simulation-enhanced education. This is especially true in patient care associated with perineal procedures and pelvic examinations where ensuring similar clinical experiences for all students may be difficult. Kiesel etal (2022) have developed a virtual model that shows selected structures of the female pelvis to enhance student learning.

Holubar etal (2021) have developed a virtual anatomy and surgery simulator for teaching pelvic surgical anatomy. The simulator also included 3D printed models. Student feedback stated that the training simulator was an efficient adjunct to medical education and surgical planning. Mazurkiewicz etal (2016) have developed a curriculum module for teaching internal medicine residents how to perform breast and pelvic exams. Sixty-six residents have completed the module. Student comfort, confidence and intention to perform breast and pelvic exams increased.

Gynecological Teaching Associates (GTAs) are individuals trained to instruct health-care professional how to use their own bodies to conduct accurate, patient-centered breast and pelvic examinations. Hopkins etal (2021) reviewed over a hundred articles and reported that the use of GTAs resulted in improvements in technical skills and communication skills. Seago etal (2023) concluded that medical simulations are educationally effective and simulation based education complements medical education in patient care settings.

Lous etal (2023) reviewed nineteen studies of pelvic examination that utilize simulation. Their review showed that learning pelvic examination through simulation-enhanced education resulted in a significant benefit as compared with classical learning without simulation. Simulation improved student skills and student comfort and student communication with the patient. Pugh etal (2009) studied the benefits of mannequin trainers when preparing students to interact with teaching associates. The authors suggested that mannequin-based simulators be used before students had learning experience with pelvic exam teaching associates.

There are a number of challenges involved in the development of pelvic trainers. One challenge is anatomical correctness. Generally rigid plastic is used for the anatomical structures with symmetrical and unrealistic vaginal openings. Another challenge is realism. The term is often used in art and literature to represent events and social conditions as they actually exist without idealization. There is generally concern for the actual, or real, as distinguished from the abstract or speculative. Several characteristics that are often used for the comparison of a thing with an actual thing are shape, color, feel, weight and surface texture. A third challenge in the development of a pelvic trainer is cost effectiveness since pelvic exam trainers are expensive.

The College of Nursing (CoN) and the Systems Management and Production (SMAP) Center have been working for several years to develop a variety of trainers and simulators. Several of these trainers include a lumbar puncture trainer (Black-Mead etal, 2023) and a computer simulation of endobronchial valves in bronchial airways (Lakin etal, 2023). In addition, a variety of "patches" have been developed to extend the life of the College's commercially purchased simulators, including a replacement chest drain pad for a chest tube and needle decompression trainer (Deason etal, 2022), as well as patches to cover needle holes on a central venous catheterization trainer (Moeller etal, 2022).

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. At the beginning of the project, the team defines the problem and establishes the design requirements. The team meets throughout the project for feedback from the nursing faculty and to ensure that the project goals are being satisfied. Prototypes are often made for testing and evaluation.

Specifically in the maternity course in this baccalaureate nursing program, faculty noted that students were hesitant and insecure in implementing the skills of perineal care and insertion of urinary catheters for a clinical setting. This hesitation caused delays in care and a sense of insecurity and anxiety as expressed by students. Furthermore, students verbalized a degree of unfamiliarity and discomfort with procedures associated with genitals and specifically, genitals impacted by hormones of pregnancy and labor-related trauma. They expressed that the perineal anatomy of simulators did not prepare them for real-patient clinical experiences. Faculty acknowledged that the existing pelvic models used for skill practice were not anatomically correct and did not provide students the opportunity to identify or manipulate perineal landmarks during simulations in preparation for patient care. Though faculty sought anatomically correct perineal trainers for clinical skills and simulations, none were found to meet the goals of this maternity faculty team. Interprofessional collaboration between the maternity faculty team and the SMAP center focused on the design and manufacturing of a pelvic patch to promote student readiness for clinical practice.

The research objective of this project was to develop 1) a realistic labia (majora and minora) overlay for the pelvic trainer in clinical simulation and 2) a realistic uterus model to augment classroom learning, while at the same time assuring anatomical correctness and maintaining minimal cost.

The models were used for enhanced training of nursing students enrolled in the maternity nursing course in the College of Nursing at the University of Alabama in Huntsville. Included in this paper are the design requirements, a detailed description of each model, the integration of the models with an existing pelvic exam trainer, and the use of the models in the training of nursing practitioner students.

2. Materials and Methods

Two 3D printers were used: 1) Prusa-i3 MK3S with PLA (polylactic acid) filament with a build volume of 25x21x21cm and 2) Elegoo Saturn2 3D resin printer with a build volume of 19.2x12x20cm. Resin printers use a photo-curing UV (ultraviolet) resin as the print medium. The 3D scanner was an Einscan SP-V1 with a fixed scan volume of 20x20x20cm and a stand volume with a tripod of 120x120x120cm.

A variety of software was used, including: 1) Autodesk Fusion360: a computer-aided design software, 2) Blender: an open source 3D computer graphics software toolset, 3) Einscan: a 3D scanning software, and 4) PrusaSlicer: a segmentation and cleanup software.

The pelvic exam trainers were Life/Form Nasco Catheterization Simulators. In addition, the simulators are useful for anatomical identification and perineal care training.

The molds and cast parts were made with Dragon Skin FX-Pro silicone rubber (Smooth-On, 2023). Dragon Skin is a soft, stable and high-performance silicone rubber designed for creating silicone makeup appliances and skin effects. Smooth-on Slacker (PartS) was added to change the feel of the silicone rubber to a softer and more flesh-like material. This addition also alters the rebound properties of the silicone rubber, making it feel more like human tissue.

The formulation of the cast labia majora, labia minora, and uterus was 1 PartA, 1 PartB, and 0.75 PartS (Slacker). The high ratio of Slacker made the silicone rubber very soft and flexible.

A flesh-tone Silc-Pig silicone pigment from Smooth-On was added to the mixture. A red Silc-Pig was added to the uterus, fallopian tubes, and ligaments. A yellow pigment was added to the ovaries. The formulation of the molds was 1 PartA, 1 PartB, and 0.5 PartS to give more firmness. Approximately two pounds of modeling clay were used to add more detail to the patterns.

The design requirements for the labia majora and labia minora were as follows:

- Flesh texture and color that included ethnically diverse tones.
- Realistic contour that was possibly more pronounced to simulate the augmented perineal anatomy of a pregnant woman.
- Layered labia minora with clitoris.
- Movable labia majora and minora that provided students an opportunity to manipulate them for required cleansing and

displacement before insertion of urinary catheter
- Flexibility that fits snuggly over and attaches to the existing pelvic exam trainer torso.

Seven initial designs of the labia majora were 3D printed. A razor-blade scraper was used to add more realism and to remove the ridges between printed layers, resulting in a smooth contour. After discussions, the maternity faculty at the College of Nursing requested that the labia majora be more pronounced to simulate a pregnant woman's altered perineal anatomy. Therefore, the height at the center of the labia majora increased from 12mm to 22mm.

Three more designs (patterns) were made with the cross-section that measured 22mm height (as seen in Figure 1). Figure 2 shows the mold box which was made with Legos and the PLA printed pattern. The plywood base supporting the pattern is 21.59x12.70x0.95inches. Figure 2 also shows the labia majora silicone rubber mold. Figure 3 shows the finished cast labia majora made with silicone rubber.

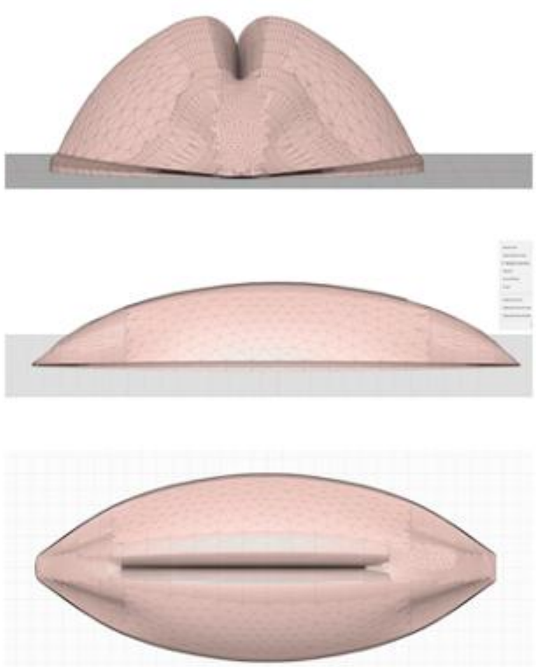

Figure 1. Cross-section of selected design S-3.

Figure 2. Labia majora PLA pattern in mold box (left) and completed silicone rubber mold (right).

Figure 3. Finished silicone rubber cast of labia majora.

The labia minora consisted of casting several large 1-2mm thick silicone rubber patches that were approximately six inches in diameter. The silicone rubber was allowed to flow freely on a waxed paper plate, thus giving a taper to the perimeter of the patch.

Figure 4 shows the two-part 3D printed mold for casting the clitoris. A long cut was made in the labia majora. The labia minora was sliced in half and fastened to the inside walls of the cut with Sil-Poxy. The silicone rubber patch also formed the hood that was wrapped around the clitoris and installed between the layers of the sliced labia minora.

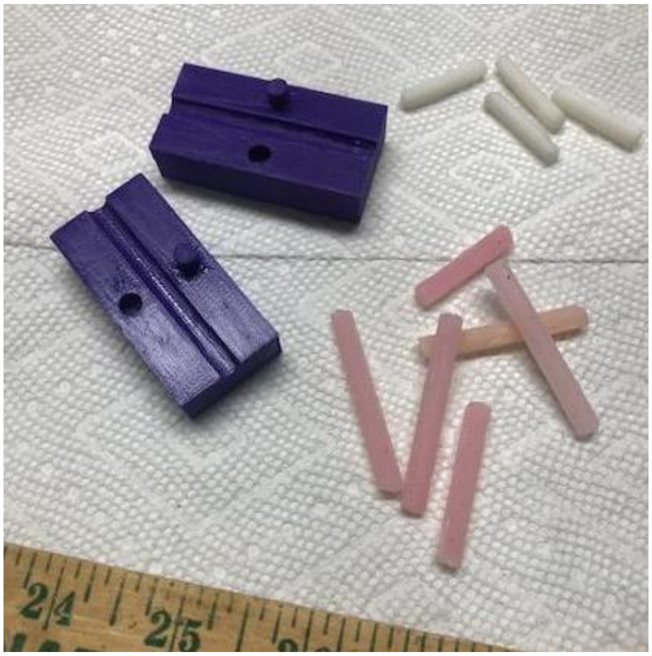

Figure 4. Clitoris two part mold box (left) and silicone rubber castings (right).

The design requirements for the uterus assembly were as follows:

- Flesh-like feel and color.
- Full scale.
- Small hole through fallopian tube to insert simulated egg. Hole should extend into the uterus.
- Ability to attach or insert simulated masses, such as uterine fibroids and cancerous tumors.
- Uterus top cover to match the bottom half of the uterus.

An STL file of the uterus was obtained from Thingiverse (2023) and developed by Amy Stenzel. The steps in constructing the silicone rubber from the initial STL file were as follows:

- Step1: Use Fusion360 software to scale the uterus that is anatomically correct and closely corresponds to the mean dimensions of the uterus in an adult female (10-12cm in length, external diameter from 5-15mm (Cleveland Clinic, 2023) and an internal diameter of 1-4mm (Jones etal, 2023).
- Step2: Use Fusion360 software to segment the model into the following submodels (patterns): uterus, right and left ovaries and right and left fallopian tubes. Then create STL files.
- Step3: 3D print uterus, ovary and fallopian tube submodels using resin printer (Figure 5). Modeling clay was added for additional anatomical features for the uterus pattern.
- Step4: Construct mold boxes for ovary and fallopian submodels, place the patterns in mold boxes and insert a 1/8 inch dowel in the fallopian mold box to make a hole (Figure 7).
- Step 5: Pour the Dragon Skin into mold boxes and let them cure. Then remove patterns resulting in Dragon Skin molds (Figures 6 and 7).
- Step6. Use Fusion360 and PrusaSlicer software to design and 3D print a two part mold for the ligaments, inserting a 1/8 inch dowel as assembly holes (Figure 7).
- Step 7. Cast uterus, ovaries, fallopian tubes and ligaments in Dragon Skin (Figure 7). Dowel rods were inserted for the assembly.

Figure 5. 3D printed patterns of uterus, ovary and fallopian tube.

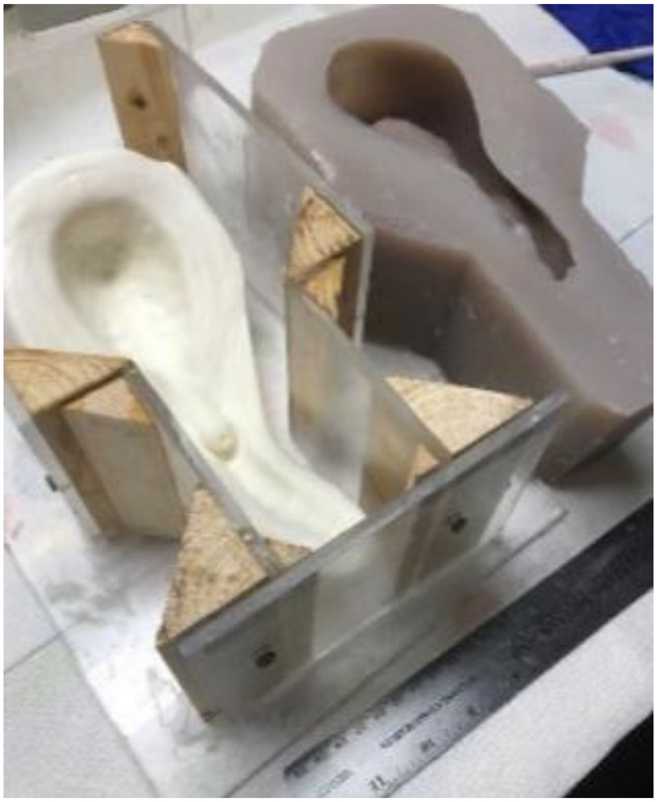

Figure 6. Uterus pattern in mold box (left) and finished silicone rubber mold (right).

Figure 7. Molds (left) and cast parts (right) of ovary, fallopian tube and ligament.

The model in Figure 5 only includes the lower half of the uterus. A thick uterine wall (muscle) surrounds the uterus and consists of three layers: endometrium (inner), myometrium (middle thick muscle layer) and perimetrium (outer). The steps in constructing the uterus cover were:

- Step1: Place a plastic egg in the 3D printed model of the uterus and use modeling clay to sculpt the cover (Figure 8 left model).
- Step2: 3D scanner (with Einscan software) to scan the sculpted model and create a STL file.
- Step3: Fusion360 software to segment a thin cover shell and PrusaSlicer software to edit the cover and create a new STL file.
- Step4: 3D print in resin the cover as a hollow shell (Figure 8 center mold).
- Step5: Modeling clay to fill in shell to correspond with the uterine walls (Figure 8 right model).
- Step6: Cast a silicone rubber mold of the cover in uterus mold box.
- Step7: Cast cover in Dragon Skin silicone rubber (Figure 11).

Figure 8. Clay model cover for 3D printed uterus (left), segmented cover shell (middle) and shell cover filled with modeling clay (right) .

3. Results and Discussion

Figure 9 is the final assembly of the labia assembly attached to the pelvic simulator. Bungee cord was stretched around the torso and connected to alligator clips which were connected to the labia majora. A surgical cover is generally draped over the simulator. Figure 10 is a close-up of the clitoris/hood installed between the labia minor and labia majora. Figure 11 is the final assembly of the uterus with the cover. Ultimately the torso's abdomen was dressed with a standard gown and students visualized the perineal surface for clinical care without noting the attachment features.

Figure 9. Final assembly of labia majora and labia minora attached to pelvic trainer.

Figure 10. Closeup of the labia minora inside the labia majora showing the clitoris (upper right).

Figure 11. Final assembly of uterus (left) with cover removed (right).

A thick uterine wall (muscle) surrounds the uterus and consists of three layers, endometrium (inner), myometrium (middle thick muscle layer) and perimetrium (outer). Uterine fibroids are abnormal growths that develop inside the uterus, within the uterine middle myometrium muscle layer and in the endometrium and perimetrium walls of the uterus. These growths are generally non cancerous and can range from the size of a small pea to the size of a lemon. Uterine fibroids can even grow to the size of a grapefruit.

Gynecological cancer is a disease in which cells in a woman's reproductive organs grow out of control. The five main types of gynecological cancer are cervical, ovarian, uterine, vaginal and vulvar. These growths are harder than noncancerous uterine fibroids growths.

A variety of masses in various shapes, sizes and colors were 3D printed and cast in Dragon Skin silicone rubber. The masses were installed with Sil-Poxy. Cuts were also made in the uterus and the growths were inserted in these cuts. Dowels were installed in some of the masses and inserted in the cuts as well. Figure 12 shows some of the masses.

Figure 12. Installation of masses in uterus bottom (left) and uterus cover (right).

Table 1 lists the cost of materials to fabricate the trainers. The costs of the prototypes are not included. The cost of Dragon Skin silicone rubber is approximately $1.20/ounce, while the PLA filament is $0.04/g. The materials for the molds were $47 and $165 for the labia majora/labia minora and the uterus, respectively. All the molds are reusable. The recurring material costs were $21 and $46 to fabricate one labia majora/minora assembly and one uterus with a cover, respectively. The bungee cords and alligator clips were an additional $6.

After using the pelvic exam simulators a labia assembly was installed on a custom 3D printed base for use by the CoN faculty during lectures. The PLA (480ml) to print the base cost $19, while the cost of the labia assembly was $46 for a total of $65. Four labia assemblies and four uteruses were fabricated.

Table 1. Materials.

	One-time mold cost		Recurring cost
	PLA	Silicone rubber	silicone rubber
Pelvic exam simulator			
Labia majora			
Printed pattern	160g		
Silicone rubber mold		1,000ml	
Silicone rubber cast part			500ml
Labia minora and clitoris			
Silicone rubber labia minora patch			20ml
Printed clitoris mold	10g		
Silicone rubber clitoris			15ml
TOTAL	170g	1,000ml	535ml
Uterus trainer			
Uterus			
Printed pattern	125g		
Silicone rubber mold		2,000ml	
Silicone rubber cast part			700ml
Uterus cover			
Printed pattern	150g		
Silicone rubber mold		1,800ml	
Silicone rubber cast part			400ml
Ovary			
Printed pattern	10g		
Silicone rubber mold		85ml	
Silicone rubber cast part(2)			15ml
Fallopian tube			
Printed pattern	10g		
Silicone rubber mold		225ml	
Silicone rubber cast part(2)			20ml
Ligament			
Printed mold	10g		
Silicone rubber cast part(2)			20ml
TOTAL	305g	4,110ml	1,155ml

There were several significant challenges in the fabrication of the trainers. The most significant challenge was designing the contour of the labia majora. Considerable hand finishing was needed to smooth the contour surface and obtain the desired detail.

Another challenge was the amount of PartS Slacker added to the mixture in order to obtain the desired flesh-like feel. Several mixture ratios were evaluated before selecting 1 PartA, 1 PartB and 0.75 PartS. The insertion of the labia minora and clitoris inside the labia majora was also a challenge.

A third challenge was adding modeling clay to build up the exterior of the uterine wall which could not be easily done using the design software. A minor challenge was the assembly of the ovaries, fallopian tubes, and ligaments since the silicone rubber was very flexible. Slices were made at the ends of the parts. Small dowel rods were inserted at the ends of each part. Sil-Poxy was used to adhere these parts together.

4. Conclusions

With the addition of the labia assemblies and uterus trainers the following procedures are now being taught to nursing students:

- Respectful and accurate delivery of care associated with:
  - Cleansing of the perineal structures
  - Manipulation of the labia majora and minora
  - Accurate identification of perineal landmarks

- Timely and accurate insertion of a urinary catheter
- Prevention of complications (CAUTIs)

Though the uterine models have been used for enhanced anatomical learning in the classroom setting, the pelvic trainers with the labial patches have been used as a pre-clinical skills simulation for all senior students enrolled in the maternity course. Simulated experiences were implemented in the Simulation, Learning, and Innovation Center of the CoN. Faculty modeled proper manipulation of external genitalia during the cleansing and insertion of a urinary catheter. Then each student received a catheter kit for practicing and insertion into the pelvic trainer. Each pelvic trainer was placed on a disposable pad. The torso was then draped with a patient gown and placed on a patient bed or exam table while students proceeded to perform the skill of providing respectful and safe care to the maternity patient in need of catheterization. Students unable to accurately complete the task received additional personalized teaching and mentoring followed by further opportunities to perform the required clinical skill. All students successfully met the goals of a respectful and accurate delivery of care associated with insertion of a urinary catheter before providing the same care to real-life patients at the hospital.

Faculty comments regarding the labia patches were:

- Provided realistic anatomical structures for student learning.
- Structures were clearly defined: labia majora, labia minora andclitoris.
- Provided a safe and professional opportunity for students to engage in care associated with a commonly-stigmatized aspect of female anatomy.
- Defined and realistic anatomical structures promoted correct manipulation and access to the urinary meatus.
- As a result of simulated patient care with the labia patches, students are more confident performing care associated with perineal structures while in the hospital setting.
- Students exhibit an understanding of the anatomical layering that requires displacement to access the urinary meatus as evidenced by correct and respectful manipulation of the labia majora and minora.
- Students seem to be more confident in the delivery of care associated with perineal structures.
- Positive perception of the realistic aspects of the trainers was expressed by faculty.
- Because of the variance in tinting of dragon skin, students had exposure to ethnically diverse patient care opportunities.
- Cost-saving was beneficial since the purchase of a new simulator was not needed.

Informal overall student comments were:

- Appreciation for the opportunity to practice a skill before performing it in a clinical setting.
- Labia patches were very life-like and added to the realness of the simulated experience.
- Realistic anatomical structures helped them learn correct manipulation of anatomy and how to access the urinary meatus.
- Felt less anxiety performing catheterizations in the clinical setting.

Additionally, a local hospital used two of the pelvic trainers at a skills fair with approximately 120 nurses participating. The trainers were used to perform catheterizations with the urinary catheter. Comments regarding the labia patches were based on these premises:

- The overlay created a more realistic density and feel when compared to the rigid mannequin alone.
- The overlay was durable. After four days of use there were no signs of tearing or damage.
- The straps properly secured the overlay. There was no unexpected sliding or movement.
- Nurses described it as a very realistic experience. They stated that these patches were very relevant to postpartum care and female patients with issues of edema and fluid retention

The flesh-like texture of the labia assembly greatly enhanced the realism of the pelvic exam simulator. Likewise, the flesh-like texture of the uterus provided a valuable supplement to the in-classroom teaching. An egg was easily inserted in the fallopian tube to simulate the release of a mature egg from an ovary and also aided in teaching about ectopic or tubal pregnancies. Fibroids and cancerous tumors were easily attached or inserted in cuts within the silicone rubber endometrium for enhanced learning of uterine pathology. The recurring material costs to fabricate one labia assembly was $24 and $46 for the uterus. The bungee cords and alligator clips were an additional $6. The labia assembly on the PLA base was $63.

In conclusion, the collaboration between the maternity faculty team and the SMAP group resulted in products that helped enhance faculty teaching efforts and promoted student learning as well in a performance of safe and respectful delivery of care. The collaboration between the CoN and hospital educators in sharing training equipment provided opportunities for partnerships and enhanced relationships between the two organizations.

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