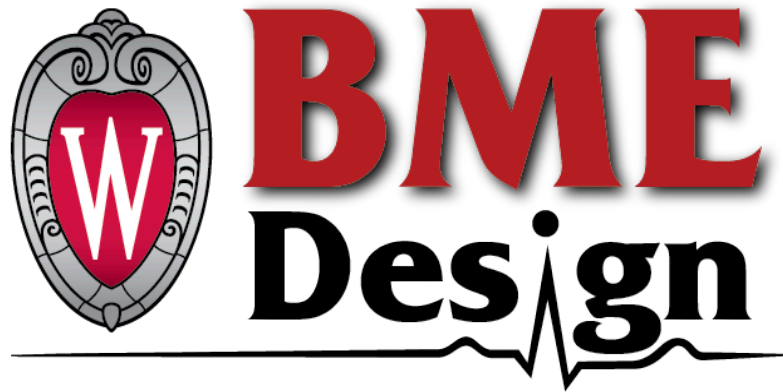




REUSABLE 3D PELVIC FLOOR TEACHING MODEL FOR LAYERED CONSTRUCTION ACTIVITIES

PRELIMINARY REPORT

Fall 2026 BME 200/300 Lab 307

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Abstract

The current Physician Assistant anatomy curriculum uses a two-dimensional paper template to teach pelvic floor anatomy, requiring students to construct musculature and tissues using Play-Doh [1]. However, the 2D model does not adequately demonstrate the three-dimensional spatial relationships needed for future clinical practice. Existing pelvic anatomy models are often expensive and typically have pre-constructed musculature, limiting hands-on learning [2]. To address this, our solution is a reusable 3D pelvic floor teaching model that provides an anatomically accurate scaffold for students to construct pelvic floor musculature layer-by-layer using Play-Doh. The model will include important anatomical landmarks, a surface coating to improve Play-Doh adhesion, and a lightweight, durable design suitable for repeated classroom use. The design will accommodate both male and female pelvic floor configurations while remaining portable and easy to clean. The final model will be evaluated for durability, stability, Play-Doh adhesion, anatomical accuracy, and ease of use. Mechanical testing will evaluate the durability of the prototype's key components. The TPU diaphragm and ligaments will undergo compressive and tensile loading to check for permanent deformation, and the rivets will be tested under shear and tensile loading. These future testing results will determine whether the prototype meets the client's requirements for a durable, reusable, and cost-effective classroom teaching tool.

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Introduction

Pelvic floor anatomy is an important component of healthcare education because of the complex relationships between the muscles, ligaments, and bony structures that make up the pelvic floor. Developing an understanding of these three-dimensional relationships can be difficult using traditional two-dimensional anatomical diagrams alone. A 2025 study demonstrated that students benefited when using a 3D-printed pelvis model as a supplemental tool for teaching pelvic anatomy [3]. The current UW–Madison Physician Assistant anatomy workshop uses a two-dimensional paper template of the bony pelvis, on which students build pelvic floor musculature and tissues using Play-Doh [1]. While this provides a hands-on learning experience, the 2D model does not adequately represent the three-dimensional spatial relationships needed to understand pelvic floor anatomy. Existing 3D pelvic models are also often expensive or have pre-constructed musculature, limiting students' ability to actively build and explore the anatomy [2]. Therefore, an affordable, reusable 3D pelvic model could provide students with a more interactive way to develop their understanding of pelvic floor anatomy.

Background

Physiology and Biology

Our project required extensive research on the anatomy of the pelvis and perineum to ensure an anatomically accurate model that rising Physician Assistants can use as an effective learning tool. The bony pelvis consists of the sacrum, coccyx, and two hip bones, both of which are formed by the fusion of the ilium, ischium, and pubis during childhood development [4] . Paired sacroiliac synovial joints connect each hip bone, or ilium, to the sacrum, the pubic

symphysis, a cartilaginous joint, connects the left and right pubic bones, and the sacrococcygeal joint connects the sacrum to the coccyx [5]. The average transverse and anteroposterior diameters are 13 and 12 cm for the pelvic inlet and 11 and 12.5 cm for the pelvic outlet, respectively [6]. The primary distinction between a male and female pelvis is shown through the differences of the bony pelvis. The female pelvic outlet is larger, with longer pubic bones, making the subpubic angle greater than males, and the sacrum is flatter and tipped more posteriorly [2]. Female subpubic angles typically range from 90° to an obtuse angle, whereas male subpubic angles are classified as acute [7].

Pelvic floor muscles contribute to closure and control of the anal canal, urethra, and vagina and support major internal organs, such as the bowel, bladder, and uterus in females [8]. The urogenital diaphragm is a strong, muscular membrane that occupies the area between the symphysis pubis and ischial tuberosities and stretches across the triangular anterior portion of the pelvic outlet [8]. The perineum consists of a layered musculature, including the urogenital sphincter muscles in the deep perineal space, vessels supplying blood to perineal structures and membrane, erectile tissues that adhere to the surface of the perineal membrane, and skeletal muscles that cover the erectile tissue, perineal body, and external anal sphincter [2].

The major artery that supplies the perineum is heavily highlighted in the Pelvis and Perineum Workshop [1]. The internal pudendal artery, as well as the pudendal nerve, travel together, exiting the pelvis through the greater sciatic foramen, around the sacrospinous ligament, and into the perineum through the lesser sciatic foramen, then finally giving out branches to the perineal structures. The inferior rectal artery is the first branch of the internal pudendal artery, followed by the perineal branches to the skin and muscles of the perineum.

Finally, the terminal branch of the internal pudendal artery is the dorsal artery of the penis or clitoris [2].

The bony pelvis also has major anatomical landmarks. The iliac crests are the curved, superior-most edges of the ilium. The anterior superior iliac spine (ASIS) is the bony protuberance at the front of the iliac crest and serves as an attachment point for the sartorius muscle and inguinal ligament. The anterior inferior iliac spine (AIIS) is a small, bony prominence below ASIS that anchors the rectus femoris muscle. The posterior superior iliac spine (PSIS) marks the location of the sacroiliac joint and often appears as dimples in the lower back. Finally, landmarks of the ischium include the ischial tuberosity, the thick, lowermost part of the ischium commonly known as the “sit bones,” and the ischial spines, which are small, bony, inward projections of the ischium on either side [6].

Client Information

The clients, Kelsey Henriquez and Sarah Traynor, are faculty members in the Physician Assistant Program at the University of Wisconsin School of Medicine and Public Health (SMPH). They lead a workshop that teaches physician assistant students the anatomy of the pelvis and its surrounding musculature, using visual and hands-on aids to support learning.

Previous and Competing Designs

Currently, the client alternates between two options to support their workshop: an oversimplified 2D paper drawing of the pelvis and a bulky, expensive, medical-grade anatomical pelvis model [1], [9]. Several existing designs have the potential to better support the client's workshop goals, as outlined below.

“The 3D Pelvic Floor - Nature” is a handmade wool-felt model priced at €195 that represents three layers of pelvic floor musculature, the coccyx, soft tissue bridge, and three pelvic organs: the bladder, uterus, and rectum [10]. While it provides a tactile representation of pelvic anatomy, the pre-cut musculature limits students’ ability to actively construct and explore the anatomical structures, and its high cost may make it less accessible for classroom use. Our design builds on this concept by allowing students to mold and construct the pelvic floor muscles layer-by-layer, creating a more interactive and affordable learning experience.

The Medi-Cross Female Pelvic Floor Anatomy Model is a PVC model priced at £159, making it a costly option for classroom use [3]. While its removable organs help students visualize pelvic anatomy, the muscles are already constructed. Our design allows students to actively build the muscle layers, creating a more hands-on learning experience.

The Female Pelvis Skeleton Model is an anatomically accurate model priced at \$114, featuring the hip bones, sacrum, coccyx, lumbar vertebrae, and movable symphysis [11]. However, it includes more skeletal anatomy than needed for the scope of our pelvic floor workshop and is not designed for easy portability. Our design focuses specifically on the pelvic floor while being more compact and portable for classroom workshops.

Design Specifications

The product design specifications (PDS) outlines the design requirements for the Reusable 3D Pelvic Floor Teaching Model for Layered Construction Activities intended to improve normal anatomy education of the pelvis and perineum by replacing the current 2D paper model with a 3D model [Appendix A]. The design must be scaled to represent normal adult pelvic anatomy, include major anatomical landmarks, as well as support the construction of both female and male pelvic anatomy. At least 30 models are required, all of which must be compatible with Play-Doh, easy to clean, easily disassembled and reassembled to maximize transportation efficiency between classrooms, be durable enough to withstand repeated classroom use of at least 3 to 5 years, and provide sufficient structural support as students are constructing layers of Play-Doh. The size of each model should be that of an average human pelvis, representing an average female pelvic inlet transverse and anteroposterior diameters of 13 and 12 cm, respectively, and an average female pelvic outlet transverse and anteroposterior diameters of 11 and 12.5 cm, respectively [6]. Our models will represent a subpubic angle of approximately 85 degrees, an angle between the average female subpubic angle of 90 to 100 degrees and the average male subpubic angle of 50 to 80 degrees [12]. As for weight, each model should weigh approximately 4.45–8.90 N to ensure comfortable handling during hands-on learning activities. To maximize Play-Doh adhesion, cross-hatching, deep ridges, or score marks will be incorporated into the design where Play-Doh is intended to be attached in addition to a primer or sealant that will be added to each model, such as matte Mod Podge, that acts as a porous layer that the Play-Doh can grip onto [13]. Additionally, the target product cost is \$3-\$7 per model, with a total budget of \$100-\$200. Overall, the goal is to create an affordable, portable, and more effective learning tool for the students.

Preliminary Designs

Design 1: Surface Texture and Diaphragm Shelf

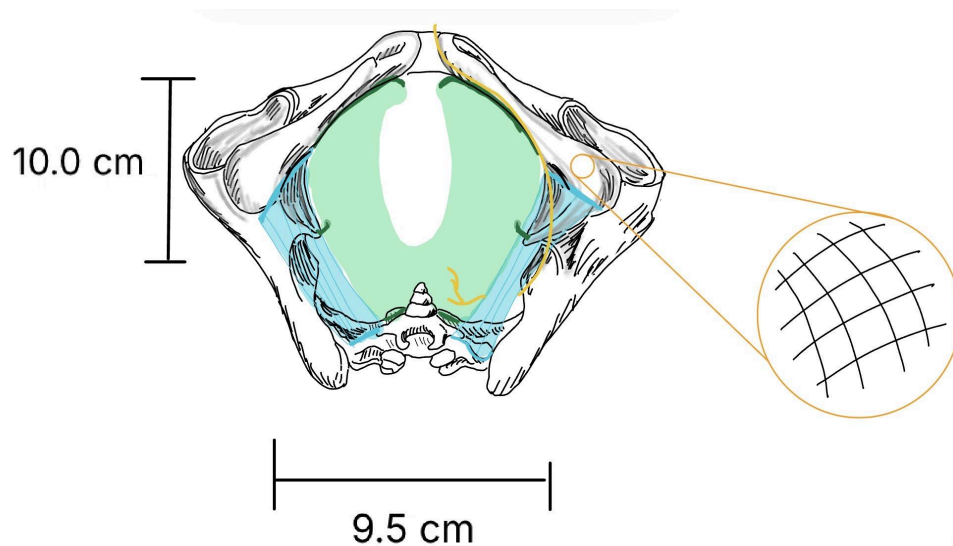


Figure 1: Sketch of 3D-printed pelvic framework featuring exterior surface scoring and a removable flexible diaphragm shelf with an insertion slot.

The Surface Texture and Diaphragm Shelf design features a 3D-printed pelvic framework engineered to withstand and support students building tissues made out of Play-Doh. The pelvis itself is a simplified model, removing the broad iliac crests while preserving core landmark anchors including the sacrum, coccyx, ischial tuberosities, and ischial spines to optimize access to the pelvic floor. All structures will be designed using the average anatomical dimensions of male and female pelvises, resulting in a gender-neutral, multi-piece pelvis model. To enhance Play-Doh and modeling clay adhesion during student builds, the outer surface of the framework includes a scoring texture across the exterior.

To facilitate layered tissue construction, the design incorporates a removable, flexible diaphragm shelf that locks into position using a slot-and-recess mechanism. The diaphragm features insertion points along the edge of the ischial tuberosities that allow it to click or slide directly into matching recesses on the model, anchored posteriorly near the coccyx. Additionally, sacrotuberous ligaments are integrated using a similar recession, enabling students to manually insert and snap them into place over the ischial spines. This removable diaphragm allows students to build individual pelvic floor muscles while providing a rigid structural shelf that prevents modeling materials from collapsing into the pelvic outlet during subsequent membrane builds.

Design 2: Foldable with Snap Buttons

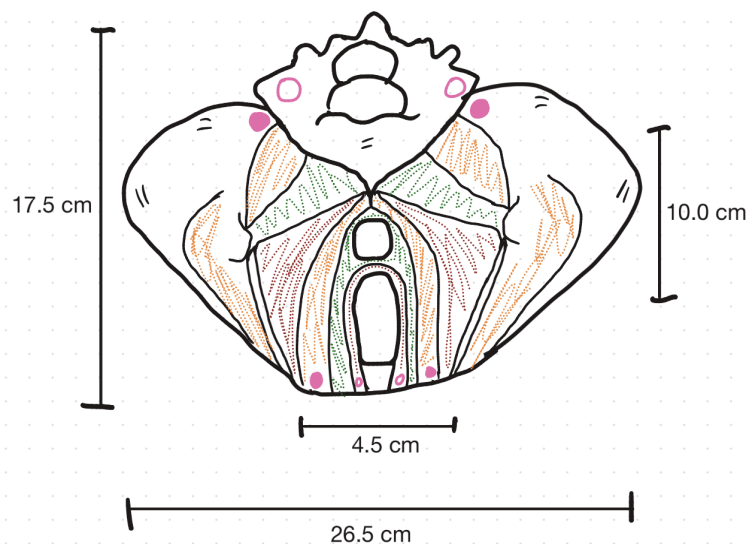


Figure 2: Sketch of polypropylene sheet pelvis design in assembled pelvic outlet setup

The Foldable with Snap Buttons design features a 3-D polypropylene pelvic outlet model engineered to provide an anatomically accurate framework for students to construct each layer of the pelvic floor using Play-Doh. The pelvic outlet model consists of a set of polypropylene sheets

that snap together with buttons to create a convex pelvic outlet. When separated, the individual polypropylene sheets lay flat and stack easily, aiding with storage and transportation between classrooms. When buttoned together, the polypropylene sheets create a 3-D pelvic outlet model that allows students to better understand pelvic floor anatomy through the workshop. The pelvic outlet is a simplified model, with no major 3-D forms other than the general pelvis shape. The polypropylene sheets are easily cleanable, waterproof, virtually tear-proof, handle clay and Play-Doh without staining or degradation, and fold without cracking [14]. The snap buttons are user friendly and need no special training to use.

Design 3: Pegs with Attachments

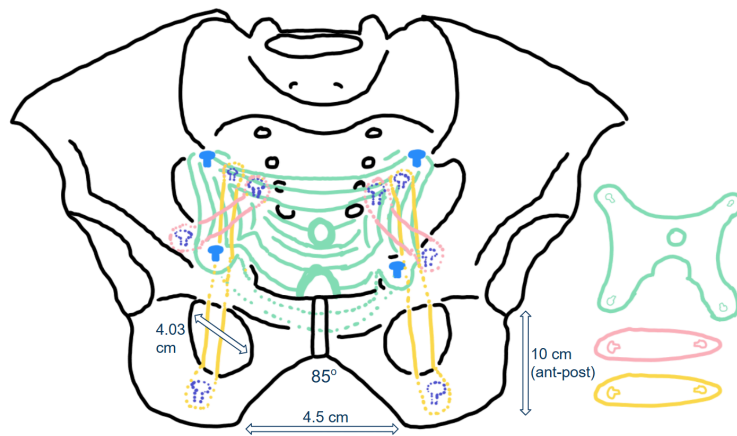


Figure 3: Sketch of 3D-printed pelvic frame with integrated mounting pegs, removable pelvic diaphragm, and flexible ligament attachments

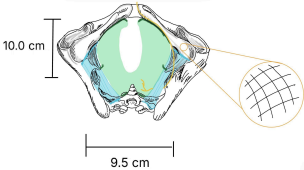
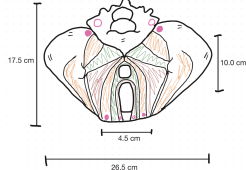
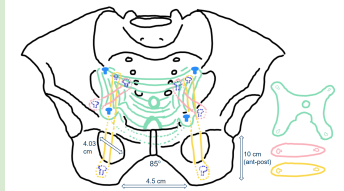
In the Pegs with Attachments design, there are 6 pieces total: a 3D printed pelvis, a flexible pelvic diaphragm, 2 flexible sacrospinous ligaments, and 2 sacrotuberous ligaments. The outer surface of the model will be coated with matte Mod Podge spray, allowing for better

Play-Doh adhesion onto the 3D printed surface [13]. The pelvis is a simplified model, with the iliac crest sections superior to the proximal end of the sacrum removed. To allow the attachment of the diaphragm and ligaments, there are pegs on the pelvis surface. The pegs have a thick base and a wider head for durability, and are 3D printed as one structure with the pelvis. Each of the flexible ligaments and diaphragm will have attachment holes at the ends with a wide and a narrow section to allow application and removal of the structures from the pegs. Finally, the diaphragm will be shaped like an 'X', with attachment sites at each corner, as well as an inlet and a hole to allow students to scaffold the male or female anatomy.

Preliminary Design Evaluation

Design Matrix

Table 1: Design Matrix Table for Preliminary Designs that judges three design options based on selected criteria.

		Design 1: Surface Texture and Diaphragm Shelf		Design 2: Foldable with Snap Buttons		Design 3: Pegs with Attachments	
							
Criteria	Weight	Score	Weighted Score	Score	Weighted Score	Score	Weighted Score
Play-Doh Adhesion	30	4/5	24	3/5	18	5/5	30
Longevity	20	4/5	16	2/5	8	3/5	12
Ease of Fabrication	15	3/5	9	2/5	6	3/5	9
Anatomical Accuracy	15	5/5	15	3/5	9	4/5	12
Cost-Effectiveness	10	3/5	6	5/5	10	3/5	6
Safety & Ease of Cleaning	10	3/5	6	4/5	8	5/5	10
Total	100	76/100		59/100		79/100	

Summary of Design Matrix

The evaluation criteria and how each design earned their score are as follows:

Play-Doh Adhesion (30%) – Adhesion carries the highest weight because constructing layered musculature without Play-Doh slipping is the model’s core educational requirement. Design 3 scored highest (5/5) because the full matte Mod Podge coating provides superior adhesion across

the whole surface. Design 1 scored 4/5 due to surface scoring, while Design 2 scored lowest (3/5) on smooth polypropylene.

Longevity (20%) – Longevity is weighted at 20% to ensure models withstand student grip forces up to approximately 487 N and possible drops from 0.75 m table height over 3-5 years in use [15]. Design 1 ranked highest (4/5) due to its one-piece, solid body lacking in weak connectivity points. Design 3 scored 3/5 due to potential peg breakage under repeated force, while Design 2 scored lowest (2/5) due to stress concentrations around and on the buttons.

Ease of Fabrication (15%) – Since 30 models must be produced efficiently within one semester, Ease of Fabrication is weighted at 15%. Designs 1 and 3 tied (3/5) as 3D printing offers high precision, although additional manual work (coating, production of attachments) is required. Design 2 scored lowest (2/5) due to extensive manual cutting, folding, and button assembly for each model.

Anatomical Accuracy (15%) – Accuracy is weighted at 15% to allow PA students to learn realistic 3D spatial relationships. Design 1 ranked highest (5/5) with detailed 3D landmarks, followed by Design 3 (4/5). Design 2 scored lowest (3/5) because flat polypropylene sheets simplify the complexity of 3D anatomical geometry.

Cost-Effectiveness (10%) – Cost effectiveness is weighted at 10% to stay within the \$3-\$7 per model budget (\$100-200 total). Design 2 scored highest (5/5) using inexpensive polypropylene

[14]. Designs 1 and 3 tied (3/5) because standard 3D printing filaments and additional materials (Mod Podge, flexible plastic material) slightly increase unit costs.

Safety & Ease of Cleaning (10%) – Models are handled by multiple students and must be cleaned between uses without trapping bacteria, so Safety and Ease of Cleaning are weighted 10%. Design 3 ranked highest (5/5) as its sealed surface prevents mold and permits easy cleaning. Design 2 scored 4/5, while Design 1 scored 3/5 due to clay lodging into textured surface grooves.

The winning design was Design 3: Pegs with Attachments, earning the highest overall score of 79/100. This design provides superior Play-Doh adhesion, strong anatomical accuracy, and easy cleaning due to its Mod Podge coating and modular attachments. Although Design 3 won based on the design matrix, the proposed final design will refine the pegs and their connectivity to resolve longevity concerns.

Proposed Final Design

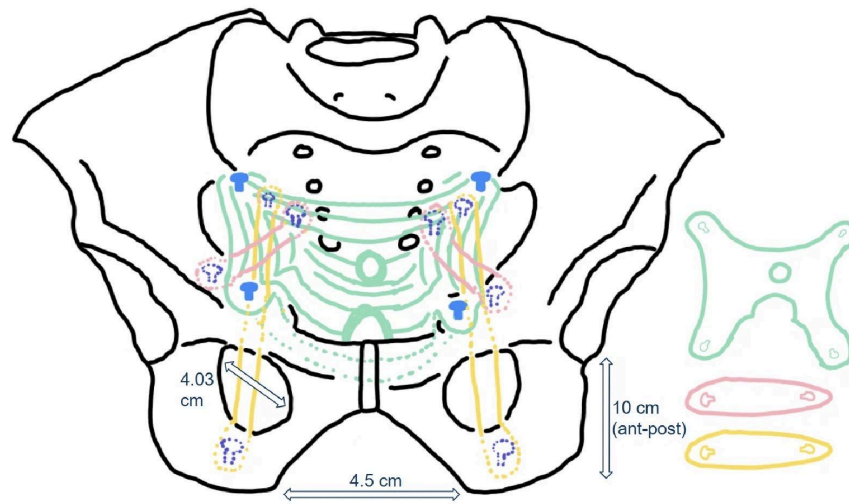


Figure 4: Final Design of Rivets with Attachments

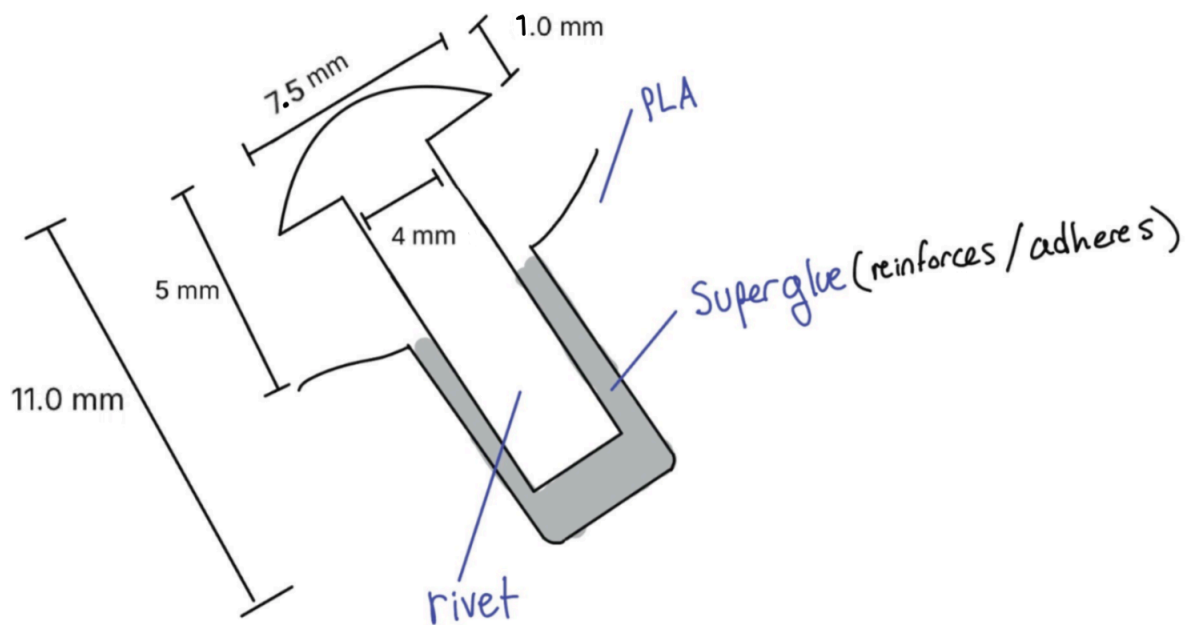


Figure 5: Detail of Rivet Modification with superglue used for adhesion and structural reinforcement of rivet

The proposed final design uses Design 3 as its foundation, consisting of a 3D-printed gender-neutral pelvic outlet model coated in matte Mod Podge spray. To address the lower longevity score, the attachment pegs will be replaced with metal semi-tubular rivets reinforced with adhesive to withstand repeated use without snapping under grip forces up to 487 N [15]. Each rivet features an exposed neck for removable attachments and a stem deeply embedded into a matching socket and secured with cyanoacrylate adhesive to distribute lateral loads and prevent failure (specific dimensions are detailed in the Fabrication section). The model maintains key landmarks—including ischial tuberosities, ischial spines, and distal sacrum—and features modular diaphragms and ligaments that snap onto the frame to enable layered anatomical construction of both the male and female pelvic floor.

Fabrication

Materials

Each pelvis model will contain 6 separate pieces: one polylactic acid (PLA) pelvic bone model, one thermoplastic polyurethane (TPU) pelvic diaphragm, two TPU sacrospinous ligaments, and two TPU sacrotuberous ligaments. The pelvic bone model will contain 12 holes, each containing an aluminum semi-tubular rivet, secured by adhesive glue, that will allow attachment of the ligaments and diaphragm (see Figure 5).

The bony portion of the pelvic outlet will utilize fused-filament 3D printed PLA [16]. 3D printed filament allows high anatomical accuracy, with the specific PLA filament having a tensile strength at break ranging from 33.1 ± 2.8 MPa in the Z direction to 56.0 ± 1.5 MPa in the YZ direction [16]. These high strength and durability properties are advantageous for the mechanical forces that the models will undergo during each workshop.

The pelvic diaphragm, sacrospinous, and sacrotuberous ligaments will be fabricated using 3D printed TPU, allowing flexibility and stretch for these structures. TPU has a 552% elongation at break along the XY axis, and 482% along the XZ axis [17]. Additionally, it has a tear strength of 84.6 N/mm, therefore maintaining structure during repeated stretching and bending [17].

The attachment pegs embedded in the pelvis model will be aluminum semi-tubular rivets. The rivet specifications are a 4 mm rivet shank diameter, 10 mm shank length, 7.5 mm head diameter, and 11 mm total length [18]. These rivets contain a hollow cavity in the center of their shanks, allowing the rivet to be installed in the PLA pelvis with less force, and creating space for the cyanoacrylate adhesive. The adhesive used will be Gorilla Super Glue Gel, which has an impact-tough and rubber-toughened formula to absorb drops and impacts, and is suitable for bonding plastic and metal [19].

The external surface will be coated in Matte Mod Podge. Mod Podge will create an exterior surface that enhances Play-Doh adhesion to the PLA pelvis. This sealant is a water-based, acrylic formula that allows the coating of plastic [13].

Methods

The team will obtain the female pelvis model STL file from the NIH 3D Print Exchange [20]. The STL file will then be imported into a computer-aided design (CAD) software, Solidworks, where it will be scaled to normal adult anatomical dimensions defined in the Background section and detailed in Appendix B: Fabrication Protocols [21].

The file will be further modified in CAD by adding holes and removing the iliac crests. Holes will be added at the designated attachment locations for the pelvic diaphragm, sacrospinous ligaments, and sacrotuberous ligaments. The holes will be sized slightly larger than

the attachment rivets, at 4.2 mm in diameter and 6.5 mm deep. The depth will provide approximately 5 mm of rivet extension beyond the hole while leaving additional space at the bottom of the hole for the cyanoacrylate adhesive. Around the holes, additional 3D printing filament will be added to strengthen the rivets attachments by increasing the infill at those locations. The iliac crests will also be removed at an angle that allows the completed pelvic outlet to sit flush against the table during the activity. The final pelvic bone models will be 3D printed using PLA on an Ultimaker 3D Printer [22].

After printing, the support material will be removed from each model and the print will be inspected for printing defects. The holes for the rivets will then be cleared of excess printing material. To attach the rivets, glue will first be placed into the designated holes, then rivets will be inserted into the holes until bottomed out. Finally, the external surface will be coated in a thin, uniform layer of Mod Podge Matte spray.

To create the pelvic diaphragm and ligaments, CAD models will be used to create the anatomical geometry and attachment points. The diaphragm and ligaments will be shaped as in Figure 4: Final Design of Rivets with Attachments. Separate CAD geometries will be created for the sacrospinous and sacrotuberous ligaments based on their anatomical lengths and attachment locations. The pelvic diaphragm and ligaments will then be 3D printed using TPU on Stratasys 3D Printers [23].

Testing and Results

MTS Machine Testing - Pelvic Diaphragm

The pelvic diaphragm's compressive strength will be tested using a MTS-Criterion C43 [24]. These tests will provide insight into the strength of the part, allowing the team to modify the design if performance expectations are not met. To replicate the maximum compressive stresses exerted by a standard human hand, the pelvic diaphragm will be tested with a compressive force of 487 Newtons [15]. The compression test will be performed three times each on two parts of the pelvic diaphragm: edge and center. After completing these tests, the design may be adjusted based on the results by increasing filament infill or considering alternative filaments.

MTS Machine Testing - Ligaments

The ligaments' tensile strength will be tested using a MTS-Criterion C43 [24]. These tests will provide insight into the tensile strength of the parts, allowing the team to modify the design if performance expectations are not met. To quantify the maximum forces the ligaments can withstand, they will be placed under tension until failure. This process will be repeated for 3 ligaments in order to identify the maximum forces that can be applied during use.

MTS Machine Testing - Attachment Rivets

The attachment rivets will undergo a tensile and shear stress test using a MTS-Criterion C43 [24]. These tests will provide insight into the strength of the rivets, allowing the team to modify the design if performance expectations are not met. Each of the rivets will undergo a tensile load until failure. The value obtained will then be compared to the maximum force from

the ligaments test to ensure that the rivets can withstand the ligament forces. The shear and tensile stress test will be performed three times each for three different rivets.

FEA Test in Solidworks to Find Stress Points

A Finite Element Analysis will be completed in Solidworks using the 3D Pelvis Model Scan. The test will help identify critical stress points throughout the design, as well as the maximum force the design can withstand before failure. This test will help guide the team as they finalize the design, allowing them to reinforce any parts that do not meet performance expectations before the manufacturing process. After completing this test, it may be repeated, and the design may be modified based on the results to improve long-term performance.

Table Fall Testing

A Table Fall Test will be performed using early prototypes. This test will help identify weaknesses throughout the design, allowing the team to reinforce weak parts before the final manufacturing process. In this test, three models will be pushed off a standard table height of 0.75 m, and checked for damages [25]. This process will be repeated five times for each model. The models will be compared, and any regions displaying damages will be evaluated for improvement.

Playdoh Adhesion Test

A Playdoh Adhesion Test will be performed using early prototypes of the model and PlayDoh. This test is designed to identify any shortcomings with PlayDoh adhesion between two prototypes. One prototype will have a mod podge coating, while the other is unmodified. A standard 1 oz Play-Doh Mini—the amount used in the workshop activity—will be applied to the surface of each model [26]. The Play-Doh on each model will be pressed until the diameter of

the circle is 8 cm. Both models will be turned upside down until the Play-Doh detaches, and attachment time will be recorded. This test will be repeated five times for 5 prototypes..

Discussion

Testing has not yet been conducted, but the anticipated results carry the following implications. If the Play-Doh remains attached to the Mod Podge-coated prototype for the full 30 seconds more consistently than to the unmodified prototype, the coating will be incorporated into the final design to ensure Play-Doh stays in place on the model during workshop use. If the TPU diaphragm and ligaments withstand compressive and tensile loading without permanent deformation, and the rivets survive the shear and tensile loading outlined in the testing methods, the model should meet the client's longevity requirement of 3-5 years of repeated use. These results would extend the work of Johnson et al., who created a complex 3D-printed pelvic model to help medical students learn anatomy, which includes musculature attachments such as the perineal membrane, the internal pudendal artery, and the pudendal nerve. [3]. The team's design simplifies that approach, making an optimized 3D pelvic model by removing iliac crests and including only the diaphragm and ligaments necessary for the client's specific workshop.

Because the model is based on average female pelvic dimensions, students must be instructed that it does not exactly represent male anatomy, even though the same pelvis will be used to construct the male pelvic floor musculature during the workshop. This disclosure avoids teaching future physician assistants an inaccurate anatomical standard. The base geometry comes from the NIH 3D Print Exchange and will be used and credited according to its attribution instructions [20]. Sustainability will also be considered during fabrication: the team will

minimize PLA waste by selecting the lowest infill percentage that still maintains the model's structural integrity.

The design was updated to address the low longevity score it received in the design matrix: the printed PLA pegs described in Design 3 have been replaced with aluminum rivets, which will be secured with cyanoacrylate adhesive. Further changes will depend on testing results. Based on the measured durability, potential alterations include, but are not limited to, changing the thickness of the ligaments, relocating the pegs on the pelvis, adding material around the rivet sockets, and adjusting the infill percentage.

The planned tests are intended to predict how the model will perform during classroom use, but several potential sources of error may limit their accuracy. Each test uses a sample size of only three, which limits statistical confidence in the results. The tests also assume uniform fabrication and material properties across all models. In particular, printer type and print orientation are assumed to be consistent, but because production of the pelvises will be outsourced to the UW Makerspace, the team will have limited control over these variables, and the tested samples may not represent every model produced. Next steps are to revise the CAD model accordingly, fabricate the 30 models, complete the planned testing, and evaluate adhesion, ease of use, and anatomical accuracy with the clients.

Conclusions

The current Physician Assistant anatomy workshop teaches pelvic floor anatomy using a two-dimensional paper template, which does not convey the three-dimensional spatial relationships students need for clinical practice. To address the concerns of high cost and limited

hands-on learning in existing 3D models, which typically come with the musculature already constructed, the team proposed a reusable, gender-neutral 3D pelvic outlet model on which students build the layers of the pelvic floor using Play-Doh. The model consists of a 3D-printed PLA pelvis coated in matte Mod Podge, with a flexible TPU pelvic diaphragm and ligaments that attach to aluminum rivets embedded in the pelvis. Because fabrication and testing have not yet begun, the model's performance is unconfirmed. Next, the team will begin fabrication of the prototype, perform the mechanical and drop testing, revise the design based on the results, and produce the 30 models needed for the workshop. Moving forward into the early fabrication phase, the team plans to meet with the consultation services at the UW Makerspace, since their expertise will help finalize logistics and printing strategies more efficiently.

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Appendix

Appendix A: Product Design Specifications

Problem Statement:

The Physician Assistant anatomy curriculum currently has a pelvic floor anatomy workshop that uses a 2-dimensional paper template of the bony pelvis, on which PA students build pelvic floor musculature and tissues using colored Play-Doh. While the activity promotes hands-on learning, the 2D model does not adequately allow students to develop the three-dimensional spatial relationships required for future clinical practice. The client needs a classroom set of pelvic outlet models that accurately represent the normal adult pelvic anatomy, including anatomical landmarks for muscle and ligament attachment, that can serve as a stable scaffold for students to build pelvic floor musculature. It should be durable enough for repeated classroom use, easy to assemble and store, and allow Play-Doh or another inexpensive modeling material to be adhered and removed without causing residue or degradation.

Client requirements:

- Create a classroom set of at least 30 reusable 3D models of the pelvic outlets
- Be anatomically accurate with each model scaled to represent normal adult pelvic anatomy
- Create a pelvic outlet at the intersection of male and female pelvic anatomy to allow the models to be used interchangeably between the workshops for both sexes
- Include important anatomical landmarks, including but not limited to, the ischial tuberosities, ischial spines, greater sciatic notches, distal sacrum, and muscle attachment sites
- Be compatible with Play-Doh or an inexpensive modeling material, allowing the material to adhere without the model shifting or being damaged
- Consist of multiple pelvis pieces, if necessary, with simple attachment mechanisms such as sliding or latching connections
- Have the combined size and weight of the models be compact and lightweight, respectively, for easy transportation and storage between classrooms
- Be durable enough to withstand repeated classroom use

Design requirements:

1. Physical and Operational Characteristics

a. Performance requirements

- i. The model must be able to withstand repeated use for multiple hours a day by students in a pelvic floor anatomy workshop, where students will continuously apply, manipulate, and remove Play-Doh from the model. During Play-Doh application and manipulation, the model must provide sufficient structural support, such that the model remains stable on the workspace surface and does not undergo deformation from grip that may reach approximately 487 Newtons while students build up to four stacked layers of musculature and tissue (pelvic diaphragm, urogenital diaphragm, erectile tissues, and superficial muscles) [1], [2]. The surface or membrane must maintain friction to support all four layers without slipping or collapsing during construction, while allowing students to inspect or lift the individual layers to view deeper anatomical relationships. During Play-Doh removal, the model must maintain its shape and structural integrity as students apply friction and force to remove residue after each classroom session.

b. Safety

- i. The 3D pelvic floor model must be safe for users in a classroom setting for the duration of operation. All structural components of the device, whether fabricated using 3D printing, plastic molding, or attached membranes, must have rounded edges and reasonably smooth surfaces to prevent cuts or injuries to the skin during usage. Since the model will be directly handled and touched, all components and adhesives must be non-toxic, hypoallergenic, and safe for skin contact. Additionally, because Play-Doh will be used repeatedly on the device, the outside and any attached membrane surface must be non-porous and not susceptible to retaining moisture or residue that could lead to bacterial growth or molding during storage.

c. Accuracy and Reliability

- i. The model must feature high anatomical accuracy, specifically focused on the main adult pelvic outlet, excluding aspects such as the iliac wings. The essential anatomical landmarks, including the distal sacrum, ischial tuberosities, ischial spines, great sciatic notches, sacrotuberous ligaments, should reflect adult anatomical dimensions within a ± 2 mm tolerance [3]. The model must allow students to explore differences in pelvic floor anatomy between the sexes by providing a base diaphragm capable of supporting either configuration of musculature across all four constructed layers. The device's surface must allow Play-Doh to adhere firmly during construction processes without slipping,

preserving 3D depth and complex anatomical relationships, while still allowing for a clean detachment without leaving behind permanent residue or causing degradation of the model over time. Lastly, the model components must remain attached and aligned in their appropriate structure during use, and should withstand pressing forces as the Play-Doh is molded.

d. Life in Service

- i. As long-term durability is a high priority for the client over realistic tissue compliance, the model must be capable of enduring repeated use in a classroom setting over a service life of at least 3 to 5 years. With roughly 30 models per class, each prototype—including bone structure, solid ligament bands, and attached membranes—must withstand the cycle of re-application of Play-Doh, molding of musculature, and removal hundreds of times without significant degradation or loss of surface adhesion. Finally, considering the need to transport the models between classrooms, the models should be able to sustain minor physical impacts or accidental drops from standard table height (approximately 0.75 m) onto carpeted or linoleum floors without failure or permanent deformation [4].

e. Shelf Life

- i. While not being actively used, sets of approximately 30 models will be kept in indoor classroom storage. The device materials should remain stable under slightly variable storage conditions, including temperatures from 20 to 25°C and humidity within the range of 20-60% [5]. Assuming the device will not be exposed to harsh outdoor elements or UV light exposure, the main structure of the device, ligaments, flexible membranes, and polymers should possess a minimum shelf life of 10 years without turning brittle or warping. Extended periods without use should pose no complications for the device performance.

f. Operating Environment

- i. The device will be used by many students throughout the academic year during class periods. It must be durable enough to withstand being dropped from tables and repeated pressure when students apply clay. The device will be stored in classroom storage rooms at temperatures ranging from 20°C to 25°C [6]. It must also be easy to clean by washing or wiping away excess clay, with materials that are resistant to corrosion and mold.

g. Ergonomics

- i. The device should be handled with care to prevent parts from breaking off. It should not be slammed against tables or walls and should be passed around carefully. Students should apply clay gently to avoid damaging the device.

h. Size

- i. The device should be approximately the same size as an average human pelvis to help students visualize and understand pelvic anatomy. The average female pelvis has pelvic inlet transverse and anteroposterior diameters of 13 and 12 cm, respectively, as well as pelvic outlet average transverse and anteroposterior diameters of 11 and 12.5 cm, respectively [7].
- i. *Weight*
 - i. The device should be lightweight, allowing students to easily carry and rotate it during hands-on learning activities. The device should weigh approximately 4.45–8.90 N to ensure comfortable handling while studying the pelvis.
- j. *Materials*
 - i. Play-Doh best sticks to porous, high-friction materials such as cardboard, matte paper, untreated wood, or heavily textured plastics. Applying a coat of primer or sealant to a material, an example being Mod Podge or matte primer, can act as a porous layer the Play-Doh can grip onto [8].
 - ii. TPU is a flexible filament with a high-friction rubbery surface that Play-Doh will stick to, however, lacks the support needed for the main bony pelvic structure. TPU could however be an effective material for the pelvic diaphragm and ligaments [9].
 - iii. Standard 3D printing materials, such as PLA, naturally repel Play-Doh, but can have surface modifications to enhance Play-Doh adhesion [10].
 - iv. Smooth plastics, silicone, glass, or foil should be avoided as the Play-Doh will release from these materials easily.
- k. *Aesthetics, Appearance, and Finish*
 - i. The shape will be anatomically accurate to a bony pelvis within the median subpubic angle between that of a male and female pelvis, allowing the student to decide whether they choose to construct male or female pelvic floor anatomy. A female pelvis has a subpubic angle generally within 90 - 100 degrees (obtuse angle), and a male pelvis has a subpubic angle within 50 to 80 degrees (acute angle) [11]. Our model therefore should represent a subpubic angle of approximately 85 degrees.
 - ii. We will design a textured surface that allows the Play-Doh to grip onto the 3D printed pelvic model. Cross-hatching, deep ridges, or score marks will be incorporated into the design where the Play-Doh is intended to be attached, according to the Pelvis and Perineum Workshop.
 - iii. Potential to incorporate color and texture difference between ligaments, bone, and muscle. Skeletal muscle will be depicted as striated whereas smooth muscle will not, but the client is not focused on the level of detail in this aspect.

2. Production Characteristics

a. *Quantity*

- i. Our client needs 1 unit per group of 2-3 students in a class size of 56 students. To meet this requirement, a minimum of 30 units are needed.
- b. *Target Product Cost*
 - i. Our target manufacturing cost is between \$3-\$7 per unit, with a total budget between \$100-\$200. This budget will need to cover all material costs for prototyping, testing, and final fabrication.
 - ii. Similar products currently on the market start around \$100 per unit [12].

3. Miscellaneous

- a. *Customer*
 - i. This pelvic floor model's target audience is anatomy students learning about standard pelvic floor anatomy and anatomy instructors.
 - ii. The model must be lightweight, durable, anatomically accurate, easily transportable, and cost-effective.
 - iii. The model must allow Play-Doh to easily attach, hold its form, and detach from the model.
 - iv. The model must be easily cleanable with standard sanitizing wipes.
- b. *Patient-related concerns*
 - i. The model must be lightweight and easily transportable between classrooms.
 - ii. The model must be durable for long-term classroom use.
 - iii. The model must allow Play-Doh to easily attach, hold its form, and detach from the model.
- c. *Additional optional patient requests*
 - i. The model could use color coding or different materials to help differentiate between muscles, bones, and ligaments.
 - ii. The model could be easily foldable or compressed to make transportation easier.
 - iii. The model could include textured detailing that students can mold their Play-Doh onto, providing a visual and hands-on representation of muscle texture as they build during the workshop.
- d. *Competition*
 - i. "The 3D Pelvic Floor - Nature" is a handmade wool-felt model priced at €195 that represents three layers of pelvic floor musculature, the coccyx, soft tissue bridge, and three pelvic organs: the bladder, uterus, and rectum [10]. While it provides a tactile representation of pelvic anatomy, the pre-cut musculature limits students' ability to actively construct and explore the anatomical structures, and its high cost may make it less accessible for classroom use. Our design builds on this concept by allowing students to mold and construct the pelvic floor muscles layer-by-layer, creating a more interactive and affordable learning experience.
 - ii. The Medi-Cross Female Pelvic Floor Anatomy Model is a PVC model priced at £159, making it a costly option for classroom use [3]. While its removable organs

help students visualize pelvic anatomy, the muscles are already constructed. Our design allows students to actively build the muscle layers, creating a more hands-on learning experience.

- iii. The Female Pelvis Skeleton Model is an anatomically accurate model priced at \$114.00, featuring the hip bones, sacrum, coccyx, lumbar vertebrae, and movable symphysis [11]. However, it includes more skeletal anatomy than needed for the scope of our pelvic floor workshop and is not designed for easy portability. Our design focuses specifically on the pelvic floor while being more compact and portable for classroom workshops.

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Appendix B: Fabrication Protocols

Pelvis Bone CAD Modeling

1. Download the female pelvis STL file from the NIH 3D Print Exchange [20].
2. Import the STL file into Solidworks.
3. Scale the pelvis uniformly to the target dimensions specified in the Preliminary Design Specifications:
 - a. Width: 13.0 cm, anterior-posterior depth: 11.0 cm, diagonal dimension: 13.5 cm.
4. Remove the superior portions of the model, specifically the iliac crests, creating a straight-line cut at an angle from the ilium-sacrum connection to the anterior inferior iliac spine.
5. Identify symmetrical the attachment locations for the pelvic diaphragm, right and left sacrospinous ligaments, and right and left sacrotuberous ligaments. Create 12 total attachment holes in the pelvic model corresponding to the attachment site locations.
 - a. Pelvic diaphragm: right and left anterior sacrum, and right and left inferior pelvic ramus [27].

- b. Right and left sacrospinous ligaments: Right and left lateral anterior sacrum and right and left ischial spines [28].
 - c. Right and left sacrotuberous ligaments: Right and left lateral inferior sacrum and right and left medial ischial tuberosities [28].
- 6. Set each attachment hole to 4.2 mm in diameter and 6.5 mm in depth.
- 7. Modify the geometry around each hole to increase the amount of surrounding PLA material.
- 8. Check the distance between neighboring attachment holes to ensure that the holes do not weaken the surrounding structures around them.
- 9. Perform a virtual assembly of the pelvis and ligaments/diaphragm in CAD to confirm that each component reaches its intended attachment point without excessive stretching, compression, or interference with adjacent structures.
- 10. Inspect and run stress tests on the completed CAD model to test for stress concentration points and other features that could cause problems during slicing or printing.
- 11. Export the finalized pelvic bone geometry as an STL file.

Pelvis Bone 3D Printing

- 1. Import the finalized pelvic bone geometry as an STL file into the 3D printing slicing software.
- 2. Oriented the model to minimize unnecessary support material and maintain the anatomical accuracy.
- 3. Print the model using PLA filament on an Ultimaker 3D printer.
- 4. After the print is complete, remove the support material from the model.
- 5. Visually inspect for defects such as incomplete layers, warping, or cracking.

6. Clear each of the 12 attachment holes of residual printing material. If necessary, use a small drill or appropriate deburring tool to create the intended 4.2 mm diameter and 6.5 mm depth for each hole.

Rivet Installation

1. Prepare twelve aluminum semi-tubular rivets for each pelvic model by checking the fit of each rivet, placing it into its corresponding attachment hole without adhesive. The rivet should fit securely without excessive force while maintaining the required extension above the pelvic surface. Once the fit has been verified, place a small quantity of Gorilla Super Glue Gel into the bottom portion of the designated hole. Then press the rivet into the hole until it reaches the bottom.
2. Wipe away any excess glue that was pushed out during the placement of the rivet and allow at least 24 hours for the glue to fully cure before performing any testing procedures [19].

TPU Pelvic Diaphragm and Ligament Fabrication

1. Create separate CAD models for the pelvic diaphragm, sacrospinous ligaments, and sacrotuberous ligaments based on the dimensions of the pelvis model. Create the dimensions such that the attachment points will reach their respective rivet on the model.
 - a. Pelvic diaphragm: right and left anterior sacrum, and right and left inferior pelvic ramus [27].
 - b. Right and left sacrospinous ligaments: Right and left lateral anterior sacrum and right and left ischial spines [28].

- c. Right and left sacrotuberous ligaments: Right and left lateral inferior sacrum and right and left medial ischial tuberosities [28].
2. The pelvic diaphragm will be modeled as a flexible, bowl-shaped structure representing the muscular and connective-tissue components spanning the pelvic outlet.
3. Run simulations to test that the TPU CAD models will have sufficient thickness to withstand repeated stretching and handling.
4. Import the finalized structures as STL files into the 3D printing slicing software.
5. Oriente the structures to minimize unnecessary support material and maintain the anatomical accuracy.
6. Print the model using TPU filament on a Stratasys 3D printer.
7. After the print is complete, remove the support material from the structures.
8. Visually inspect for defects such as incomplete layers, warping, or tears.

Pelvis Surface Coating

1. Apply a thin, uniform layer of Matte Mod Podge to the external surface of the model.
2. Allow the coating to dry completely before additional coats are applied, if necessary, or additional testing is completed.

Appendix C: Prospective Materials and Expenses

Item	Description	Manufacturer	Mft Pt#	Vendor	Vendor Cat#	Date	#	Cost Each	Total	Link
3D-Printed Scaffold										
Main body of pelvic model	3D printed using PLA from the UW Madison Makerspace	UW Madison Maker space	N/A	N/A	N/A	10/06.2026	30	5	150	N/A
Rivets	360 rivets needed for 30 models' ligament attachment sites. 8 50 pks needed.	Uxcell	N/A	Amazon	N/A	10/06.2026	8	5.36	42.88	Link
Modpodge	The entire outer surface requires coating.	Modpodge		Plaid	SKU 1469	10/06.2026	3	7.79	23.37	Link
Gorilla Glue	Used to secure 360 rivets into place	Gorrilla	N/A	Amazon	N/A	10/06.2026	2	8.98	17.96	Link
Pelvic accessories: Ligaments & Diaphragm										
TPU	3D printed using from the UW Madison Makerspace	UW Madison Maker space	N/A	N/A	N/A	10/06.2026	120	Awaiting Cost Estimate		N/A
								TOTAL	\$234.21	