ACCESSIBLE EDUCATION FOR LUTO PATIENTS: A STUDY OF MULTIMODAL TOOLS TO SUPPORT LITERACY AND EMOTIONAL WELLBEING

by
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ABSTRACT

Lower Urinary Tract Obstruction (LUTO) is a rare congenital condition that impairs fetal urinary and respiratory development due to urethral blockage, leading to urine retention, reduced amniotic fluid, and potential lung hypoplasia, kidney damage, and compression injuries (Capone et al., 2022; Haeri, 2015).

Current patient education materials often fail to adequately convey the condition's severity and full implications, limiting understanding for patients and families. Existing materials are majorly text-based and not conducive to helping patients and families fully understand LUTO, despite studies showing that effective education is critical for parental comprehension (Denny et al., 2014; Żyrek et al., 2024). There is a clear need for improved resources to explain the condition, its implications, and available treatments.

This project developed and evaluated multimedia-based educational resources—including a 3D-animated video, a patient-focused webpage, and a printable handout—to improve comprehension of LUTO, its consequences, and treatment options. An IRB-approved study assessed their effectiveness through pre- and post-tests and participant surveys. Additionally, 3D-printed anatomical models were prototyped for tactile learning in clinical settings.

Results demonstrated that video-based education significantly improved knowledge retention compared to text-based materials, with a paired two-sample T-test confirming a statistically significant increase in post-test scores ($p = 0.006$). Participants also reported higher engagement and a preference for the video format. Survey feedback identified areas for improvement, such as accessibility enhancements.

This study reinforces the value of multimedia tools in patient education and suggests further research into optimizing materials for diverse learning needs.

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INTRODUCTION

Overview

Lower Urinary Tract Obstruction (LUTO) is a rare congenital condition, occurring in approximately 1 in 5,000 pregnancies (Capone et al., 2022; Haeri, 2015). It involves a blockage in the fetal urethra, which prevents the normal flow of urine (Haeri, 2015). This obstruction affects the entire urinary system, including the bladder, urethra, kidneys, and ureters, and can severely impact the development of the respiratory system, particularly the lungs.

LUTO can sometimes be caused by chromosomal abnormalities or genetic disorders, which may be associated with additional medical problems, or can happen for no known reason (**"isolated" LUTO**) (Center for Fetal Therapy, 2021; Haeri, 2015; Morris & Kilby, 2011). Whether genetic or isolated, LUTO is caused by a structural issue with the urethra, such as:

- **Posterior Urethral Valves (PUV):** A fold of tissue that blocks the urethra, completely obstructing urine flow (Haeri, 2015; Malin et al., 2012).
- **Urethral Atresia:** The absence of the urethra, preventing urine from exiting the body (Haeri, 2015; Malin et al., 2012).
- **Urethral Stricture:** A narrowing of the urethra, often associated with triad syndrome or prune belly syndrome, which partially restricts urine flow (Mandaletti et al., 2024).

The blockage leads to a buildup of urine in the bladder, which can back up into the kidneys, causing irreversible damage. This damage may manifest as **hydronephrosis** (swollen kidneys with a thin cortex) or **polycystic dysplastic kidneys** (where cysts replace functional kidney tissue).

By 16 weeks, the fetus becomes primarily responsible for amniotic fluid production through urination, with fetal urine making up most of the amniotic fluid in the second and third trimester (Fitzsimmons & Bajaj, 2025). Because of either kidney damage causing reduced urine production, or the lack of urine excretion, LUTO drastically reduces amniotic fluid levels, which are critical for fetal lung development (Hooper & Harding, 1995).

Between weeks 16 and 23 of gestation, the fetal lungs are in the **canalicular stage**, where respiratory bronchioles begin to form (Schittny, 2017). Amniotic fluid is essential for the lungs to progress to the **saccular stage** (weeks 24–36), where terminal saccules capable of limited gas exchange develop (Schittny, 2017). Without sufficient amniotic fluid, the lungs may remain underdeveloped, leading to **pulmonary hypoplasia** (Haeri, 2015; Morris & Kilby, 2011). The lack of fluid also restricts the fetal chest's ability to expand, further compromising lung growth (Center for Fetal Therapy, 2021).

The reduced amniotic fluid also results in **uterine compression**, which can cause physical deformities known as **Potter syndrome**. These deformities include facial abnormalities called "Potter facies", shortened limbs, clubbed feet, and joint contractures (Bhandari et al., 2025).

During pregnancy, the placenta supports the fetus by performing the functions of the kidneys and lungs. This allows a fetus with severe kidney and lung damage to survive in utero. However, after birth, the baby must rely on its own organs, which, because of the LUTO, will be underdeveloped or damaged, leading to life-threatening complications (Morris & Kilby, 2011).

The prognosis for LUTO varies depending on the timing and severity of the obstruction (Kohl, 2022; Ruano et al., 2017). Severe cases often have a poor prognosis, leading some families to consider pregnancy termination.

Babies born with LUTO require evaluation in a neonatal intensive care unit (NICU) to confirm the cause of the obstruction and assess for other birth defects. Depending on the severity of kidney and lung damage, long-term care may include dialysis, kidney transplants, or ventilator support (Morris & Kilby, 2011). While some children with LUTO grow up healthy, others face lifelong challenges, and many do not survive despite interventions (Klaus & Lange-Sperandio, 2022; Kohl, 2022; Morris & Kilby, 2011).

Fetal interventions are reserved for cases where the benefits are likely to outweigh the risks. Thorough prenatal testing is essential to determine eligibility for fetal therapy (Ruano et al., 2017). Several prenatal interventions may be considered to mitigate the effects of LUTO:

- **Vesicocentesis:** A temporary procedure where urine is removed from the fetal bladder using a needle to relieve pressure and reduce further kidney damage. This may need to be repeated throughout the pregnancy.
- **Pigtail Shunt:** A small tube inserted into the fetal bladder to drain urine into the amniotic space, maintaining the amniotic fluid to preserve pulmonary function. This is a temporary measure until birth.
- **Amnioinfusion:** A procedure where amniotic fluid is injected into the uterus to cushion the fetus and support lung development. This may require repetition during pregnancy.

- **Fetal Cystoscopy:** A minimally invasive procedure where a small surgical camera is inserted into the baby's urethra and bladder to remove blockages and restore urine flow (Klaus & Lange-Sperandio, 2022).

However, these interventions are not without risks. Shunts can become dislodged, requiring replacement, and complications such as fetal infection, preterm labor, or miscarriage may occur. Importantly, these procedures cannot reverse existing damage to the kidneys or lungs (Klaus & Lange-Sperandio, 2022).

Existing Materials for Patients

Current patient-facing resources about LUTO are predominantly text-heavy, with few visuals to aid understanding. This reliance on dense, technical language makes it difficult for patients and families to grasp the complex and multifaceted effects of the condition. The lack of accessible, visually engaging materials adds to the emotional burden on families, who often struggle to fully comprehend LUTO and its implications (Denny et al., 2014; Żyrek et al., 2024). This can lead to challenges in explaining the condition to their support networks, resulting in misunderstandings, feelings of isolation, or added stress.

Patients often access online information to influence their decisions and try to understand the diagnosis (Chang et al., 2020). Without strong online resources, unprepared patients may find it difficult to engage effectively during medical appointments, where the volume and complexity of information can be overwhelming (Menendez et al., 2017; Parikh et al., 1996). Patients who arrive informed, however, are better equipped to discuss treatment options, ask relevant questions, and participate in shared decision-making, making these critical appointments more productive (Kraft et al., 2017; Lindau et al., 2002; Meade et al., 1994; Menendez et al., 2017).

While some resources exist, they often fail to adequately address key aspects of LUTO, such as the severity of the condition, its impact on lung development, and the long-term outcomes for affected infants. Visuals, when present, are frequently limited to ultrasounds or a single unlabeled illustration, which do not effectively convey the physical deformities or systemic consequences of LUTO. These gaps highlight the need for more comprehensive, patient-friendly educational tools that combine clear explanations with engaging visuals to improve understanding and support informed decision-making.

Multimedia in Medical Education

The choice of animation as the primary medium for this project is grounded in its ability to convey complex medical information in an accessible and engaging way. Animation is a dynamic and visually compelling medium that can explain intricate processes, show changes over time, and hold the viewer's attention—features that are particularly valuable when explaining a condition like LUTO, which involves multiple organ systems and developmental stages.

To complement the video, a webpage was created to improve accessibility and offer additional educational resources. While the video is also accessible through the webpage, the use of still images and other information allows patients to print or skim content and includes details not covered in the video.

Similarly, the patient handout serves as a concise summary, distilling key points from both the video and the webpage. While it contains less information than the other formats, it provides an effective introduction to the topic, offering patients a quick and accessible reference.

These multimedia resources are accessible at any time, allowing the patient to revisit them after their appointments, or review them in advance. The webpage and handout can be printed or shared with friends and family. This continual access enhances access to information and reinforces understanding.

Advantages of Visuals Over Text

Visual media, such as animations, offer several advantages over text-heavy materials:

- **Reduced Cognitive Load:** Reading dense medical text can be overwhelming, especially for individuals under emotional stress (Fiore-Silfvast et al., 2013; Meade et al., 1994). Visuals allow for more passive consumption, making it easier for viewers to absorb information without requiring significant mental effort (Tarchi et al., 2021).
- **Emotional Accessibility:** For expecting parents and families facing the emotional burden of discussing pregnancy outcomes, visuals can provide a gentler way to engage with difficult information.
- **Broader Accessibility:** Visuals can transcend language and literacy barriers, making the content more inclusive and easier to understand for a wider audience, including family members and friends who may not have a medical background (Kraft et al., 2017; Paasche-Orlow & Wolf, 2007).

The Broader Impact of Multimedia in Healthcare Communication

Multimedia tools, particularly animations and videos, have been recognized as effective strategies for improving patient education and communication (Choi et al., 2009; Deshpande et al., 2023; Fiore-Silfvast et al., 2013; Leiner, 2004; Meade et al., 1994). They offer a dynamic way to present information, making it easier for patients to understand and retain key concepts. While traditional methods like written materials and lectures have their place, multimedia resources often outperform them in terms of engagement and accessibility, particularly for audiences with varying levels of health literacy (Choi et al., 2009; Leiner, 2004). On webpages and handouts, images and animations can break up text, making content more engaging and easier to navigate (Alegría et al., 2008; Schooley et al., 2015). They also provide visual context that text alone cannot convey, helping to explain concepts and processes more effectively.

The Role of Multimedia in Patient Preparedness

Informed patients are better equipped to engage in productive discussions with their healthcare providers. Multimedia resources, such as animations and videos, can help patients and families arrive at appointments with a clearer understanding of the condition, its implications, and the available options (Meade et al., 1994; Stockwell et al., 2015). This preparedness not only reduces the emotional strain of navigating complex medical information but also fosters more meaningful conversations during critical appointments (Kraft et al., 2017; Lindau et al., 2002; Meade et al., 1994; Menendez et al., 2017).

The Role of Physical Models in Patient Education

Research has shown that tactile interaction with physical objects significantly enhances learning and comprehension (Novak & Schwan, 2021). Physical models have been proven to improve understanding more effectively than static images, especially in medical contexts (Bernhard et al., 2016; Karsenty et al., 2021; McMillan et al., 2023; Zhuang et al., 2019). With the advent of desktop 3D printing, it is now possible to quickly and affordably produce handleable models that can be used during patient consultations.

The 3D-printed models in this project are designed to help parents grasp the scale and severity of LUTO by allowing them to hold and compare life-sized representations of a healthy fetus and one affected by the condition. This tactile experience not only aids in understanding the anatomical changes but also serves as a practical tool for doctors, offering a clear visual and tactile aid to explain complex concepts during appointments.

Learning Theories

To create an effective educational resource, the design of the 3D animation and accompanying webpage was guided by several key learning theories.

Cognitive Load Theory emphasizes that overwhelming working memory with too much information can hinder learning and make it difficult to encode information into long-term memory (De Jong, 2010). To address this, the animation was designed to present information in a linear, easy-to-follow storyline. By breaking down the complex pathophysiology of LUTO into clear, sequential chapters, the animation reduces cognitive overload and helps viewers process and retain the information more effectively.

Dual Coding Theory highlights the benefits of combining visual and verbal representations to enhance learning and retention (Sadoski & Paivio, 2013). In the animation, this principle was applied by pairing voiceover narration with frequent text labels and visual cues. This dual approach reinforces key concepts, ensuring that viewers can both see and hear the information, which improves comprehension and recall.

Minimalist Theory advocates for self-contained and self-directed learning, which is particularly relevant for the webpage (Carroll, 2014). The webpage was designed with this principle in mind, featuring a clear content flow and table of contents that allows users to navigate the information at their own pace. By minimizing distractions and providing a logical structure, the resource empowers users to engage with the material independently and effectively.

Multimedia Learning Theory stresses the importance of clear signaling cues and the avoidance of extraneous information to focus learning. To achieve this, the animation and webpage use consistent visual elements, such as reused graphics and a cohesive color scheme, to create a unified learning experience. Visual hierarchy is established through bold text, graphical cues, and strategic placement of key information, guiding users to prioritize the most important concepts. Additionally, presenting LUTO pathology through both video and visuals on the webpage ensures that users can engage with the material in multiple ways, catering to different learning preferences (Tarchi et al., 2021).

Objectives

The goal of this thesis was to create an animation and supporting materials to improve patient understanding of LUTO. The project aims to address gaps in existing resources by providing engaging tools for patients, families, and healthcare providers. The specific objectives are as follows:

1. **Communicate Complex Information Effectively**
   Develop an engaging animation that explains the anatomy, causes, and treatment options for LUTO in a way that is accessible to a lay audience. The animation will help patients and families grasp the condition's implications and arrive at medical appointments with foundational knowledge. This preparation can lead to more productive discussions with healthcare providers and reduce the emotional burden on families.
2. **Facilitate Communication with Support Networks**
   Create shareable materials that empower patients to explain LUTO to their family and friends. Existing resources are often dense and difficult to navigate, making it challenging for parents to relay accurate information to their support networks. By providing a comprehensive, low-commitment resource, parents can direct others to the material, reducing the need for repeated explanations and minimizing feelings of stress or isolation.
3. **Support Patient Education and Engagement**
   Develop tactile models and printed documents to aid in discussions with healthcare providers.
4. **Evaluate the Efficacy of the Animation**
   Analyze the effectiveness of the narrative animation and its ability to engage learners through pre- and post-tests, surveys, and statistical analysis.

Intended Audience

The **primary** audience for this project is pregnant individuals whose fetuses have been diagnosed with LUTO and who need to make informed decisions about their fetus's health.

The **secondary** audience includes family members and friends seeking to better understand the condition to provide effective support, as well as healthcare providers who can use these materials to enhance patient education during consultations.

METHODS AND MATERIALS

Research

Patient-facing materials and scientific articles on LUTO were reviewed. Research was conducted on specific pathologies, including variants of kidney disease, causes of urethral blockages, and related peripheral conditions. Additionally, relevant anatomical topics such as lung development and gestational checkpoints were explored.

Ultrasounds and medical visuals of LUTO cases were collected, as patient-facing materials often oversimplified or omitted critical details. These resources provided a more accurate representation of the condition's severity which aided in the creation and modeling of assets.

Patient Experience

To understand how patients encounter information about LUTO, a typical simulated search experience was performed. When searching for "LUTO" on Google, the topmost relevant results were limited, but included:

1. A webpage from **Children's Hospital of Philadelphia** that includes a text explanation of the condition, three unlabeled illustrations of the different structural abnormalities that can lead to LUTO, a couple of ultrasounds, and a series of videos that consist of doctors talking to a camera about the condition.
2. **The Texas Children's Hospital** webpage featured a video of doctors discussing the condition, a textual explanation, and two unlabeled illustrations—presumably depicting a vesicocentesis procedure and a pigtail shunt

The image results were irrelevant, primarily showing black ribbons associated with the Portuguese word *luto*, meaning 'grief,' or the Spanish translation, which means 'mourning.'

Adding search terms like "fetus" or "baby" yielded more relevant results, but the only images showing the extent of the condition were ultrasounds, which fail to convey the severity or physical deformities associated with LUTO.

This investigation highlighted a significant gap in accessible, patient-friendly resources that accurately depict the condition and its implications.

Literature Review

During literature review, existing patient-facing educational resources about LUTO were evaluated for whether the resources included:

1. **Common Causes**: Atresia, narrowing, posterior urethral valves (PUV), and whether the condition was isolated or genetic.
2. **Significance**: Clear communication of the poor prognosis associated with LUTO.
3. **Diagnosis Methods**: Ultrasound, MRI, amniocentesis, and fetal urinary tests.
4. **Severity**: Explicit description of potential lung and kidney damage.
5. **Treatments**: Shunts, amnioinfusion, vesicocentesis, and surgery.
6. **Treatment Success and Risks**: Chances of success, risks to parent and fetus, and clarification that treatments aim to prevent further damage rather than reverse existing harm.
7. **Outcomes**: Long-term implications, such as kidney transplants, dialysis, chronic lung issues, and the need for a large caregiving team.

Quality and relevance of multimedia content within these resources was evaluated, focusing on:

1. **Content of Images**: Medical accuracy versus realism (e.g., showing the bladder's size relative to the fetus or its compression of the diaphragm).
2. **Engagement**: Whether visuals were engaging and well-designed.
3. **Labels**: Presence of labels to aid understanding.
4. **Relevance**: Direct connection between visuals and content.

Key Findings

The review revealed several recurring issues:

1. **Text-Heavy Content**: Most resources relied heavily on text, with limited or no multimedia support.
2. **Lack of Emphasis on Severity**: The critical nature of the condition was often buried in paragraphs rather than highlighted.
3. **Inadequate Coverage of Lung Issues**: Few resources effectively explained the connection between LUTO and lung development.
4. **Limited Realism in Visuals**: Images often failed to depict the true severity of the condition.

These gaps guided the development of more effective and empathetic educational tools.

Content Preparation

Ideation

After the literature review, experts were consulted to understand the typical patient visit and the key topics covered. Several challenges of note are:

- **Describing Anatomy and Development**: Significant time is spent explaining fetal anatomy, lung development, and the specifics of the condition. The lung development issue is particularly hard for parents to grasp.
- **Lack of Visual Aids**: A physician will often draw diagrams to help parents visualize the issues.
- **Managing Expectation**: Parents arrive with hope, seeking answers, but often leave overwhelmed by the complexity of the information and the difficult prognosis.

By the end of the hour-long appointment, patients are often emotionally and mentally saturated, making it difficult to introduce new concepts or discuss treatment options effectively.

This feedback inspired two main goals for this project:

1. **Better Preparation for Parents**: Existing online resources are dense and difficult to navigate, making it easy for parents to miss critical information. Accessible, easy-to-understand materials can help parents arrive at appointments better prepared—both intellectually and emotionally. This preparation can lead to more productive conversations and reduce the emotional burden on families.
2. **Empowering Parents to Explain to Others**: If it takes an hour for a trained medical professional to explain the condition, relaying that information from memory to family and friends can be overwhelming and inaccurate. This can lead to feelings of hopelessness and anxiety as parents relive the stressful moment while trying to convey complex details. By creating a comprehensive, low-commitment resource that facilitates passive learning, parents can direct their support network to the material, reducing their emotional burden and ensuring accurate information is shared.

Script

A rough script was developed that underwent multiple revisions to ensure clarity and conciseness. The script was structured into three distinct chapters:

1. **Normal Development**: Establishing the baseline for healthy fetal growth.
2. **LUTO Issues**: Explaining the condition, its causes, and its effects.
3. **Treatments**: Outlining the available interventions and their implications.

This three-part structure provided a logical flow for the narrative, making complex information more accessible and easier to follow. The script can be found in **Appendix A**.

Storyboards and Animatics

With the rough script as a guide, storyboards were created in Procreate and Storyboarder at a resolution of 1920x1080 px (**Appendix B**). The storyboards were reviewed for accuracy, clarity of information, and overall engagement. At this stage, the focus was on the content and narrative flow rather than framing or asset fidelity, as those details would be refined for 3D production.

After finalizing the storyboards, they were imported into Adobe AfterEffects and timed to a rough voiceover to evaluate the pacing of the video. Preliminary transitions and motion graphics were produced during this stage, though everything remained flexible and subject to change once the final voiceover and 3D scenes were rendered.

3D Video Production

Considerations

This thesis involves the depiction of human fetuses, including their faces, and must clearly distinguish between healthy and unhealthy states. Additionally, the fetuses are shown at earlier developmental stages (16–20 weeks) than typically visualized, which presents unique challenges. At these stages, fetuses may appear unhealthy to the untrained eye, requiring careful design to convey their condition accurately. Key considerations include:

1. **Lifelike Appearance**: The fetus must appear alive and natural, with subtle movements such as breathing, twitching, and shifting.
2. **Health Representation**: Healthy fetuses must look healthy without resembling full-term babies, as this could be perceived as emotional manipulation.
3. **Sensitive Topics**: The thesis addresses sensitive topics, including the option of terminating a pregnancy. To maintain objectivity and avoid emotional manipulation, the fetuses must be depicted accurately for their developmental stage without being portrayed in a way that could unintentionally evoke strong emotional responses or make them appear more developed or endearing than they truly are.
4. **Physical Changes**: The fetus undergoes drastic changes in appearance due to conditions like LUTO, including significant swelling. These changes are highly specific and cannot be fully achieved programmatically using deformers in Cinema4D.

To address these challenges, the main stages of fetal development were created in ZBrush. This allowed for precise control over the fetus's appearance and enabled the creation of highly detailed models that could accurately represent both healthy and unhealthy states.

Making the Assets

Fetus

Modeling

Seven different fetal variations were modeled in ZBrush, starting with a base mesh—the 20-week fetus, as it represents the central age range (**Figure 1**). From this base, the models were modified to represent each specific age and condition. Initially, the Sculptris Pro mode in ZBrush was used to focus on the general forms without concern for topology. The fetuses were modeled symmetrically and in a neutral pose. Once the basic shapes were finalized, LUTO models were derived by sculpting a distended bladder and adjusting the overall form to reflect the condition. Each model was painted using ZBrush's Polypaint feature.

List of Models:

- 16-week healthy fetus
- 16-week LUTO fetus
- 20-week healthy fetus
- 20-week LUTO fetus
- 20-week "prune-belly" fetus
- 30-week healthy fetus
- 30-week LUTO fetus

Base Mesh and Retopology

Using the largest fetus (30-week) for maximum mesh flexibility, edge flow was defined using Polygroups, focusing on natural contours and loop continuity. This ensured seamless edge loops and avoided abrupt changes in topology, which could lead to unnatural deformations.

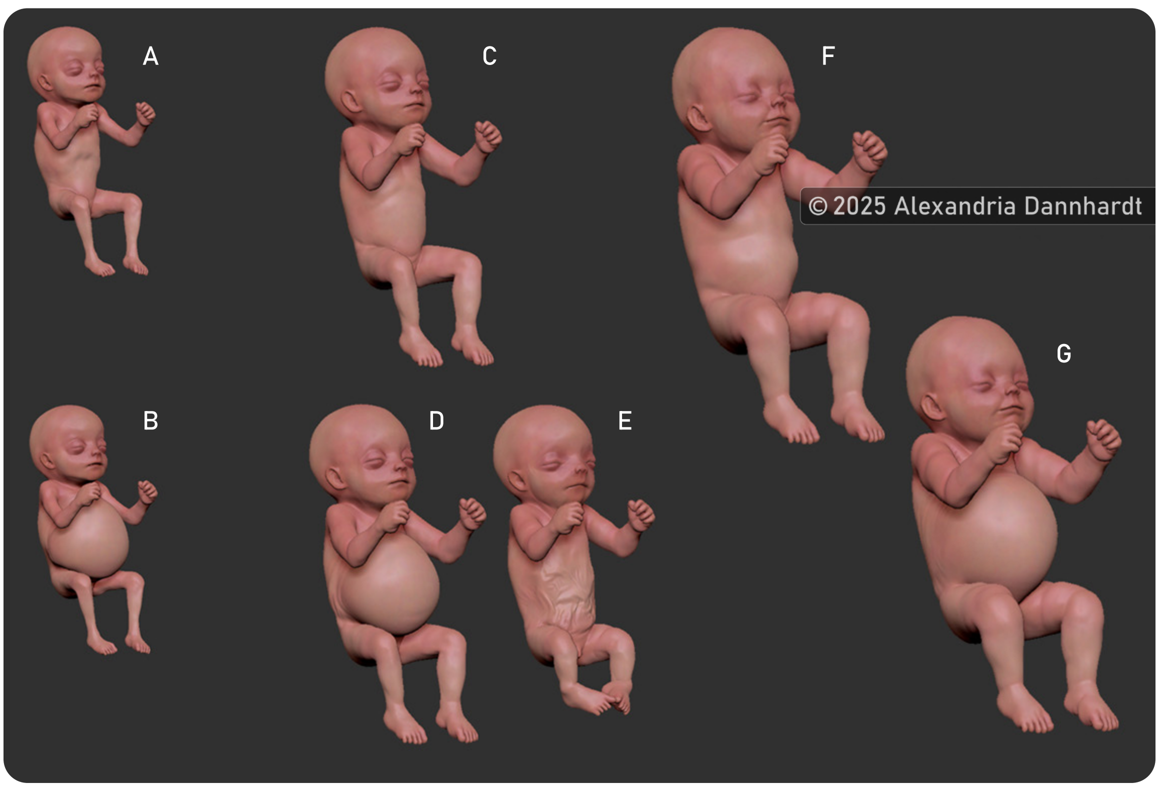


Figure 1. Screenshot of fetal models from ZBrush, including (A) 16-week healthy fetus, (B) 16-week LUTO fetus, (C) 20-week healthy fetus, (D) 20-week LUTO fetus, (E) 20-week "prune-belly" fetus, (F) 30-week healthy fetus, and (G) 30-week LUTO fetus. Models not to scale.

ZRemesher was used to retopologize the model into clean, animation-friendly topology, with particular attention to areas of deformation, such as separate loops around the scapulae for correct deformation (**Figure 2**).

The final model was kept at approximately 20k polygons—a balance between detail and performance. While high poly counts were acceptable for a 3D animation, excessive geometry was avoided to prevent software strain and ensure smooth Pose Morphing.

Figure 2. Base mesh topology (lines) and polygroups (colors) of the base mesh in ZBrush screenshot.

UV Mapping

UVs were created for the base mesh, placing seams in areas of natural deformation or hidden regions. Since most textures were intentionally painted and not procedural, it was ensured that the UVs were packed efficiently to maximize texture resolution.

ZWrap for Consistent Topology

To streamline the process, ZWrap (formerly R3DS) was used, a ZBrush plugin designed to wrap base meshes around 3D models for consistent topology (**Figure 3**). With a free student license from ZWrap, the base mesh topology was applied to the other six models. This allowed all models to share identical topology, simplifying texturing, rigging, and animation. For the LUTO models, some manual adjustments were required before ZWrap could retopologize effectively. After wrapping, the new meshes were subdivided and the detail was projected back from the original sculpts. Texture and normal maps were exported from ZBrush, and the low-poly models were imported into Cinema4D.

Figure 3. ZWrap screenshot: (A) Overlapping meshes (light blue = base mesh), (B) Wrapped mesh.

Pose Morph

The Pose Morph tag was set up in Cinema4D to reference all seven models, enabling seamless transitions between them. This allowed for the reuse of rigging, weighting, and animations across all fetal variations, as well as use the variations in the animation itself. For example, adjusting the percentage of LUTO deformation could simulate breathing motions.

The Pose Morph tag was set up on the largest model (30-week healthy fetus), with all source models placed in a null object tagged as “sources” for organization. A Pose Morph controller was attached to a User Data tag on the Fetus Parent Null (“Fetal Controller”), allowing easy access to morph options and reducing workflow interruptions (**Figure 5**). This strategy of linking relevant controls to a User Data tag on the parent null was used for most of the animated models in this project (**Figure 4**).

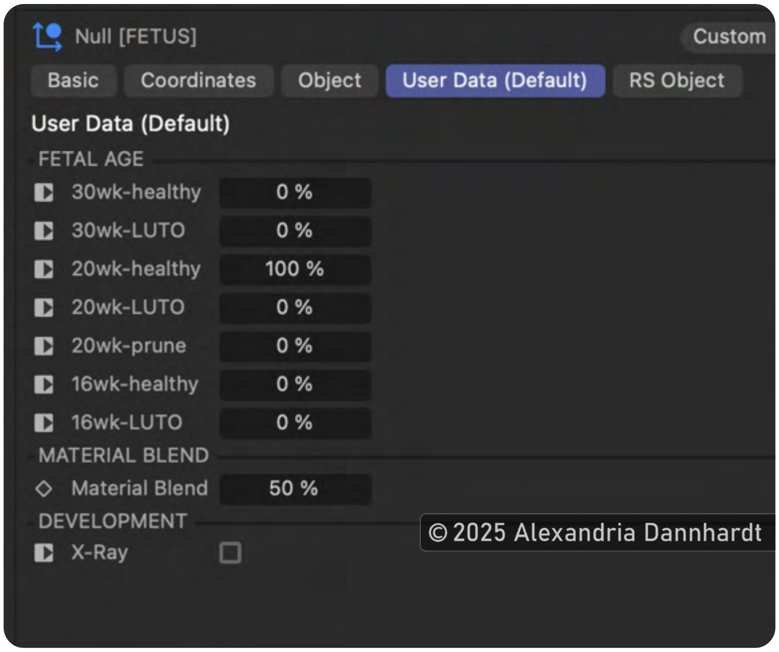


Figure 4. Cinema4D screenshot showing the User Data controls on the Fetal Controller.

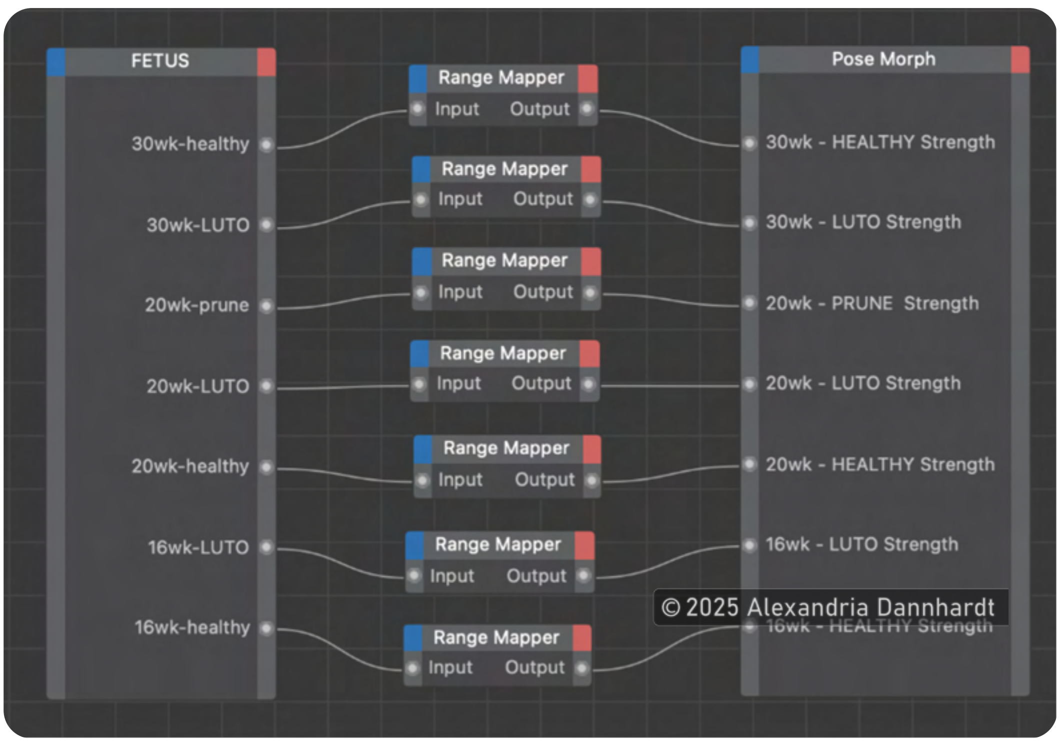


Figure 5. Cinema4D screenshot showing the XPresso nodes on the Fetal Controller.

Materials

A base material was created using the diffuse map from ZBrush for color, combined with subsurface scattering and light skin texture to maintain a smooth, lifelike appearance (**Figure 6**). To handle the morphing between different UV maps for each fetal stage, each UV map was linked to the User Data scalar input that controlled the Pose Morph percentage on the Fetal Controller. The textures fed into a color layer, with the User Data percentage controlling the mask for smooth transitions between UVs.

To enhance the realism of the fetal model but remain adaptable, a User Data input was used to control the visibility of vasculature, reflecting the natural transparency of younger fetal skin. This was achieved by linking the User Data to the mask of a Material Blend node, which allowed for seamless transitions between two distinct material states:

- **Material 1:** Designed to mimic an older fetus, this material featured minimal vasculature and lower transparency.
- **Material 2:** Representing a younger fetus, this material was highly translucent with pronounced vasculature.

The vasculature for both materials was created using procedural textures generated with Maxon Noise.

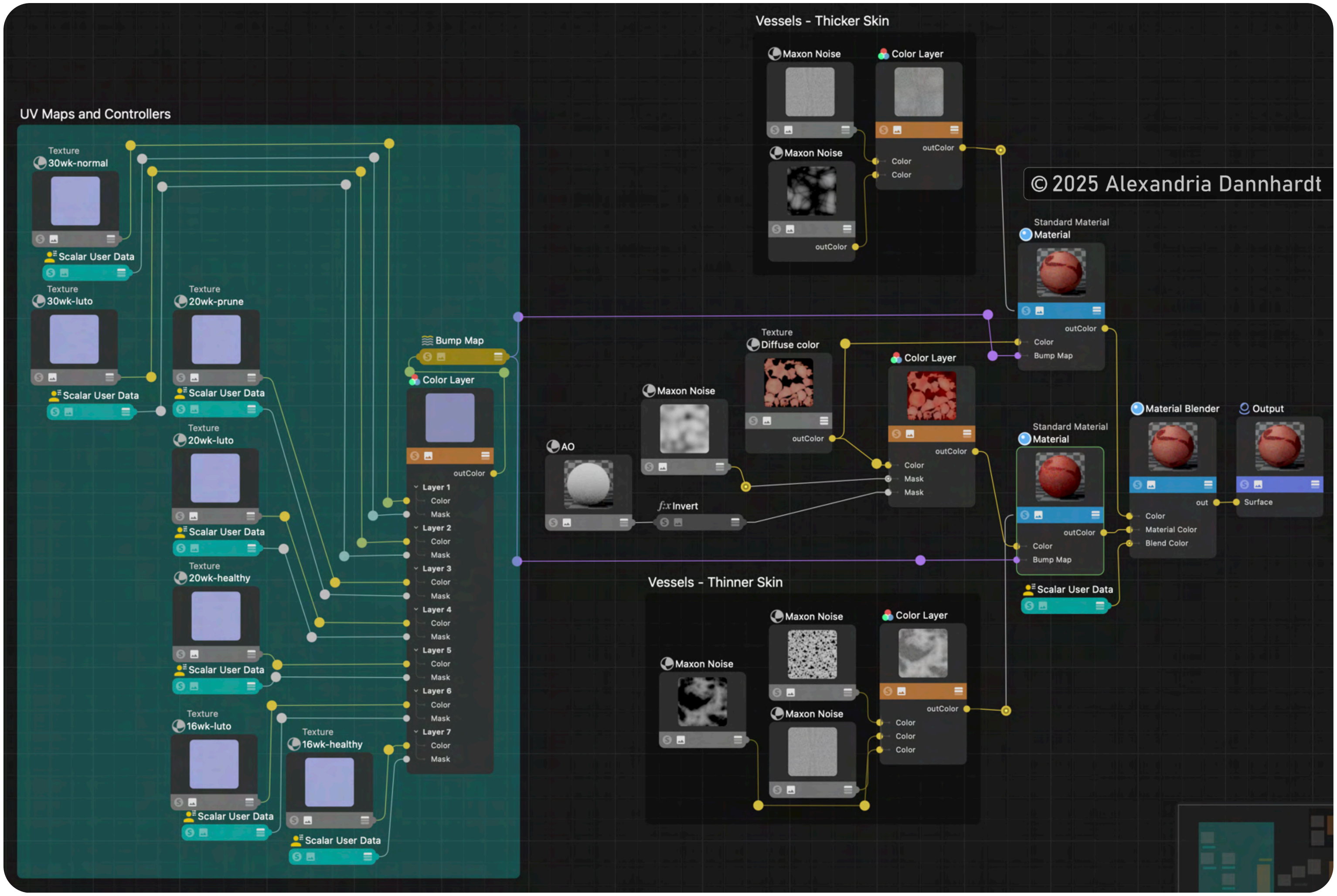


Figure 6. Cinema4D screenshot showing RedShift material on fetus. Text not intended to be read.

Rigging and Weighting

The 30-week healthy fetus was rigged in Cinema4D after setting up the Pose Morph states. Bones were added for all major joints, excluding fingers, toes, and facial deformations, as these were unnecessary for the animation (**Figure 7**). Auto-weights were initially applied but proved inadequate. Therefore, it was necessary to manually paint the weights to ensure clean and natural deformations (**Figure 8**).

Figure 7. Cinema4D screenshot showing the joints on the fetal model.

Figure 8. Cinema4D screenshot showing the hand-painted weights on the fetal skin. Each color is associated with a joint.

Organs

Organs with more rigid and conventional shapes—such as the bladder, kidneys, placenta, and uterus—were modeled in ZBrush to ensure anatomical accuracy, as they required more detail and could not be created procedurally. These models were textured in either Cinema4D or ZBrush, depending on how homogeneous the texture needed to be. More dynamic elements, such as the ureters, fluids, and umbilical cord, which required flexibility rather than precise anatomical accuracy, were created procedurally in Cinema4D.

Kidneys

The kidneys were sculpted in ZBrush, with anatomy and positioning confirmed by content experts (**Figure 9**). Both the exterior and interior were sculpted using a base mesh to enable morphing between states. XPresso controllers were set up to toggle the visibility of the half-kidneys and expose Pose Morph controllers, which also adjusted texture maps and subsurface scattering (**Figure 11**).

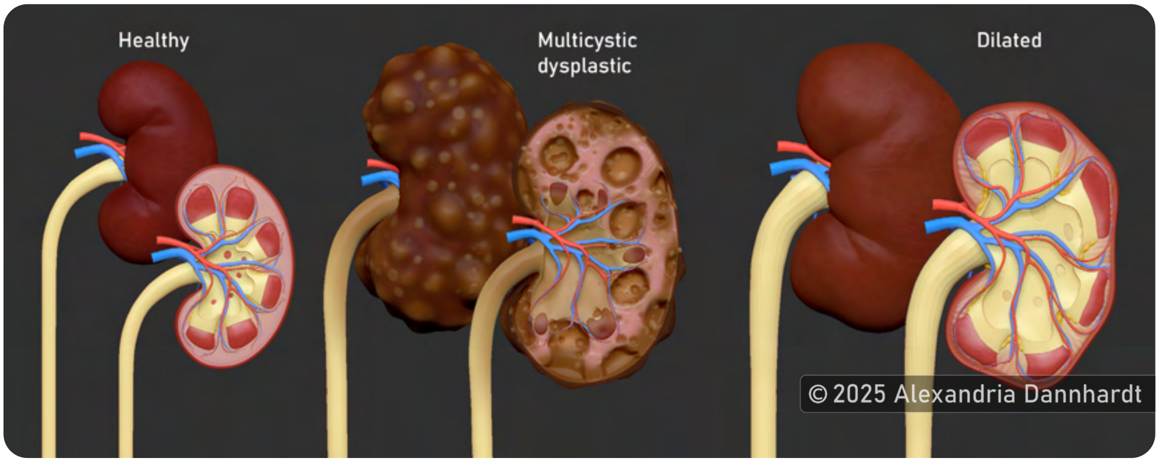


Figure 9. Screenshot of the healthy, multicystic dysplastic, and dilated kidney models from ZBrush.

Material Setup

User Data controls were used to manage color and normal maps. A slider was added to adjust subsurface scattering color, transitioning from deep red (healthy) to orange/yellow (sick). This was implemented using a ramp for percentage-based control (**Figure 10**).

Visibility Toggles:
Math nodes in C4D XPresso handled visibility toggles, such as revealing the kidney interiors. A boolean (check-box) User Data input was used, with math nodes converting the output (0 or 1) to the correct visibility state (2 for default, 1 for off) using the equation "2-x". This ensured the parent-level visibility control remained functional (**Figure 12**).

The right kidney was a reflected instance of the left kidney, moved slightly into anatomical position.

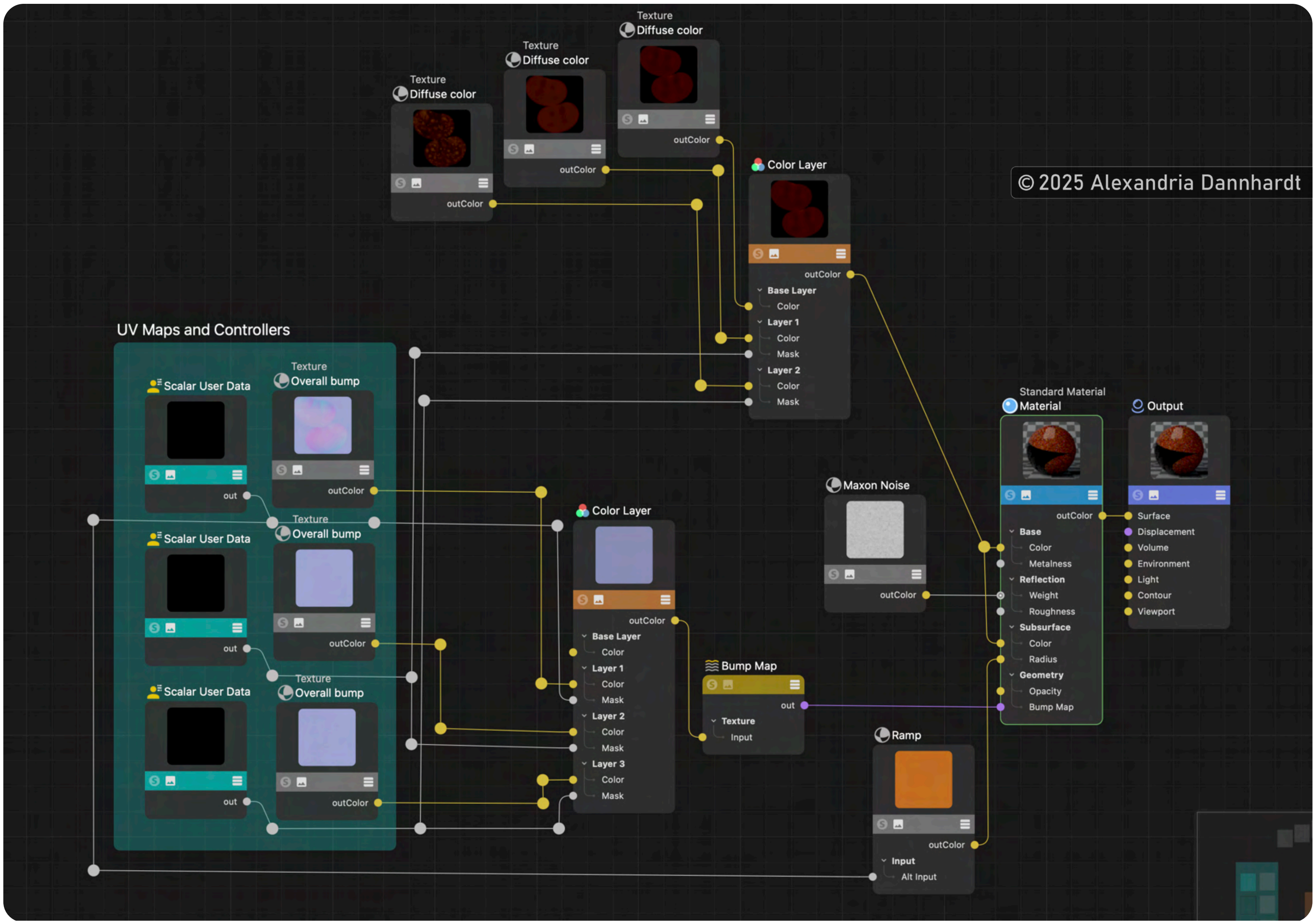


Figure 10. Cinema4D screenshot showing RedShift material on kidneys. Text not intended to be read.

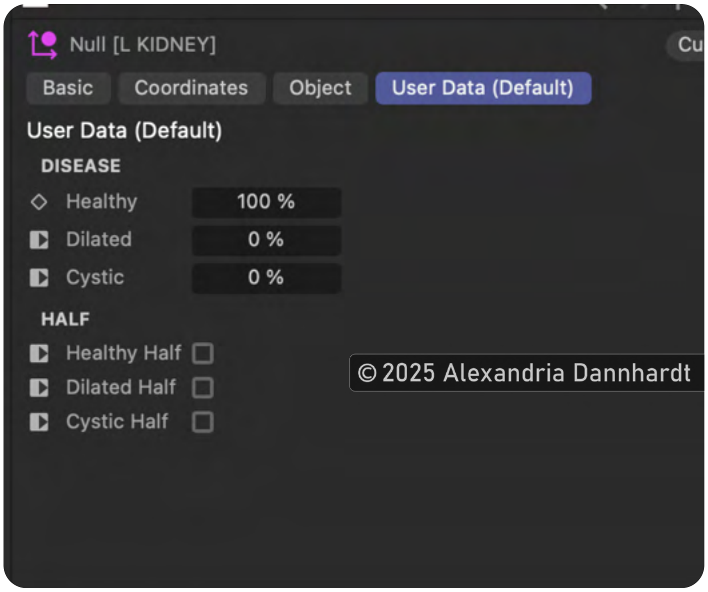


Figure 11. Cinema4D screenshot showing the User Data controls on the Kidney Controller.

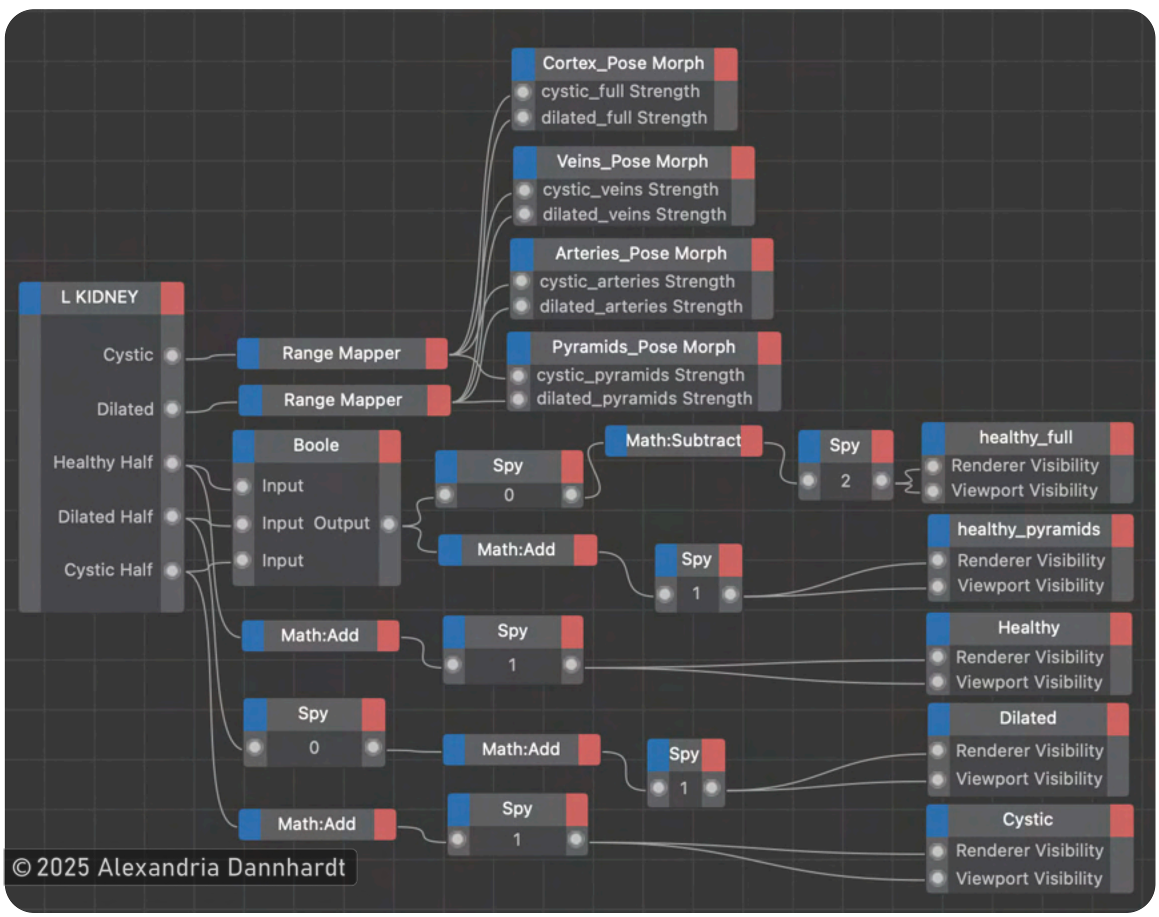


Figure 12. Cinema4D screenshot showing the XPresso nodes on the Kidney Controller.

Urinary Bladders

Similar to other assets, the bladders were designed to morph between different states, allowing control over how they fill and how they change morphologies. Two meshes of empty bladders (a healthy bladder and an empty bladder with an incomplete urethra), and the three LUTO variations (posterior urethral value (PUV), atresia, stricture) were made, ensuring each mesh had both an inside and an outside (**Figure 13**).

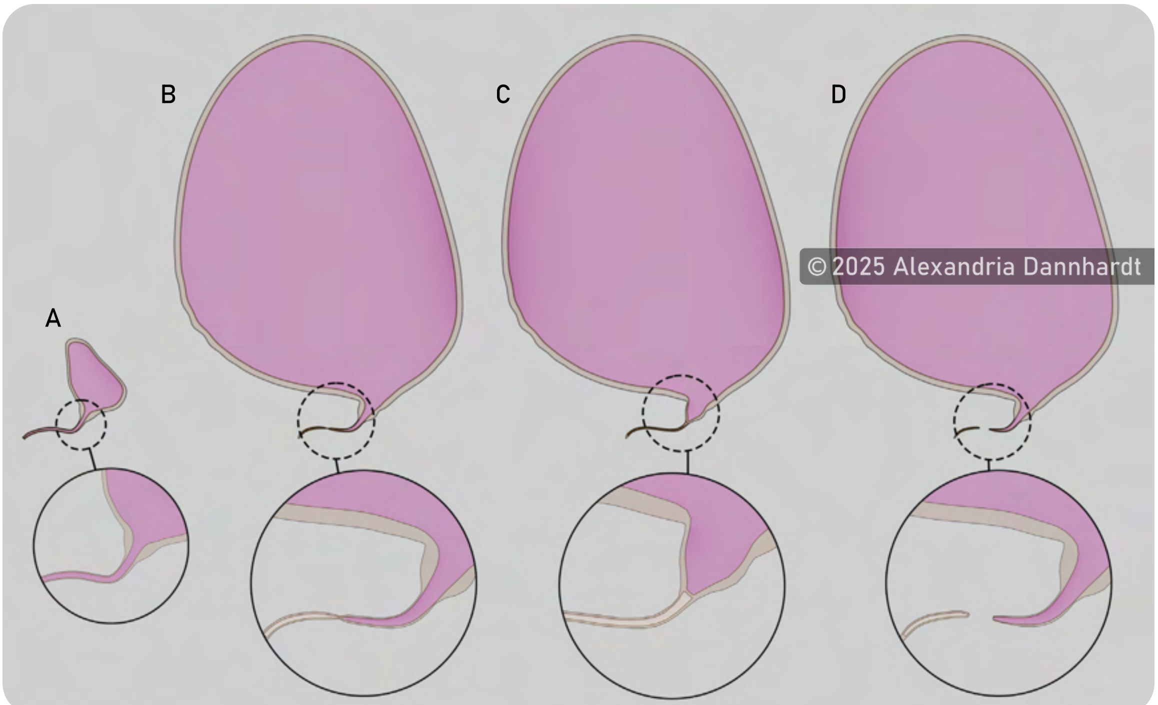


Figure 13. Cinema4D render of the various bladders, including (A) a healthy bladder, (B) a bladder with urethral stricture, (C) a bladder with PUV, and (C) a bladder with urethral atresia.

To optimize polycount, a LUTO bladder was used as the base mesh, as it was the largest model. ZWrap was used to conform this base mesh to the other LUTO sculpts. For the empty bladders, some manual adjustment to the base mesh was needed to approximate the smaller sculpts before using ZWrap. Once complete, the bladder meshes were imported into Cinema4D, where Pose Morph states, XPresso (**Figure 14**) and User Data sliders (**Figure 13**) were set up, enabling seamless morphing between states.

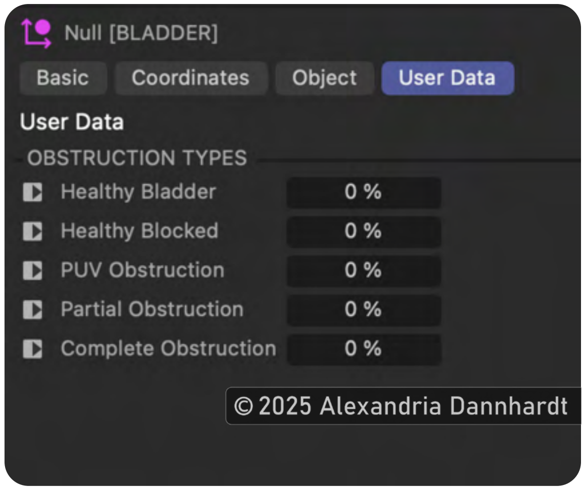


Figure 15. Cinema4D screenshot showing the User Data controls on the Bladder Controller.

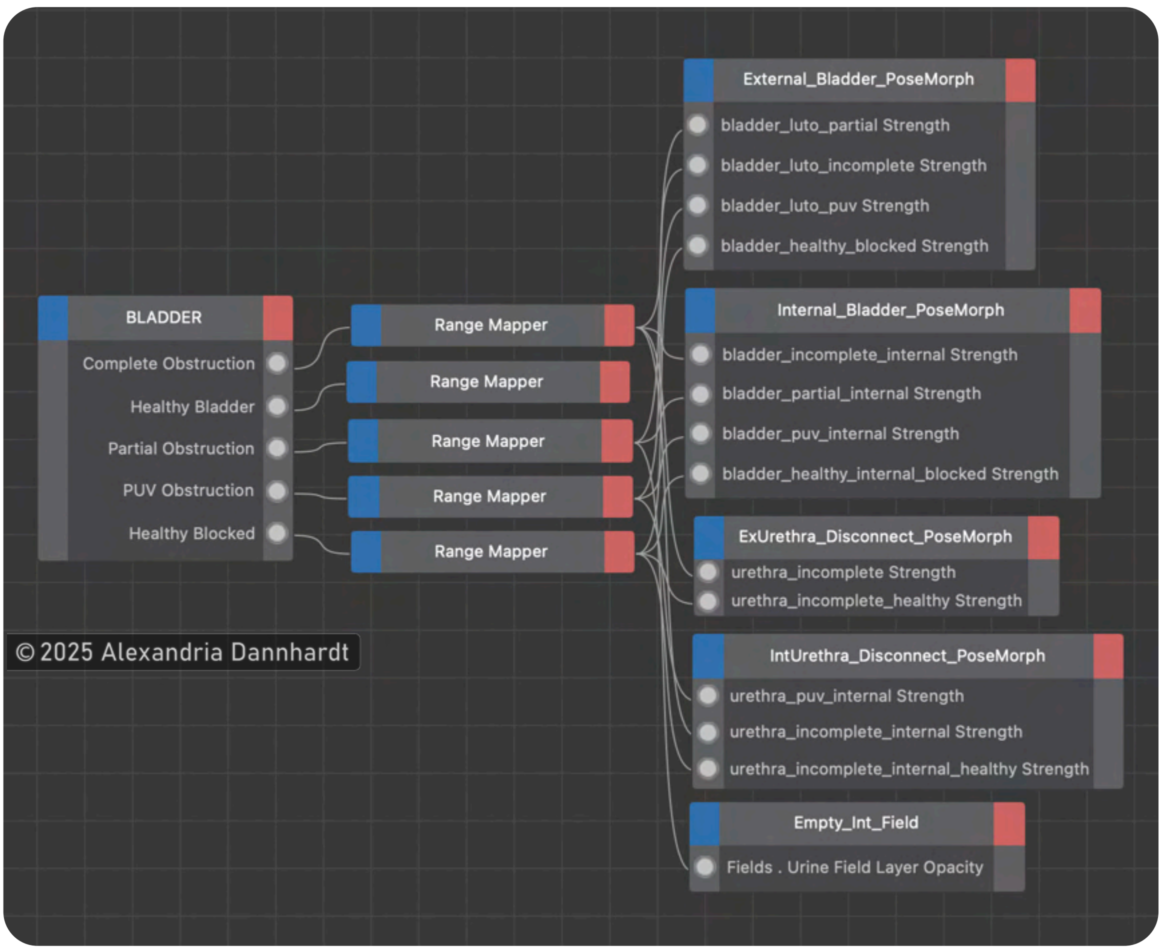


Figure 14. Cinema4D screenshot showing the XPresso nodes on the Bladder Controller.

Materials Setup:

- **Opaque material:** The opaque material used the rounded corners node in the displacement input for smooth transitions between ureters and bladder (**Figure 16**).
- **Transparent material:** An additional material was created for the outside of the bladder that had animatable transparency (**Figure 17**). The transparency was controlled with a Vector Map and linked it to a field, which controlled the opacity node of the pass-through bladder material. This allowed for dynamic transparency adjustments using fields.
- **Internal Material**: For the inside, a similar setup was used, but the Vector Map influenced a color ramp, so that the field could be used to indicate the presence or absence of "urine." This material a slight contour and transmission to give the appearance of a flat color, tying the white "no urine" color to a Vertex Map/field for precise control (**Figure 18**).

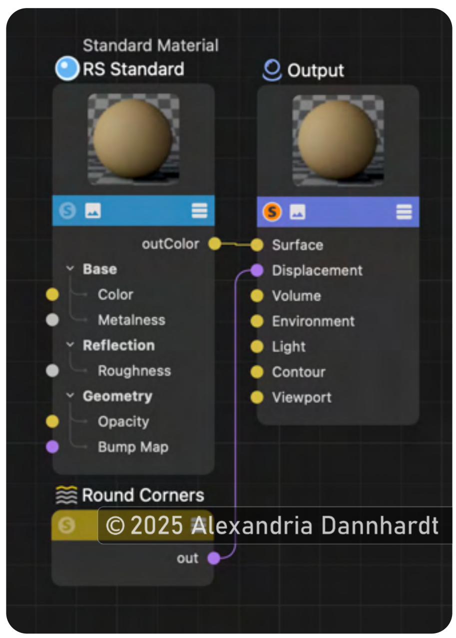


Figure 16. Cinema4D screenshot showing opaque RedShift material on the bladders.

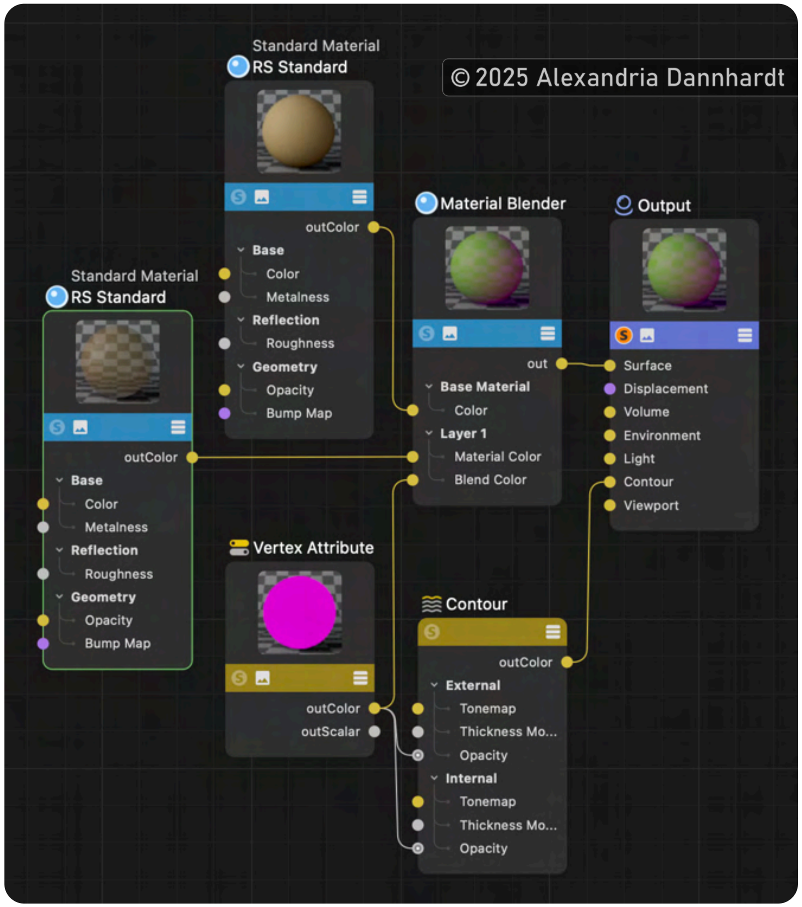


Figure 17. Cinema4D screenshot showing transparent RedShift material on the bladders. Text not intended to be read.

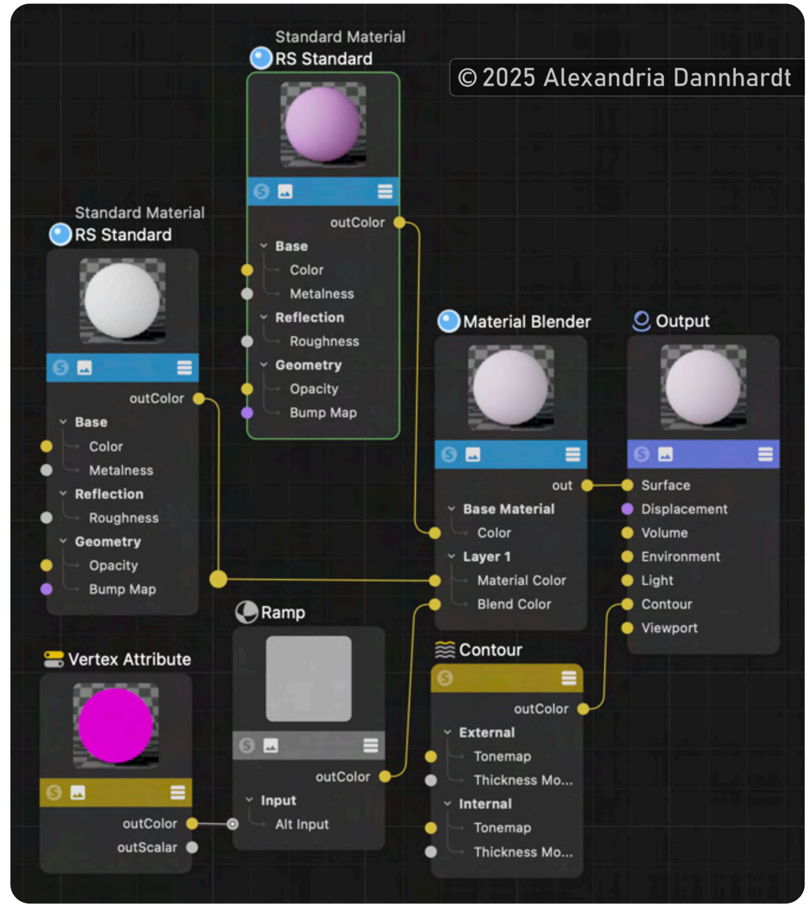


Figure 18. Cinema4D screenshot showing internal RedShift material for the internal bladder. Text not intended to be read.

Lungs

Lungs were sculpted in ZBrush, starting with healthy lungs and a full bronchial tree, then simplifying for earlier developmental stages (**Figure 19**). Each stage looked visually distinct from each other, exaggerating the differences so the viewer would be able to see the growth. Once the lungs were modeled, a LUTO bladder was imported for reference, and TPoseMesh with the Topology Move tool (BMT) was used to compress the lungs into their deformed state. The mid-development 12-week lungs was chosen for this purpose because their smoother, less-defined appearance subtly reinforced the idea that they were unable to develop properly.

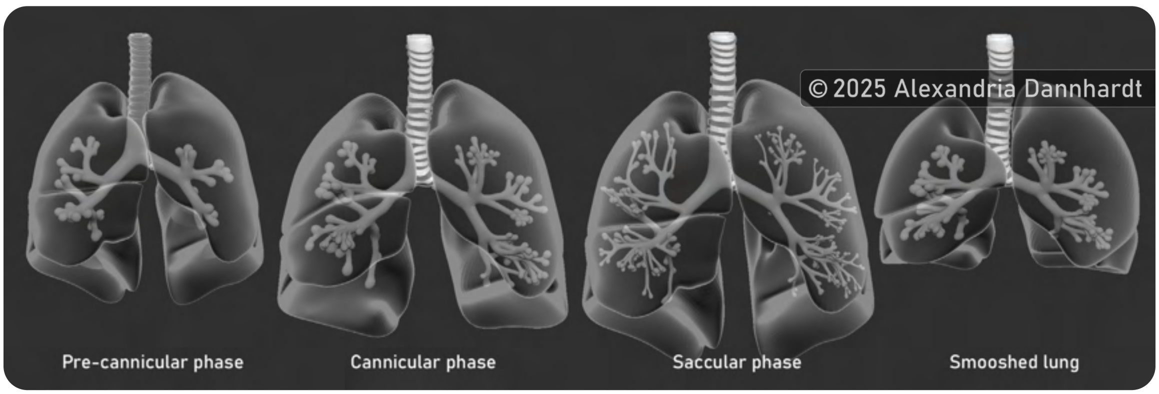


Figure 19. ZBrush screenshot showing the lung models. Lung tissue is transparent.

Pose Morph and Automation:

As with previous models, a base mesh was created for the trachea, cartilage rings, and lung tissue, then ZWrap was used to generate Pose Morph-able meshes. These were imported into Cinema4D, where simple materials were applied and User Data (**Figure 20**)/XPresso controllers (**Figure 21**) were set up to manage the Pose Morphs.

To simulate breathing, a displacer deformer was added under each lobe of the lungs, and the deformer's strength was linked to a User Data slider, allowing control over inflation and deflation from the parent null. Through XPresso, User data toggles were set up to control visibility different states of the lungs, such as viewing the bronchial tree or adjusting the transparency of the lung material, which could be keyframed as needed.

Finally, the diaphragm was sculpted in ZBrush, and its deformations and visibility controls were integrated into the lung User Data controllers.

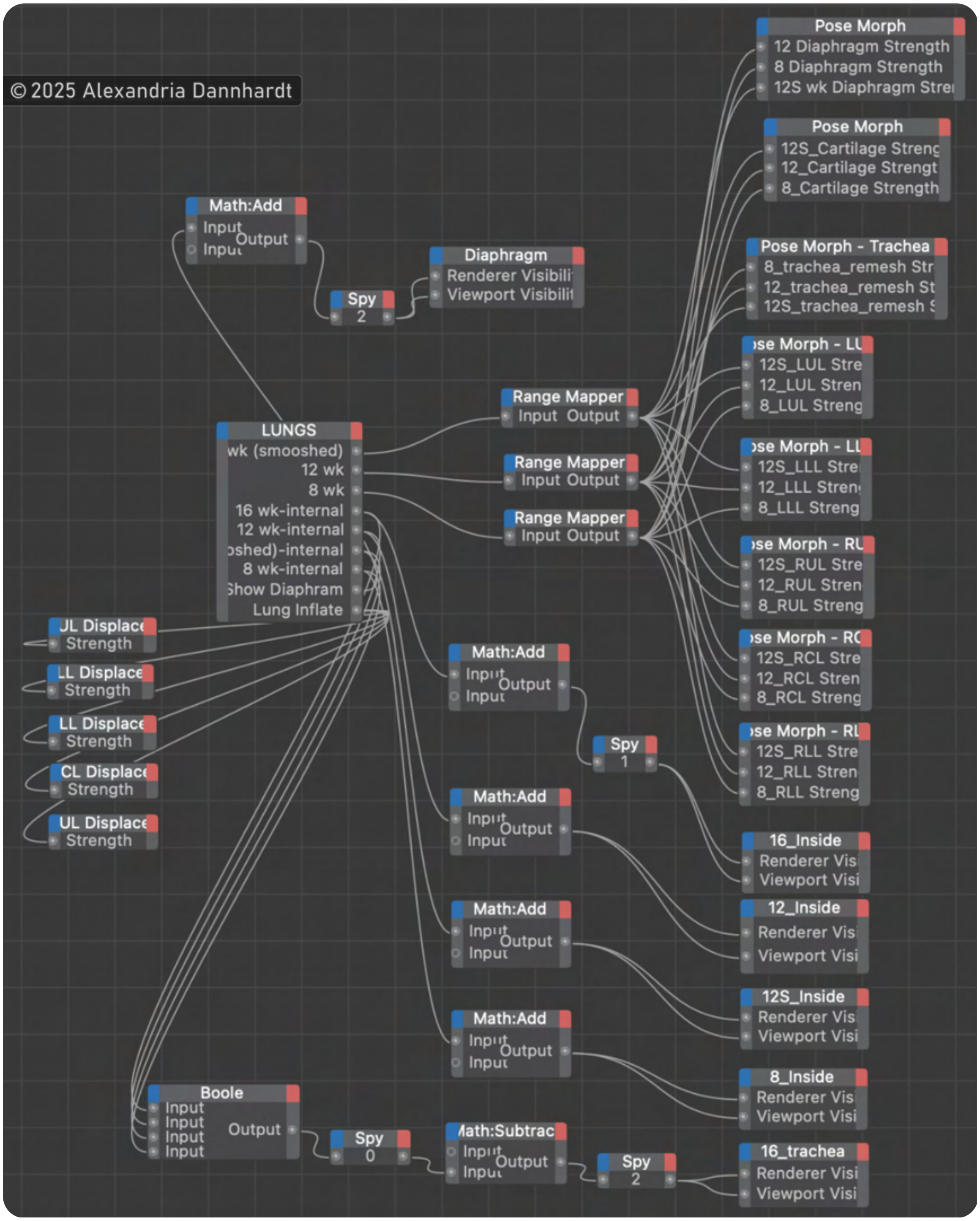


Figure 20. Cinema4D screenshot showing the XPresso nodes on the Lung Controller.

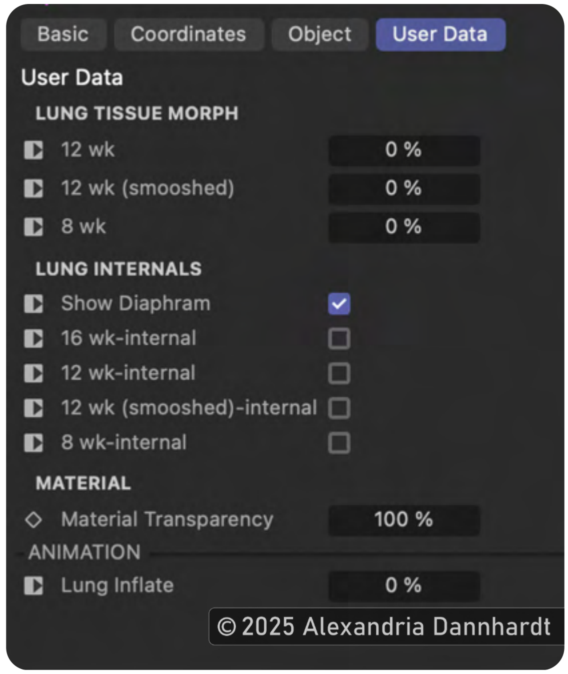


Figure 21. Cinema4D screenshot showing the User Data controls on the Lung Controller.

Ureters

For the ureters, two rough splines were made using the Spline Sketch tool in C4D , focusing primarily on form and placement. To ensure even point distribution, a Matrix object was used to place 25 cubes along the spline. A Tracer object then connected these cubes, resulting in a smoother spline with evenly spaced points. The spline was baked down, and this process was repeated for the "unhealthy" ureters. Maintaining the same point count for both splines was crucial to use a Pose Morph tag to morph between the two splines, and the Matrix/Tracer workflow made this achievable.

Next, a sweep object with a circle gave the splines width. A Pose Morph was applied to the ureter spline, enabling morphing between the healthy and unhealthy states. However, the morph deformer affected the entire ureter at once, which looked unnatural. The goal was for the ureters to fill up gradually and become more "wiggly" over time.

To achieve this, a morph deformer was linked to the Pose Morph so that fields could be used to control into the animation. A linear field, moving in the Y direction, simulated the ureters backing up. Two base circle sizes were defined—0.5 cm for the healthy state and 3 cm for the unhealthy state—to represent the different stages of dilation. Displacement fields were also added to adjust thickness at specific points, such as thickening near the renal pelvis or thinning where the ureters pressed together at larger sizes.

All parameters—the strength of the deformers, the position of the morph field, and the size of the root circle—were linked to a User Data slider using XPresso (**Figure 22**) This allowed the entire effect to be controlled with a single keyframe (**Figure 23-24**).

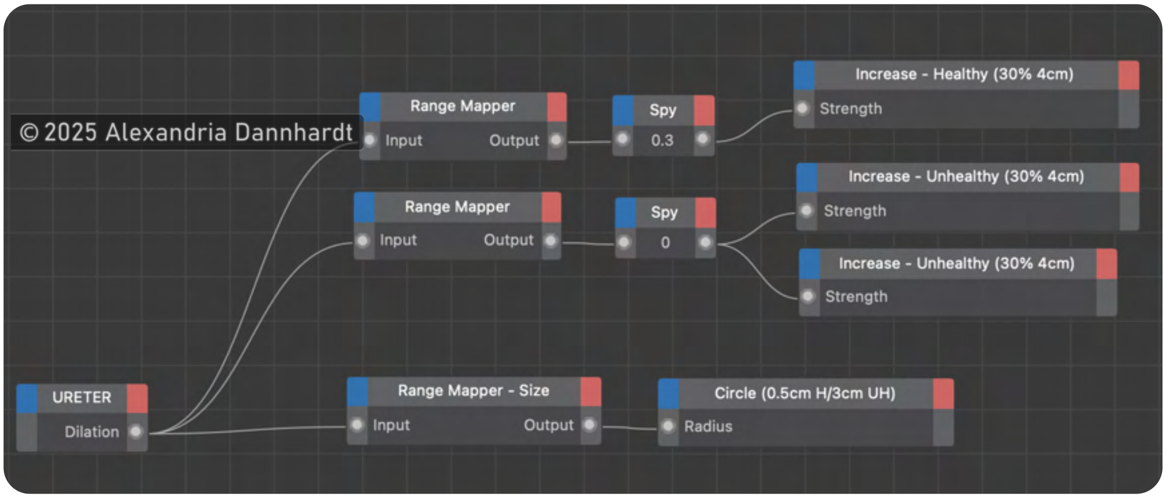


Figure 22. Cinema4D screenshot showing the XPresso nodes on the Ureter Controller.

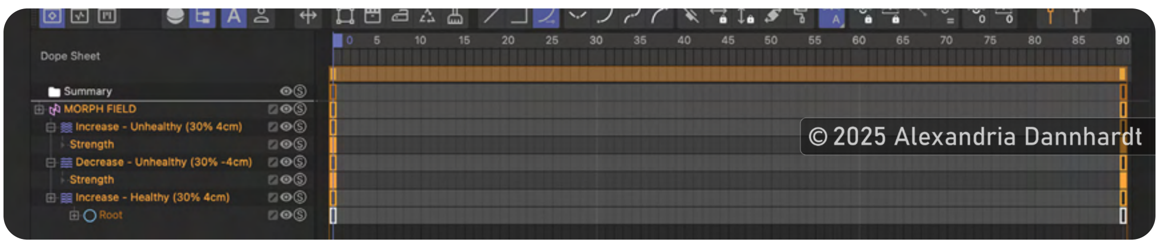


Figure 23. Cinema4D screenshot showing the number of keyframes needed to dilate the ureters without an Xpresso controller. Text not intended to be read.

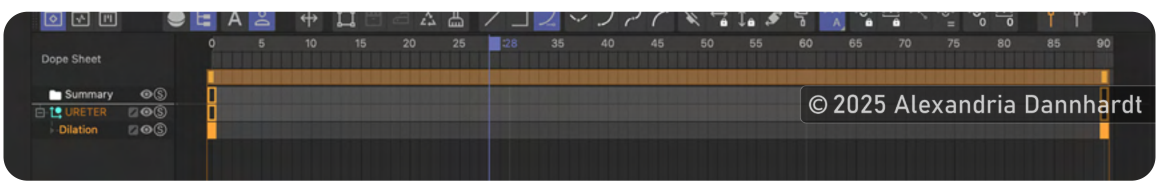


Figure 24. Cinema4D screenshot showing the keyframes needed to dilate the ureters with an Xpresso controller. Text not intended to be read.

Finally, the same material that was used for the opaque bladder was applied to the ureters. The rounded corners node in the material ensured a cohesive look between the bladder and ureters.

FFD for Organ Positioning

Once all the organs were completed, a FFD (Free-Form Deformation) was nested into an instance of the entire organ block (**Figure 25**). This setup allowed deformation of the organs as a unified group, ensuring they could bend and move naturally with the fetus. It also provided a way to gently adjust their positioning if they clipped through the posed fetal skin.

Using the FFD allowed for significant non-destructive flexibility, making it easier to refine the placement and movement of the organs throughout the animation.

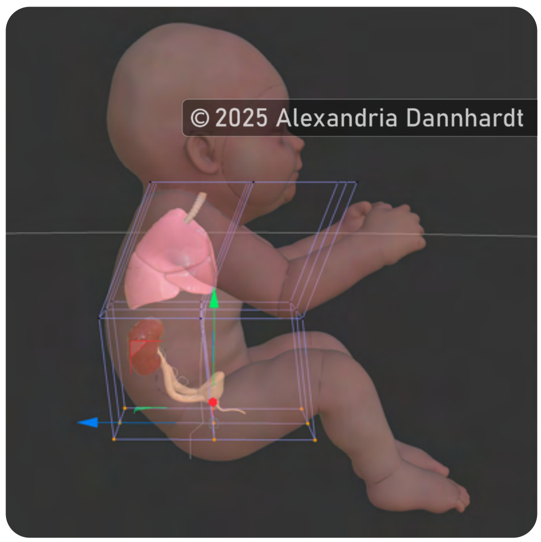


Figure 25. Cinema4D screenshot showing the FFD deforming the organ block.

Uterus

Both forms of the uterus—compressed and non-compressed—were sculpted in ZBrush. Materials were created in Cinema4D. User data sliders controlled the Pose Morph transition between the two states. To create a cross-sectional view, a cube in a Boole operation was used to dynamically slice the uterus in half.

Amniotic Fluid

The amniotic fluid was procedurally generated using the uterus model in C4D. The interior points of the uterus were referenced to create an instance, which then was used in a Volume Builder/Mesher to generate the fluid mass (**Figure 26**). Instances of the fetal and placental models were subtracted from the fluid, and an instance of the cube used for the Boole operation for the uterus sliced the fluid in half. After smoothing the fluid, a displacer was added with animated noise to create gentle ripples on the surface, ensuring it looked dynamic and alive—nothing in this animation was meant to appear static.

The fluid was given a slightly blue hue to offset the dominant red tones without introducing green or grey. Transparency was added to enhance the liquid effect, and carefully placed lights highlighted the edges, reinforcing the illusion of fluidity (**Figure 27**).

Figure 26. Screenshot from Cinema4D of the amnotic fluid made in a Volume Mesher.

Figure 27. Render from Cinema4D showing the amnotic fluid.

Placentas

ZBrush Placenta

Two versions of the placenta were made. The first is a highly detailed, realistic model that floats behind the fetus. This version was sculpted in ZBrush, and hand-painted with several texture maps to enhance its realism.

A hand-painted Depth map defined the opacity of the edges, as well as the amount of SSS. The maps ensured that the modelled vasculature had low SSS (**Figure 28**). The depth map included hand-painted vasculature, causing the edges of placenta to transition into fine capillaries, ensuring it didn't resemble a solid organ, like the spleen. Instead, the placenta took on the appearance of a soft mucosal mass, which is more characteristic of a placenta. Giving it this appearance also allows it to fade into the background and not be a distracting object in the frame.

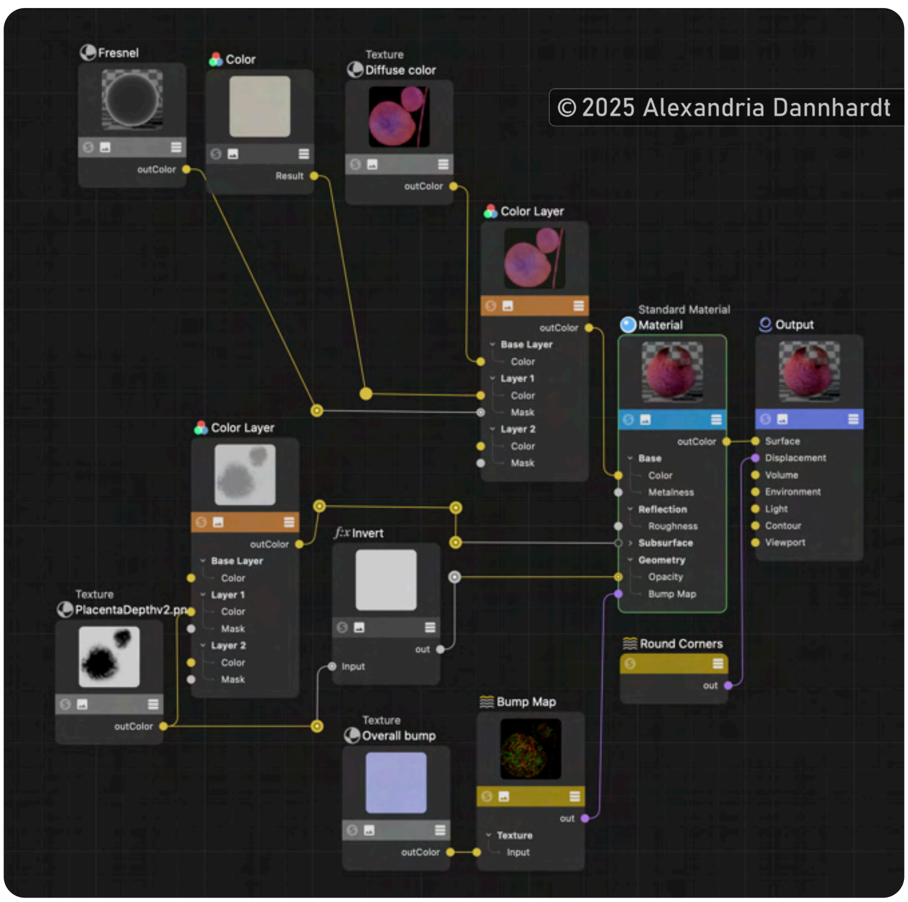


Figure 28. Cinema4D screenshot showing RedShift material on placenta. Text not intended to be read.

Procedural Placenta

The second placenta is a simpler, flat plane that conforms to the top of the uterus. Designed to avoid distracting from the scene, it was created using a Volume Builder/Mesher in C4D and given a subsurface red material. This version has two states—uncompressed and compressed—controlled by a Pose Morph. The Pose Morph percentage was linked to the User Data tag on the uterus, allowing the placenta to compress in sync with the uterus (**Figure 29**).

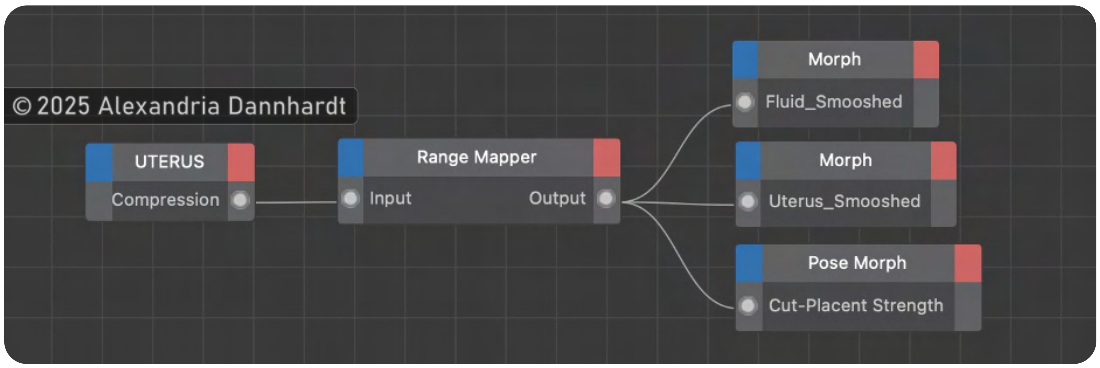


Figure 29. Cinema4D screenshot showing the XPresso nodes on the Uterus Controller.

Umbilical Cord

The umbilical cord was constructed using three sweeps in C4D: one for the 2 arteries (the source, a pair of off-center circles) and one for the vein (sourcing a larger off-center circle), and the umbilical cord epithelium (sourcing a combined version of the vein and artery, smoothed and enlarged slightly). Since all circles share a common center axis, the "twist" function was used on the sweep to twist the entire cord. Each set of arteries, the vein and umbilical cord epithelium were created as individual sweeps, then duplicated using cloners to achieve the full length of the twisted cord (**Figure 30**). The clones were grouped under a parent object, and an instance was created. This instance was referenced by a Spline Wrap with an up-vector of 180 degrees. The Spline Wrap sourced the umbilical guide spline, which had rope dynamics.

Figure 30. Cinema4D screenshot showing a unit of the twisted umbilical vein and arteries.

Spline and Dynamics

To create a smooth spline for the spline wrap, a Matrix object was used to evenly distribute cubes along a rough spline drawn with the Spline Sketch tool. A Tracer connected these cubes, resulting in a smoother spline with evenly spaced points—essential for rope dynamics. After baking the spline, a rope tag was applied and two constraints defined:

1. A standard rope constraint at the far end, attached to the placenta.
2. A rope belt tag at the proximal end, linked to a hidden cube.

Since Cinema4D doesn't allow direct constraints to a point on another object, an XPresso Point Node was used to link the global position of the cube to the global position of a specific point on the fetus (**Figure 31**). That point's reference number was identified in the Structure Explorer.

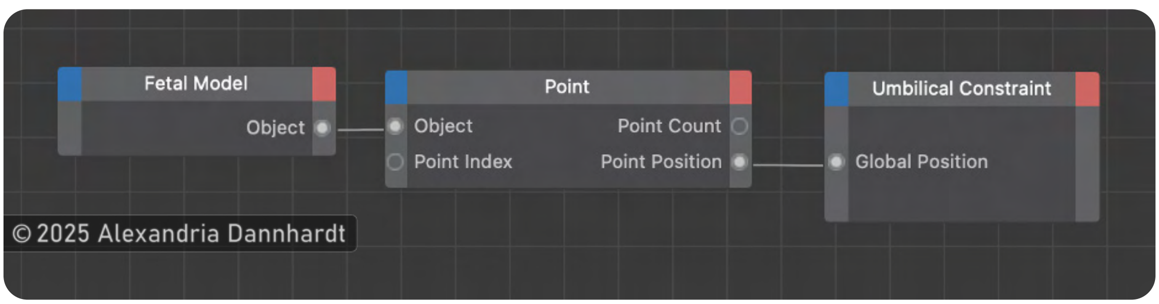


Figure 31. Cinema4D screenshot showing the XPresso nodes on the umbilical rope-tag constraint object.

With this setup, the umbilical cord moves naturally with the fetal belly, while the other end remains attached to the placenta.

Hard Surface Assets

The remaining assets were created either in ZBrush for static objects—such as the needle, diaper, cloth, and medical equipment—or procedurally within Cinema4D.

Procedural Assets:

1. **Cables and Medical Equipment**:
   These were created using mainly sweeps along splines, with additional details (like the ends or the connection points to the fetus) added through quick ZBrush sketches. The diaper, for example, was a ZBrush model. Animation was achieved using displacers or point animation along the source splines.

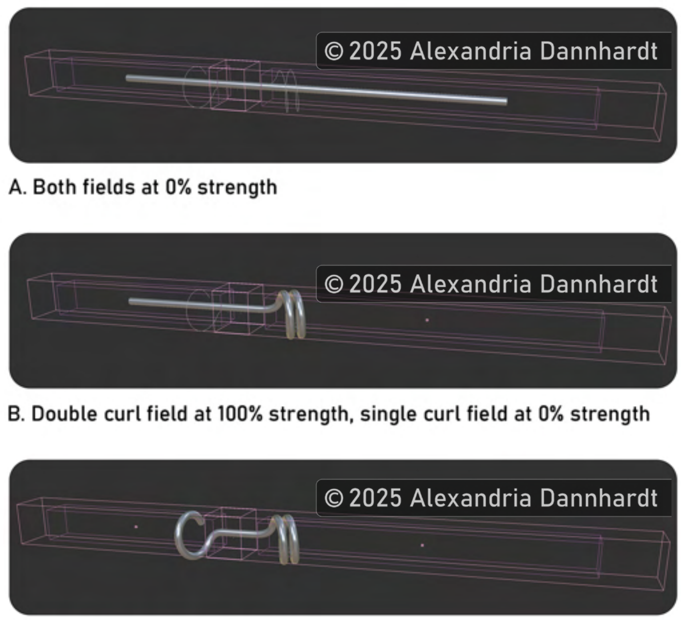
2. **Dialysis**:
   The dialysis setup was built using a spline with a sweep. The liquid inside was represented by a smaller diameter sweep referencing an instance of the same spline. Animation was applied using start/end points to simulate the flow of liquid.

3. **Pigtail Shunt:**
   The pigtail shunt was created using two splines for the two states of the shunt. The first spline, which was the form of the curled shunt, was built with a helix spline in Cinema4D, which was made it editable, and manually shaped by pulling the two curl ends apart and tilting them to the appropriate angles. To ensure uniform topology, the Matrix/Tracer technique was used.

   The second spline had the same point count but was completely flat. A Pose Morph was applied to this spline, referencing the curled shunt, allowing it to morph between the flat and curled forms. A spline sweep with a ring was added to give the shunt thickness.

   To control the deformation, a morph tag was linked to the Pose Morph and fields were used to manage the transition. To ensure only one side deformed at a time while maintaining a smooth transition, two large Box fields were made on the morph tag. The transitions were controlled by manipulating the fields' strength (**Figure 32**).

   Once the setup was complete, an instance of the entire arrangement was placed in the fetal bladder. The size and positioning of the shunt were confirmed with fetal therapy doctors. While standard instructions typically place the single coil inside and the double coil outside, the doctors explained that they flip this configuration for fetal surgery to reduce the risk of dislodgement.



A. Both fields at 0% strength

B. Double curl field at 100% strength, single curl field at 0% strength

C. Both fields at 100% strength

Figure 32. Cinema4D screenshot showing the effect of the fields influencing the pig-tail shunt's Morph deformer.

2D Assets

The icons for the different doctors were made in Illustrator using the pen tool, after first sketching them out on paper. The designs were kept simple and light, ensuring they complemented the overall visual style without overwhelming the scene.

For the transplant scene, the sutures were hand-painted onto an exported frame of the healthy kidney. Although animating the transplant was initially considered, its brief appearance on screen made additional movement unnecessary. A static representation was chosen instead to maintain focus on the key elements of the scene.

Lighting

The lighting design was intended to evoke specific moods and environments throughout the animation. For the beginning scenes, a cool blue/purple scheme (**Figure 33-A**) was initially used, which contrasted well with the red organs and skin tones. However, this approach felt too clean and visually flat, failing to convey the intended atmosphere.

Ultimately, a dark red background with a yellow light was chosen to create the sensation of being inside the body. This combination evoked warmth and depth, aligning with the desired emotional tone (**Figure 33-C**). For the final chapter, "Treatments," the lighting transitioned to a light purple background (**Figure 33-B**) to convey a more clinical and sterile environment, contrasting with the earlier womb scenes.

A. Cool blue environment   A. Purple environment   C. Red environment

Figure 33. Cinema4D renders showing the different lighting enviroments considered.

Lighting Setup

- **Womb Environment**:
  The womb scenes were lit using RSEnvironments and a dome light to provide ambient illumination. To minimize shadows and maintain a soft, diffuse look, front-facing area or directional lights were avoided. Instead, a large circular area light was nested so that it would always oppose the camera's position, ensuring the fetus was consistently backlit. This approach enhanced the subsurface scattering (SSS) effect, giving the fetus a lifelike appearance.

- **Amniotic Fluid Scenes**:

  Additional lights were placed to the left and top of the scene, set to illuminate only the amniotic fluid (**Figure 34**). These lights highlighted the fluid's edges and created a sheen, adding depth and richness to its appearance. This technique made the presence (or absence) of the fluid visually distinct.

A. No fluid lights A. Fluid lights

Figure 34. Cinema4D renders showing the effect of the fluid lights.

- **Outside of the Womb:**

  For the final scene, after the baby is born, the lighting was significantly brightened to signal a change in environment. A directional area light was positioned from the top left, simulating a more natural, external light source and contrasting with the earlier womb lighting.

Figure 35. Cinema4D render showing the bright external light.

Animating

Using the voiceover and the animatic as a guide, the duration and key points of each scene were noted (**Figure 36**), along with their corresponding frame numbers for the entire video. These frame numbers were then converted to scene-specific frame numbers ("relative frame"), starting at frame 25 to provide approximately one-second of buffer at the beginning and end of each scene.

Frames v2

Animation Frame	Relative Frame	Notes
2020	000	Buffer
2045	025	Shot start
2090	070	Unblur
2175	155	Urethra blocked, buffer 30 each side
2225	205	Blur (15 frames)
2340	320	Unblur (15 frames)
2400	380	See urine backing up
2500	480	Injured kidneys
2645	625	Multicystic
2745	725	Dilated
2850	830	Begin diaphragm compression
2950	930	Lung compression finish
2975	955	Begin zoom out
3000	980	Rest on zoom out
3060	1040	Shot end
3085	1065	Buffer

Figure 36. Screenshot of frame notes.

Fetus Animation

The fetus was animated primarily using sliders and the rigging system. For each scene, the fetus was animated first, and then the umbilical cord animation was cached.

Umbilical Cord Animation

The umbilical cord was animated using constraints and the rope tag, which minimized manual effort. To achieve natural movement, alight turbulence was applied to the cord, the simulated damping was set to 50%, and the collision passes, smoothing iterations, and simulation substeps were raised to simulate a slow, underwater-appearing movement. The animation was then cached for consistency.

For collision detection, an issue was encountered where the fetus mesh (in its posed state) could not function as a collider. Specifically, the collider tag on the fetus model would reference the default pose of the fetal mesh, not the animated mesh. To resolve this, an instance of the fetus was created (and the uterus, when necessary) and used a Volume Mesher/Builder to generate a dynamic collision object. The meshes were slightly dilated to prevent unwanted collisions.

In some cases, the simulation did not produce the desired results. To address this, either a slight wind force was added to guide the cord's movement, or the cord was manually animated by deleting the rope tag and animating the source spline directly.

Urine Animation

The urine was created using a particle emitter, with fields and deformers controlling its flow. A turbulence field was applied to create a natural spread, while a circular field near the stream's origin provided initial direction and force. A wind field was also used to refine the flow direction. Once the particle simulation achieved the desired behavior, it was cached using Alembic for consistency (**Figure 37**).

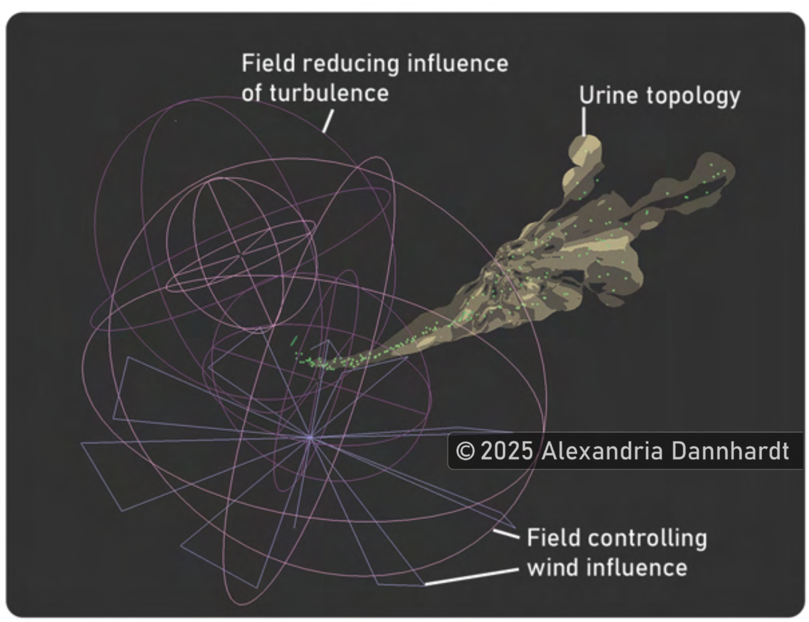


Figure 37. Cinema4D screenshot of the fields influencing the urine particle simulation movement.

The particle simulation was nested within a Volume Builder/Mesher. The point radius was set to a neutral value, and a Dilate node was employed with a spherical field to enlarge the urine stream further from the body. Closer to the body, an Erode node was used with another spherical field to narrow the stream and refine its radius (**Figure 38**).

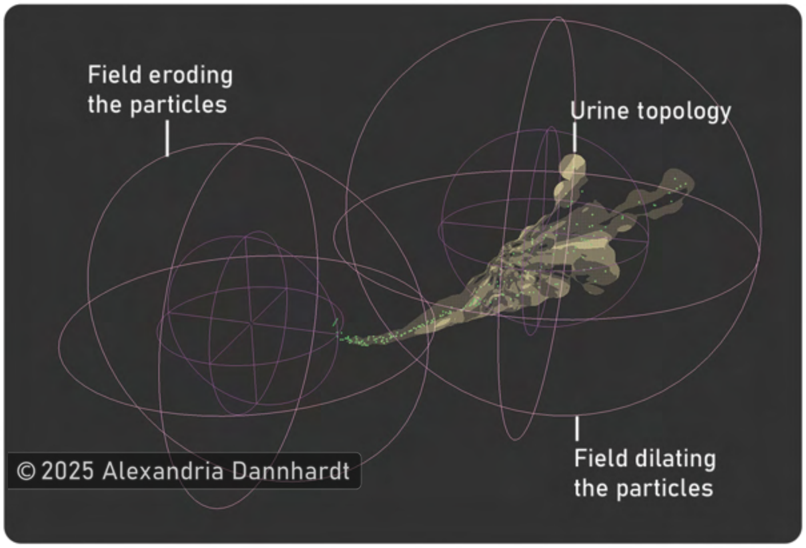


Figure 38. Cinema4D screenshot of the fields influencing the urine particle appearance.

To replicate the effect of urine pouring into liquid—a challenging task in 3D due to the limitations of solid shapes— a Vertex Map tag was added to the Volume Builder/Mesher, which was controlled by a spherical field positioned away from the body. This Vertex Map was ported into the material using a Vertex Attribute node, and its field strength was converted into a black-and-white scale with a Ramp node to control transparency (**Figure 39**). This allowed the urine stream to fade naturally as it moved away from the body.

The opacity was layered in a Color Layer using a Fresnel node to soften the edges of the stream and an animated Maxon Noise texture to create the appearance of eddies within the fluid. This combination ensured the stream avoided a blocky, topological look and instead appeared fluidlike.

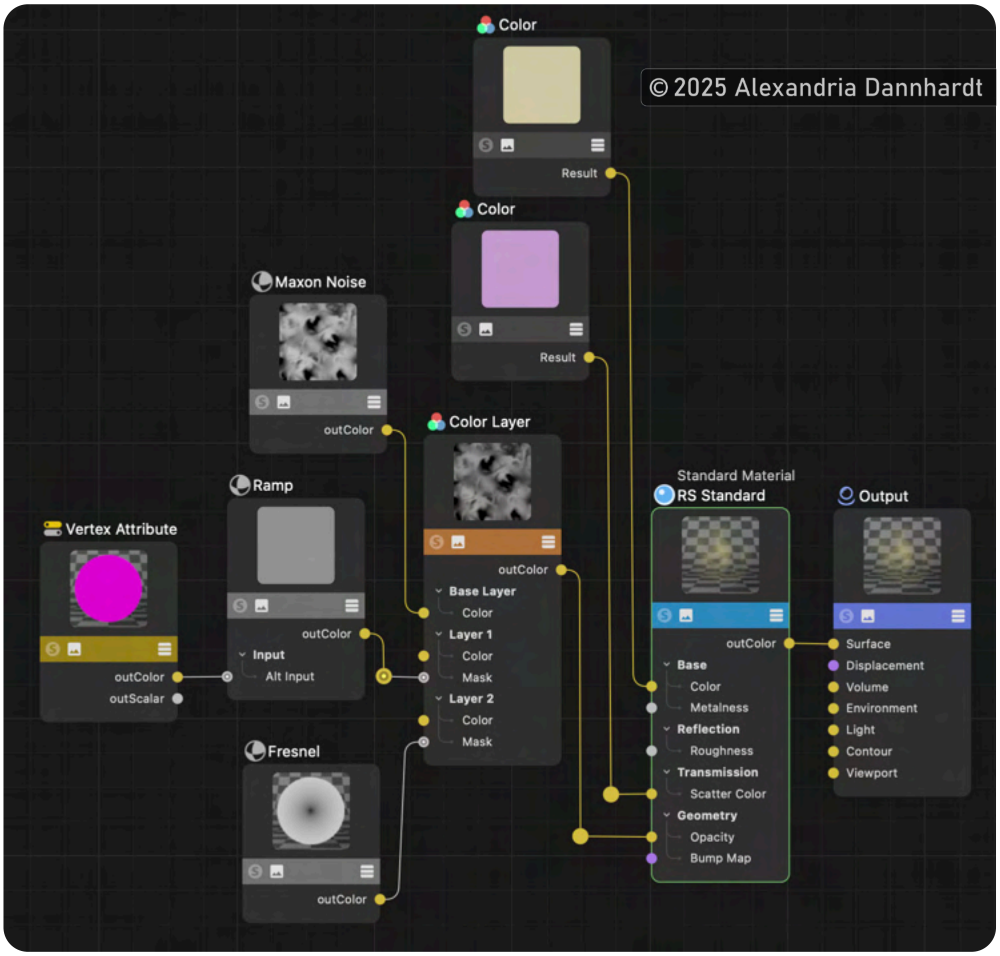


Figure 39. Cinema4D screenshot showing RedShift material for urine. Text not intended to be read.

Camera Animation

Camera movements were designed to be smooth and controlled to maintain a professional and polished look. To achieve this, a track—such as a circle spline referenced by an Align to Spline tag on the camera— was combined with an animated null object that acted as the camera's target through a Target tag. Both the track and the target were keyframed simultaneously to create controlled motion.

- The **target's position** was animated to achieve tilts or tracking shots, guiding the camera's focus.

- The **circle track's Y position and diameter** were adjusted to create dollying effects, such as moving inward or orbiting around the subject.

This dual-control approach ensured that camera movements were fluid and intentional, avoiding abrupt or erratic swings.

Preparing for Render

Once the animation and timing were finalized, a viewport preview of the scene was exported, typically with the fetus in X-ray mode to visualize the underlying organs. This allowed for a quick export of a timed version of the animation into Adobe AfterEffects, enabling review of the timing and confirming the animation was smooth and natural. After confirming the timing, the necessary passes were rendered at full resolution.

1. **Puzzle Matte Setup**: Redshift render tags were attached to all objects requiring puzzle mattes, and each object was assigned a unique Object ID. These IDs, and the color channels they were assigned to, were documented for reference during compositing.

PuzMattes:
Fetus - AOV1, Fetus B
Umbilical - AOV2, Fetus G
Urine - AOV10, Urine B, Fetus B
Lungs - AOV5, Lungs R
Diaphragm - AOV6, Lungs G
Kidney - AOV7, Organs R
Ureter - AOV8, Organs G
Bladder - AOV9, Organs B

Figure 40. Screenshot of puzzle matte notes.

2. **Transition Planning**: The transitions required for each scene were planned and the necessary "takes" were determined to achieve the desired effect.

Shots:
- Obstructed organs (blur transition) - (120-1065)
    - One with the diaphragm (750-1065), AOV
- Unobstructed organs (blur transition) - (0-140), AOV
- Fetus and urine (0-1065), AOV

Figure 41. Screenshot of shot notes.

Initially, using Cinema4D's built-in "render takes" was explored, but the process cumbersome was cumbersome for the workflow being used. Instead, each take was saved as separate versions of the file with the appropriate rendering settings, object visibility, and frame counts, which were then added to the render queue as separate jobs.

Render Settings Optimization

Render settings were balanced to achieve high-quality visuals while minimizing render times. Given the complexity of the scenes—featuring volume scattering, subsurface scattering, and intricate materials—render times were a significant concern.

To address this, a small Team Render network was set up using the JHU AAM student studio computers. Three classmates who were not using Maxon graciously allowed their computers and licenses to be used. Using Redshift Team Render and their Redshift GPU licenses, the three additional computers were networked together, which reduced render times by approximately 83%. This exceeded the expected time savings for the number of additional licenses used, demonstrating the efficiency of Team Render.

Example Render Times for Scene 9:

- **Render on primary computer only**: 2/11/2025, 5:33 AM to 2/11/2025, 9:37 PM (475 frames, 16 hours and 4 minutes, ~2.03 minutes per frame).
- **Team Render**: 2/15/2025, 3:23 PM to 2/15/2025, 6:05 PM (475 frames, 2 hours and 42 minutes, ~0.34 minutes per frame).

This efficiency was critical for meeting deadlines, as each scene required a minimum of two renders (e.g., only organs and fetus) and often more. Additionally, most scenes were re-rendered an average of three times to accommodate style changes, feedback from content experts, and minor adjustments to timing or glitches identified during compositing.

Composite Passes

Besides the beauty passes, several composite passes for each scene were rendered (**Figure 42**). The set up for each composite pass is as follows:

1. **Fresnel Passes**: All lighting was removed, and materials on relevant objects were replaced with a custom Fresnel material, resulting in black-and-white renders for masking purposes in After Effects.
2. **Depth Passes**: ZDepth passes (using Z-Normalized instead of the default setting) were rendered occasionally without lighting to produce a usable depth pass for compositing.
3. **Puzzle Matte Passes**: These were rendered alongside the main frames as AOV passes, simplifying the compositing workflow.

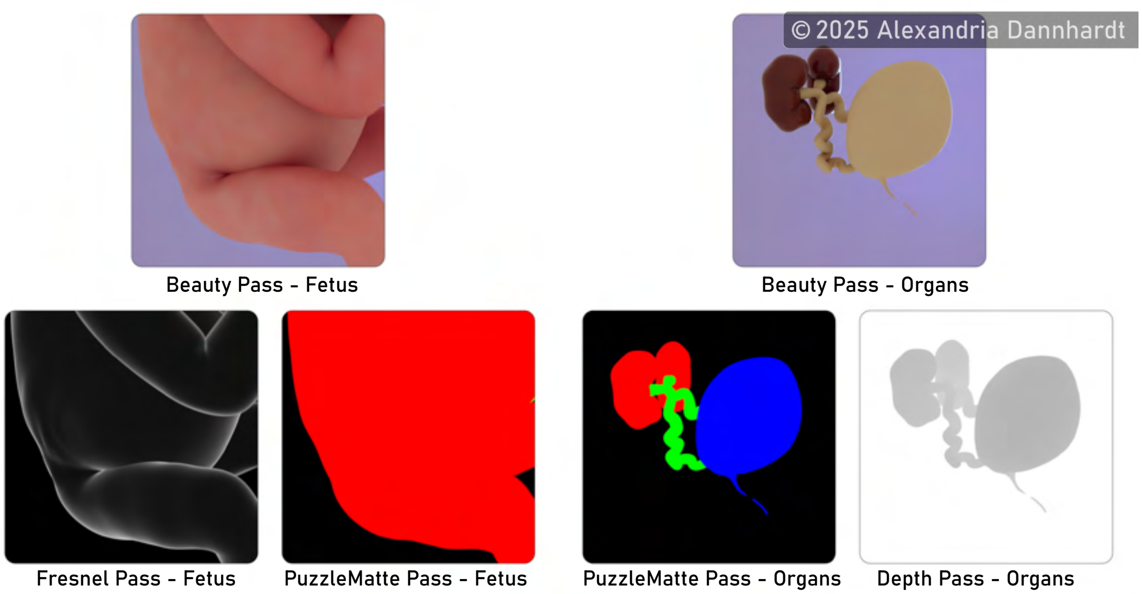


Figure 42. Examples of each render pass rendered from Cinema4D.

Adobe AfterEffects Compositing

The compositing process in AfterEffects involved importing frames rendered in Cinema4D as PNG sequences. The composite layers were structured as follows:

1. PuzzleMattes were placed on top and turned off. A Linear Color Key effect was applied to key out the black, allowing the PuzzleMattes to function as mattes for individual organs/models and for the entire content chunk with the alpha channel.

2. For scenes featuring a transparent fetus (**Figure 43**), the stacking order was as follows:
   - **Fetal render** with a luminance matte applied from the Fresnel pass, ensuring full visibility of edges and overlaps.
   - **Fetal render** with the area of transparency masked out (to preserve the appearance of the face and hands, avoiding a grey or unhealthy look).
   - **Organ render** with a Set Matte effect applied to the alpha channel of the OrgansAOV.
     - When necessary, a depth render of the organs was used, overlayed on "Soft Light" and matted to the organs to further the contrast overlapping organs.
   - **Fetal render** at 50% opacity, with contrast adjusted to -100, and a colorized Hue/Saturation layer to a light red to minimize distractions and color interference in transparent areas.
   - **Background render** of the environment without any foreground elements.

Transitions and Animated Elements

- The Mister Horse plugin (Animation Composer 3) was used for scene transitions, animated text, and pop-ups.
- Labels were created using the Bahnschrift font at 30-45pt, with leader lines set to a 5px width to match the font's thickness.
- The Trim Path effect was applied to animate leader lines.

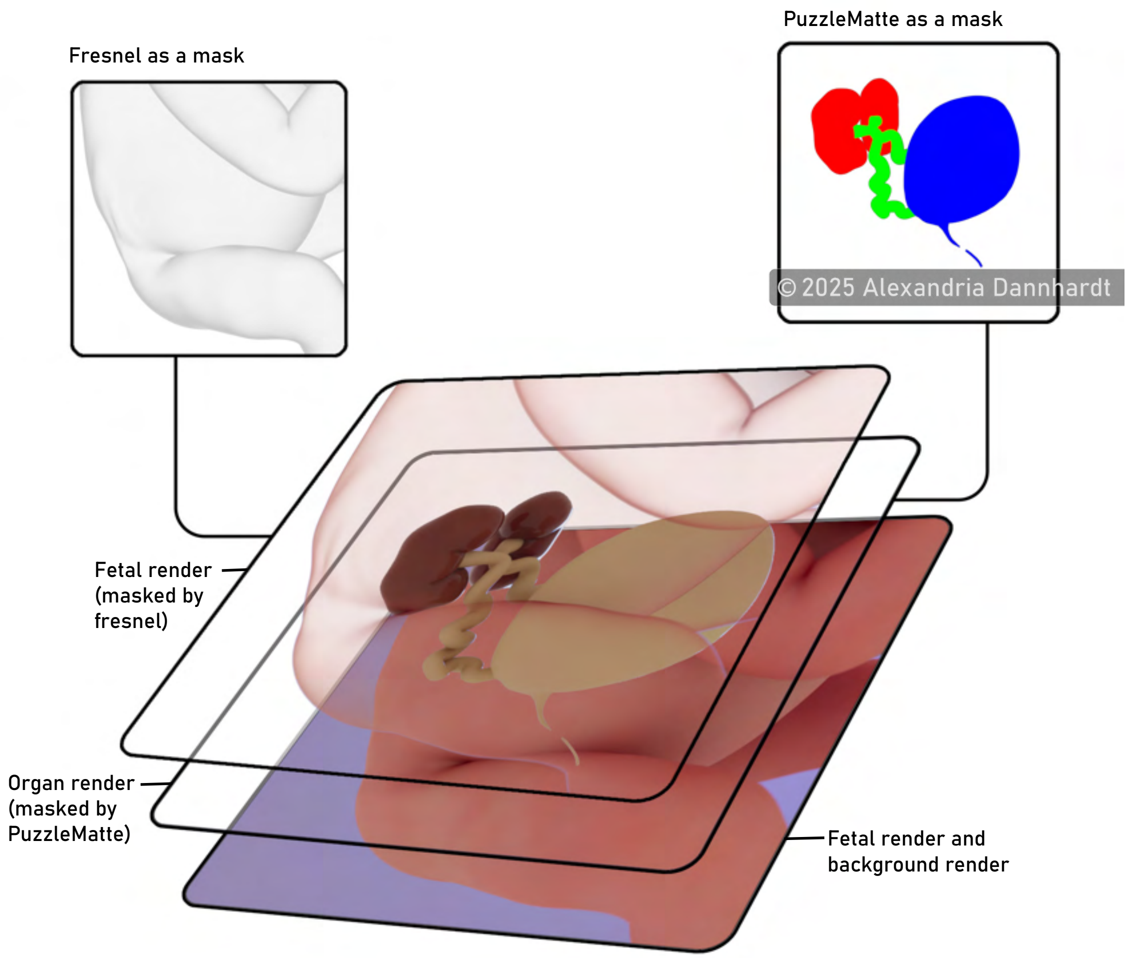


Figure 43. Diagram of the composite layers.

Visual Enhancements

A subtle purple gradient/vignette effect was added around the edges of each scene after rendering. This technique created depth, reinforced the sensation of being "inside," and focused the viewer's attention on the center of the frame by gently darkening the periphery.

Voiceover

The voiceover was provided by Kaden Catalina, who collaborated closely throughout the project. Kaden was selected for their clear diction and female-presenting voice, which was deemed suitable for a video on pregnancy. Their flexibility was invaluable as the video underwent revisions, including changes to wording and scene sequences.

Video Accessibility

To ensure the video was accessible to a broad audience, it was uploaded to YouTube and segmented into chapters, allowing viewers to navigate to specific sections easily. Subtitles were added and made toggleable to accommodate viewers with hearing impairments or those who prefer to watch without sound or with subtitles.

Colorblind accessibility was evaluated using DaltonLens, a colorblindness simulator. The Vienna 2009 simulation method was applied for all three types of colorblindness (protanopia, deuteranopia, and tritanopia) at 100% severity (**Figure 44-46**). This method is widely regarded as the most accurate for sRGB monitors and effectively simulates color vision deficiencies. Since DaltonLens processes only static images, a set of three Look-Up Tables (LUTs) was generated for each type of colorblindness. These LUTs were applied as filters in OBS Studio, enabling the simulation of colorblind viewing conditions across the entire video. This approach ensured that all visual elements remained distinguishable and effective for viewers with color vision deficiencies.

Figure 44. Deuteranopia simulation. Text not intended to be read.

Figure 45. Protanopia simulation. Text not intended to be read.

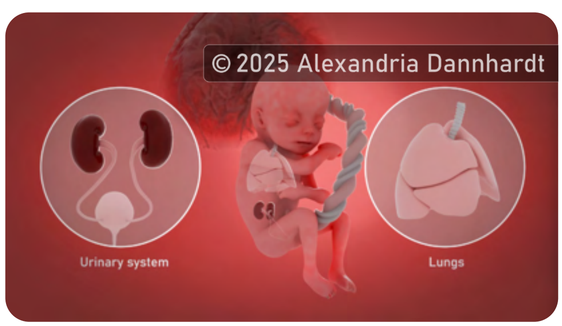


Figure 46. Tritanopia simulation. Text not intended to be read.

Additionally, key visual elements in the video were assessed for sufficient color contrast using the WebAIM Color Contrast Checker (available at https://webaim.org/resources/contrastchecker/). This tool verified that text and critical graphical components met WCAG (Web Content Accessibility Guidelines) standards for contrast, ensuring readability and clarity for all users.

Website Production

The website was developed using Divi (by Elegant Themes), a WordPress-based theme and visual page builder, which provided granular control over design elements and enabled the implementation of scroll transitions for an engaging user experience. To enhance navigation, a reading progress bar was integrated at the top of the page, along with a chapter-based structure that allows users to jump between sections efficiently.

Visual assets, including stills and scenes from the 3D animation, were repurposed to create labeled informational images using Adobe Photoshop. These images were incorporated to make skimming easier and improve information retention. To balance visual and textual content, design techniques such as bolding, highlighting, and strategic spacing were employed to emphasize key information and maintain readability. Each image was designed to convey a single concept, and related concepts were grouped together to reduce cognitive load and improve user comprehension.

The website's layout was designed to prioritize user engagement. The complete animation was placed at the top of the homepage to serve as the primary introduction to the content. Below the video, a hyperlink labeled "Read about this condition" was included to encourage users to scroll down and explore the textual content. This design choice ensures that users are immediately engaged with the animation while providing clear guidance for further exploration. The webpage does not feature any obfuscating interactive elements; although this might increase engagement, we did not want to hide any information behind interactivity or minimize the severity of the condition.

Accessibility was a key consideration throughout the website's development. Compliance with Section 508 standards was verified using ANDI (Accessible Name and Description Inspector), an accessibility testing tool from ssa.gov. This included ensuring proper text contrast, providing descriptive alt text for all images, and confirming that the website is navigable for users with disabilities. Additionally, all images were designed to be colorblind-accessible, utilizing color palettes that are distinguishable by individuals with various forms of color vision deficiency (**Figure 47-49**).

Figure 47. Deuteranopia simulation.
Text not intended to be read.

Figure 48. Protanopia simulation.
Text not intended to be read.

Figure 49. Tritanopia simulation. Text not intended to be read.

Physical Media

Patient Hand-Out

The patient handout was created in InDesign as a double-sided printable summary of LUTO, designed for use in doctors' offices or for sharing with family. Its structure mirrored existing JHU patient education materials for LUTO but significantly reduced the text while increasing visual elements.

Visuals and design elements were repurposed from the animation and webpage to maintain visual cohesion across all three resources. Content was adapted from the webpage and reviewed by subject matter experts. QR codes were added to the second page, providing quick access to key resources, including the JHU LUTO webpage, the thesis webpage, and the thesis video.

Patient Education Anatomical Models

Preparing the Models

To prepare the 3D prints, two posed two fetal models from Cinema4D—one healthy and one with LUTO— were exported to ZBrush using the Go*Z* Exporter. The model was cleaned and a section of the fetus's back was selected to be separated from the fetal hull and attach to the organs. The diaphragm was not included in these prints, as it isn't directly injured in LUTO and wouldn't be a key focus for doctors during explanations.

The kidneys with hydronephrosis were chosen over polycystic dysplastic kidneys for simplicity, allowing parents to easily compare healthy and affected organs. The organ print included the lungs, kidneys, and ureters but omitted the urethra pathology for the LUTO model, as it would either require printing a small remnant urethra (urethral atresia) or remain internal and invisible.

Backplate Design

The backplate had to be large enough to allow the entire organ block to slide out smoothly. The backplate section was Polygrouped and the full model was retopologized to set up a smooth edge loop along the division of backplate and fetal hull. Two semi-circle tabs were made using the circle Slice tool on the backplate to align (or "register") with the fetal body hull once the pieces were divided.

The LUTO fetus was divided into upper and lower sections. The upper section connected to the entire organ block without occluding the kidneys. The lower section could be removed first to reveal the kidneys, followed by the upper section with the organ block (**Figure 50**). This design prevented the kidneys from being obscured by the enlarged bladder and backplate.

The backplate included keys so that it would align with the fetal model, as well as anchor points for small magnets (4mm x 4mm x 1.3mm) so the model would snap together with a .3mm tolerance (**Figure 51**).

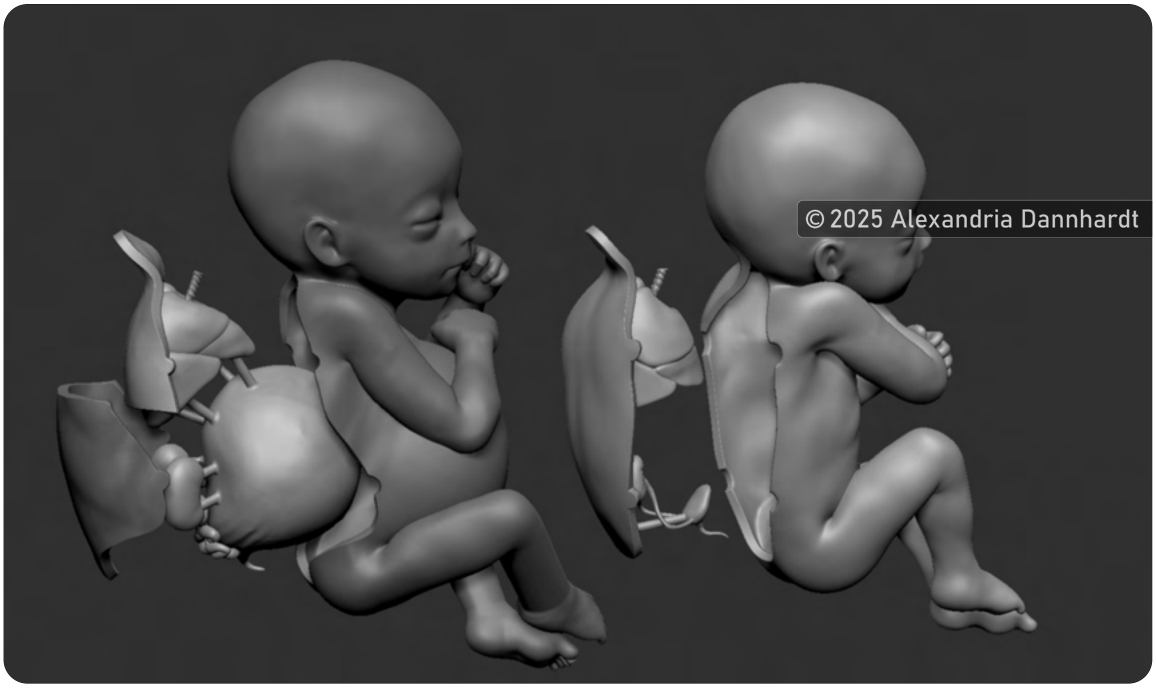


Figure 50. ZBrush screenshot showing the 5 pieces of the print.

Figure 51. ZBrush screenshot showing the tolerances between pieces.

Scaling and Thickness

The scene was scaled using the ScaleMaster plugin so the longest side of the print would be approximately 4 inches, reflecting the size of the fetus at this developmental stage. The fetal hull and backplate were given a thickness of 2 mm using a custom method: PanelLoops with elevation set to -100, polish off, and 0 bevel. This approach conformed closely to the original mesh shape and minimized mesh errors compared to an extrude.

To ensure smooth sliding, the backplate was smaller than the fetal body by 0.3 mm. Both thicknesses were verified using a scale cube imported with the ScaleMaster.

Anchoring and Decimation

The posts anchoring the organs to the backplate had a minimum diameter of 2 mm. The backplate, organs, and posts were combined using a Boolean operation. Finally, the model, backplate with organs, and second backplate (for the LUTO fetus) were decimated to approximately 200k polygons using Decimation Master, prioritizing the organ/backplate section to maintain intricate details while ensuring the model could be easily sliced for printing.

Prototyping

The prints were first printed on a Creality K1 SE printer with PLA (FDM printing) to check scale and confirm the tolerances were appropriate (**Figure 52-54**). FDM printing allows for faster and cheaper prototyping.

Once printed, minor changes were made to allow the pieces to fit together easier, then a second prototype was printed on a FormLabs3A printer (SLA printing) with FormLabs Model resin for the opaque pieces (organs), and FormLabs Clear v4 resin for the transparent pieces (fetal hulls). This prototype would be less fragile, and allowed for higher resolution, as well as clear materials.

Figure 52. 3D-printed prototype with healthy anatomy: (A) posterior view, (B) lateral view, and (C) anterior view.

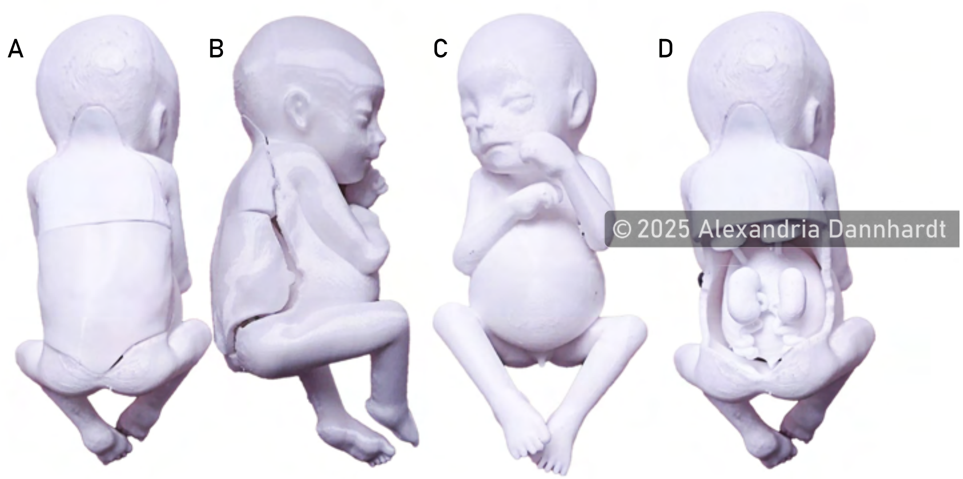


Figure 53. 3D-printed prototype showing LUTO-affected anatomy: (A) posterior view, (B) lateral view, (C) anterior view, and (D) posterior view with internal organs visible.

Figure 54. 3D-printed prototype with organ blocks removed: (A) healthy fetus, (B) healthy organs, (C) LUTO-affected fetus, (D) LUTO-affected organs, and (E) LUTO backplate.

Study Design

The study was conducted with volunteer participants aged 18 and older to assess the efficacy and engagement of the animation. The study was approved by the Johns Hopkins Medicine Institutional Review Board (IRB IRB00486267).

Recruitment

Participants were recruited through social media and the Johns Hopkins Center for Fetal Therapy's Parent Advisory Council, which includes families of prior pregnancies managed by the Center.

Procedure

The survey was administered via Qualtrics, accessible through a link or QR code. The survey flow included:

1. A pre-test to establish baseline knowledge (Q3.1-Q3.9) and confidence (Q3.10).
2. Random assignment to either the control group (viewing current materials – Q4.1) or the experimental group (viewing the narrative animation – Q5.1).
3. A post-test to measure learning outcomes (Q6.1-Q6.9) and confidence (Q6.10).
4. Exposure to the alternative material (whichever was not viewed initially – Q4.1 or Q5.1).
5. An engagement survey to collect attitudes toward both forms of content (Q4.2 to Q4.3, Q5.2 to Q5.3, and Q7.1 to Q7.4).

The survey was designed to take approximately 15 minutes to complete. The full survey is available in **Appendix C**.

Data Analysis

Within the pre-test (Q3.1-Q3.9) and post-test (Q6.1-Q6.9) analysis, for multiple-response questions (select all that apply), each correct answer was awarded +1 point, and each incorrect answer resulted in a -1 point deduction. The maximum possible score for the test was 13, and the minimum was -12. The score potential for each question is detailed in **Table 1**.

	Sum	Q-1	Q-2	Q-3	Q-4	Q-5	Q-6	Q-7	Q-8	Q-9
Min Score	-12	0	-3	0	0	-4	0	2	0	2
Max Score	13	1	2	1	1	2	1	-3	1	-2

Table 1. Score potential for each question in the test.

The normality of the data was assessed using the Shapiro-Wilk test ($\alpha = 0.05$). Since most data sets were non-normal, the Wilcoxon signed-rank test was used to evaluate score changes within each group. For comparisons between groups, an independent t-test was used for normally distributed data, while the Mann-Whitney U test was applied for non-normal data. Engagement survey results were analyzed qualitatively to identify recurring themes.

RESULTS

Narrative Animation

A four minute narrative animation (04:03) was created, which contained four chapters: an Overview of LUTO (00:00-00:27), which summarizes the content the viewer is about to view (**Figure 55-56**); Normal Development (00:27-01:12) which establishes a baseline for how development normal goes (**Figure 57-61**); The Pathophysiology of LUTO (01:12-02:40) which describes the changes seen in a fetus with LUTO and how LUTO effects the fetus (**Figure 62-69**); and Treatments (03:55-04:03) which summarizes some of the potential treatment options and care options after birth (**Figure 70-76**), and credits (**Figure 77**). The video is available on YouTube with subtitles, transcript, and chapter select (**Figure 78**) .

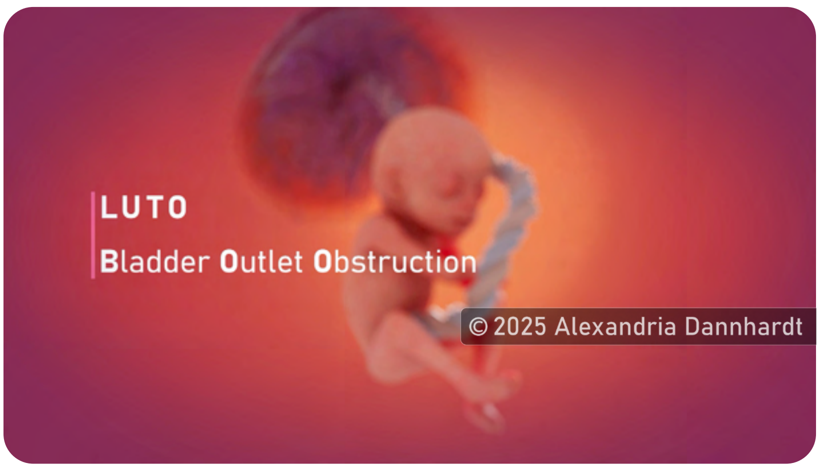


Figure 55. Animation still from “Overview”: Introducing the condition.

Figure 56. Animation still from “Overview”: Introducing the affected anatomy.

Figure 57. Animation still from “Normal Development”: Introducing amniotic fluid.

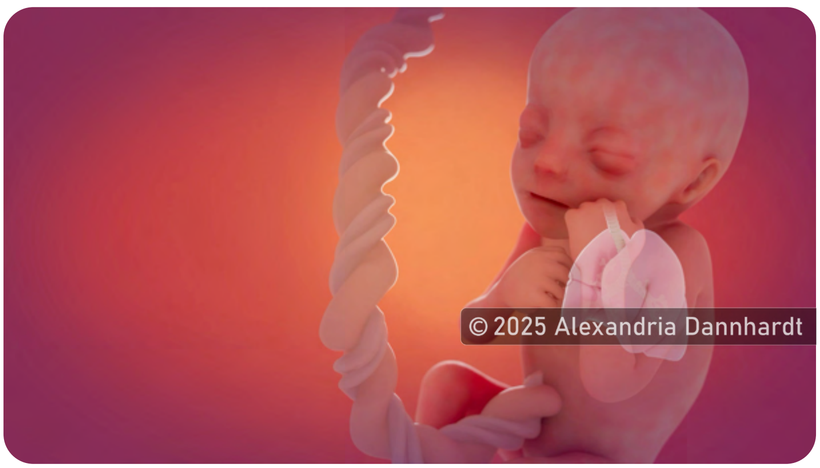


Figure 58. Animation still from “Normal Development”: Introducing lung growth.

Figure 59. Animation still from “Normal Development”: Introducing stages of lung development.

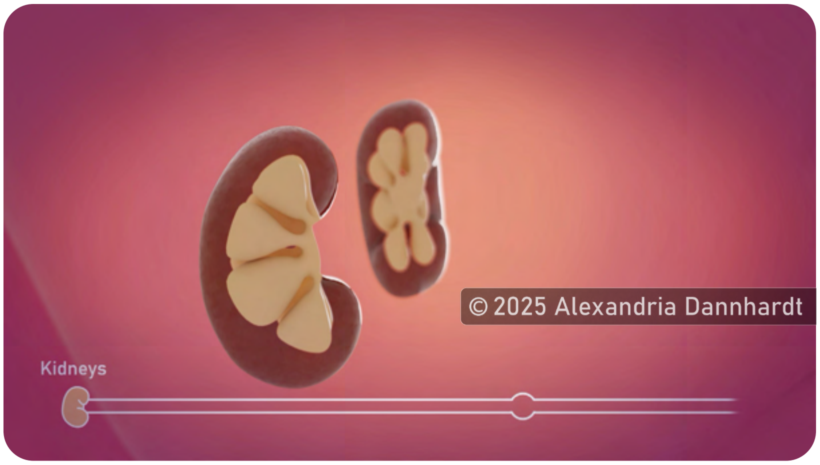


Figure 60. Animation still from “Normal Development”: Normal kidneys and their function.

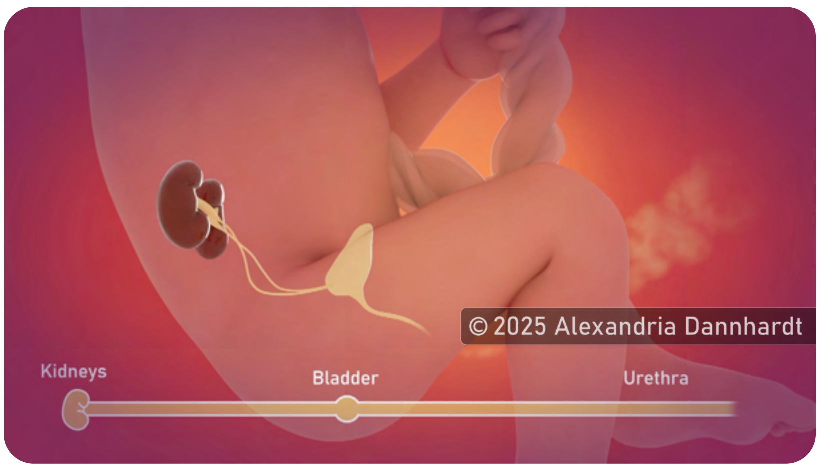


Figure 61. Animation still from “Normal Development”: The function of the organs in the urinary system.

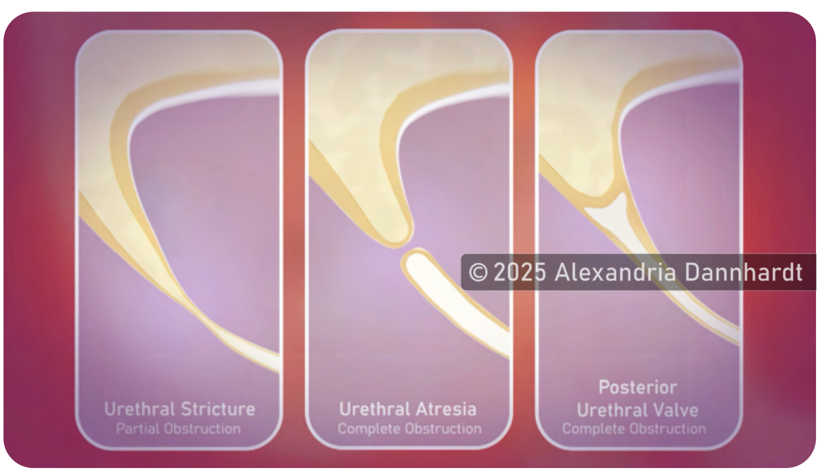


Figure 62. Animation still from “LUTO”: Common structural anomalies that lead to LUTO. Text not intended to be read.

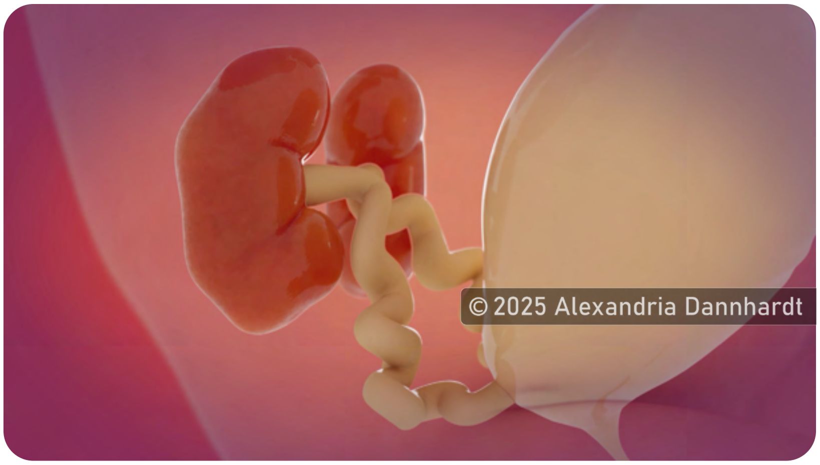


Figure 63. Animation still from "LUTO": Showing the kidney damage.

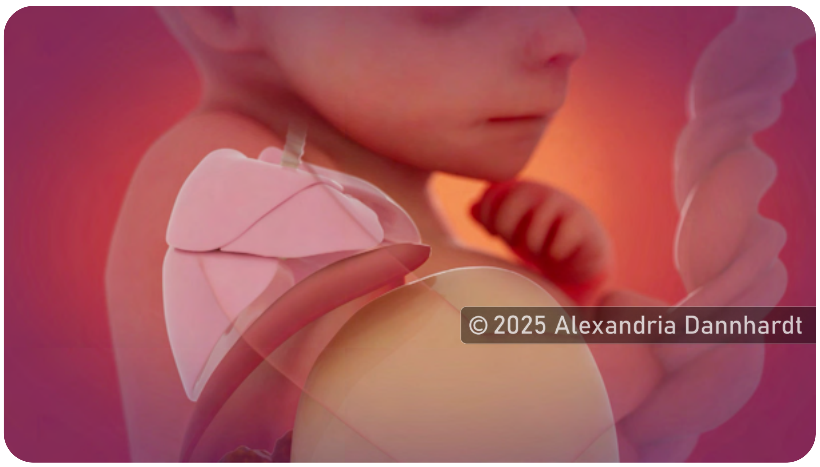


Figure 64. Animation still from "LUTO": The large bladder compresses the lungs.

Figure 65. Animation still from "LUTO": Loss of fluid in the uterus.

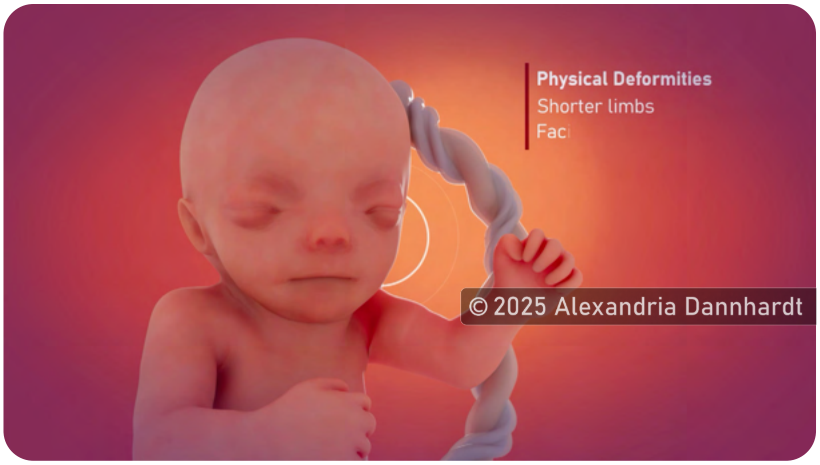


Figure 66. Animation still from “LUTO”: Physical deformities arising from uterine compression.

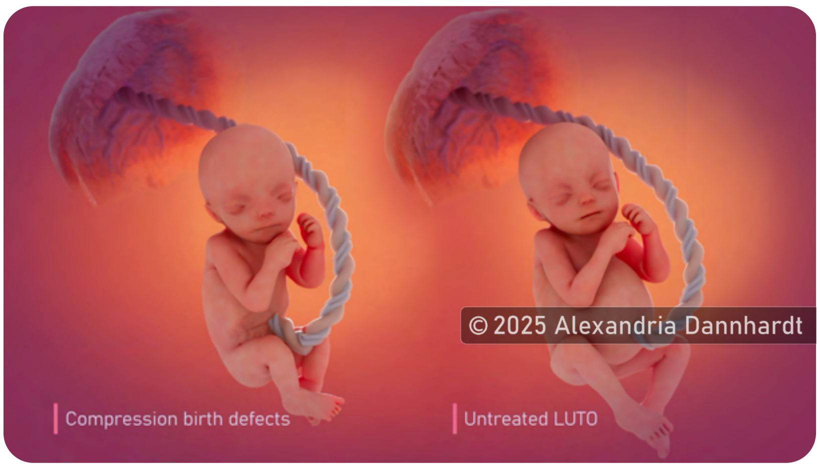


Figure 67. Animation still from “LUTO”: Showing different appearances of LUTO fetuses.

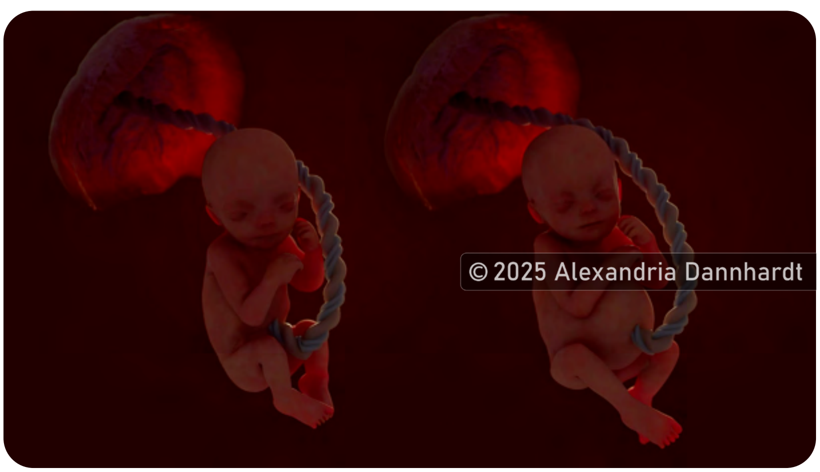


Figure 68. Animation still from “LUTO”: Lights dim to imply the pregancy is not continued.

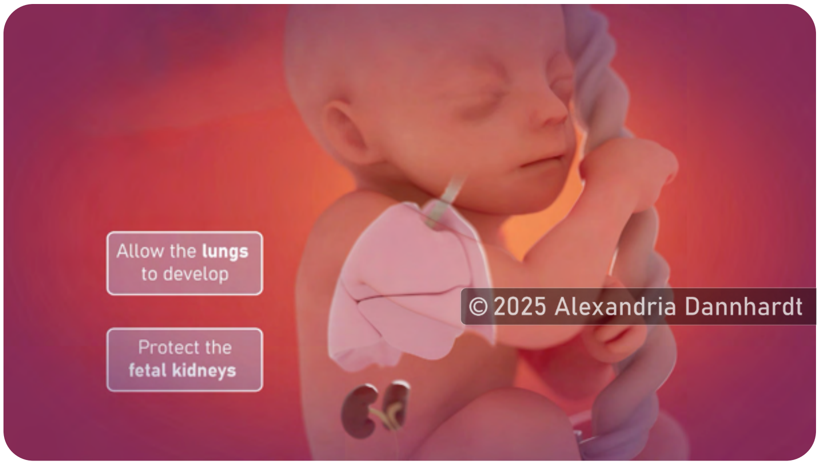


Figure 69. Animation still from "LUTO": Transiting into treatment section.

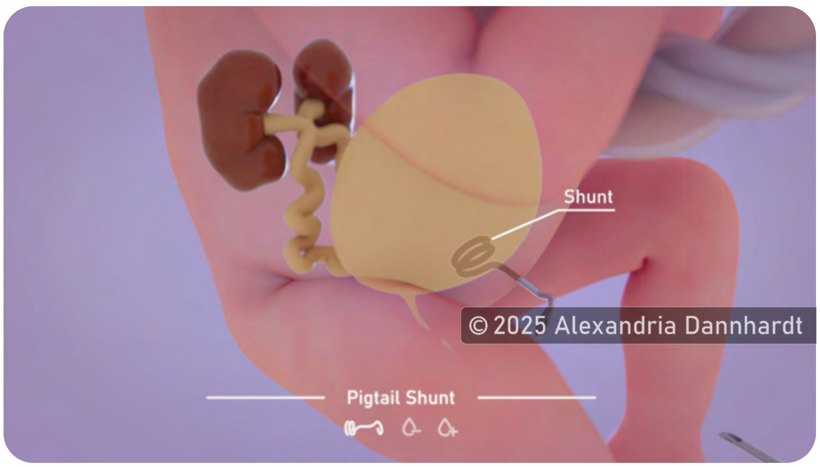


Figure 70. Animation still from "Treatments": Pigtail Shunt.

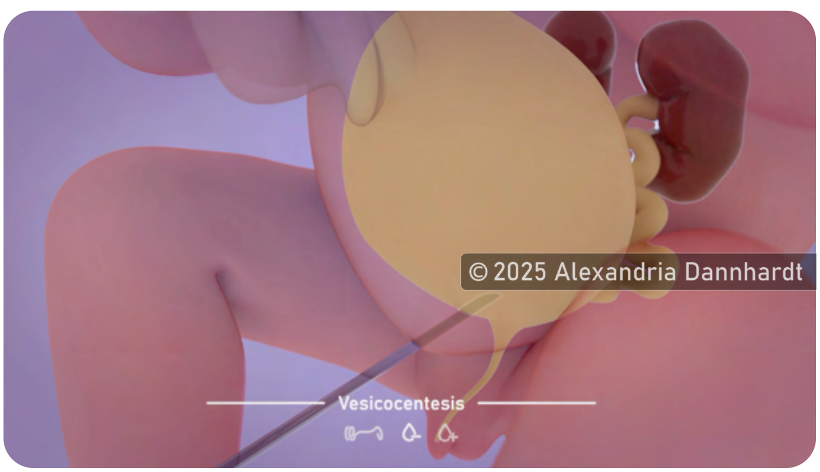


Figure 71. Animation still from "Treatments": Vesicocentesis.

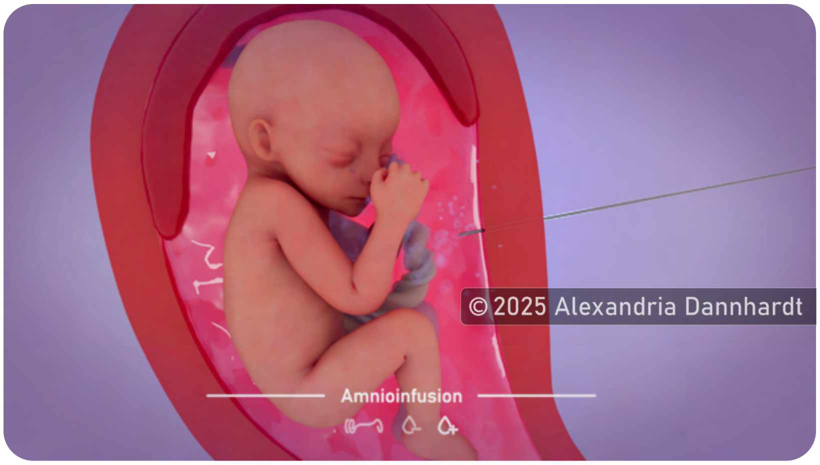


Figure 72. Animation still from “Treatments”: Amnioinfusion.

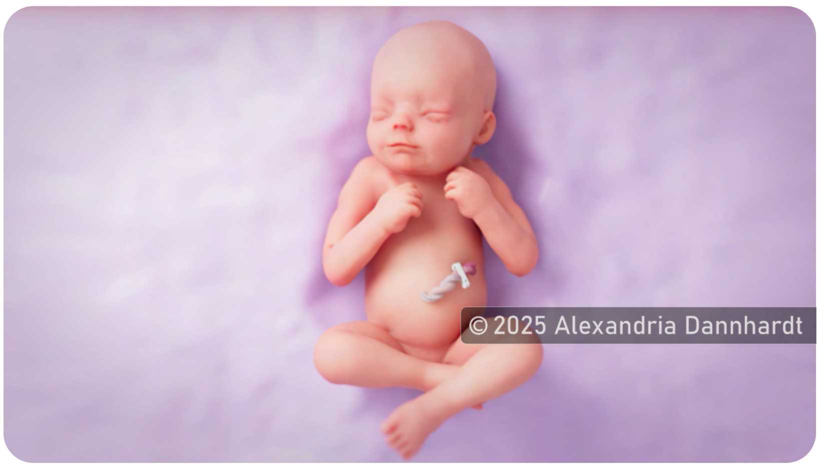


Figure 73. Animation still from “Treatments”: Neonate.

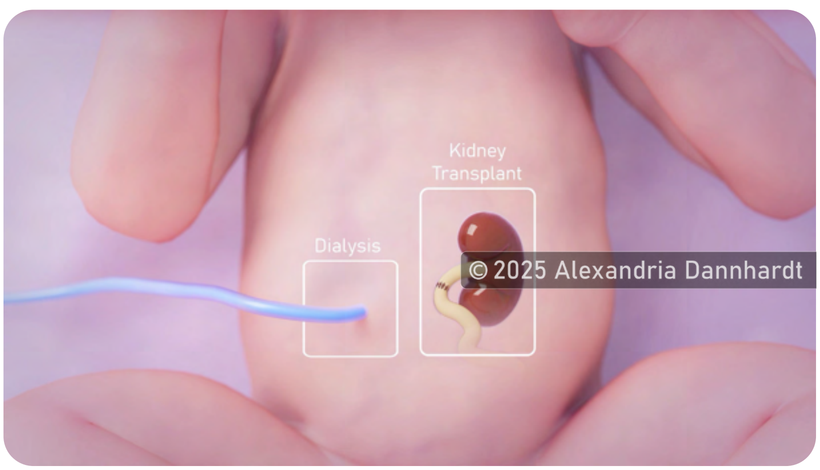


Figure 74. Animation still from “Treatments”: Post-birth medical care.

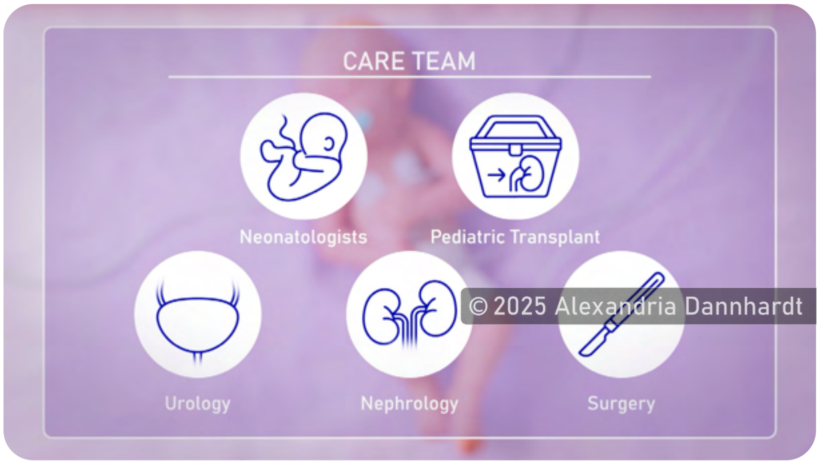


Figure 75. Animation still from “Treatments”: Describing the care team.

Figure 76. Animation still from “Treatments”: Baby with medical equipment.

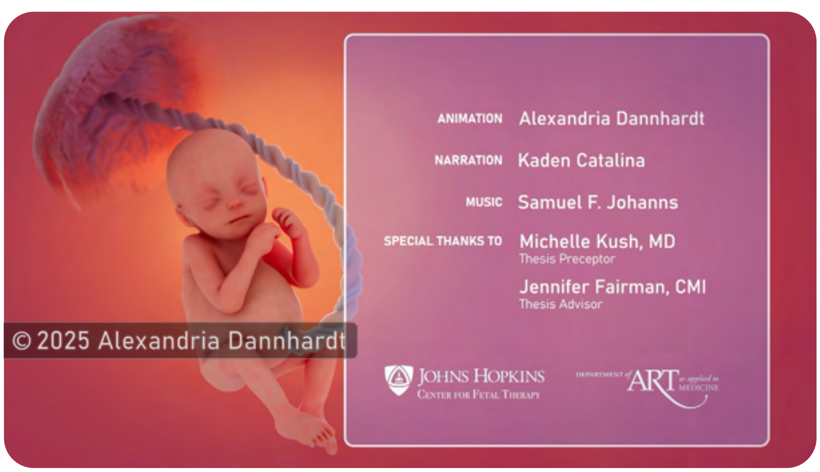


Figure 77. Animation still: Credits. Text not intended to be read.

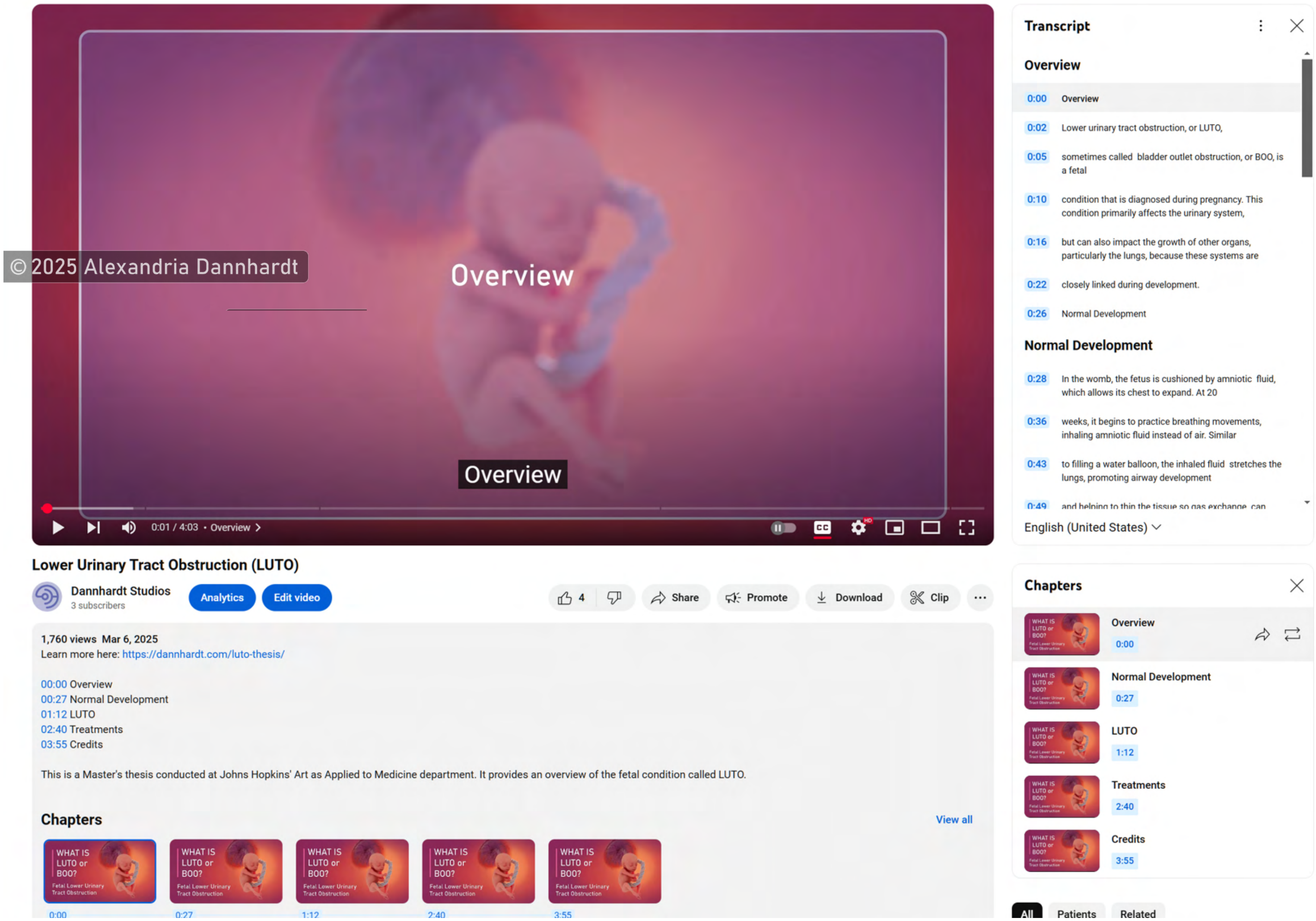


Figure 78. Screenshot from YouTube showing transcript, captions, and chapter select. Figure displays layout; text is not intended to be read.

Study Results

A total of 162 participants engaged with the survey. Of these, 80 participants completed it in full, while 82 did not complete the survey in its entirety. However, among the partial responses, 8 participants completed more than 70% of the survey, including both the pre- and post-test, but did not finish the engagement survey at the end. Their data was included in the test analysis.

For clarity, test questions will be referred to using simplified notation (e.g., Q-1, Q-2) rather than their original Qualtrics labels. When referring to survey-specific identifiers in data tables, the official Qualtrics numbering will be retained (e.g., Q6.5 for a particular post-test response).

For the control group (C), who viewed the text resource, average test scores increased by 3.85 points after viewing the current patient handout, rising from 3.37 points on the pre-test (Q3.1–Q3.9) to 7.22 points on the post-test (Q6.1–Q6.9). In the experimental group (E), who viewed the video resource, average scores increased by 6.00 points after viewing the animation, from 3.49 points on the pre-test to 9.49 points on the post-test.

Shapiro-Wilk test p-values for the overall scores, which check for data skewedness, are summarized in **Table 2**:

	Control (n = 41)	**Experimental** (n = 45)
Pre-Test	$W = 0.91$, $p = 0.003$	$W = 0.97$, $p = 0.270$
Post-Test	$W = 0.94$, $p = 0.044$	$W = 0.89$, $p < .001$
Δ Scores	$W = 0.98$, $p = 0.709$	$W = 0.96$, $p = 0.167$

Table 2. Shapiro-wilk test scores for the overall scores data sets. p-values are indicated in green if normally distributed ($p > 0.05$).

A Wilcoxon Signed-Rank test revealed significant score improvements in both groups, with p-values of < 0.001 for both the control and experimental, both well below the 0.05 threshold. To determine if the experimental group's improvement was significantly greater than the control group's improvement, a paired two-sample T-test was performed, yielding a p-value of 0.006, indicating a statistically significant difference.

Overall scores are summarized in **Table 3**.

	Control (C) (n=41)		**Experimental (E)** (n=45)	
	Pre-Test Score	**Post-Test Score**	**Pre-Test Score**	**Post-Test Score**
x̄	3.37 (x%)	7.22 (x%)	3.49 (x%)	9.49 (x%)
Σ	±2.88	±3.54	±3.65	±2.49
Δx̄	+3.85		+6.00	
Wilcoxon	$Z = 4.9$, $p = 9.172e{-7}$		$Z = 5.8$, $p = 7.577e{-9}$	
(Δx̄E - Δx̄C)	+2.15			
T-test	T = -2.8157, $p = 0.00619$			

Table 3. Average pre- and post-test scores (x̄) for both the experimental and control group. p-values are indicated in green if statistically significant ($p < 0.05$).

Shapiro-Wilk test p-values for the individual question scores, which check for data skewedness, are summarized in **Table 4-5**:

Control (C) (n=41)

	Q-1	Q-2	Q-3	Q-4	Q-5	Q-6	Q-7	Q-8	Q-9
Pre-Test	$W = 0.63$ $p < 0.001$	$W = 0.69$ $p < 0.001$	$W = 0.62$ $p < 0.001$	$W = 0.62$ $p < 0.001$	$W = 0.9$ $p = 0.002$	$W = 0.62$ $p < 0.001$	$W = 0.85$ $p < 0.001$	$W = 0.62$ $p < 0.001$	$W = 0.87$ $p < 0.001$
Post-Test	$W = 0.43$ $p < 0.001$	$W = 0.66$ $p < 0.001$	$W = 0.34$ $p < 0.001$	$W = 0.56$ $p < 0.001$	$W = 0.89$ $p - 0.001$	$W = 0.55$ $p < 0.001$	$W = 0.91$ $p = 0.003$	$W = 0.53$ $p < 0.001$	$W = 0.78$ $p < 0.001$
Δ Scores	$W = 0.62$ $p < 0.001$	$W = 0.91$ $p = 0.003$	$W = 0.73$ $p < 0.001$	$W = 0.74$ $p < 0.001$	$W = 0.95$ $p = 0.080$	$W = 0.74$ $p < 0.001$	$W = 0.93$ $p = 0.015$	$W = 0.72$ $p < 0.001$	$W = 0.9$ $p = 0.002$

Table 4. Shapiro-wilk test scores for the Control question response data sets. p-values are indicated in green if normally distributed ($p > 0.05$).

Experimental (E) (n=45)

	Q-1	Q-2	Q-3	Q-4	Q-5	Q-6	Q-7	Q-8	Q-9
Pre-Test	$W = 0.62$ $p < 0.001$	$W = 0.64$ $p < 0.001$	$W = 0.6$ $p < 0.001$	$W = 0.62$ $p < 0.001$	$W = 0.92$ $p = 0.004$	$W = 0.62$ $p < 0.001$	$W = 0.87$ $p < 0.001$	$W = 0.62$ $p < 0.001$	$W = 0.88$ $p < 0.001$
Post-Test	$W = 0.45$ $p < 0.001$	$W = 0.54$ $p < 0.001$	$W = 0.15$ $p < 0.001$	$W = 0.43$ $p < 0.001$	$W = 0.75$ $p < 0.001$	$W = 0.22$ $p < 0.001$	$W = 0.74$ $p < 0.001$	$W = 0.32$ $p < 0.001$	$W = 0.84$ $p\ 0.001$
Δ Scores	$W = 0.69$ $p < 0.001$	$W = 0.64$ $p < 0.001$	$W = 0.69$ $p < 0.001$	$W = 0.74$ $p < 0.001$	$W = 0.92$ $p = 0.004$	$W = 0.69$ $p < 0.001$	$W = 0.89$ $p < 0.001$	$W = 0.92$ $p < 0.001$	$W = 0.92$ $p = 0.004$

Table 5. Shapiro-wilk test scores for the Experimental question response data sets. No p-values are normally distributed ($p > 0.05$).

Because the data is not normally distributed, to assess how effectively the animation addressed each learning objective, a Wilcoxon Signed-Rank test was performed for individual questions and a Mann-Whitney U test was performed to compare score changes between groups. Results for individual questions are summarized in **Table 6-8**:

Control (C) (n=45)

	Q-1	Q-2	Q-3	Q-4	Q-5	Q-6	Q-7	Q-8	Q-9
$\bar{x}$ Pre-Test	0.49	0.83	0.54	0.56	-0.41	0.59	-0.05	0.44	0.39
$\bar{x}$ Post-Test	0.90	1.46	0.90	0.71	0.32	0.73	0.24	0.76	1.20
Δ Scores	0.41	0.63	0.37	0.15	0.73	0.15	0.29	0.32	0.80
Wilcoxon	$Z = 4.1$ $p < 0.001$	$Z = 3.1$ $p = 0.002$	$Z = 3.4$ $p < 0.001$	$Z = 1.6$ $p = 0.117$	$Z = 2.7$ $p = 0.007$	$Z = 1.6$ $p = 0.117$	$Z = 1.2$ $p = 0.207$	$Z = 3.1$ $p = 0.002$	$Z = 3.6$ $p < 0.001$

Table 6. Average pre- and post-test scores ($\bar{x}$) for individual questions in the control group. Changes in scores ($\Delta\ \bar{x}$) are highlighted in green if they exceed the corresponding change in the experimental group. p-values are indicated in green if statistically significant ($p < 0.05$).

	Experimental (E) (n=45)								
	Q-1	Q-2	Q-3	Q-4	Q-5	Q-6	Q-7	Q-8	Q-9
x̄ Pre-Test	0.47	0.76	0.62	0.56	-0.40	0.42	0.13	0.47	0.47
x̄ Post-Test	0.93	1.80	0.98	0.84	1.02	0.96	1.24	0.91	0.84
Δ Scores	0.47	1.04	0.36	0.29	1.42	0.53	1.11	0.44	0.38
Wilcoxon	$Z = 4.3$ $p < 0.001$	$Z = 5.6$ $p < 0.001$	$Z = 3.7$ $p < 0.001$	$Z = 2.9$ $p = 0.003$	$Z = 4.5$ $p < 0.001$	$Z = 4.7$ $p < 0.001$	$Z = 4.4$ $p < 0.001$	$Z = 4.5$ $p < 0.001$	$Z = 2.1$ $p = 0.034$

Table 7. Average pre- and post-test scores (x̄) for individual questions in the experimental group. Changes in scores (Δ x̄) are highlighted in green if they exceed the corresponding change in the control group. p-values are indicated in green if statistically significant ($p < 0.05$).

	Difference (Δx̄E - Δx̄C)								
	Q-1	Q-2	Q-3	Q-4	Q-5	Q-6	Q-7	Q-8	Q-9
Δx̄E - Δx̄C	0.05	0.41	-0.01	0.14	0.69	0.39	0.82	0.13	-0.43
Mann-Whitney	$Z = -0.4$ $p = 0.722$	$Z = -1.5$ $p = 0.131$	$Z = 0.2$ $p = 0.862$	$Z = -1.1$ $p = 0.251$	$Z = -2.2$ $p = 0.029$	$Z = -3.1$ $p = 0.002$	$Z = -2.7$ $p = 0.008$	$Z = - 1.0$ $p = 0.332$	$Z = 1.9$ $p = 0.063$

Table 8. Average difference (Δx̄) between experimental and control group scores. p-values are indicated in green if statistically significant ($p < 0.05$).

Bar graphs (**Figure 79-86**) below illustrate individual trends in selected responses for each question.

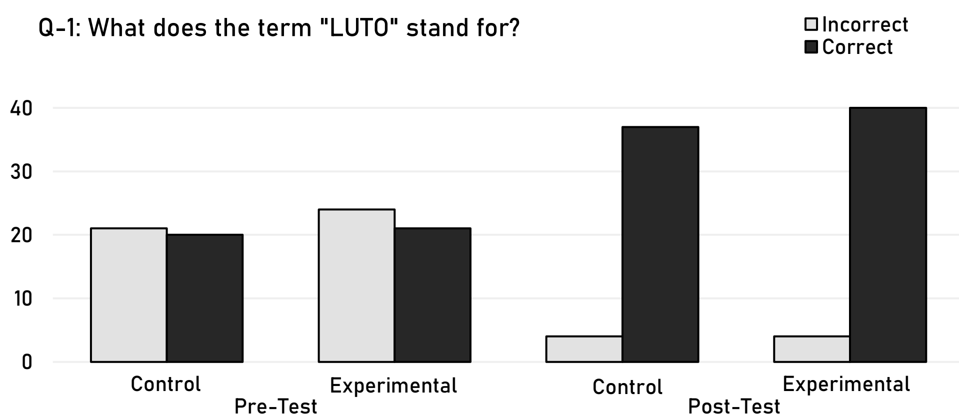


Figure 79. Response breakdown for Q-1 (bar graph)

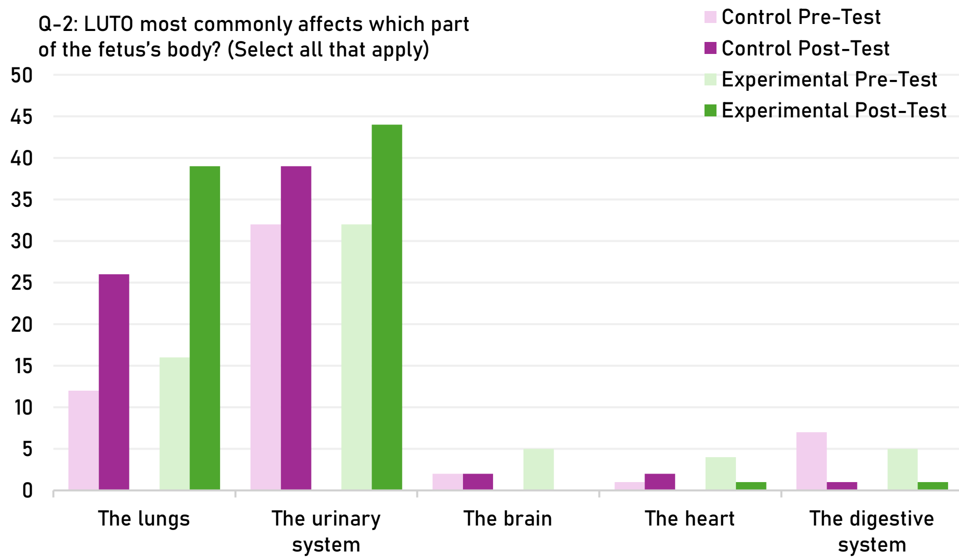


Figure 80. Response breakdown for Q-2 (bar graph)

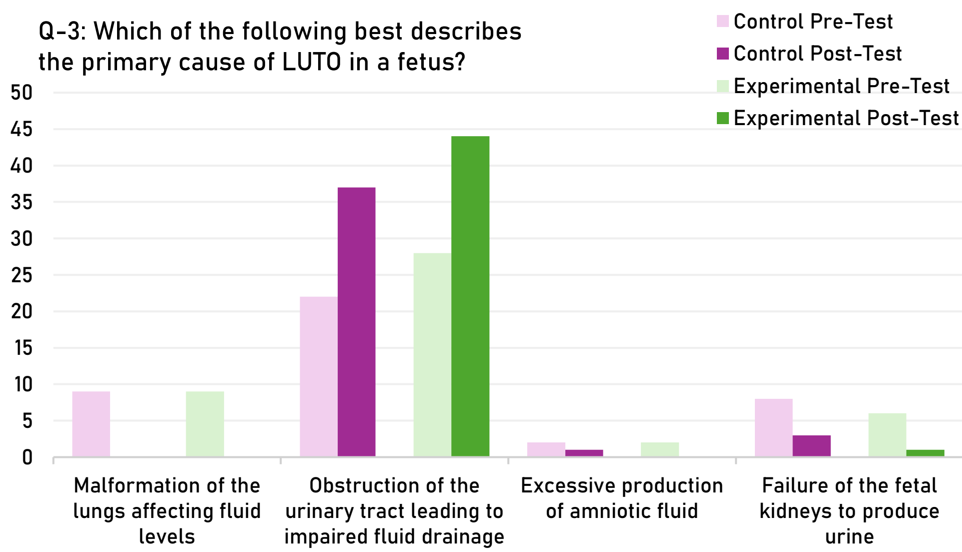


Figure 81. Response breakdown for Q-3 (bar graph)

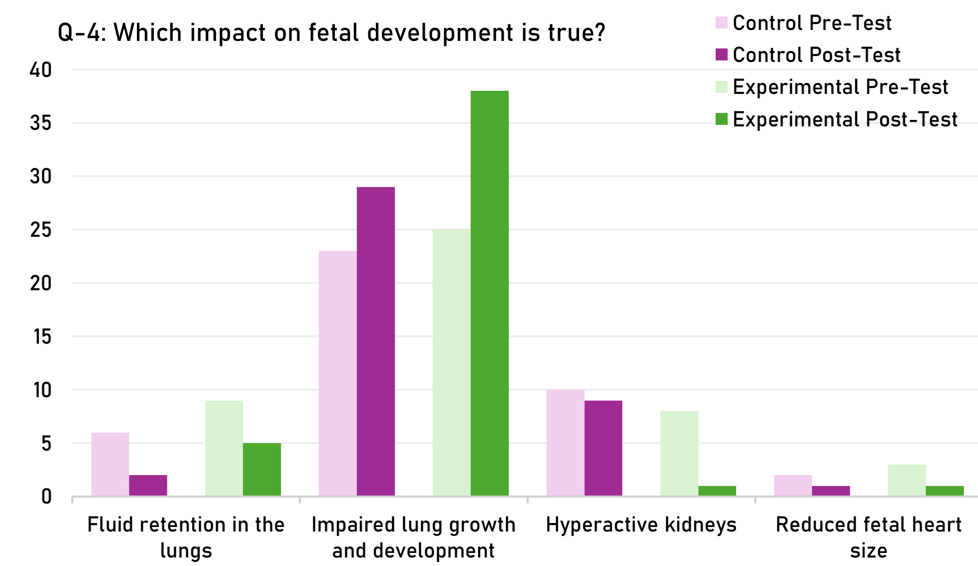


Figure 82. Response breakdown for Q-4 (bar graph)

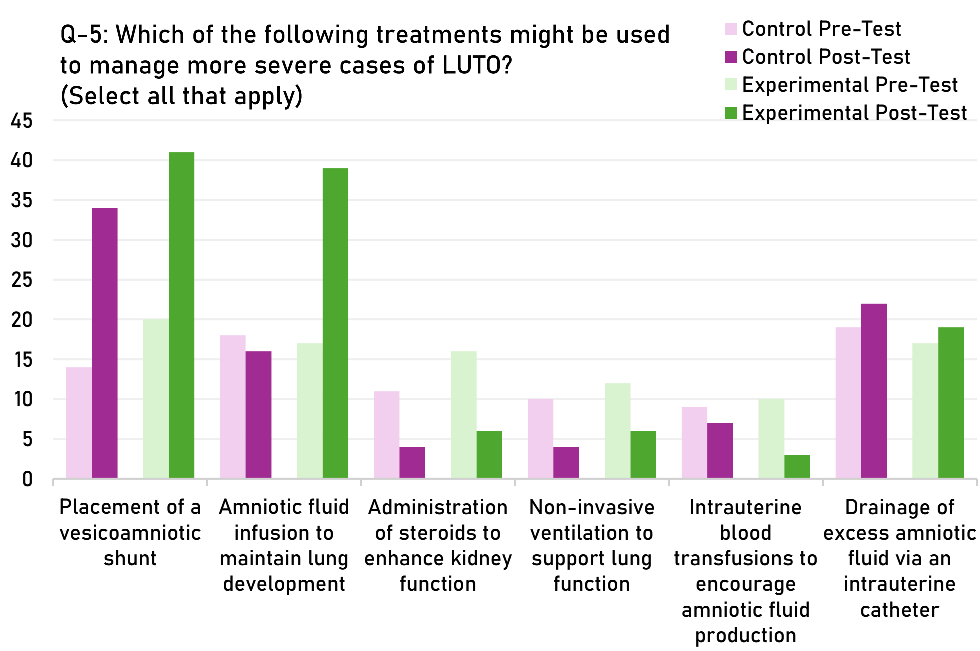


Figure 83. Response breakdown for Q-5 (bar graph)

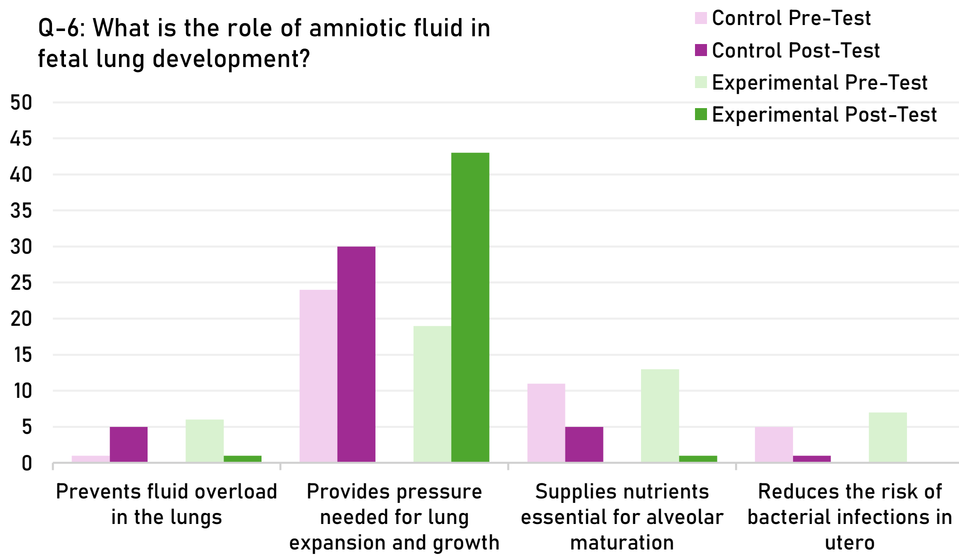


Figure 84. Response breakdown for Q-6 (bar graph)

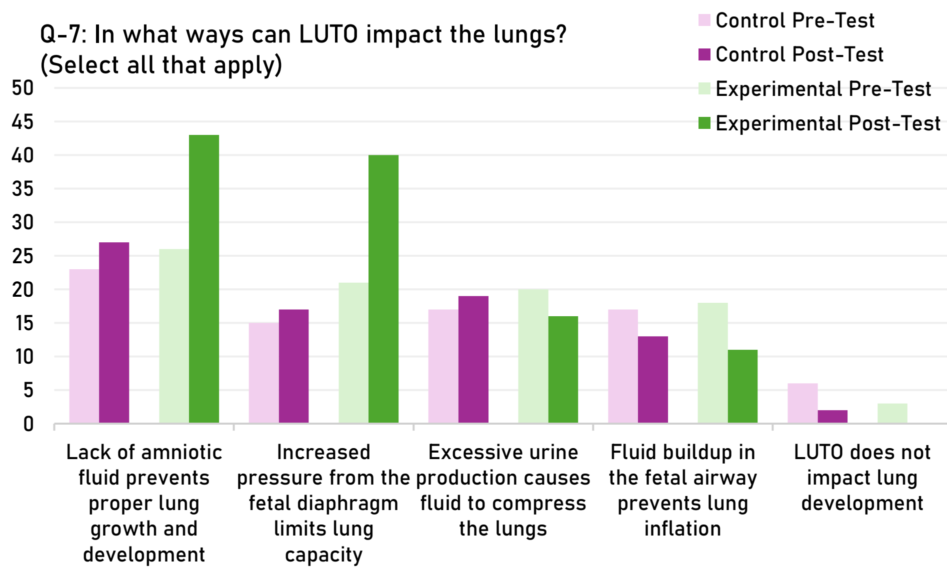


Figure 85. Response breakdown for Q-7 (bar graph)

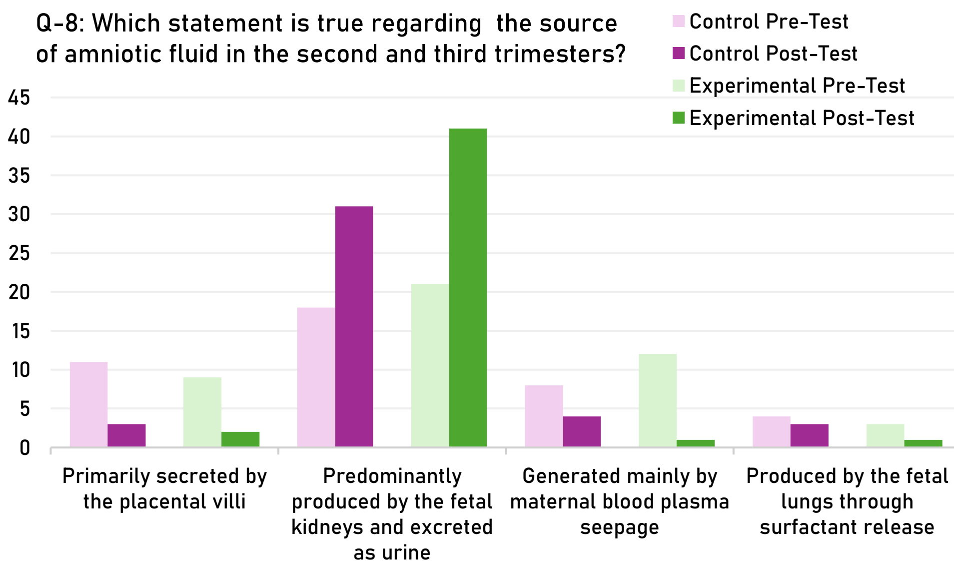


Figure 87. Response breakdown for Q-8 (bar graph)

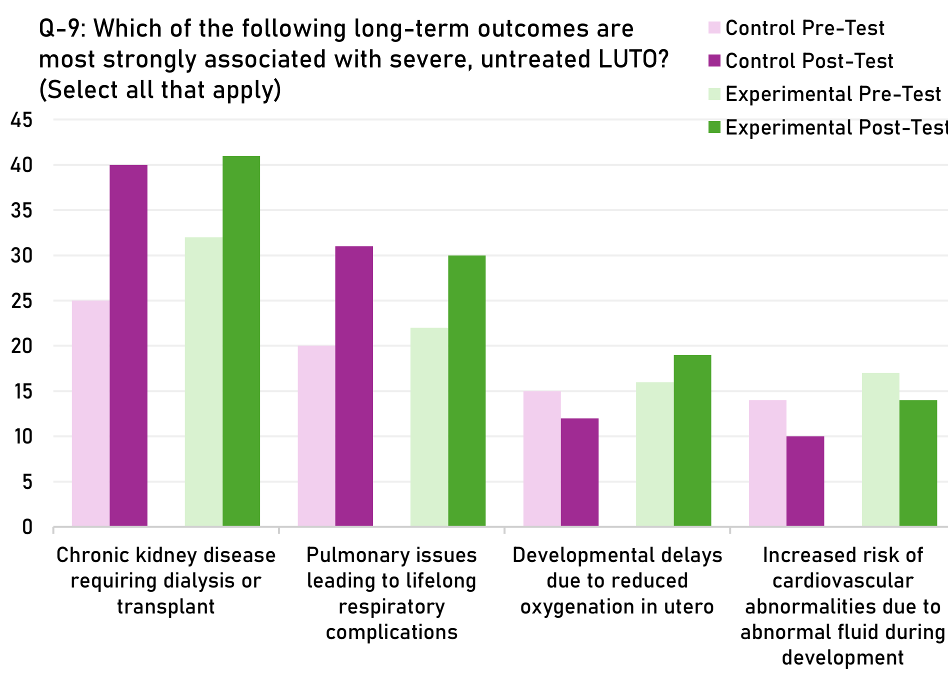


Figure 86. Response breakdown for Q-9 (bar graph)

Engagement Survey

Likert-scale questions (ranging from 1 = strongly disagree to 5 = strongly agree) and free-response questions were used to assess participant engagement.

Shapiro-Wilk test p-values for the Likert-scale ratings, which check for data skewedness, are summarized in **Table 9**:

	The content held my attention.	**The content was easy to understand.**	**The content addressed most of my questions.**	**The amount of content was appropriate.**	**I would recommend this content to someone interested in fetal health or LUTO.**
Control (n = 41)	$W = 0.76$ $p < 0.001$	$W = 0.83$ $p < .001$	$W = 0.73$ $p < 0.001$	$W = 0.77$ $p < 0.001$	$W = 0.6$ $p < 0.001$
Experimental (n = 42)	$W = 0.88$ $p < 0.001$	$W = 0.81$ $p < 0.001$	$W = 0.8$ $p < 0.001$	$W = 0.77$ $p < 0.001$	$W = 0.75$ $p < 0.001$

Table 9. Shapiro-wilk test p-scores for the Likert-scale question responses. No p-values are normally distributed ($p > 0.05$).

Average scores for the control group ranged from 3.9 to 4.4, while the experimental group averaged 4.6 to 4.8, with an overall average difference of 0.5. A Mann-Whitney U test to compare the two scores shows that this difference was not statistically significant ($p = 0.3138$). However, the results suggest a trend toward higher scores in the experimental group. Detailed scores are provided in **Table 10**:

	The content held my attention.	**The content was easy to understand.**	**The content addressed most of my questions.**	**The amount of content was appropriate.**	**I would recommend this content to someone interested in fetal health or LUTO.**
Control $\bar{x}$	3.878	3.829	4.195	4.171	4.439
Experimental $\bar{x}$	4.556	4.578	4.600	4.778	4.756
Mann-Whitney	$Z = 1.924$ $p = 0.05435$	$Z = 0.0816$ $p = 0.935$	$Z = 0.9608$ $p = 0.3367$	$Z = 0.2203$ $p = 0.8256$	$Z = 1.6068$ $p = 0.1081$
$\bar{x}E - \bar{x}C$	0.678	0.749	0.405	0.607	0.317
$\bar{x}(\bar{x}E - \bar{x}C)$	+0.551				
Mann-Whitney	$Z = 1.0072$, $p = 0.3138$				

Table 10. Average score ($\bar{x}$) for the Likert-scale responses of the experimental and control group scores. Higher value for each question is highlighted in green. No p-values indicate significance ($p < 0.05$).

Question responses are shown below, in **Figure 88**:

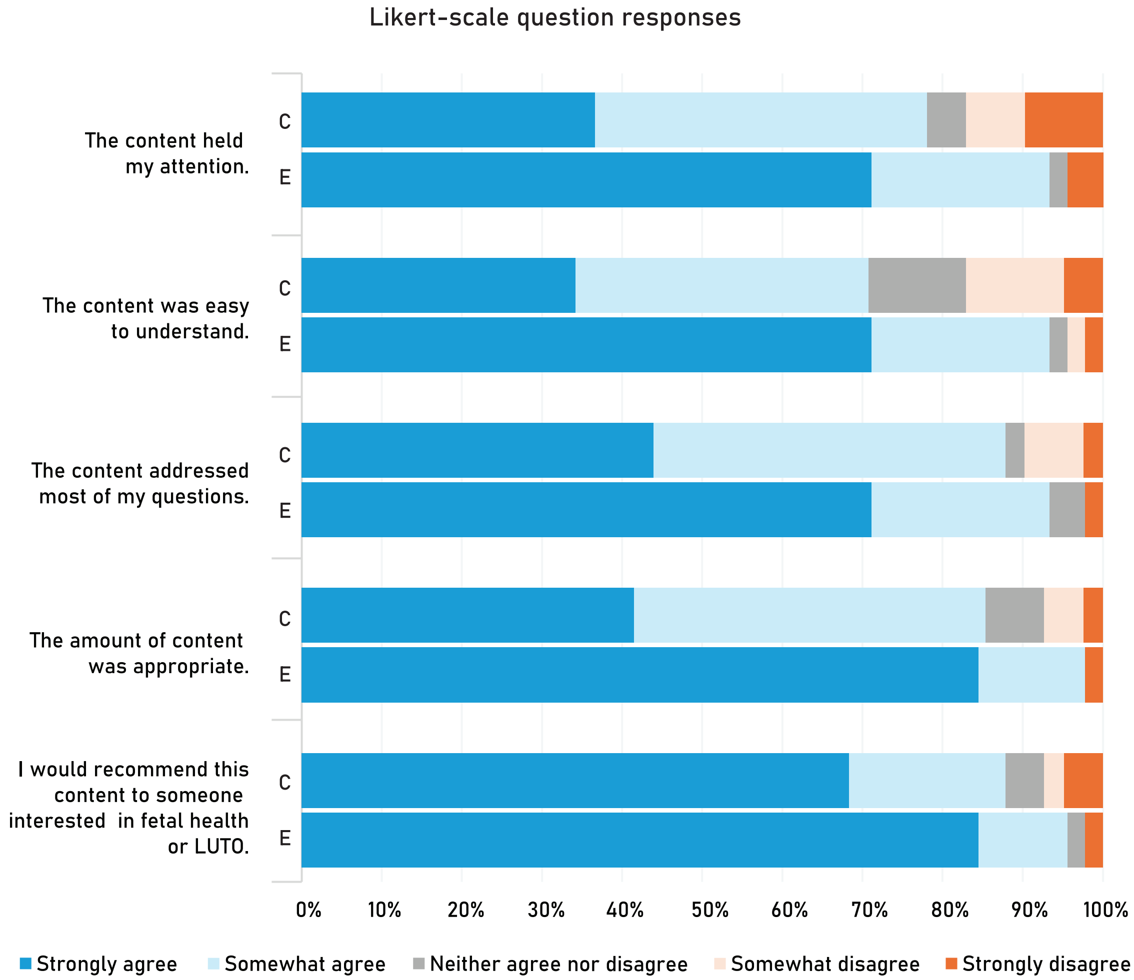


Figure 88. Response breakdown for Likert-scale questions (bar graph), showing the proportion of control (C) responses (n = 41) to experimental (E) responses (n = 42).

Confidence Ratings

Participants were asked to rate their confidence (on a scale of 1 to 10) in their ability to explain LUTO to someone else, both before and after viewing the material.

Shapiro-Wilk test p-values for the confidence rating, which check for data skewedness, are summarized in **Table 11**:

	Control (n = 41)	**Experimental** (n = 45)
Pre-Test	$W = 0.82$, $p < 0.001$	$W = 0.75$, $p < 0.001$
Post-Test	$W = 0.96$, $p = 0.163$	$W = 0.93$, $p = 0.010$
Δ Confidence	$W = 0.9$, $p = 0.002$	$W = 0.95$, $p = 0.035$

Table 11. Shapiro-wilk test p-scores for the Q 7.1 response. p-values are indicated in green if normally distributed ($p > 0.05$).

The control group showed an average increase of 2.7 points, while the experimental group increased by 5.3 points. Both increases were statistically significant (control: $p < 0.001$, experimental: $p < 0.001$), and the difference between groups was also significant ($p = 0.005695$). Confidence ratings are summarized in **Table 12**.

	Control Confidence (Cc) (n=41)		**Experimental Confidence (Ec)** (n=45)	
	Pre-Test	**Post-Test**	**Pre-Test**	**Post-Test**
$\bar{x}$	2.8	5.5	2.2	7.4
Σ	±3.08	±2.45	±2.91	±1.54
$\Delta\bar{x}$	+2.7		+5.3	
Wilcoxon	$Z = 5.2$, $p = 2.214\text{e-}7$		$Z = 5.7$, $p = 1.526\text{e-}8$	
($\Delta\bar{x}Ec - \Delta\bar{x}Cc$)	+2.6			
Mann-Whitney	$Z = -2.76$, $p = 0.005695$			

Table 12. Average confidence rating ($\bar{x}$) for both the experimental and control group. p-values are indicated in green if statistically significant ($p < 0.05$).

Resource Preference

To measure preference, participants were asked which resource they preferred (Q7.1). Out of 78 responses, 75 preferred the visual resource, while 3 favored the text-based material.

Written Feedback

Participants were given opportunities to provide written feedback on each resource and to offer additional comments at the end of the survey. Responses varied widely within each group, with participants expressing curiosity, academic interest, negative emotions (e.g., fear, sadness, concern), empathy, and hope. No clear patterns emerged between the two groups.

However, in the last comment section (Q7.1), participants often compared the two resources or provided critiques. Seven individuals explicitly stated a preference for the video, while two stated a preference for the text content. Critiques of the text content included comments about its density and lack of engagement (14 responses). Critiques of the video included feedback about its pacing and the difficulty of absorbing on-screen text (5 responses). Two individuals complimented the text content, and 12 individuals complimented the video resource.

These comments can be found in **Appendix D**.

Other Assets

Webpage

A webpage was designed and hosted on a personal website for demonstration purposes. The webpage includes custom icons and diagrams illustrating the condition, along with corresponding text descriptions. It is structured into five chapters: An Overview of LUTO (**Figure 90**), Causes of LUTO (**Figure 91**), Diagnosis of LUTO (**Figure 92**), Impact on Development (**Figure 93**), and Intervention Options (**Figure 94**). It also includes a header (**Figure 89**) which includes a table of contents and the embedded video, and a footer (**Figure 95**) which contains additional resources and information about the thesis.

The webpage includes a link to download the patient handout PDF and a link to download the PDF of the webpage for printing. The full text of the webpage can be found in **Appendix E**.

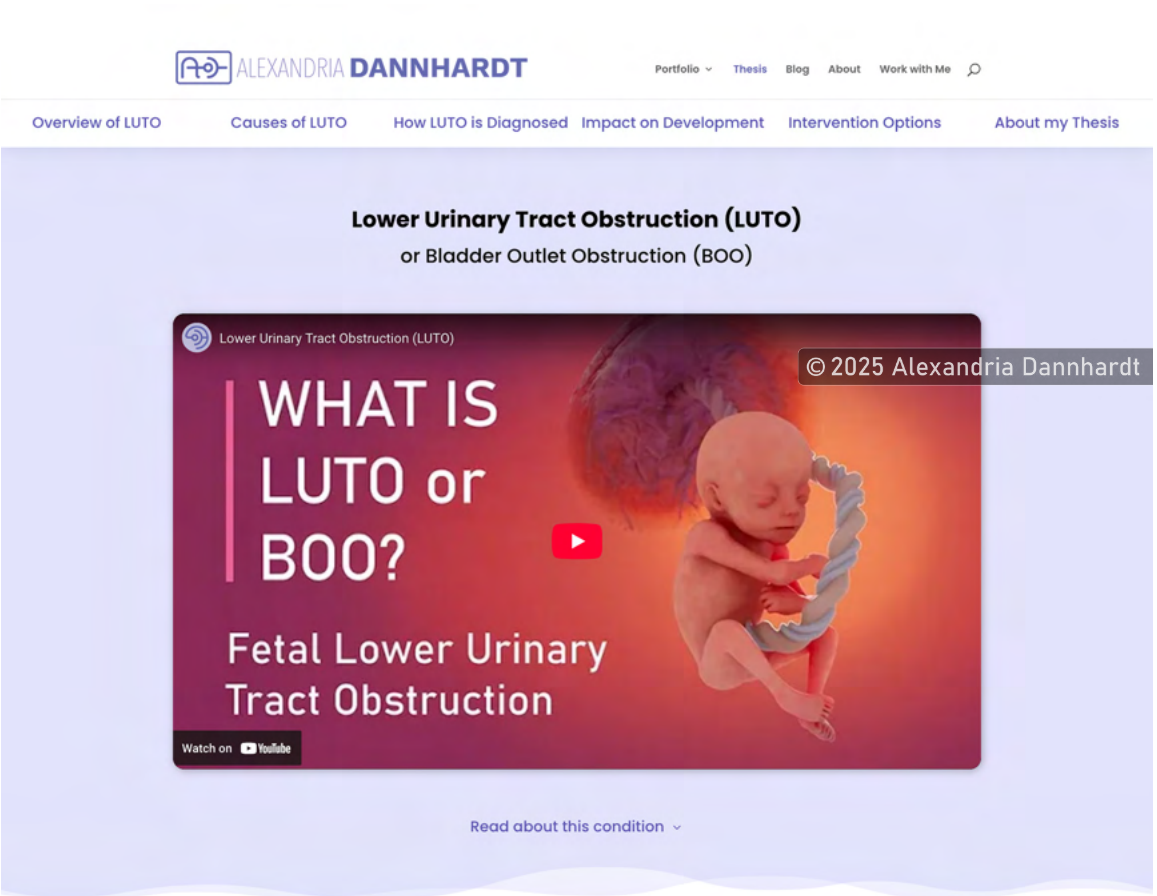


Figure 89. Screenshot of webpage's header section. Figure displays layout and illustrations; text is not intended to be read. Full text content is available in **Appendix E.**

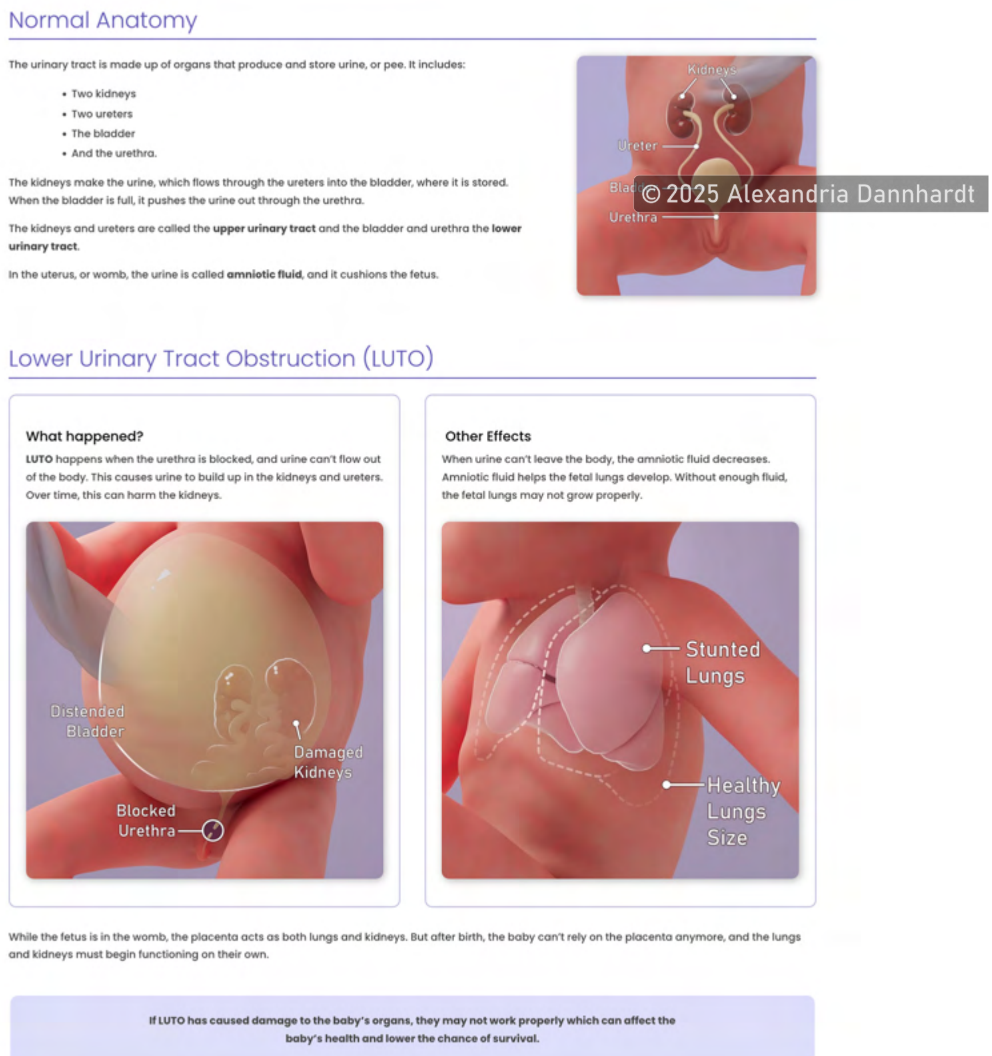


Figure 90. Screenshot of webpage's An Overview of LUTO section. Figure displays layout and illustrations; text is not intended to be read. Full text content is available in **Appendix E.**

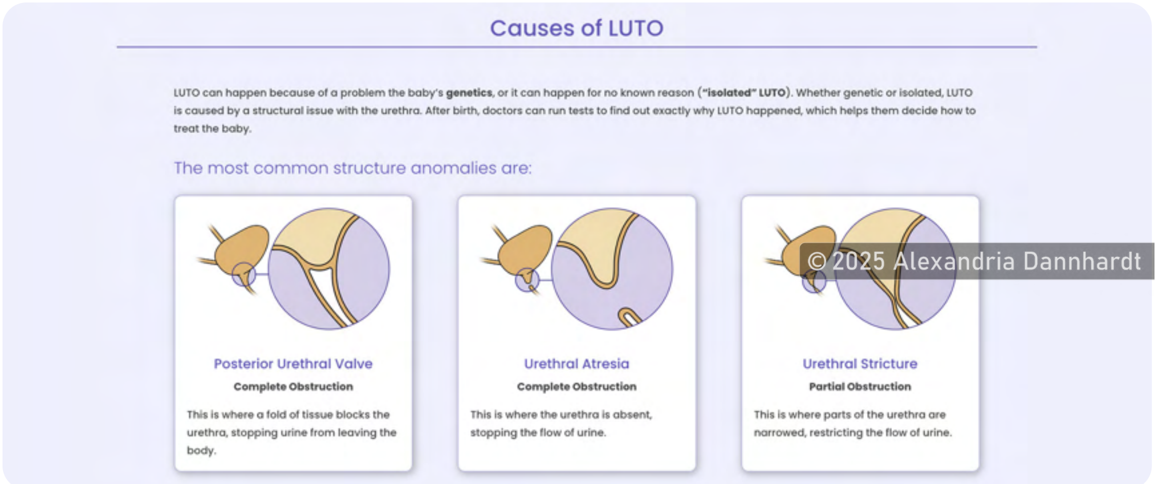


Figure 91. Screenshot of webpage's Causes of LUTO section. Figure displays layout and illustrations; text is not intended to be read. Full text content is available in **Appendix E.**

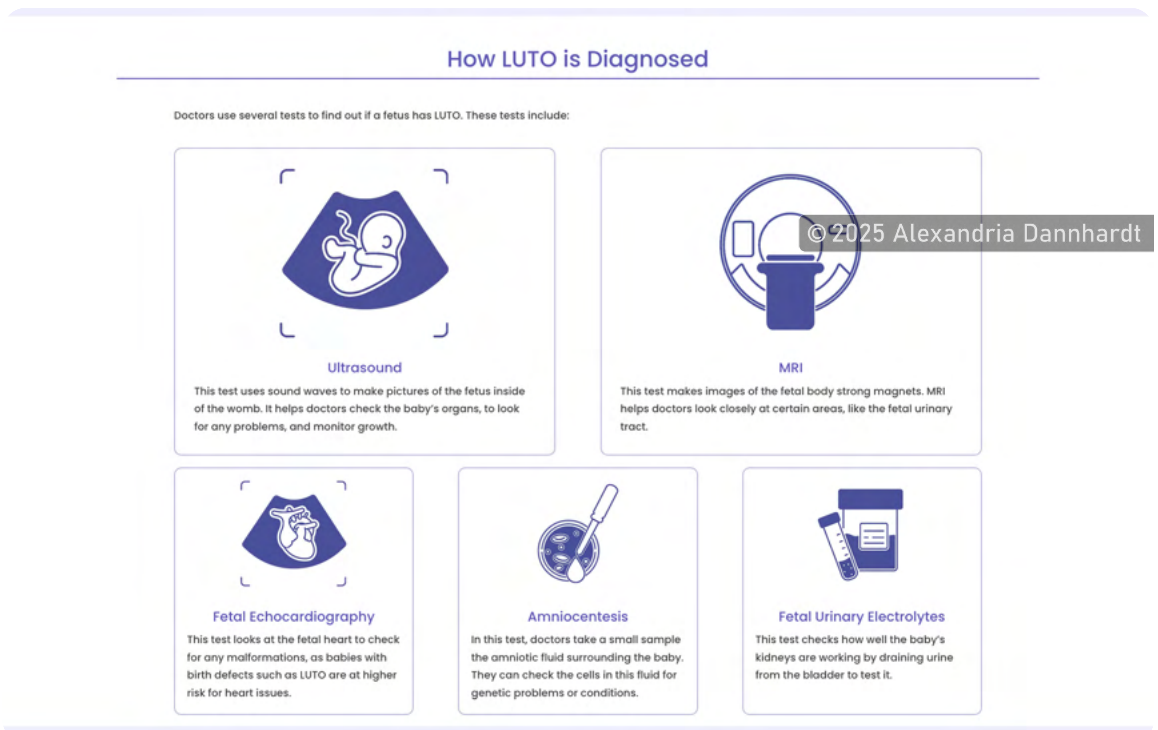


Figure 92. Screenshot of webpage's Diagnosis of LUTO section. Figure displays layout and illustrations; text is not intended to be read. Full text content is available in **Appendix E.**

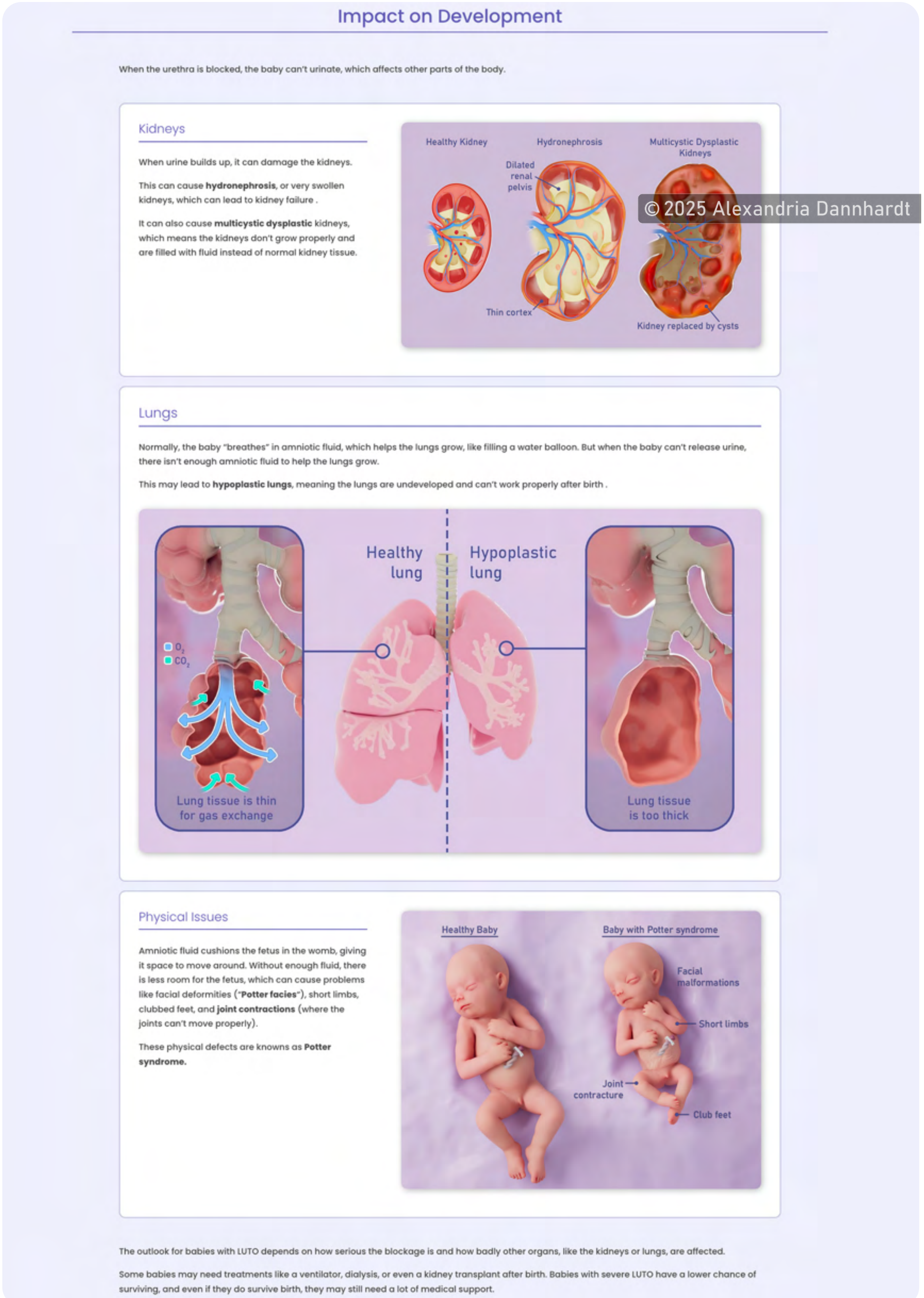


Figure 93. Screenshot of webpage's Impact on Development section. Figure displays layout and illustrations; text is not intended to be read. Full text content is available in **Appendix E**.

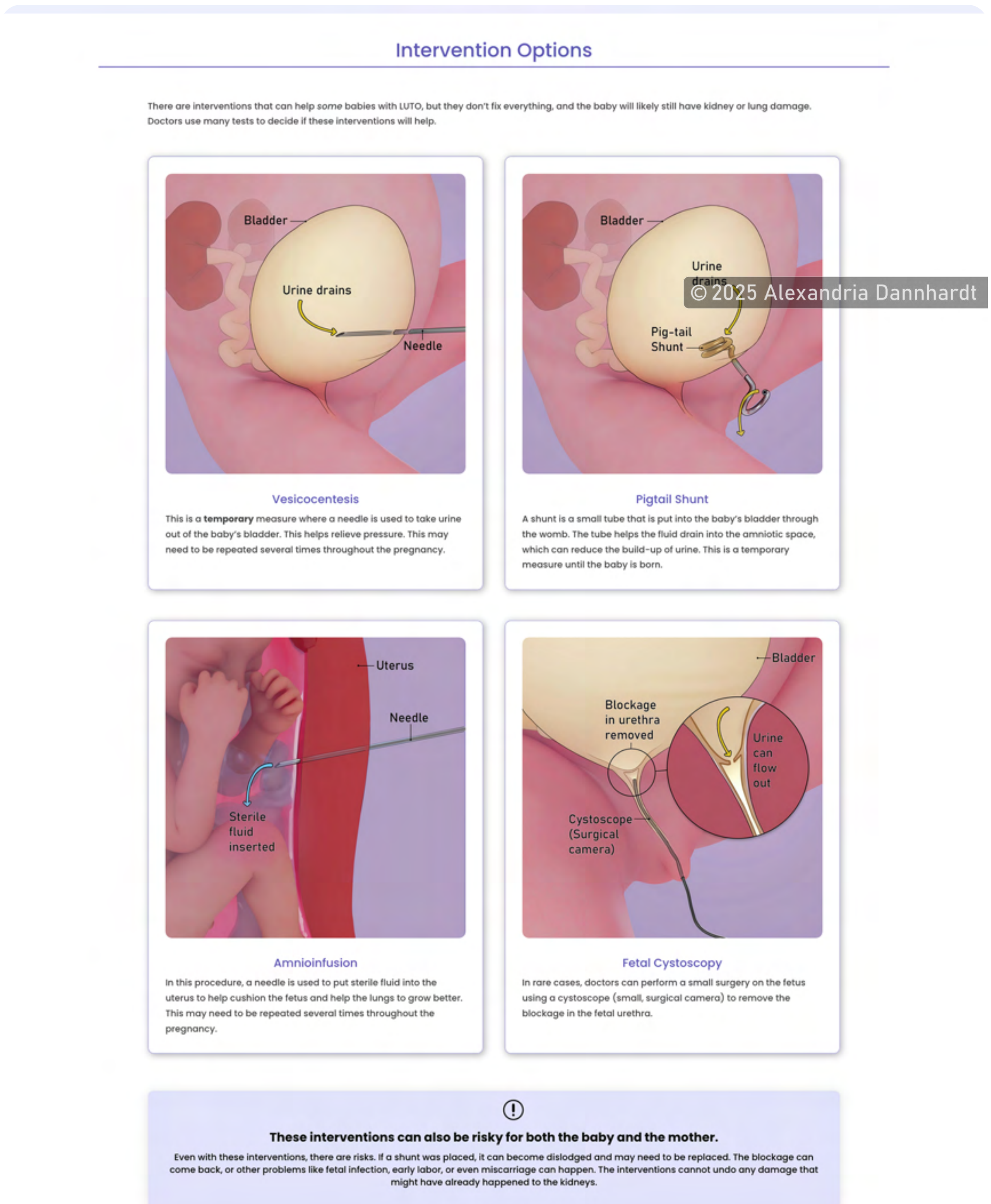


Figure 94. Screenshot of webpage's Intervention Options section. Figure displays layout and illustrations; text is not intended to be read. Full text content is available in **Appendix E.**

Figure 95. Screenshot of webpage's footer. Figure displays layout; text is not intended to be read. Full text content is available in **Appendix E.**

Patient Handout

A two-page (one sheet, front and back) hand-out was created. The full handout can be found in **Appendix F** and is available for download from the thesis webpage. The full text of the handout can be found in **Appendix G**.

3D Printed Model

A prototype set of models were printed. The models include:

- A healthy fetus, printed in FormLabs Clear v4 resin (**Figure 97**)
- Healthy organs, printed with FormLabs Model resin (**Figure 96A-B**)
- A fetus with LUTO, printed with FormLabs Clear v4 resin (**Figure 98**)
- Organs affected by LUTO, printed with FormLabs Model resin (**Figure 96C-E**)

The models are held together by magnets.

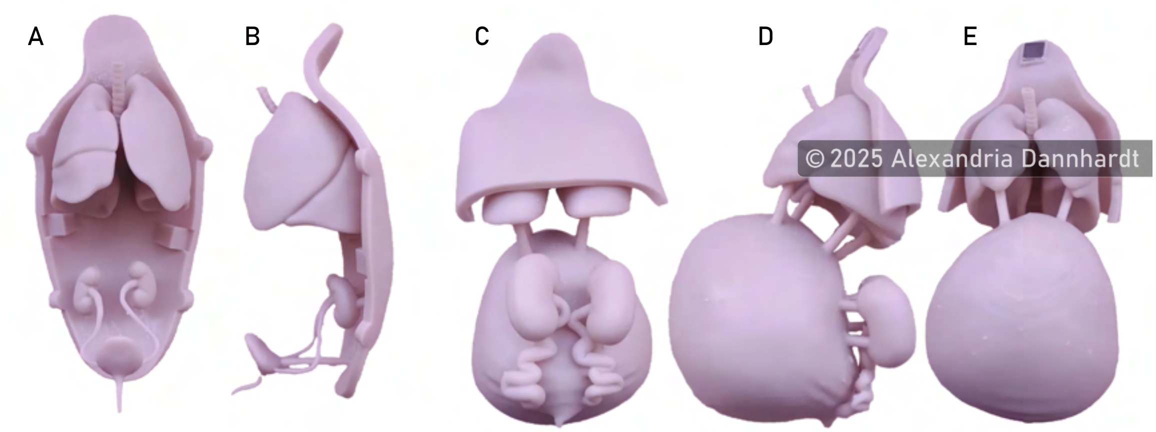


Figure 96. D-printed model showing healthy organs: (A) anterior view, (B) lateral view and LUTO-affected organs: (C) posterior view, (D) lateral view, and (E) anterior view.

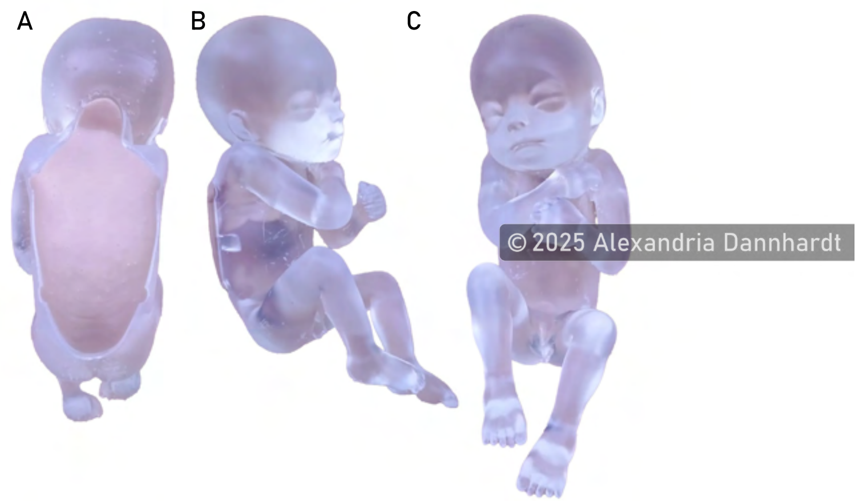


Figure 97. 3D-printed model with healthy anatomy: (A) posterior view, (B) lateral view, and (C) anterior view.

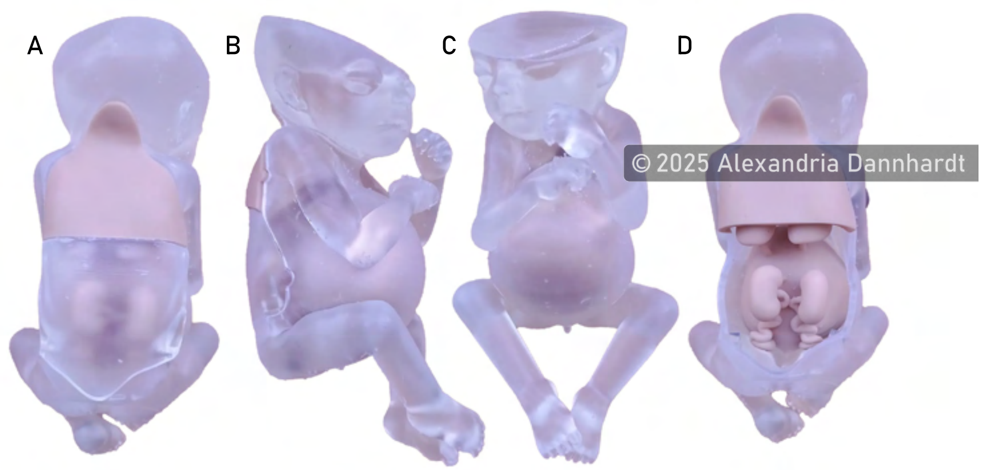


Figure 98. 3D-printed model showing LUTO-affected anatomy: (A) posterior view, (B) lateral view, (C) anterior view, and (D) posterior view with internal organs visible.

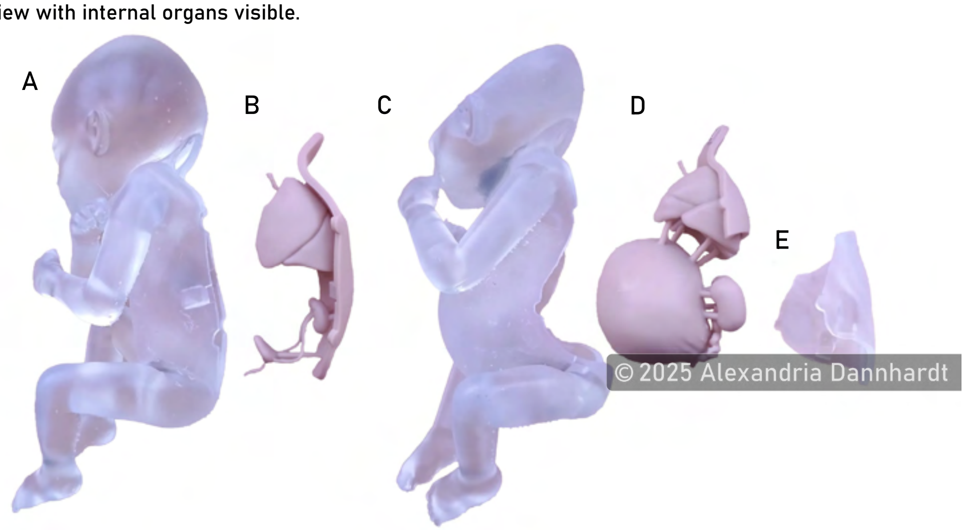


Figure 99. 3D-printed model with organ blocks removed: (A) healthy fetus, (B) healthy organs, (C) LUTO-affected fetus, (D) LUTO-affected organs, and (E) LUTO backplate.

Access to Assets Resulting from this Thesis

The animation produced for this thesis can be viewed at https://dannhardt.com or by contacting the artist at alexandria.dannhardt@gmail.com. The author of this project can be reached through the Johns Hopkins University School of Medicine Department of Art as Applied to Medicine at the following website: https://medicalart.johnshopkins.edu/.

DISCUSSION

Pre- and Post-test Performance

The study demonstrated that the patient education materials we created were highly effective. The group that viewed the video improved their scores by **6.00 points (46.1%)**, compared to the group that reviewed the written material, which improved by **3.85 points (29.6%)**. This difference in improvement was statistically significant, supporting our hypothesis that video-based media would enhance post-test scores.

At the individual question level, all questions but Q-3 and Q-9 exhibited a trend toward higher scores in the experimental group. Q-3 showed greater improvement in the control group, though final scores were not higher, while Q-9 showed both higher scores and greater improvement in the control group compared to the experimental group. However, neither difference was statistically significant . Q-4, Q-5, and Q-6, which specifically address lung development, showed significant differences in scores between the two groups, with higher scores in the experimental group. Q-1, Q-2, Q-7, and Q-9 showed no significant difference, but trended

	Overall	Q-1	Q-2	Q-3	Q-4	Q-5	Q-6	Q-7	Q-8	Q-9
Experimental	★*	★	★		★*	★*	★*	★	★	
Control				★						★

Table 13. Score summary for the pre- and post-test. Higher trending improvement is marked with a ★ (star). Significant improvements are indicated with an * (asterisk) and highlighted in green.

Both groups trended higher on the post-test, but the experimental group showed significant improvement on every question, while the control group only showed statically significant improvement on every question but Q-4, Q-6, and Q-7.

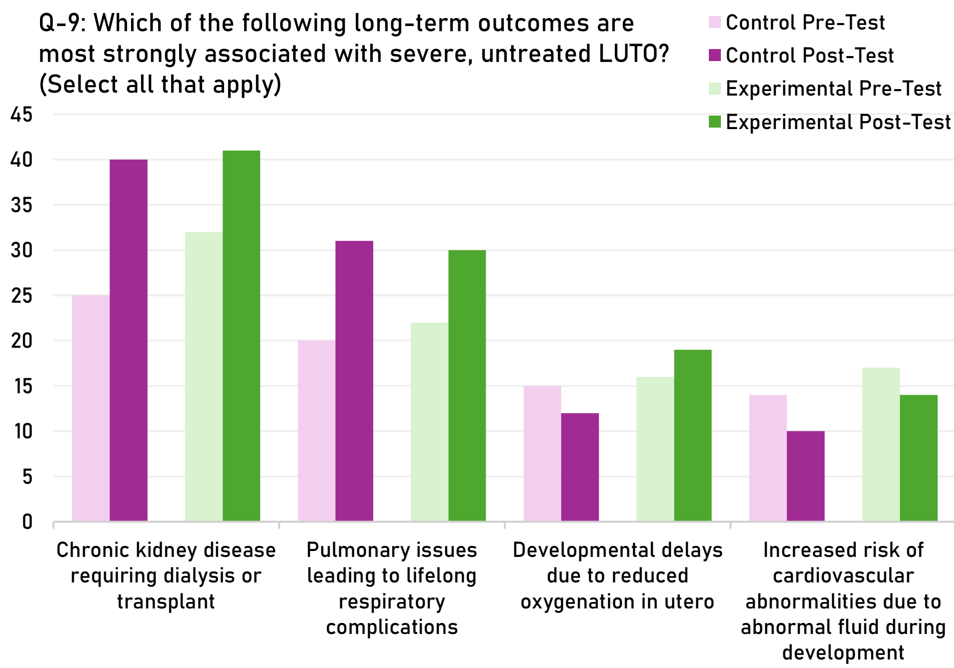


Figure 100. Response breakdown for Q-9 (bar graph)

higher in the experimental group.

Q-9 yielded an interesting result: the control and experimental groups diverged in their responses regarding whether developmental delays occur due to reduced oxygenation in utero.

The control group correctly indicated this answer less frequently on the post-test, while the experimental group indicated it more frequently (**Figure 100**). Although the difference was not statistically significant, this finding suggests a potential area for reevaluation in the video content to ensure clarity and avoid unintended implications.

Overall, this study supports the use of video-based patient education materials as an effective tool for improving knowledge retention, particularly for complex topics. However, the patterns observed in Q-9 highlight the importance of careful design and testing to prevent misunderstandings.

Engagement Survey

Participants strongly preferred the video resource over the text-based material. Feedback indicated that viewers found the video more engaging, whereas the text resource was described as feeling like "studying for a test." This aligns with our goal of creating accessible and engaging educational materials (Kraft et al., 2017; Wiljer & Catton, 2003).

Q7.1 clearly demonstrated this preference, with many participants favoring the video. The Likert-scale responses further suggested the preference for the video. However, it is important to note that the preferences indicated by the Likert-scale questions were not statistically significant.

For individuals with less personal investment in the diagnosis—such as family and friends—the mental energy required to understand complex medical information may be a barrier (De Jong, 2010).

Similarly, those directly receiving the diagnosis are often emotionally overwhelmed and may struggle to process dense, text-heavy documents. Research has shown that improved patient communication reduces anxiety and leads to better outcomes and more productive discussions (Knudsen et al., 2024; Lindau et al., 2002; Menendez et al., 2017). The webpage and video, as learning materials that can be continually referenced before or after the visit, allow individuals to learn at their own pace, reinforce understanding, and support their ability to explain the disorder by acting as a reference (Patterson & Teale, 1997). This access provides opportunities for ongoing engagement, which can lead to increased retention.

Study Limitations

While the study demonstrated the effectiveness of the video resource, several limitations should be noted. There may be some bias in the results, as the questions and educational materials were created by the same individual. However, the questions were developed before the materials were finalized to minimize this bias.

The sample size was limited, which may affect the generalizability of the findings. The study used high-level questions and unfamiliar terminology, which led some participants to feel like they were expected to know the material, even from the pre-test stage. The complexity caused some participants to be discouraged from completeting the entire survey.

The study compared two different mediums—a video and a text handout—rather than comparing similar formats (e.g., handout vs. handout). This approach assessed the impact of auditory and visual modalities on learning, but did not directly evaluate the effects of organization and visuals versus text. Additionally, only the video was evaluated; future studies could explore the effectiveness of the additional of other modalities, such as interactive websites or infographics.

The patient handout used in the study may not fully represent what patients typically encounter. In real-world scenarios, individuals are more likely to begin their search with online resources rather than a detailed handout from Johns Hopkins. The survey participants had no emotional stake in the diagnosis, but in real-life situations, individuals may be encountering this information for the first time while feeling emotional and lacking a full understanding of the severity of the condition and its implications. This is particularly true when referring physicians have not fully disclosed the diagnosis, due to factors such as uncertainty about the diagnosis or discomfort with delivering bad news.

In such an uncertain emotional state, would a more superficial webpage be preferred over the video if the latter provided too much information at once? That preference has been implied in findings from other studies (Marteau et al., 1996), which suggest that information overload can negatively impact engagement.

Finally, the study design may have introduced unconscious bias, as the video was more visually dynamic compared to the text handout , and likely perceived as “new” content. This is supported by comments such as “good job!”, “thank you for your hard work,” and “impressed,” which suggest participants may have favored the video due to its artistic quality rather than its educational value alone.

Future Directions

Research

Future research should explore the long-term retention of knowledge and the impact of these materials on patient outcomes, such as adherence to treatment plans or health behaviors. Additionally, studies could compare emotional and cognitive responses to different types of resources, including superficial webpages versus detailed materials, to better understand how to balance information depth and accessibility.

Responding to Feedback

Based on participant comments, several adjustments will be made to improve the resources. For instance, some participants noted that the voiceover sounded like a computer-generated voice. To address this, the voice actor, Kaden, may soften or slightly lower the pitch of their delivery to avoid resemblance to the TikTok computer-generated voice. Accessibility will also be enhanced; while subtitles are already included, further research into deaf and hearing impaired video preferences will guide the addition of more accessibility features.

All aspects of the project will continue to be refined based on feedback from patients, survey participants, and content experts. The final resources will be hosted online, with PDF materials freely available for download.

3D Models

The 3D models, currently prototyped with magnets and hand-painted finishes, will be used in patient education rooms. Future iterations will explore alternative manufacturing methods, such as print-only models with more functional registration design to hold the pieces together, or higher-quality Stratasys prints. As feedback from participants and practitioners is collected, these models will be further developed to better meet educational needs.

CONCLUSION

LUTO is a complex condition involving multiple developing organ systems, with a wide range of etiologies and outcomes. This complexity makes it challenging to explain to patients, particularly given the need to cover detailed normal anatomy as well as abnormal anatomy, organ development, and guide parents through difficult decisions. To address this, we identified a need for clearer, more accessible patient education materials that thoroughly explain the condition without requiring medical expertise.

To meet this need, a 4-minute 3D color animation, a patient education webpage, and a handout/leaflet were developed. The effectiveness of the video was evaluated through an IRB-approved study using a Qualtrics survey with lay-audience participants. The study measured engagement and compared pre-test and post-test results, revealing significant improvements in scores among the video group compared to the text group. These findings underscore the potential of multimedia tools to enhance patient understanding and engagement, aligning with existing literature on the benefits of visual and auditory learning in health education (Meade et al., 1994).

In addition to digital resources, 3D-printed educational model was prototyped for use in clinical settings. This model supports practitioners' verbal explanations by providing a tangible reference for anatomy, size, and the differences between healthy and LUTO-affected fetuses. It also allows doctors to point to specific anatomical features when discussing potential interventions.

The materials created for this study are available online, and the 3D-printed models will continue to be refined based on feedback. Future research should build on these findings by exploring the long-term retention of knowledge from video-based interventions and their impact on patient outcomes, such as adherence to treatment plans or health behaviors.

Appendix A: Animation Script

Overview:

Lower urinary tract obstruction, or LUTO, sometimes called bladder outlet obstruction, or BOO, is a fetal condition that is diagnosed during pregnancy. This condition primarily affects the urinary system, but can also impact the growth of other organs, particularly the lungs, because these systems are closely linked during development.

Normal Development:

In the womb, the fetus is cushioned by amniotic fluid, which allows its chest to expand. At 20 weeks, it begins to practice breathing movements, inhaling amniotic fluid instead of air. Similar to filling a water balloon, the inhaled fluid stretches the lungs, promoting airway development and helping to thin the tissue so gas exchange can occur—an important step in lung development.

Nearly all the amniotic fluid that the fetus is breathing is produced by urination. Normally, the fetal kidneys produce urine, which flows into the bladder and then leaves the body through a tube called the urethra.

LUTO:

LUTO occurs when there's an interruption to the urinary outflow. This makes it hard or even impossible for urine to leave the bladder. As urine backs up, it puts pressure on the kidneys. This can lead to mild or severe renal conditions, such as significantly enlarged kidneys, or multicystic dysplastic kidneys. Distended organs can push against the diaphragm, compressing the lungs. Damage to the kidneys, or total obstruction of the urethra, can lead to a complete absence of amniotic fluid.

With less fluid, the lung tissue is unable to stretch and grow properly. The reduced cushioning makes it even harder for the chest to expand. This, and the internal compression from the diaphragm, can significantly stunt lung growth. With less room in the uterus, the fetus can develop physical deformities, such as shorter limbs or facial malformations.

In some cases, parents may consider not continuing the pregnancy. In other cases, specialized care helps to protect the fetal kidneys and allow the lungs to develop.

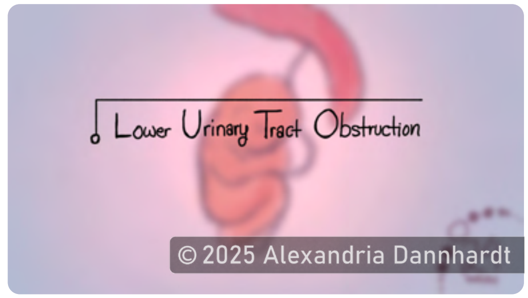
Treatments:

The most common treatment for LUTO is placing a shunt, which drains urine from the bladder into the womb in an effort to maintain the amniotic fluid around the fetus. Sometimes, a temporary measure such as draining the urine via a needle in the bladder, called vesicocentesis, can be used. Another option is amnioinfusion, where sterile fluid is introduced into the amniotic sac to increase fluid volume and reduce lung issues.

These treatments can improve chances of fetal survival, but there still may be long-term health challenges. Newborns may face issues with kidney function, requiring dialysis or kidney transplant, as well as an increased risk of medical complications. To manage these potential complications, your baby's care team may include neonatologists, pediatric transplant doctors, and pediatric specialists in urology, nephrology, and surgery. Your doctor will discuss these possibilities with you so you can make the best decisions for your situation.

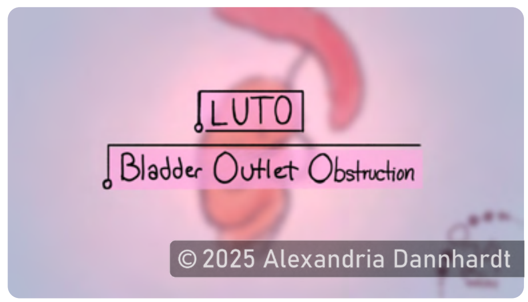
Appendix B: Animation Storyboard

1A
Video: Fetus kicking and breathing. EDIT - NO TIME-LINE ON SCENE 1
Audio:



1B
Video: Text types out
Audio: Lower urinary tract obstruction,

1C
Video: Text disappears down to just L-U-T-O
Audio: or LUTO,

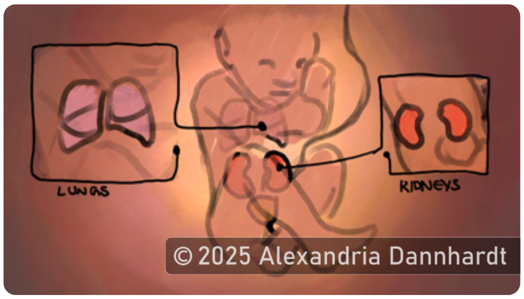


1D
Video:
Audio: Also known as Bladder Outlet Obstruction,

1E
Video: Same effect
Audio: or BOO, is a fetal condition.

1F
Video: Fetus turns. Transparency for kidneys, call out.
Audio: It primarily affects the urinary system,

Figure 101. Animation storyboard, page 1.



1G
Video: Fetus turns around, show lungs.
Audio: But can also impact the growth of other organs, especially the lungs,

1H
Video: Infinity symbol to show connection.
Audio: Because these systems are closely linked during development.

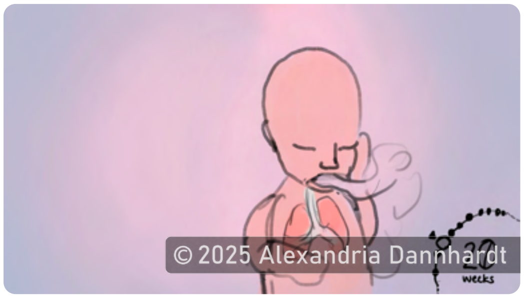
2A
Video: Cut to fetus in woman, the timeline appears.
Audio: During development,

2B
Video: Zoom in, sparkles/shimmers on the placenta through the fetus to show nutrients.
Audio: The placenta acts as the fetus' lungs and kidneys, oxygenating the blood and removing waste.

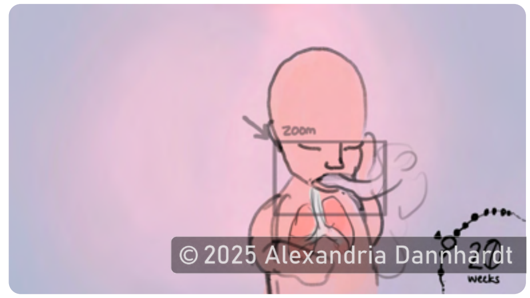
3A
Video: Ticker matures to 20 weeks, fade (or morph?) to the older fetus. Zoom in.
Audio: This allows fetal organs to develop. By around 20 weeks of pregnancy,

3B
Video: Show lungs, fetus doing breathing movements.
Audio: The fetus starts to practice breathing movements,

Figure 102. Animation storyboard, page 2.

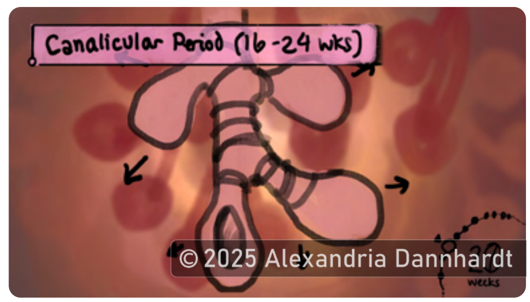


3C
Video: Fetus drinks in liquid.
Audio: Inhaling amniotic fluid instead of air.

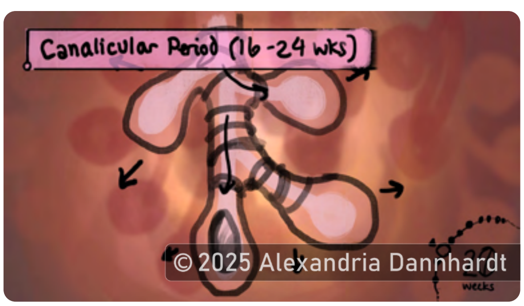


3D
Video: Zoom in on mouth.
Audio: The fluid helps stretch and expand the lungs,

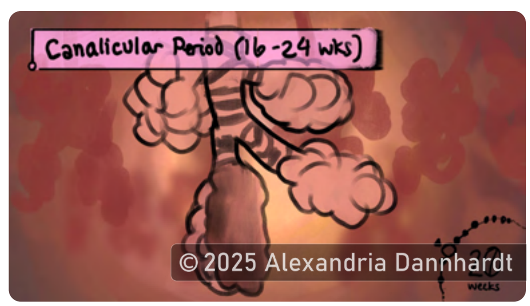
3E
Video: BIG zoom.
Audio: Encouraging them to grow and develop.



4A
Video: Cut to alveoli, early canalicular stage.
Audio: Think about how you can blow into a balloon a little bit a couple of times



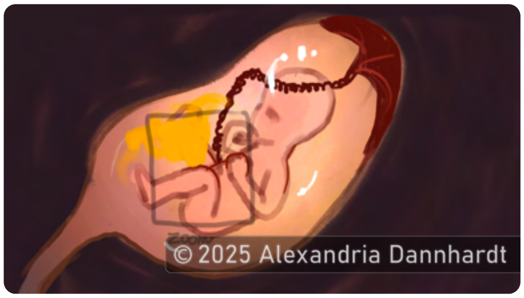
4B
Video: Liquid rushes in and pushes against the edges.
Audio: To get it to stretch out



4C
Video: Timer ticks up to 30 weeks, fade to fully formed alveoli.
Audio: Before you can blow it up all the way.

Figure 103. Animation storyboard, page 3.

5A
Video: Cut to fetus. Fetus is breathing, see ripples in the amniotic fluid.
Audio: This process is helped by the cushioning provided by the amniotic fluid outside, which gives the fetus room to expand its chest.



5B
Video: Urine comes out, start zooming on the fetus.
Audio: Nearly all the amniotic fluid that the fetus is breathing is produced by urination.

5C
Video: Show kidneys.
Audio: Normally, the fetal kidneys produce urine,

5D
Video: Urine moves down. Labels appear.
Audio: Which flows into

5E
Video: Follow fade to the bladder. Labeled.
Audio: The bladder

5F
Video: Continue fade through the urethra, urine comes out. Labeled.
Audio: And then leaves the body through a tube called the urethra.

Figure 104. Animation storyboard, page 4.

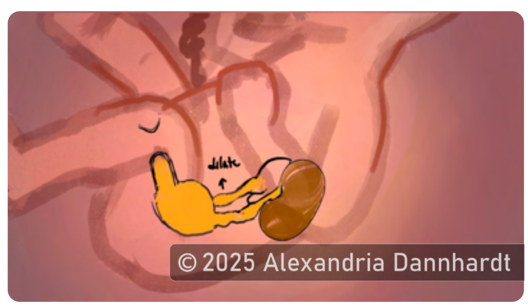
5G
Video: Urine stream stops, urethra closes.
Audio: LUTO occurs when there's an interruption to the urinary outflow,

6A
Video: Fade background, partial blockage shows.
Audio: Making it hard

6B
Video: Complete blockages show.
Audio: Or even impossible for urine to leave the bladder.

6C
Video: Complete expands out (wipe in circle) for more context.
Audio: As urine backs up,

6D
Video: Show bladder filling and then the urine backing up the ureters.
Audio: It puts pressure on the kidneys,



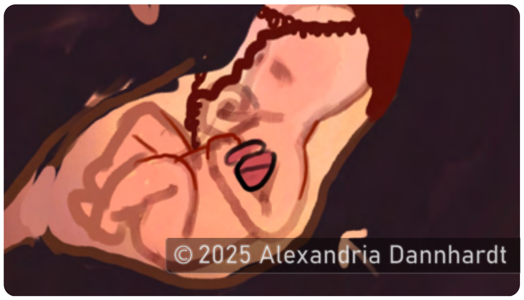
6E
Video: Kidneys dilate.
Audio: Causing them to dilate, and potentially leading to mild or severe renal disease.

Figure 105. Animation storyboard, page 5.

6F
Video: Fade in diaphragm.
Audio: The dilated kidneys can push against the diaphragm.

6G
Video: Fade in lungs, squishing up.
Audio: Compressing the lungs.

6H
Video: Zoom out & fade to this shot (fade in "uterus").
Audio: The trapped urine reduces amniotic fluid.



6I
Video: Uterus compresses. Show lungs squishing.
Audio: With less fluid, the lungs struggle to grow, and the reduced cushioning makes it even harder for the chest to expand.

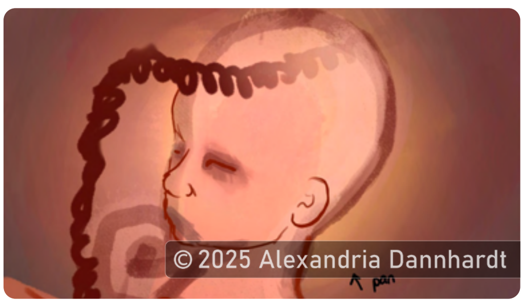
6J
Video:
Audio: This, and the internal compression from the diaphragm, can stunt lung growth.

6K
Video: Zoom to arm and fade uterus, arm extends.
Audio: The external pressure can lead to physical deformities.

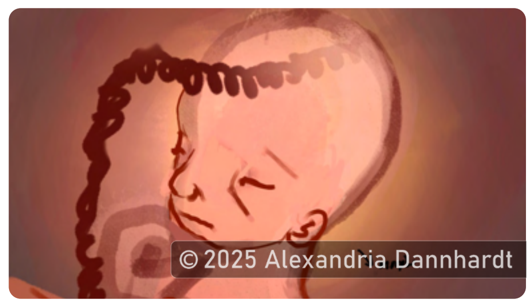
Figure 106. Animation storyboard, page 6.

6L
Video:
Audio:

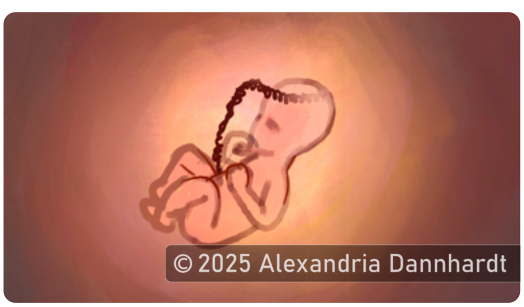
6M
Video:
Audio:



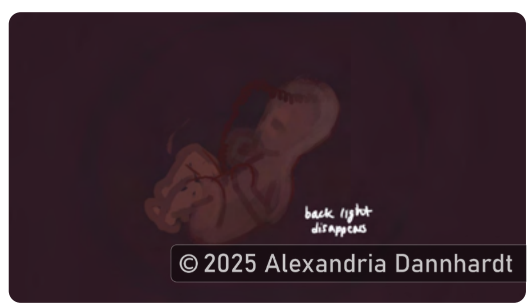
6N
Video: Pan up to the face, arm can pull back in.
Audio:



6O
Video: Arm shortens.
Audio:



6P
Video: Morph.
Audio:



6Q
Video: Back-light disappears; essentially, the light turns off.
Audio: Parents may consider ending the pregnancy.

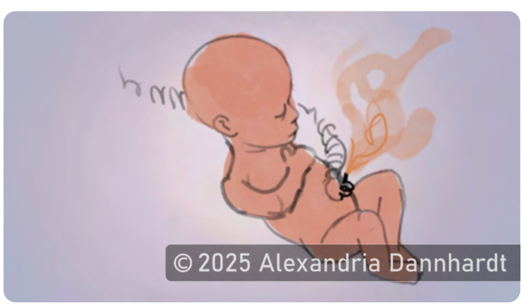
Figure 107. Animation storyboard, page 7.

7A
Video: Zoom out, fetus returns to position.
Audio: In severe cases,

7B
Video: Cut to sterile, organs are visible but gray.
Audio: In other cases, specialized care can focus on

7C
Video:
Audio:

7D
Video: Fetus rotates so we can see it a bit more laterally, zoom on the bladder/shunt.
Audio: The most common treatment is placing a shunt, which drains urine from the bladder.



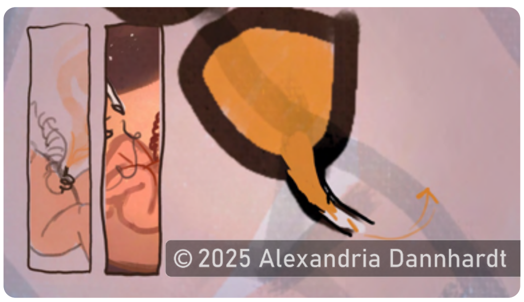
7E
Video: Shunt starts working, fade to no transparency.
Audio: Into the womb to relieve pressure on the kidneys.

8A
Video: Image scooches over, bring in amnioinfusion.
Audio: Another option is amnioinfusion.

Figure 108. Animation storyboard, page 8.

8B
Video: Fill with fluid, relax fetus.
Audio: Where sterile fluid is introduced into the amniotic sac to increase fluid volume and reduce lung issues.

9A
Video: Image scooches over. Zoom in on PUV.
Audio: If LUTO is caused by urethral blockage, rather than an absent urethra,



9B
Video: PUV just opens (no tools shown).
Audio: Fetal surgery can be performed to reopen the urethra.

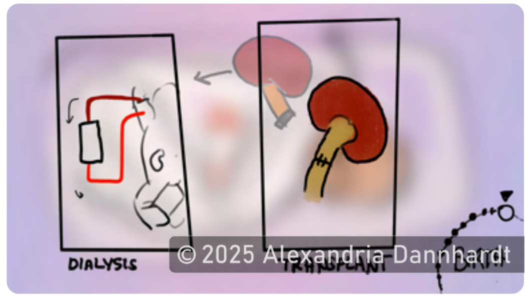
9C
Video: All three expand to show the options.
Audio: These treatments can improve chances of fetal survival.

10A
Video: Cut to baby in hospital, with supportive care.
Audio: But there still may be long-term health challenges requiring palliative care.

10B
Video: Ghost kidneys.
Audio: Newborns may especially face issues with kidney function.

Figure 109. Animation storyboard, page 9.

11A
Video: Symbolic representation of dialysis.
Audio: Requiring dialysis and



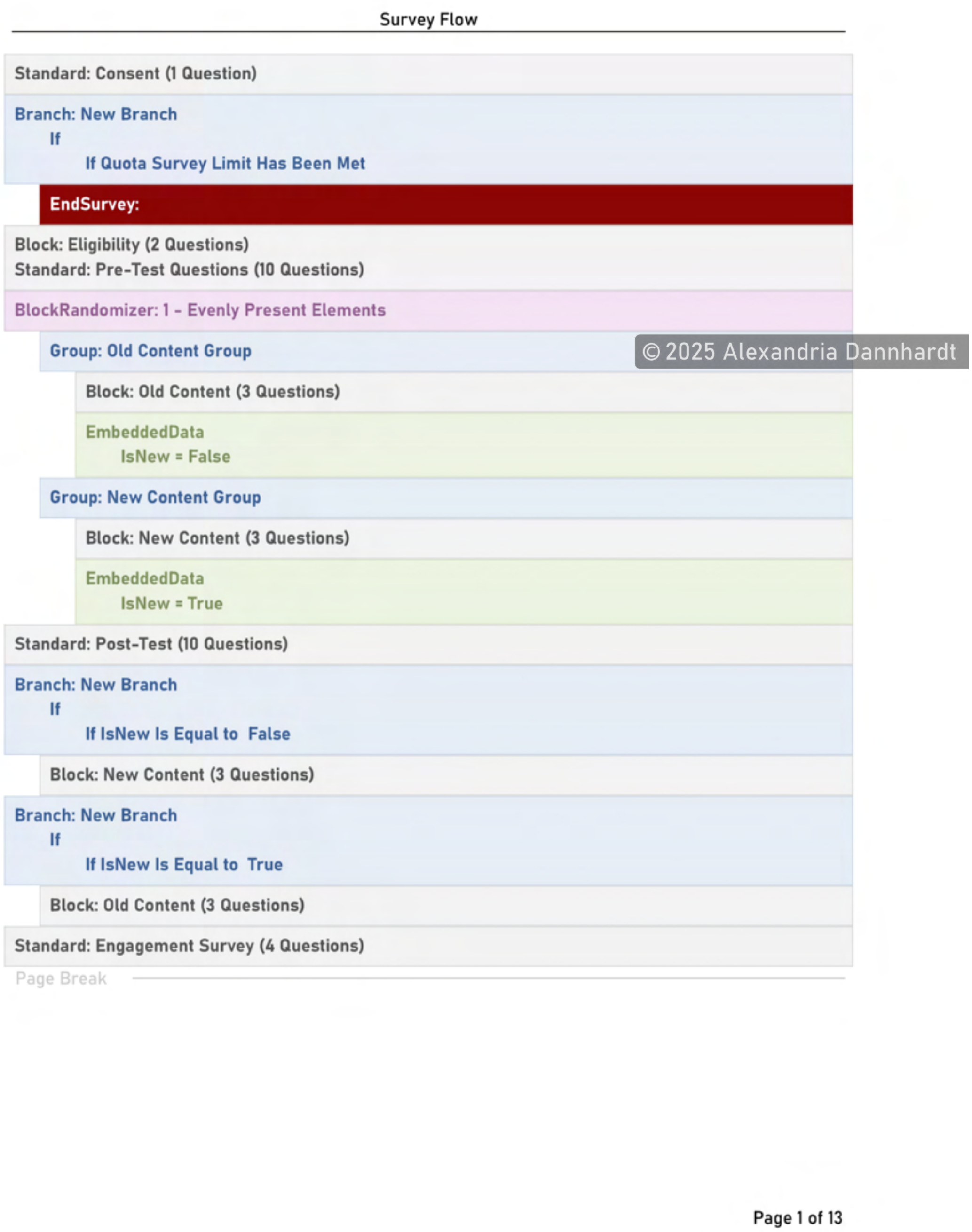
12A
Video: Old kidney goes away, new transplant!
Audio: Kidney transplant.

13A
Video: Return to first scene, fetus kicking and breathing.
Audio: Doctors will discuss these possibilities with families so they can make the best decisions for their situation.

13B
Video:
Audio: Credits.

Figure 110. Animation storyboard, page 10.

Appendix C: Qualtrics Module


Survey Flow

Standard: Consent (1 Question)

Branch: New Branch
If
If Quota Survey Limit Has Been Met

EndSurvey:

Block: Eligibility (2 Questions)
Standard: Pre-Test Questions (10 Questions)

BlockRandomizer: 1 - Evenly Present Elements

Group: Old Content Group

Block: Old Content (3 Questions)

EmbeddedData
IsNew = False

Group: New Content Group

Block: New Content (3 Questions)

EmbeddedData
IsNew = True

Standard: Post-Test (10 Questions)

Branch: New Branch
If
If IsNew Is Equal to False

Block: New Content (3 Questions)

Branch: New Branch
If
If IsNew Is Equal to True

Block: Old Content (3 Questions)

Standard: Engagement Survey (4 Questions)

Page Break

Page 1 of 13

Figure 111. Qualtrics module, page 1.

Start of Block: Consent

Q1.1 **Survey Information and Consent** The survey will ask some basic eligibility questions before you begin. If eligible, participation in the study involves completing a 20-minute survey, where you'll view the educational content, answer related multiple-choice questions, and provide feedback. We would love to hear your thoughts to make these resources more effective. This study has been approved by the Johns Hopkins University IRB (IRB00486267). The principal investigator is Dr. Michelle Kush. **Your completion of this survey will serve as your consent to participate in this research study.** Your responses will remain completely anonymous, and Johns Hopkins University will not be able to identify you as an individual. The aggregate and analyzed data of this study may be published.

End of Block: Consent

Start of Block: Eligibility

Q2.1 Are you 18 years or older?

- ○ Yes (1)
- ○ No (2)

Skip To: End of Survey If Q2.1 = 2

Page Break

Page 2 of 13

Figure 112. Qualtrics module, page 2.

Q2.2 Thank you for taking part in this survey. Your feedback is crucial in helping us develop effective teaching materials that can support patients in discussing their diagnosis with healthcare providers. The purpose of this survey is to evaluate the effectiveness of these materials. Please note that this survey is designed to gauge your response to the provided materials. **We ask that you do not consult any external resources while completing the survey,** as we want to measure the impact of the materials we've created. The survey will consist of three parts: **1) Pre-test:** A set of questions before you view the materials. **2) Materials Review:** A short presentation of the teaching materials. **3) Post-test:** A set of questions after reviewing the materials. It's perfectly okay if you don't know the answer to a question—please just submit your best guess. Your honest responses will help us improve the quality of these resources. Thank you again for your valuable participation!

End of Block: Eligibility

Start of Block: Pre-Test Questions

Q3.1 What does the term "LUTO" stand for?

____

____

____

____

____

Q3.2 LUTO most commonly affects which part of the fetus's body? (Select all that apply)

- ☐ The brain (1)
- ☐ The lungs (2)
- ☐ The urinary system (3)
- ☐ The heart (4)
- ☐ The digestive system (5)

Page 3 of 13

Figure 113. Qualtrics module, page 3.

Q3.3 Which of the following best describes the primary cause of LUTO in a fetus?

- ○ Malformation of the lungs affecting fluid levels (1)
- ○ Obstruction of the urinary tract leading to impaired fluid drainage (2)
- ○ Excessive production of amniotic fluid (3)
- ○ Failure of the fetal kidneys to produce urine (4)

Q3.4 Which impact on fetal development is true?

- ○ Fluid retention in the lungs (1)
- ○ Impaired lung growth and development (2)
- ○ Hyperactive kidneys (3)
- ○ Reduced fetal heart size (4)

Q3.5 Which of the following treatments might be used to manage more severe cases of LUTO detected? (Select all that apply)

- ☐ Placement of a vesicoamniotic shunt (1)
- ☐ Administration of steroids to enhance kidney function (2)
- ☐ Non-invasive ventilation to support lung function (3)
- ☐ Intrauterine blood transfusions to encourage amniotic fluid production (4)
- ☐ Drainage of excess amniotic fluid via an intrauterine catheter (5)
- ☐ Amniotic fluid infusion to maintain lung development (6)

Q3.6 What is the role of amniotic fluid in fetal lung development?

- ○ Prevents fluid overload in the lungs (1)
- ○ Provides pressure needed for lung expansion and growth (2)
- ○ Supplies nutrients essential for alveolar maturation (3)
- ○ Reduces the risk of bacterial infections in utero (4)

Page 4 of 13

Figure 114. Qualtrics module, page 4.

Q3.7 In what ways can LUTO impact the lungs? (Select all that apply)

- ☐ Lack of amniotic fluid prevents proper lung growth and development (1)
- ☐ Increased pressure from the fetal diaphragm limits lung capacity (2)
- ☐ Excessive urine production causes fluid to compress the lungs (3)
- ☐ Fluid buildup in the fetal airway prevents lung inflation (4)
- ☐ LUTO does not impact lung development (5)

Q3.8 Which statement is true regarding the source of amniotic fluid in the second and third trimesters?

- ○ Primarily secreted by the placental villi (1)
- ○ Predominantly produced by the fetal kidneys and excreted as urine (2)
- ○ Generated mainly by maternal blood plasma seepage (3)
- ○ Produced by the fetal lungs through surfactant release (4)

*

Q3.9 Which of the following long-term outcomes are most strongly associated with severe, untreated LUTO? (Select all that apply)

- ☐ Chronic kidney disease requiring dialysis or transplant (1)
- ☐ Pulmonary issues leading to lifelong respiratory complications (2)
- ☐ Developmental delays due to reduced oxygenation in utero (3)
- ☐ Increased risk of cardiovascular abnormalities due to abnormal fluid during development (4)

Page 5 of 13

Figure 115. Qualtrics module, page 5.

Q3.10 On a scale of 1 (not confident at all) to 10 (extremely confident), how confident are you in your understanding of LUTO so that you could explain it to someone else?

- 0 (0)
- 1 (1)
- 2 (2)
- 3 (3)
- 4 (4)
- 5 (5)
- 6 (6)
- 7 (7)
- 8 (8)
- 9 (9)
- 10 (10)

End of Block: Pre-Test Questions

Start of Block: Old Content

Q4.1 Please view the resource below:

[[EMBEDDED VIDEO]]

If it doesn't load, you can visit it at this link.

Page Break

Page 6 of 13

Figure 116. Qualtrics module, page 6.

Q4.2 Please indicate your level of agreement with the following statements regarding the resource you just reviewed:

	Strongly agree (1)	Somewhat agree (2)	Neither agree nor disagree (3)	Somewhat disagree (4)	Strongly disagree (5)
The content held my attention. (1)	○	○	○	○	○
The content was easy to understand. (2)	○	○	○	○	○
The content addressed most of my questions. (3)	○	○	○	○	○
The amount of content was appropriate. (4)	○	○	○	○	○
I would recommend this content to someone interested in fetal health or LUTO. (5)	○	○	○	○	○

Q4.3 What emotion(s) do you associate with this resource?

____

____

____

____

____

End of Block: Old Content

Start of Block: New Content

Page 7 of 13

Figure 117. Qualtrics module, page 7.

Q5.1 Please view the resource below:

[[EMBEDDED VIDEO]]

If it doesn't load, you can visit it at this link.

Page Break

Page 8 of 13

Figure 118. Qualtrics module, page 8.

Q5.2 Please indicate your level of agreement with the following statements regarding the resource you just reviewed:

	Strongly agree (1)	Somewhat agree (2)	Neither agree nor disagree (3)	Somewhat disagree (4)	Strongly disagree (5)
The content held my attention. (1)	○	○	○	○	○
The content was easy to understand. (2)	○	○	○	○	○
The content addressed most of my questions. (10)	○	○	○	○	○
The amount of content was appropriate. (3)	○	○	○	○	○
I would recommend this content to someone interested in fetal health or LUTO. (5)	○	○	○	○	○

Q5.3 What emotion(s) do you associate with this resource?

____

____

____

____

____

End of Block: New Content

Start of Block: Post-Test

Page 9 of 13

Figure 119. Qualtrics module, page 9.

Q6.1 What does the term “LUTO” stand for?

Q6.2 LUTO most commonly affects which part of the fetus's body? (Select all that apply)

- ☐ The brain (1)
- ☐ The lungs (2)
- ☐ The urinary system (3)
- ☐ The heart (4)
- ☐ The digestive system (5)

Q6.3 Which of the following best describes the primary cause of LUTO in a fetus?

- ○ Malformation of the lungs affecting fluid levels (1)
- ○ Obstruction of the urinary tract leading to impaired fluid drainage (2)
- ○ Excessive production of amniotic fluid (3)
- ○ Failure of the fetal kidneys to produce urine (4)

Q6.4 Which impact on fetal development is true?

- ○ Fluid retention in the lungs (1)
- ○ Impaired lung growth and development (2)
- ○ Hyperactive kidneys (3)
- ○ Reduced fetal heart size (4)

Page 10 of 13

Figure 120. Qualtrics module, page 10.

Q6.5 Which of the following treatments might be used to manage more severe cases of LUTO detected? (Select all that apply)

- ☐ Placement of a vesicoamniotic shunt (1)
- ☐ Administration of steroids to enhance kidney function (2)
- ☐ Non-invasive ventilation to support lung function (3)
- ☐ Intrauterine blood transfusions to encourage amniotic fluid production (4)
- ☐ Drainage of excess amniotic fluid via an intrauterine catheter (5)
- ☐ Amniotic fluid infusion to maintain lung development (6)

Q6.6 What is the role of amniotic fluid in fetal lung development?

- ○ Prevents fluid overload in the lungs (1)
- ○ Provides pressure needed for lung expansion and growth (2)
- ○ Supplies nutrients essential for alveolar maturation (3)
- ○ Reduces the risk of bacterial infections in utero (4)

Q6.7 In what ways can LUTO impact the lungs? (Select all that apply)

- ☐ Lack of amniotic fluid prevents proper lung growth and development (1)
- ☐ Increased pressure from the fetal diaphragm limits lung capacity (2)
- ☐ Excessive urine production causes fluid to compress the lungs (3)
- ☐ Fluid buildup in the fetal airway prevents lung inflation (4)
- ☐ LUTO does not impact lung development (5)

Q6.8 Which statement is true regarding the source of amniotic fluid in the second and third trimesters?

- ○ Primarily secreted by the placental villi (1)
- ○ Predominantly produced by the fetal kidneys and excreted as urine (2)
- ○ Generated mainly by maternal blood plasma seepage (3)
- ○ Produced by the fetal lungs through surfactant release (4)

Page 11 of 13

Figure 121. Qualtrics module, page 11.

Q6.9 Which of the following long-term outcomes are most strongly associated with severe, untreated LUTO? (Select all that apply)

- ☐ Chronic kidney disease requiring dialysis or transplant (1)
- ☐ Pulmonary issues leading to lifelong respiratory complications (2)
- ☐ Developmental delays due to reduced oxygenation in utero (3)
- ☐ Increased risk of cardiovascular abnormalities due to abnormal fluid during development (4)

Q6.10 On a scale of 1 (not confident at all) to 10 (extremely confident), how confident are you in your understanding of LUTO so that you could explain it to someone else?

- ○ 0 (0)
- ○ 1 (1)
- ○ 2 (2)
- ○ 3 (3)
- ○ 4 (4)
- ○ 5 (5)
- ○ 6 (6)
- ○ 7 (7)
- ○ 8 (8)
- ○ 9 (9)
- ○ 10 (10)

End of Block: Post-Test

Start of Block: Engagement Survey

Q7.1 Please indicate which resource you preferred:

- ○ The text information (1)
- ○ The visual information (2)

Q7.2 How familiar were you with LUTO before engaging with this survey?

- ○ Very familiar (1)
- ○ Somewhat familiar (2)
- ○ Not familiar (3)

Page 12 of 13

Figure 122. Qualtrics module, page 12.

Display this question:

If Q7.2 = 1

Or Q7.2 = 2

*

Q7.3 If you answered "Somewhat familiar" or "Very familiar," how did you learn about LUTO? (Select all that apply)

- ☐ Learning materials from JHU (1)
- ☐ Other educational sources (2)
- ☐ Medically trained (3)
- ☐ Personal experience with a LUTO diagnosis in a fetus or family member (4)

Q7.4 Do you have any feedback regarding the content and/or the presentation of the video resource you watched?

____

____

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____

____

End of Block: Engagement Survey

Page 13 of 13

Figure 123. Qualtrics module, page 13.

Appendix D: Survey Open Response Comments

Answers sorted alphabetically.

Notatoin Key:
▲ Critique for pamphlet
▲ Critique for video
● Expressed preference for pamphlet
● Expressed preference for video
♥ Compliment for the pamphlet
♥ Compliment for the video

Responses to the control media (Q4.3)

"What emotion(s) do you associate with this resource?"

	Amazement that so many things can go wrong in a pregnancy
	annoyance
	anxiety
	Anxiety
	Anxiety about pregnancy, worry,
	Atention
	Boredom
	Boredom, sadness
	Boring
	boring
	Boring
	Calm easy going unstressed
	calm, mostly. it feels like reading a resource on something.
	Caring for others
	Challenging
	clarification?
	Clinical or Academic
	concern

	concern about severity of LUTO
	Concern for the unborn foetus diagnosed with Luto
	Concern.
	Confidence and a little worry
	Confusion
	Curiosity, Hopelessness
	curiosity, interest
	Curiosity, intrigue
	curious
	Curiousity
	Curiously interested
	Dry
	Eh. Boredom? Part of that was because it was a repeat of the video, so it felt like I was reviewing something I already knew, so why bother.
	Empathy
	Empathy, concern, hope, relief and awe.
	Empathy,stress and depression
	Empowering providing knowledge, easing worries, simplifying information
	Fear
▲	Frustration due to font and design of text boxes. Makes me feel like Im studying for a test.
	Good
▲	Good, but the pamphlet design is too dense. For a normie, that would get skimmed so fast and little retained.
	Happy
	Happy to learn about this.
	helpful, value
	Hopeful
	I associate shock and empathy.
	I feel sad for those that have to experience this.
	I feel we all need to be aware of LUTO and have concrete knowledge about it

	I felt lucky that this wasn't my experience. Sad for the families that go through this
	I found the material interesting and well organized
● ▲	I think that the piece were a bit to long to keep my attention - there was to much things to read. The video was much nicer
	important to my childs future
♥	Impressed
	Interest
	Interest
	Interest
	Interest and understanding
	interested, got a bit zoned out
	interesting resource
	Intrigue, fear
	Intrigued
	maybe pleasure (at learning something new which may have affected me in my development, as well as others in my family)
	Meh. Boring
	mild empathy
	more boring but i guess good info still
	n/a
	neutral
▲	Neutral - its useful but I both wish I had more/it was organized in a way that was easier to parse
● ▲	Neutral. It had some extra information that the video didn't include, and that held my attention, but the relative dearth of visuals made it hard to conceptualize what this condition looks like and how it behaves compared to the dynamic examples in the video.
●	Not as good at holding your attention so a bit sad.
	overwhelmed
	Relief
	Sadness
	sadness

	Sadness and intrigue
	Sadness as my first daughter was stillborn and any pregnancy complications cam be scary
	satisfied
	Satisfied
	Shocked and sad
	Surprised
	Sympathetic
	Tiring
	Unsure
	Very good

Response to the experimental media (Q5.3)

"What emotion(s) do you associate with this resource?"

	Amazing!!!!
	Absolute terror at the idea of getting pregnant. But also fascinated by the fact that doctors have these ways to help the development of fetuses when it seems so likely that they wouldn't be able to survive, so that's pretty cool. But it was also just an interesting watch.
	Amazed
	Annoyance - I have severe hearing loss
	anxiety
	Calm, warm, direct
	Calmness, sadness, hope
	Care
	caring
	concern
	concern
	Concern
	Concern for fetal health and development

	Concern, mostly. It looks like a very uncomfortable and dire fetal condition
	Concern/worry, urgency.
	Concerned
	concerned
	curiosity
	Curiosity
	curiosity- the video was interesting and want to learn even more.
	Curiosity, enlightenment
	curiosity, excitement, the joy of learning
	Curiosity, Sadness
	curiousity
	disturbed, scared, interested
💚	Excitement (I'm a medical provider and this was wonderful)
	Fascination and curiosity
	Fascination, nervousness, awe, intrigue
	fear and distress this seems like a very difficult thing to deal with
	Grateful and Sad. My son had LUTO and passed away shortly after birth (7 years ago), so this video was difficult to watch, but I would've loved this resource when I was going through this and to be able to share it with family.
	gratitude, acceptance
	Happy to learn about this.
	helpful
	Helpful, intrigue, fascination
	Hope
	Hopeful, optimistic and encouraged
	I didn't have an emotional reaction.
	I felt concern and empathy.
	I was shocked to see that the kidneys can actuallly create so much problems even while still unborn. The video is a real eye opener, and I can acturally explain this to someone else if I need to
	I was very happy learning some added information about LUTO

	Informative
	Interest
	Interest
	Interest and understanding
	Interest insight
	interest, a mild discomfort due to the subject matter but mostly calm. it feels like a hospital.
	interest, some amazement
	Interest?
	interested
	Interested, intrigued, informed.
	Interesting
	Intrigue, fulfillment
	Intrigued
	Knowledge is comforting
	Mild interest
	More sadness than the text-based explanation. Seeing the fetus run out of amniotic fluid made me feel sad and slightly horrified.
	Much easier to follow than the leaflet, more engaging and feel even more informed
	None
	none. it was simply informative
	Relief
	sad
	Sad and shocking
	Sadness
	Sadness
	sadness
	sadness
	Sadness for the babies and families facing this issue.
	Sadness. worried

	scared
	Shock and some fascination
	Still felt sad knowing that this happens but I have more clarity about it now.
	Stress, Anxiety
	Stress, depression and anxiety
	Sympathetic
	Understanding
	understanding
	Very good resource for pts
	Was happy to learn something new.
	was scary knowing this condition exists, but good to know there are treatments to help the unborn child during growth in the womb
	Well, Done good explanation
	WORRIED
	Worry and concern
	Worry, curiosity, slight discomfort due to phobias regarding needles and things inside the body, interest

Further feedback (Q7.4)

"Do you have any feedback regarding the content and/or the presentation of the video resource you watched?"

♥	The video was amazing. I am not in the medical field and feel I could aptly explain the issue now. Incredible.
	Amazing graphics!
♥	Amazing video
▲ ▲	Both forms of information were useful - but may need accessibility re-approached.
▲ ▲	Both items of content I had trouble loading on mobile device.
	Both were well done and explained the issue well
	content was educative
	Great job! Great explanation and visuals.

	Great study, very informative.
	great video
	I just learned about a baby's condition that I never knew existed
	I think it was very informative and I actually learned about something that I did not even know existed. Thanks
	I think the order of the content presentation was pretty significant. Personally, I like seeing a video first and then reading about a condition later now that I've seen it in action and want to know the finer points of it. Both resources are useful but the video was much better for packing information in and holding attention, so if I only was given one, the video would teach me about LUTO much better.
	I wish the voice was not AI-generated and was actually a voice-over recorded by a human person.
	I'm a visual learner, therefore the visual content was more easily digestible. However, the short in length reading paired with the visual component held my attention enough to comprehend the lesson.
	It is interesting
	it seemed complete, competent, and polished to me.
	It was great
	It's a bit hard to read the paper bc idk all the terms and how it works I am glad there is a video
	No I don't have any feedback except that it was a good educational content that I can recommend to those with lesser information regarding luto
	no! Visually they looked very clean. The information was direct and easy to comprehend.
	Please add back buttons to the survey
	Text definitions for the more medical terms?
	Thank you for your hard work and dedication to this project!
	The animation was great, clear and directed my attention naturally along with the narration.
	The content is eye opening and very easy to understand
	The content was clear and easy to understand
	The content was very informative
	The first resource (read only) caused some confusion.
	The information was enlightening, the video content increased my knowledge of LUTO

●	The text contained more information, such as how urine gets blocked in the bladder. For that reason, I stated that I preferred it. In all honesty, I liked both sources; the information was there, and it was enough.
▲ ▲	The text information could have borders to help separate the paragraphs into more isolated chunks, and having less space in the top to allow the text to be larger and more accessible to read. The cuts to descriptions of the procedures and key words are very short and make catching the text difficult without pausing. Clarifying the trimester and/or weeks in which LUTO is usually diagnosed or noted in would be nice. The animations are both interesting and appealing.
▲	The text information was very small on the screen which made it hard to read. Don't know if that was just on my end or not. But it was annoying to try and read it and that may have impacted how useful it was to me
▲	the text one doesn't emphasise the lung issues at all, whereas it's the focus of the video. there's one offhand sentence about it in the pdf. what's more important to emphasise, the kidney or the lung damage?
▲	The text still have some terms that are not easily understandable without prior knowledge - Some extra infographics may be helpful
♥	The video did an excellent job explaining LUTO!
♥	The video is amazingly easy to understand due to how the animation compliments the narration so much
♥	The video was clear. Simple yet full of information
♥	The video was excellent
♥	The video was great
	This is a great resource for learning about LUTO
	This was very helpful, I learnt a lot.
●	Video was a lot easier, visual plus verbal plus readable material makes it more likely to absorb information

Not included in table of responses: 16 variations of “No, none, nope, N/A” etc.

Appendix E: Webpage Text

Overview

The urinary tract is made up of organs that produce and store urine, or pee . It includes two kidneys, two ureters, the bladder, and the urethra. The kidneys make the urine, which flows through the ureters into the bladder, where it is stored. When the bladder is full, it pushes the urine out through the urethra. The kidneys and ureters are called the upper urinary tract and the bladder and urethra the lower urinary tract.

Lower Urinary Tract Obstruction (LUTO) happens when the urethra is blocked, and urine can't flow out of the body. This causes urine to build up in the kidneys and ureters. Over time, this can harm the kidneys. When urine can't leave the body, the amniotic fluid (fluid around the baby in the womb, or uterus) decreases. Amniotic fluid helps the fetal lungs develop. Without enough fluid, the fetal lungs may not grow properly.

While the fetus is in the womb, the placenta acts as both lungs and kidneys. But after birth, the baby can't rely on the placenta anymore, and the lungs and kidneys must begin functioning on their own. If LUTO has caused damage to the baby's organs, they may not work properly which can affect the baby's health and lower the chance of survival.

Causes of LUTO

LUTO can happen because of a problem with the baby's genetics, or it can happen for no known reason ("isolated" LUTO).

Whether genetic or isolated, LUTO is caused by a structural issue with the urethra. The most common structure anomalies are:

- **Posterior Urethral Valve:** This is where a fold of tissue blocks the urethra, stopping urine from leaving the body.
- **Urethral Atresia:** This is where the urethra is absent, stopping the flow of urine.
- **Urethral Stricture:** This is where parts of the urethra are narrowed, restricting the flow of urine.

After birth, doctors can run tests to find out the location of the blockage causing the obstruction, which helps them decide how to treat the baby.

How LUTO is Diagnosed

Doctors use several tests to find out if a fetus has LUTO. These tests include:

- **Ultrasound:** This test uses sound waves to make pictures of the fetus inside of the womb. It helps doctors check the baby's organs, to look for any problems, and monitor growth.
- **MRI**: This test makes images of the fetal body using strong magnets. MRI helps doctors look closely at certain areas, like the fetal urinary tract.
- **Fetal Echocardiography:** This test looks at the fetal heart to check for any malformations, as babies with birth defects such as LUTO are at higher risk for heart issues.
- **Amniocentesis:** In this test, doctors take a small sample the amniotic fluid surrounding the baby. They can check the cells in this fluid for genetic problems or conditions.
- **Fetal Urinary Electrolytes:** This test checks how well the baby's kidneys are working by draining urine from the bladder to test it.

Impact on Development

When the urethra is blocked, the baby can't urinate, which affects other parts of the body.

- **Kidneys:** When urine builds up, it can damage the kidneys. This can cause hydronephrosis, or very swollen kidneys, which can lead to kidney failure . It can also cause multicystic dysplastic kidneys, which- means the kidneys don't grow properly and are filled with fluid instead of normal kidney tissue.
- **Lungs:** Normally, the baby "breathes" in amniotic fluid, which helps the lungs grow, like filling a water balloon. But when the baby can't release urine, there isn't enough amniotic fluid to help the lungs grow. This may lead to hypoplastic lungs, meaning the lungs are undeveloped and can't work properly after birth .
- **Physical issues:** Amniotic fluid cushions the fetus in the womb, giving it space to move around. Without enough fluid, there is less room for the fetus, which can cause problems like facial deformities, short limbs, clubbed feet, and joint contractions (where the joints can't move properly).

The outlook for babies with LUTO depends on how serious the blockage is and whether other organs, like the kidneys or lungs are also affected.

Some babies may need treatments like a ventilator, dialysis, or even a kidney transplant after birth. Babies with severe LUTO have a lower chance of surviving, and even if they do survive birth, they may still need a lot of medical support.

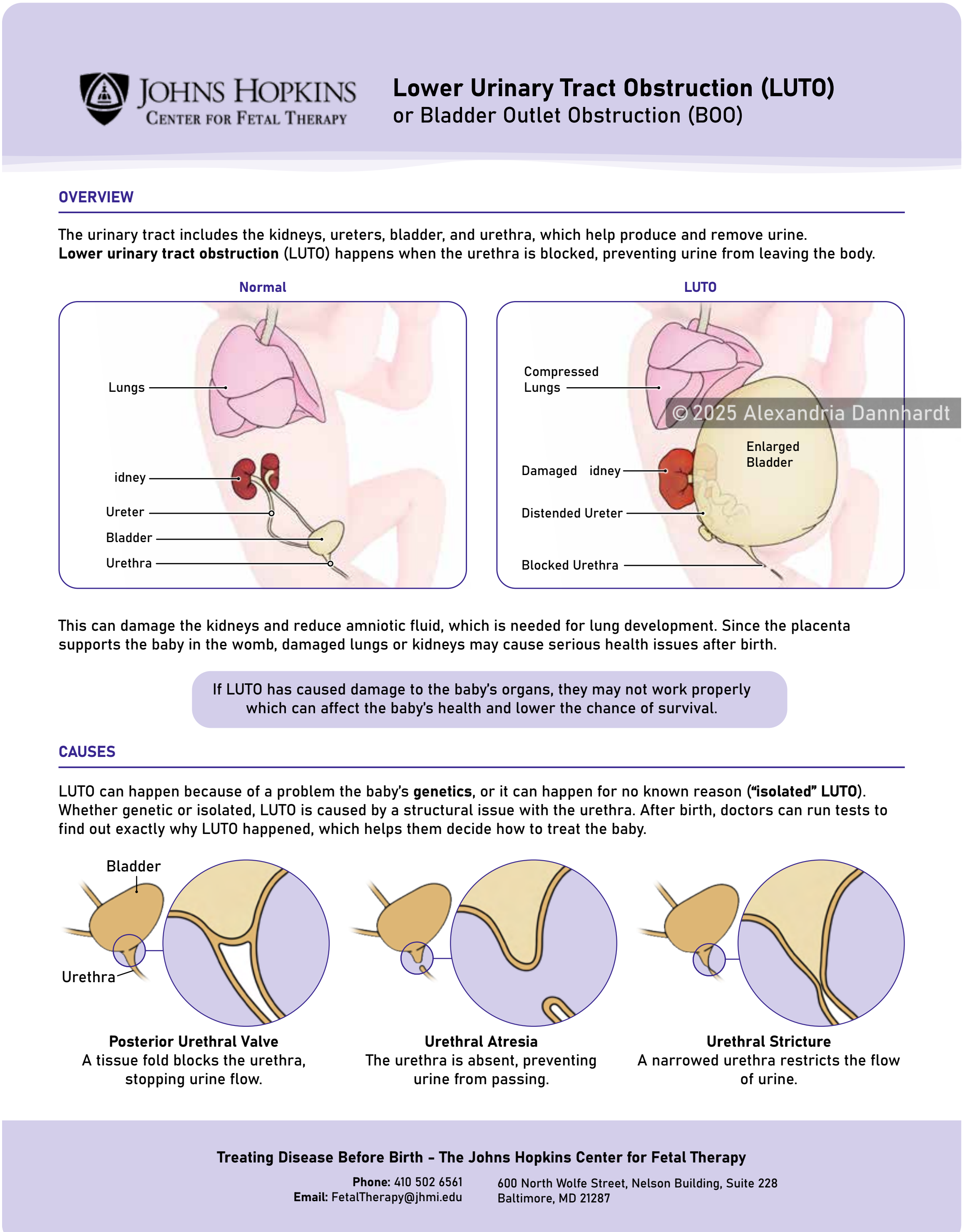
Intervention Options

There are interventions that can help some babies with LUTO, but they don't fix everything, and the baby will likely still have kidney or lung damage. These interventions can also be risky for both the baby and the mother. Doctors use many tests to decide if these interventions will help.

- **Vesicocentesis:** This is a temporary measure where a needle is used to take urine out of the baby's bladder. This helps relieve pressure. This may need to be repeated several times throughout the pregnancy.
- **Pigtail Shunt:** A shunt is a small tube that is put into the baby's bladder through the womb. The tube helps the fluid drain into the amniotic space, which can reduce the build-up of urine. This is a temporary measure until the baby is born.
- **Amnioinfusion:** In this procedure, a needle is used to put amniotic fluid into the uterus to help cushion the fetus and help the lungs to grow better. This may need to be repeated several times throughout the pregnancy.
- **Fetal Surgery**: In rare cases, doctors can perform a small surgery on the fetus using a camera to remove the blockage in the fetal urethra.

Even with these interventions, there are risks. If a shunt was placed, it can become dislodged and may need to be replaced. The blockage can come back, or other problems like fetal infection, early labor, or even miscarriage can happ en. The interventions cannot undo any damage that might have already happened to the kidneys.

Appendix F: Patient Handout



Lower Urinary Tract Obstruction (LUTO)
or Bladder Outlet Obstruction (BOO)

Johns Hopkins Center for Fetal Therapy

OVERVIEW

The urinary tract includes the kidneys, ureters, bladder, and urethra, which help produce and remove urine.
Lower urinary tract obstruction (LUTO) happens when the urethra is blocked, preventing urine from leaving the body.

This can damage the kidneys and reduce amniotic fluid, which is needed for lung development. Since the placenta supports the baby in the womb, damaged lungs or kidneys may cause serious health issues after birth.

If LUTO has caused damage to the baby's organs, they may not work properly which can affect the baby's health and lower the chance of survival.

CAUSES

LUTO can happen because of a problem the baby's **genetics**, or it can happen for no known reason (**"isolated" LUTO**). Whether genetic or isolated, LUTO is caused by a structural issue with the urethra. After birth, doctors can run tests to find out exactly why LUTO happened, which helps them decide how to treat the baby.

Posterior Urethral Valve
A tissue fold blocks the urethra, stopping urine flow.

Urethral Atresia
The urethra is absent, preventing urine from passing.

Urethral Stricture
A narrowed urethra restricts the flow of urine.

Treating Disease Before Birth – The Johns Hopkins Center for Fetal Therapy

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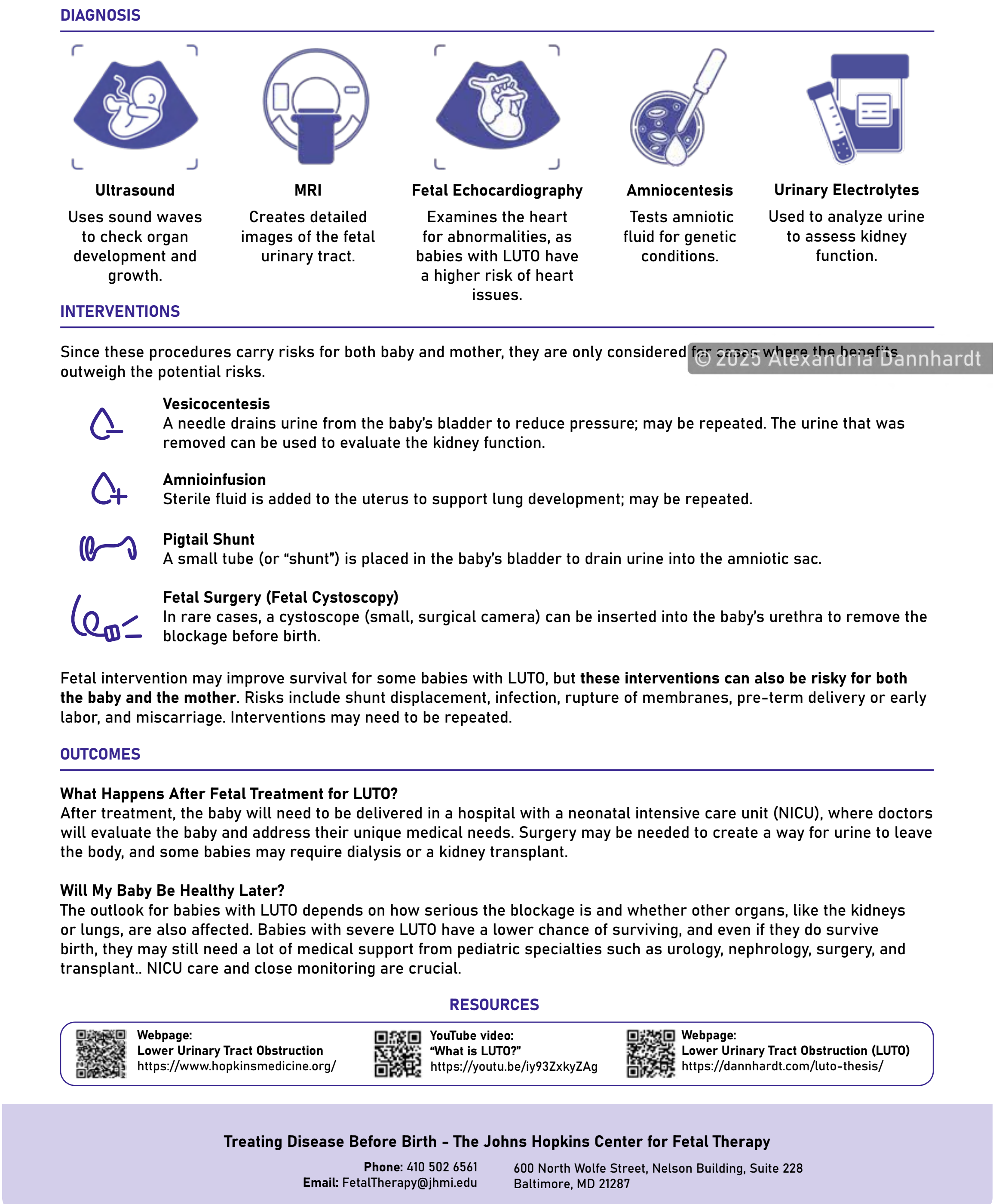
Baltimore, MD 21287

Figure 124. Patient Handout, page 1. Figure displays layout and illustrations; text is not intended to be read. Full text content is available in **Appendix G.**



DIAGNOSIS

Ultrasound
Uses sound waves to check organ development and growth.

MRI
Creates detailed images of the fetal urinary tract.

Fetal Echocardiography
Examines the heart for abnormalities, as babies with LUTO have a higher risk of heart issues.

Amniocentesis
Tests amniotic fluid for genetic conditions.

Urinary Electrolytes
Used to analyze urine to assess kidney function.

INTERVENTIONS

Since these procedures carry risks for both baby and mother, they are only considered for cases where the benefits outweigh the potential risks.

Vesicocentesis
A needle drains urine from the baby's bladder to reduce pressure; may be repeated. The urine that was removed can be used to evaluate the kidney function.

Amnioinfusion
Sterile fluid is added to the uterus to support lung development; may be repeated.

Pigtail Shunt
A small tube (or "shunt") is placed in the baby's bladder to drain urine into the amniotic sac.

Fetal Surgery (Fetal Cystoscopy)
In rare cases, a cystoscope (small, surgical camera) can be inserted into the baby's urethra to remove the blockage before birth.

Fetal intervention may improve survival for some babies with LUTO, but **these interventions can also be risky for both the baby and the mother**. Risks include shunt displacement, infection, rupture of membranes, pre-term delivery or early labor, and miscarriage. Interventions may need to be repeated.

OUTCOMES

What Happens After Fetal Treatment for LUTO?
After treatment, the baby will need to be delivered in a hospital with a neonatal intensive care unit (NICU), where doctors will evaluate the baby and address their unique medical needs. Surgery may be needed to create a way for urine to leave the body, and some babies may require dialysis or a kidney transplant.

Will My Baby Be Healthy Later?
The outlook for babies with LUTO depends on how serious the blockage is and whether other organs, like the kidneys or lungs, are also affected. Babies with severe LUTO have a lower chance of surviving, and even if they do survive birth, they may still need a lot of medical support from pediatric specialties such as urology, nephrology, surgery, and transplant.. NICU care and close monitoring are crucial.

RESOURCES

Webpage:
Lower Urinary Tract Obstruction
https://www.hopkinsmedicine.org/

YouTube video:
"What is LUTO?"
https://youtu.be/iy93ZxkyZAg

Webpage:
Lower Urinary Tract Obstruction (LUTO)
https://dannhardt.com/luto-thesis/

Treating Disease Before Birth - The Johns Hopkins Center for Fetal Therapy

Phone: 410 502 6561
Email: FetalTherapy@jhmi.edu

600 North Wolfe Street, Nelson Building, Suite 228
Baltimore, MD 21287

Figure 125. Patient Handout, page 2. Figure displays layout and illustrations; text is not intended to be read. Full text content is available in **Appendix G.**

Appendix G: Patient Handout Text

Lower Urinary Tract Obstruction (LUTO)
or Bladder Outlet Obstruction (BOO)

Overview

The urinary tract includes the kidneys, ureters, bladder, and urethra, which help produce and remove urine. Lower urinary tract obstruction (LUTO) happens when the urethra is blocked, preventing urine from leaving the body.

This can damage the kidneys and reduce amniotic fluid, which is needed for lung development. Since the placenta supports the baby in the womb, damaged lungs or kidneys may cause serious health issues after birth.

If LUTO has caused damage to the baby's organs, they may not work properly, which can affect the baby's health and lower the chance of survival.

Causes

LUTO can happen because of a problem the baby's genetics , or it can happen for no known reason ("isolated" LUTO). Whether genetic or isolated, LUTO is caused by a structural issue with the urethra. After birth, doctors can run tests to find out exactly why LUTO happened, which helps them decide how to treat the baby.

- **Posterior Urethral Valve:** A tissue fold blocks the urethra, stopping urine flow.
- **Urethral Atresia**: The urethra is absent, preventing urine from passing.
- **Urethral Stricture:** A narrowed urethra restricts the flow of urine.

Diagnosis

- **Ultrasound**: Uses sound waves to check organ development and growth.
- **MRI:** Creates detailed images of the fetal urinary tract.
- **Fetal Echocardiography:** Examines the heart for abnormalities, as babies with LUTO have a higher risk of heart issues.
- **Amniocentesis**: Tests amniotic fluid for genetic conditions.
- **Urinary Electrolytes:** Used to analyze urine to assess kidney function.

Interventions

Since these procedures carry risks for both baby and mother, they are only considered for cases where the benefits outweigh the potential risks.

- **Vesicocentesis:** A needle drains urine from the baby's bladder to reduce pressure; may be repeated. The urine that was removed can be used to evaluate the kidney function.
- **Amnioinfusion:** Sterile fluid is added to the uterus to support lung development; may be repeated.
- **Pigtail Shunt:** A small tube (or "shunt") is placed in the baby's bladder to drain urine into the amniotic sac.
- **Fetal Surgery (Fetal Cystoscopy):** In rare cases, a cystoscope (small, surgical camera) can be inserted into the baby's urethra to remove the blockage before birth.

Fetal intervention may improve survival for some babies with LUTO, but these interventions can also be risky for both the baby and the mother. Risks include shunt displacement , infection, rupture of membranes, pre-term delivery or early labor, and miscarriage. Interventions may need to be repeated.

Outcomes

What Happens After Fetal Treatment for LUTO?

After treatment, the baby will need to be delivered in a hospital with a neonatal intensive care unit (NICU) , where doctors will evaluate the baby and address their unique medical needs . Surgery may be needed to create a way for urine to leave the body, and some babies may require dialysis or a kidney transplant.

Will My Baby Be Healthy Later?

The outlook for babies with LUTO depends on how serious the blockage is and whether other organs, like the kidneys or lungs, are also affected. Babies with severe LUTO have a lower chance of surviving, and even if they do survive birth, they may still need a lot of medical support from pediatric specialties such as urology, nephrology, surgery, and transplant. NICU care and close monitoring are crucial.

Resources:

Links and QR codes to: JHU Webpage, Thesis Video, Thesis Webpage

REFERENCES

Alegría, M., Polo, A., Gao, S., Santana, L., Rothstein, D., Jimenez, A., Hunter, M. L., Mendieta, F., Oddo, V., & Normand, S.-L. (2008). Evaluation of a patient activation and empowerment intervention in mental health care. Medical Care, 46(3), 247–256. https://doi.org/10.1097/MLR.0b013e318158af52

Bernhard, J.-C., Isotani, S., Matsugasumi, T., Duddalwar, V., Hung, A. J., Suer, E., Baco, E., Satkunasivam, R., Djaladat, H., Metcalfe, C., Hu, B., Wong, K., Park, D., Nguyen, M., Hwang, D., Bazargani, S. T., De Castro Abreu, A. L., Aron, M., Ukimura, O., & Gill, I. S. (2016). Personalized 3D printed model of kidney and tumor anatomy: A useful tool for patient education. World Journal of Urology, 34(3), 337–345. https://doi.org/10.1007/s00345-015-1632-2

Bhandari, J., Thada, P. K., & Sergent, S. R. (2025). Potter Syndrome. In StatPearls. StatPearls Publishing. http://www.ncbi.nlm.nih.gov/books/NBK560858/

Capone, V., Persico, N., Berrettini, A., Decramer, S., De Marco, E. A., De Palma, D., Familiari, A., Feitz, W., Herthelius, M., Kazlauskas, V., Liebau, M., Manzoni, G., Maternik, M., Mosiello, G., Schanstra, J. P., Vande Walle, J., Wühl, E., Ylinen, E., Zurowska, A., … Montini, G. (2022). Definition, diagnosis and management of fetal lower urinary tract obstruction: Consensus of the ERKNet CAKUT-Obstructive Uropathy Work Group. Nature Reviews Urology, 19(5), 295–303. https://doi.org/10.1038/s41585-022-00563-8

Carroll, J. M. (2014). Creating Minimalist Instruction. International Journal of Designs for Learning, 5(2). https://doi.org/10.14434/ijdl.v5i2.12887

Center for Fetal Therapy. (2021, August 8). Lower Urinary Tract Obstruction. Johns Hopkins Medicine. https://www.hopkinsmedicine.org/health/conditions-and-diseases/lower-urinary-tract-obstruction

Chang, K., Berthelet, E., Grubbs, E., Hamilton, S., Karvat, A., Tran, E., Wu, J., & Ingledew, P.-A. (2020). Websites, Websites Everywhere: How Thyroid Cancer Patients Use the Internet. Journal of Cancer Education, 35(6), 1177–1183. https://doi.org/10.1007/s13187-019-01576-5

Choi, S., Ahn, J., Lee, D., & Jung, Y. (2009). The Effectiveness of Mobile Discharge Instruction Videos (MDIVs) in Communicating Discharge Instructions to Patients with Lacerations or Sprains: Southern Medical Journal, 102(3), 239–247. https://doi.org/10.1097/SMJ.0b013e318197f319

De Jong, T. (2010). Cognitive load theory, educational research, and instructional design: Some food for thought. Instructional Science, 38(2), 105–134. https://doi.org/10.1007/s11251-009-9110-0

Denny, E., Quinlan-Jones, E., Bibila, S., & Kilby, M. (2014). The experience of pregnant women with a diagnosis of fetal lower urinary tract obstruction (LUTO). Midwifery, 30(6), 636–642. https://doi.org/10.1016/j.midw.2013.10.023

Deshpande, N., Wu, M., Kelly, C., Woodrick, N., Werner, D. A., Volerman, A., & Press, V. G. (2023). Video-Based Educational Interventions for Patients With Chronic Illnesses: Systematic Review. Journal of Medical Internet Research, 25, e41092. https://doi.org/10.2196/41092

Fiore-Silfvast, B., Hartung, C., Iyengar, K., Iyengar, S., Israel-Ballard, K., Perin, N., & Anderson, R. (2013). Mobile video for patient education: The midwives' perspective. Proceedings of the 3rd ACM Symposium on Computing for Development, 1–10. https://doi.org/10.1145/2442882.2442885

Fitzsimmons, E. D., & Bajaj, T. (2025). Embryology, Amniotic Fluid. In StatPearls. StatPearls Publishing. http://www.ncbi.nlm.nih.gov/books/NBK541089/

Haeri, S. (2015). Fetal Lower Urinary Tract Obstruction (LUTO): A practical review for providers. Maternal Health, Neonatology and Perinatology, 1, 26. https://doi.org/10.1186/s40748-015-0026-1

Hooper, S. B., & Harding, R. (1995). FETAL LUNG LIQUID: A MAJOR DETERMINANT OF THE GROWTH AND FUNCTIONAL DEVELOPMENT OF THE FETAL LUNG. Clinical and Experimental Pharmacology and Physiology, 22(4), 235–241. https://doi.org/10.1111/j.1440-1681.1995.tb01988.x

Karsenty, C., Guitarte, A., Dulac, Y., Briot, J., Hascoet, S., Vincent, R., Delepaul, B., Vignaud, P., Djeddai, C., Hadeed, K., & Acar, P. (2021). The usefulness of 3D printed heart models for medical student education in congenital heart disease. BMC Medical Education, 21(1), 480. https://doi.org/10.1186/s12909-021-02917-z

Klaus, R., & Lange-Sperandio, B. (2022). Chronic Kidney Disease in Boys with Posterior Urethral Valves–Pathogenesis, Prognosis and Management. Biomedicines, 10(8), 1894. https://doi.org/10.3390/biomedicines10081894

Knudsen, B. M., Søndergaard, S. R., Stacey, D., & Steffensen, K. D. (2024). Impact of timing and format of patient decision aids for breast cancer patients on their involvement in and preparedness for decision making—The IMPACTT randomised controlled trial protocol. BMC Cancer, 24(1), 336. https://doi.org/10.1186/s12885-024-12086-z

Kohl, T. (2022). Management of very young fetuses with LUTO. Nature Reviews Urology, 19(10), 627–628. https://doi.org/10.1038/s41585-022-00636-8

Kraft, S. A., Constantine, M., Magnus, D., Porter, K. M., Lee, S. S.-J., Green, M., Kass, N. E., Wilfond, B. S., & Cho, M. K. (2017). A randomized study of multimedia informational aids for research on medical practices: Implications for informed consent. Clinical Trials, 14(1), 94–102. https://doi.org/10.1177/1740774516669352

Leiner, M. (2004). Patient communication: A multidisciplinary approach using animated cartoons. Health Education Research, 19(5), 591–595. https://doi.org/10.1093/her/cyg079

Lindau, S. T., Tomori, C., Lyons, T., Langseth, L., Bennett, C. L., & Garcia, P. (2002). The association of health literacy with cervical cancer prevention knowledge and health behaviors in a multiethnic cohort of women. American Journal of Obstetrics and Gynecology, 186(5), 938–943. https://doi.org/10.1067/mob.2002.122091

Malin, G., Tonks, A., Morris, R., Gardosi, J., & Kilby, M. (2012). Congenital lower urinary tract obstruction: A population-based epidemiological study. BJOG: An International Journal of Obstetrics & Gynaecology, 119(12), 1455–1464. https://doi.org/10.1111/j.1471-0528.2012.03476.x

Mandaletti, M., Cerchia, E., Ruggiero, E., Teruzzi, E., Bastonero, S., Pertusio, A., Della Corte, M., Sciarrone, A., & Gerocarni Nappo, S. (2024). Obstructive or non-obstructive megacystis: A prenatal dilemma. Frontiers in Pediatrics, 12, 1379267. https://doi.org/10.3389/fped.2024.1379267

Marteau, T. M., Kidd, J., Cuddeford, L., & Walker, P. (1996). Reducing anxiety in women referred for colposcopy using an information booklet. British Journal of Health Psychology, 1(2), 181–189. https://doi.org/10.1111/j.2044-8287.1996.tb00501.x

McMillan, D., Hung, M., Vu, T., Dang, P., & Kritz-Silverstein, D. (2023). Student engagement and comprehension using tactile and virtual learning. Journal of Dental Education, 87(6), 797–803. https://doi.org/10.1002/jdd.13181

Meade, C. D., McKinney, W. P., & Barnas, G. P. (1994). Educating patients with limited literacy skills: The effectiveness of printed and videotaped materials about colon cancer. American Journal of Public Health, 84(1), 119–121. https://doi.org/10.2105/AJPH.84.1.119

Menendez, M. E., Van Hoorn, B. T., Mackert, M., Donovan, E. E., Chen, N. C., & Ring, D. (2017). Patients With Limited Health Literacy Ask Fewer Questions During Office Visits With Hand Surgeons. Clinical Orthopaedics & Related Research, 475(5), 1291–1297. https://doi.org/10.1007/s11999-016-5140-5

Morris, R. K., & Kilby, M. D. (2011). Long-term renal and neurodevelopmental outcome in infants with LUTO, with and without fetal intervention. Early Human Development, 87(9), 607–610. https://doi.org/10.1016/j.earlhumdev.2011.07.004

Novak, M., & Schwan, S. (2021). Does Touching Real Objects Affect Learning? Educational Psychology Review, 33(2), 637–665. https://doi.org/10.1007/s10648-020-09551-z

Paasche-Orlow, M. K., & Wolf, M. S. (2007). The Causal Pathways Linking Health Literacy to Health Outcomes. American Journal of Health Behavior, 31(1), 19–26. https://doi.org/10.5993/AJHB.31.s1.4

Parikh, N. S., Parker, R. M., Nurss, J. R., Baker, D. W., & Williams, M. V. (1996). Shame and health literacy: The unspoken connection. Patient Education and Counseling, 27(1), 33–39. https://doi.org/10.1016/0738-3991(95)00787-3

Patterson, C., & Teale, C. (1997). Influence of written information on patients' knowledge of their diagnosis. Age and Ageing, 26(1), 41–42. https://doi.org/10.1093/ageing/26.1.41

Ruano, R., Dunn, T., Braun, M. C., Angelo, J. R., & Safdar, A. (2017). Lower urinary tract obstruction: Fetal intervention based on prenatal staging. Pediatric Nephrology, 32(10), 1871–1878. https://doi.org/10.1007/s00467-017-3593-8

Sadoski, M., & Paivio, A. (2013). Imagery and text: A dual coding theory of reading and writing. Routledge.

Schittny, J. C. (2017). Development of the lung. Cell and Tissue Research, 367(3), 427–444. https://

doi.org/10.1007/s00441-016-2545-0

Schooley, B., San Nicolas-Rocca, T., & Burkhard, R. (2015). Patient-Provider Communications in Outpatient Clinic Settings: A Clinic-Based Evaluation of Mobile Device and Multimedia Mediated Communications for Patient Education. JMIR mHealth and uHealth, 3(1), e2. https://doi.org/10.2196/mhealth.3732

Stockwell, B. R., Stockwell, M. S., Cennamo, M., & Jiang, E. (2015). Blended Learning Improves Science Education. Cell, 162(5), 933–936. https://doi.org/10.1016/j.cell.2015.08.009

Tarchi, C., Zaccoletti, S., & Mason, L. (2021). Learning from text, video, or subtitles: A comparative analysis. Computers & Education, 160, 104034. https://doi.org/10.1016/j.compedu.2020.104034

Wiljer, D., & Catton, P. (2003). Multimedia Formats for Patient Education and Health Communication: Does User Preference Matter? Journal of Medical Internet Research, 5(3), e889. https://doi.org/10.2196/jmir.5.3.e19

Zhuang, Y., Zhou, M., Liu, S., Wu, J., Wang, R., & Chen, C. (2019). Effectiveness of personalized 3D printed models for patient education in degenerative lumbar disease. Patient Education and Counseling, 102(10), 1875–1881. https://doi.org/10.1016/j.pec.2019.05.006

Żyrek, J., Klimek, M., Apanasewicz, A., Ciochoń, A., Danel, D. P., Marcinkowska, U. M., Mijas, M., Ziomkiewicz, A., & Galbarczyk, A. (2024). Social support during pregnancy and the risk of postpartum depression in Polish women: A prospective study. Scientific Reports, 14(1), 6906. https://doi.org/10.1038/s41598-024-57477-1

VITA

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In 2023, Alexandria began her M.A. in Medical and Biological Illustration at Johns Hopkins University. During her first year, she received an Award of Merit at the 2024 Association of Medical Illustrators Salon for her work. She will graduate in May 2025.

Alexandria believes effective visuals transform complex science into engaging stories. Through multimedia education—whether 2D, 3D, or interactive—she strives to make anatomy and medicine accessible, inspiring curiosity in learners and researchers alike.