Neonatal Intubation Simulation with Virtual Reality and Haptic Feedback

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Abstract

Respiratory distress syndrome (RDS), a neonatal disease characterized by difficulty breathing, is remarkably common among premature infants, affecting up to 60% of the population. Patient outcomes resulting from RDS are undesirably poor. Neonatal intubation, the primary treatment for RDS, is an extremely difficult procedure to perform. Unsatisfactory patient outcomes are in part due to ineffective training methods, which include video instruction and intubation performed on mannequins. A more realistic training method that better replicates the procedure’s technical challenges and stressful nature would enhance physician competency, resulting in improved clinical outcomes. Virtual reality (VR) is an innovative tool becoming increasingly used in the medical field, particularly for simulations. VR provides a means by which individuals can be visually and acoustically immersed in a non-physical, yet responsive, environment. Via the incorporation of haptic feedback devices, virtual simulations can include somatosensory feedback, greatly increasing simulation realism. Cutting edge medical VR simulations with haptic feedback already exist and represent the future of medical training. Integration of a well-designed virtual environment with haptic devices that imitate a neonatal intubation procedure would provide a more effective means of training. Currently, the simulation includes a prototype operating room, and beginnings of a 3D replication of a neonate and upper respiratory anatomy. Future progress will involve integrating and improving upon current 3D replications to create a virtual reality simulation similar to a real-life neonatal intubation. Successful implementation of the proposed system would increase training efficacy, lower healthcare costs, and improve patient outcomes.

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I. Introduction

Respiratory distress syndrome (RDS) is characterized by difficulty breathing in neonates and is the leading cause of death for newborns [1,2]. In the U.S. in 2015, infant mortality rates were nearly 6%, with 13.4% of those deaths attributable to RDS [3,4]. Around 7% of infants experience respiratory distress worldwide, with domestic rates closer to 1% [2,5]. RDS prevalence in neonates can range from 10-60% depending on gestation age, with increased rates in premature infants [2]. According to the World Health Organization, in 2005, nearly 10% of all births were premature, with higher numbers in lesser-developed countries, and it is expected that this number has increased due to a rise in the frequency of Cesarean section procedures [6]. Given the current state of medical technology, these numbers seem surprisingly high.

Currently, RDS is treated via a variety of methods including surfactant replacement therapy, oxygen therapy, and breathing support from a nasal continuous positive airway pressure (NCPAP) machine. For each of these methods, it is often required that a neonatal intubation procedure be performed [7]. While each method is accompanied by its own difficulties, neonatal intubation is a difficult procedure to perform. Neonatal intubation must be performed quickly, precisely, and gently. Failure to comply by these guidelines can result in suffocation, tissue damage, or even head trauma [8]. According to a variety of studies, neonatal intubation attempts are often unsuccessful, especially among residents (as would be expected). One study listed success rates of resident intubations as low as 24%, while that of fellows and consultants was closer to 80% [9]. Other studies have revealed similar results [10,11].

According to an expert in the field, Dr. Ryan McAdams, one of the primary reasons for poor outcomes is the lack of adequate training methods for physicians. Current methods are mainly restricted to video demonstration and intubation practice on neonate mannequins [12,13]. Video demonstrations can be useful, but do not emulate the high-stress environment of the delivery room, and do not involve any physical manipulations. Similarly, the hard shelled mannequins with easily identifiable vocal cords, and the stress free environment in which practice intubations are performed provide a poor representation of the actual procedure. Based on the low success rates in residents, it is obvious that these methods are not sufficient and effective training comes primarily from experience. Thus, it would be extremely beneficial to develop more effective and accessible training methods that could improve patient outcomes.

Virtual reality (VR) is an emerging tool in clinical medicine with functionalities ranging from medical training to pain management [14]. Current methods are usually limited to VR alone, but 3D Systems (Rock Hill, SC) produces cutting edge simulations which incorporate haptic feedback devices [15]. The use of haptic feedback motor arms allows developers to give virtual objects apparent physical properties by providing force feedback when an individual “touches” an object in virtual space with the motor arm stylus. VR with haptic feedback provides a possibility to create a wide variety of advanced medical training methods, which will allow for the development of realistic and effective medical training, encompassing the future of medical procedural training. Successful implementation of devices like these could reduce medical training costs, increase patient outcomes, advance medical treatments, and provide avenues by which effective medical training could be implemented in less developed regions of the world.

Neonatal intubation is a difficult procedure with poor patient outcomes, and an increase in procedural efficacy provides an opportunity to substantially decrease infant mortality rates. Current training methods including video instruction and intubation on neonatal mannequins are seemingly inadequate based on procedural success rates among medical residents [9-11]. An advancement in training techniques is thus desirable, and VR with haptic feedback provides a promising alternative to current training methods. The development of a novel VR simulation that incorporates haptic feedback to accurately emulate a neonatal intubation procedure could greatly improve patient outcomes, reduce medical costs, and expand medical training capabilities far beyond its current state.

II. Background

Dr. Ryan McAdams, our client and chief of neonatology at University of Wisconsin Hospital, is seeking a VR system incorporating haptic feedback to provide a method of neonatal intubation training for emergent physicians. Dr. McAdams has a great deal of experience in this area, having completed a fellowship in neonatology in 2005, and having performed intubations across the globe in parts of Asia and Africa as well as the United States. He stresses the importance of proper preparation before attempting to perform intubations oneself.

Prior to conducting a neonatal intubation firsthand, it is critical that residents and practicing physicians alike receive sufficient training. It is common for preterm infants to weigh less than five pounds [16], leaving these underdeveloped neonates in an incredibly fragile state. The physician’s dexterity and precision is vital in preserving an infant’s health when performing intubation. The procedure must be conducted gently yet quickly; if performed carelessly, brain bleeds and tracheal scuffing are possible [8]. If done too slowly, the neonate could suffocate [8].

Though technically challenging, intubation is a straightforward procedure, typically requiring around 20 seconds to perform [17]. First, the newborn is laid face-up, with a raised support beneath its shoulders. The head is then tilted upwards, exposing the larynx, and a laryngoscope blade is inserted into the mouth with the nondominant hand. The tongue is scooped or depressed until the vocal cords are visible. Finally, with the dominant hand, the endotracheal tube is inserted through the vocal cords into the trachea, the stylet is removed, and the tube is secured, allotting a steady flow of oxygen to the lungs via a respirator [18]. See Figure 1 for a visual depiction of a neonatal intubation.

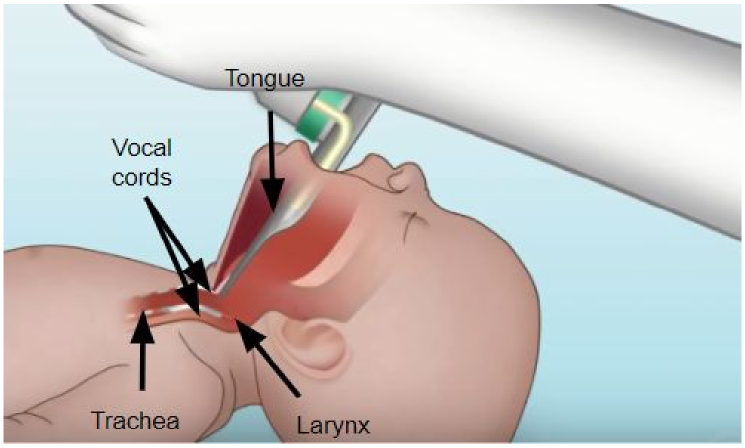

Figure 1: A diagram illustrating the anatomy of an infant's mouth and throat during a neonatal intubation. During insertion, tilting the head is important to keep the pathway to the trachea unobstructed [18].

This procedure is typically rehearsed using roughly proportioned neonate mannequins, which can cost more than $1000 [19] and do not offer sufficient anatomical accuracy or lifelike texture. Virtual simulations with haptic feedback could offer a promising alternative, allowing precise yet alterable anatomical features to be constructed using CAD software and made tangible via haptic systems.

VR, most commonly used in video games and flight training simulations, has also been used to provide additional realism to medical simulations [20]. The Oculus Rift, manufactured by Oculus (Menlo Park, CA), is regarded as the leading piece of VR display technology in the industry, and is commonly paired with the Unity game engine made by Unity Technologies (San Francisco, California) [21]. While innovative, this technology is not an effective means of procedural training by itself; tactile sensation is necessary when developing the muscle memory and confidence sufficient to conduct a successful operation. Haptic feedback fills this role.

Designed to relay intuitive analog feedback to a user's physical input, haptic devices have application in a wide variety of fields. Haptic technology has become a popular feature in automobiles, video games, and military simulations because of its capability to increase the user's proprioceptive awareness [22]. Unsurprisingly, haptic-driven medical simulations are not a new concept. Haptic feedback devices have been used to quantify the efficacy of virtual procedures performed by physicians as a method of minimizing surgical error. Virtual procedural simulations using haptic feedback have existed for at least ten years, integrating haptic devices manufactured by SenseAble Technologies (Woburn, MA) with detailed models of the human body to give physicians a highly anatomically accurate and consistent method of honing their skills [23]. Systems such as these, which incorporate visual, auditory, and somatosensory feedback, have been successfully implemented in laparoscopy and prostatectomy [24, 25].The PHANToM Touch (now owned by 3D Systems) was one of the first haptic devices available on the market, allowing the user to "feel" virtual elements along a single point of contact manipulated via a stylus integrated with a responsive motor arm [22]. See Figure 2 for a depiction of the PHANToM Touch.

Figure 2: The image depicts a PHANToM Touch (3D Systems), comprised of a handheld stylus attached to a motor arm. The device interacts with an independent computer running Geomagic software via USB [26].

The PHANToM Touch and its successors, the PHANToM Touch X and the PHANToM Premium, remain the most commercially popular haptic feedback systems on the market and dominate the playing field in medical VR simulations [27,28]. We will be using the PHANToM Touch to simulate procedural motions and generate feedback during VR simulation.

The force feedback provided by the PHANToM stylus is subjective, depending on the pseudo-physics integrated by the developer. A perfect physical simulation using a haptic device is impossible due to its finite processing capabilities. However, algorithms are capable of approximating a wide variety of physical materials. Compressible materials (such as human tissues) are inherently more complex to model than incompressible ones due to their dynamic physical properties, but have been approximated sufficiently to create artificial skin [23].

In order to develop realistic 3D models for the simulation, a series of development platforms must be used. Each platform will be used in conjunction with its strengths and weaknesses: 3D Slicer, a powerful image processing software, will be used to render 2D computed tomography (CT) images into 3D images. Solidworks and Blender, which are used for 3D modelling, will be used to further refine and synthesize props for the virtual environment. Finally, Unity's powerful physics engine will combine all of the virtual components, providing physical attributes to the neonatal model and integrating haptic feedback into the simulation.

3D Slicer

3D Slicer is an open source software platform that is designed for image processing, medical image informatics, and three-dimensional visualization [29]. It can be used for viewing and manipulating 3D Dicom data for integration into 3D modelling software. For this project, it will be used to view a CT scan of a neonate's head and upper respiratory tract. The CT data will be segmented into regions of interest such as the trachea and tongue using a manual segmentation tool which allows the user to define regions of interest (ROIs). Once defined, the ROIs can be further refined using built in functionalities such as the thresholding tool which allows the user to extract pixels within a certain intensity range. Once segmented, the ROIs will be exported as 3D .STL files. Each part will be imported into Blender as separate objects. There, they will be refined and integrated into a single neonate, with physical constraints (such as joints) pre-defined. It is worth noting that it is important to import the different anatomical regions as separate objects into Blender because this will allow us to give each object different mechanical properties. Ultimately, this process will allow for creation of an anatomically correct neonate model with a mechanically accurate internal anatomy.

Solidworks

Solidworks, manufactured by Dassault Systèmes (Vélizy-Villacoublay France) is a computer aided design software that is free to UW students and used extensively in the medical field to create realistic 3D models. Solidworks has a wide range of advanced surfacing features that will be useful when creating rigid, non-anatomical features within the virtual simulation, such as the virtual tools that the physician will use. Solidworks also supports 2D Drawing, 3D Modeling, Parametric Modeling, Photorealistic Rendering, and 3D viewing. Additionally, Solidworks has 21 writable file types, allowing for compatibility with a wide range of software [30]. See Figure 3 for an example of a SolidWorks model.

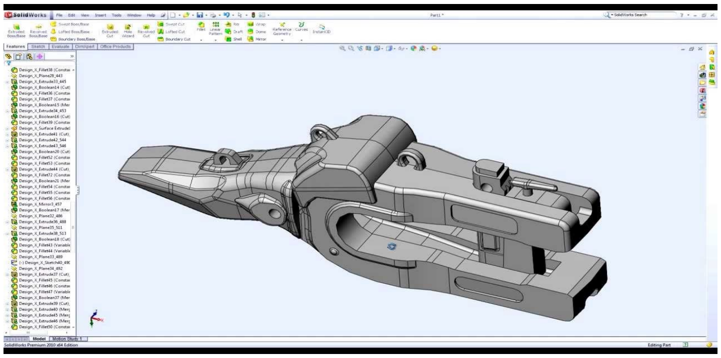

Figure 3: A 3D model created in Solidworks [30].

Blender

Blender (Amsterdam, Netherlands) is a free, open source software used to create visual effects, animation and interactive 3D models [31]. Blender will be used to synthesize a realistic 3D model of a neonate for use in the virtual simulation; the exterior skin of the neonate will be entirely created in Blender, while the internal upper respiratory tract will be first constructed in 3D Slicer and subsequently refined in Blender. Blender will also be used to mesh, rig, and texture the final model. Meshing, or the process of converting 3D images into 3D objects, unifies adjacent pixels into sections that can be manipulated as a collective whole. The process of rigging provides the model with realistic joints. Finally, texturing will provide the model with a surface “skin” representative of a real neonate, including coloration of the face and interior. Once finalized, the neonate model can be saved as a .blend file and imported directly into Unity.

Unity

Unity is the world's leading real-time gaming/development engine and is used to create half of the world's games [32]. Unity will be used to create the virtual environment and run the simulation. Ultimately, Unity will integrate 3D models made in Blender and Solidworks and allow users to interact with them in real time in a way that emulates the real procedure. Unity plugins and scripts combine the functionality of the haptic device with the properties of the 3D models in the virtual environment [33].

III. Preliminary Designs

Virtual Reality Headsets

There are a wide range of headsets available that are used to create the display in VR systems. They generally fall into two categories: Standalone VR headsets and Mobile phone VR headsets. Standalone headsets tend to be more realistic but more expensive, while mobile phone VR headsets are generally cheaper and feel less realistic.

Standalone VR headsets: Oculus Rift

There are a few standalone VR headsets currently on the market but the Oculus Rift, shown in Figure 4, is the most reasonable for our budget. The Rift costs $400-500 and has an OLED display. This display has a resolution of 2160 x 1200 pixels and a refresh rate of 90 Hz. The field of view is 110 degrees and has an 8 x 8 feet tracking area when using three sensors. The Rift also comes with custom motion tracked controllers known as Oculus Touch. The controllers have a joystick and button setup that allow for simple gesture mapping based on how the user is holding the controller [35].

Figure 4: An Oculus Rift headset.
Dimensions: 184 x 114 x 89 mm [36]

Mobile phone VR headsets: Samsung Gear VR

The most popular mobile phone VR headset is the Gear VR, developed by Samsung (Seoul, South Korea). The Gear VR headset, shown in Figure 5a, costs $99 but requires a Samsung phone, shown in Figure 5b, to operate, which would increase the price slightly. The super AMOLED display has a resolution of 2560 x 1440 pixels with a 60 Hz refresh rate. The field of view is 96 degrees. The Gear VR headset comes with a remote that allows the user to point and click in the Virtual environment; however, this remote lacks motion tracking capabilities [35].

Figure 5a: Samsung Gear VR Headset. Dimensions: 208 x 123 x 99 mm [37].

Figure 5b: A Samsung phone used with the Gear VR [37].

IV. Preliminary Design Evaluation

Virtual Reality Headset Design Matrix

Design Criteria (weight)	Oculus Rift	Samsung Gear VR
Cost (35)	2/5 (14)	5/5 (35)
Resolution (20)	4/5 (16)	5/5 (20)
Refresh Rate (20)	5/5 (20)	3/5 (12)
Cranial Tracking Ability (15)	5/5 (15)	4/5 (12)
Versatility (10)	3/5 (6)	4/5 (8)
Total (100)	71	87

Table 1: VR headset technologies are compared based on a variety of criteria. Total weight is out of 100.

Cost:

Overall weight: As shown in Table 1, cost is the most important factor because of our client's limited budget. In full-scale production, high-quality headset hardware would be paramount to the product's success. In this stage of development, though, a relatively simple proof-of-concept prototype will suffice. Additionally, a low overall cost will make the system more globally accessible. Cost is weighted at 35% of our total matrix.

Score Rationale: The Samsung Gear VR headset is cheaper than the Oculus Rift by around $400. Samsung is also more widely established and accessible globally. The Samsung Gear VR earns 5/5 in this category, while the Oculus Rift earns 2/5.

Resolution:

Overall weight: High resolution is vital in making a simulation feel lifelike. Furthermore, neonatal intubation is an incredibly precision-oriented procedure, and visibility issues could compromise the user’s experience. Again, however, a proof-of-concept device does not need to operate at full functionality.

Score Rationale: The Samsung Gear VR headset received a higher score because the Samsung Galaxy S6 resolution is higher by 42 percent, with newer phones emerging with even finer resolution [35]. The Oculus Rift is limited to only one resolution. The Samsung VR headset scores 5/5 due its greater resolution, leaving the Oculus Rift with a 4/5.

Refresh rate:

Overall weight: A high refresh rate prevents lag and buffering while simulation is taking place. Refresh weight has been evaluated at 20% of our total matrix.

Score Rationale: In this category the Oculus Rift has a higher refresh rate by 50%, earning it the edge in this category. The Samsung VR headset earns a 3/5 while the Oculus Rift earns a 5/5.

Cranial tracking ability:

Overall weight: The ability to accurately follow the motions of the user’s head is highly dependent on the system’s hardware. Cranial tracking ability will be crucial in positioning one's point of reference. The ability to position oneself in VR should be as effortless as possible, as in real life.

Score Rationale: The Oculus Rift has more precise proprioceptive capabilities than the Samsung VR earning it a score of 5/5. Despite this, the Samsung VR still does an excellent job tracking movement, yielding a score of 4/5.

Versatility:

Overall weight: Versatility is evaluated in regards to the headsets interfacing capabilities. In order to emulate a realistic virtual environment, a multitude of third-party softwares will likely need to be incorporated into the virtual system. Thus, the headset needs to be compatible with all software ranging from the gaming engine to the haptic device. In many circumstances, compatibility issues can be worked around, however, earning this category a weight of 10.

Score Rationale: The Samsung Gear VR headset is connected to Google Play, the open-source app store offered by Android. Oculus Rift, however, is run from a Windows operating system. This gives the Samsung Gear VR headset access to a wider range of third party tools and plugins that are not available on a Windows computer.

Proposed Final Design

The final neonatal model will be developed in Solidworks, Blender, and 3D Slicer. Unity, the 3D Systems Touch haptic device, and Samsung Gear VR headset will be used to create the VR simulation and environment. Unity will also be responsible for handling the pseudo physics and material property information sent to the haptic device. This device works alongside 3D Systems OpenHaptics software to attribute physical properties to objects in Unity. OpenHaptics will essentially serve as the liaison between the game engine and the Phantom Touch. When a collision occurs in the virtual environment, OpenHaptics will receive the information and communicate with the Phantom Touch to provide the proper force feedback to the user's hand. Finally, the Samsung Gear VR headset will be used in tandem with a Samsung phone to generate the display. A computer will provide the processing power necessary to run these programs, and the display will be sent to the Samsung phone for projection.

V. Fabrication

Spring 2018:

Materials

In the Spring of 2018 our team began developing a prototype virtual operating room environment using Solidworks, Blender and Unity. Additional realism was added by incorporating medical props available for download at no charge on the internet.

Solidworks, downloaded for free from the UW Campus Software Library, was used to create the simulation's endotracheal tube. Blender, another free software, was used to reorient a virtual character's arms before importing them into Unity. A free version of the powerful game development platform was used to stitch together virtual components into a 3D environment.

A variety of other virtual objects were downloaded from the internet as well. A laryngoscope model and a pair of arms were downloaded for free. Similarly, the Morgue and DeKit assets were downloaded from the Unity Asset Store at no cost. These models were subsequently used to create the final prototype environment. A list of the downloaded files can be found in Appendix B.

Methods

We began constructing the virtual environment using Unity. The room itself was defined as an oblong rectangular prism, while its floor, walls, and ceiling were distinguished by altering their color. We provided the floor a tiled texture by repeatedly inserting small squares separated by thin gaps on all sides. Most props were simply imported, resized, and placed into the simulation as RigidBody entities. However, some props required more specific alterations.

The user's arms were first reoriented in Blender to more precisely replicate a first-person perspective. Once imported into Unity, the arms' orientation were made dependent on the camera's position, providing the impression that the arms belonged to the user. As downloaded, the arms were flexed which did not appear natural as shown in Figure 6. They were modified to be extended which created a more realistic first person view as shown in Figure 7. Rough hitboxes were defined around the arms to allow the user to interact with RigidBody items.

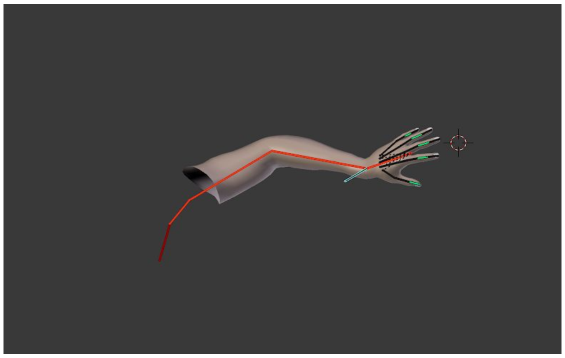

Figure 6: As downloaded, the arm was flexed, appearing slightly awkward and impractical.

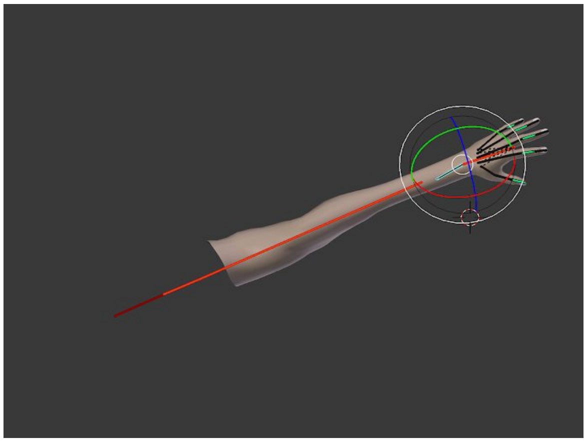

Figure 7: The modified arm model is extended, and more visible from a first-person point of view.

Rather than a RigidBody entity, the deformable sphere (Figure 8) was modelled as a series of vertices and springs. 386 vertices and 1964 springs were used. An arbitrary spring constant was experimentally derived to give the sphere deformable properties. Currently, the sphere is not intended to replicate any aspect of the procedure; it is simply intended to act as a foundation from which we create a semisolid comparable to the tissue found within the respiratory tract of a neonate.

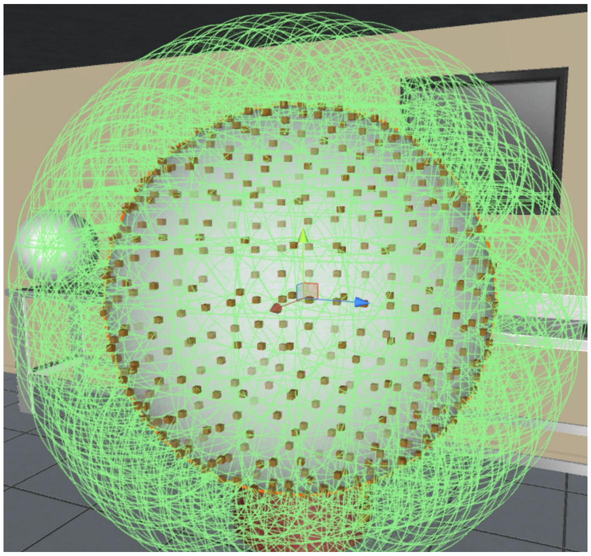

Figure 8: The deformable sphere, pictured above, is comprised of 386 vertices (brown squares) connected by a network of 1964 springs (green threads), whose stiffness can be altered by adjusting Unity's arbitrary spring constant value.

<u>Spring 2018 Prototype</u>

The mock operating room created last spring (Figure 9) includes various props including an operating table, doors, lighting, laryngoscopes (Figure 10), an endotracheal tube (Figure 10), and a deformable sphere (Figure 11). The deformable sphere will be used as a basis for the soft tissue models that will be necessary to create a neonate with realistic textures. Additionally, the arms described above and pictured in Figures 9 and 11 are the main way the user interacts with the environment.

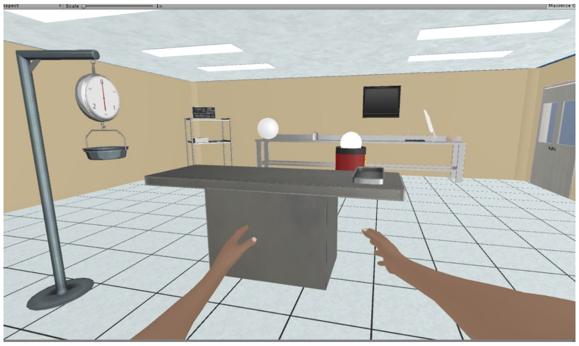

Figure 9: A first person view of the OR scene.

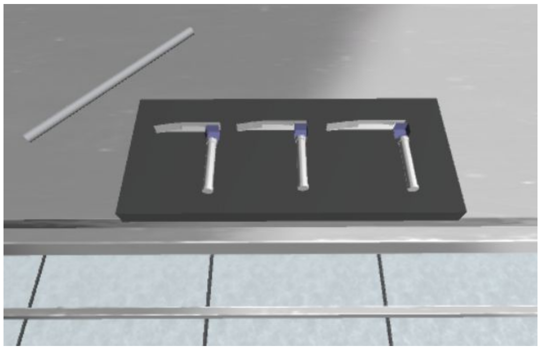

Figure 10 : Close up of models for the laryngoscopes and endotracheal tube within the OR scene.

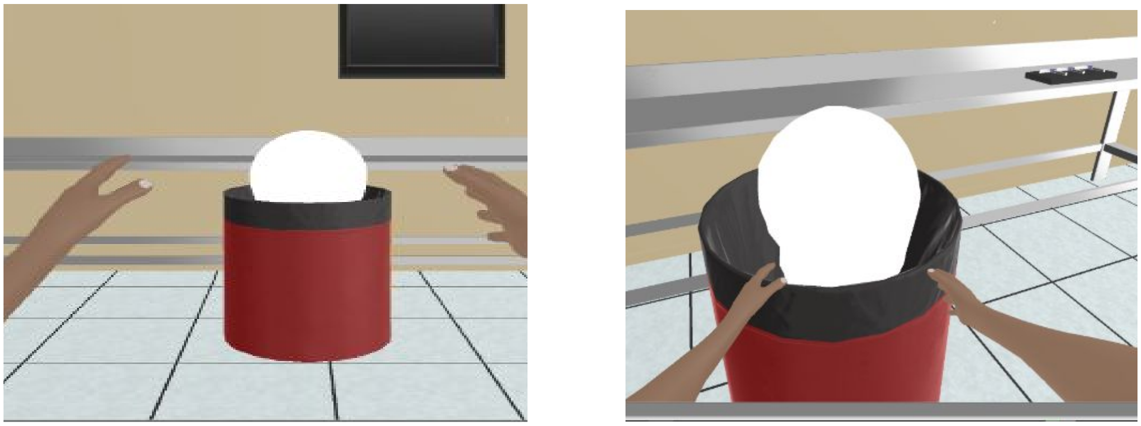

Figure 11: The deformable sphere before and after colliding with the hands.

Fall 2018

Materials

This semester our team began to develop the anatomy that will be used in the final simulation, one of the most time-consuming tasks that will be completed in order to construct the final design. Specifically, we began to refine the outer skin of a neonate, which was modified from a downloadable file on free3d.com [37]. Further, we started reconstructing a CT scan of an actual neonate's upper respiratory tract, which was obtained from the client. The bulk of this development was done in Blender, where the models will continue to be refined in the future.

Methods

Blender was utilized to modify the downloaded neonate file. As we will be adding anatomy from the neonatal CT scans, the baby was hollowed out, creating a shell to house future components. The baby was also made symmetrical to streamline future development. This will allow all rigging and texturing to be mirrored, thus decreasing workload. As the 3D baby was not originally symmetric, the baby was divided down the center of the nose and mirrored, deleting half of the original mesh. Additional surfaces were added to fill resulting gaps. The seam connecting the two halves was remeshed to ensure there were no discontinuities. Figure 12 depicts the modifications made to the original 3D baby. As the focus of our project is to provide an accurate simulation of neonatal intubation, the mouth needed to be cut open to allow for an opening and closing mouth/jaw. See Figure 13 for an example to the corrected mesh along the seam.

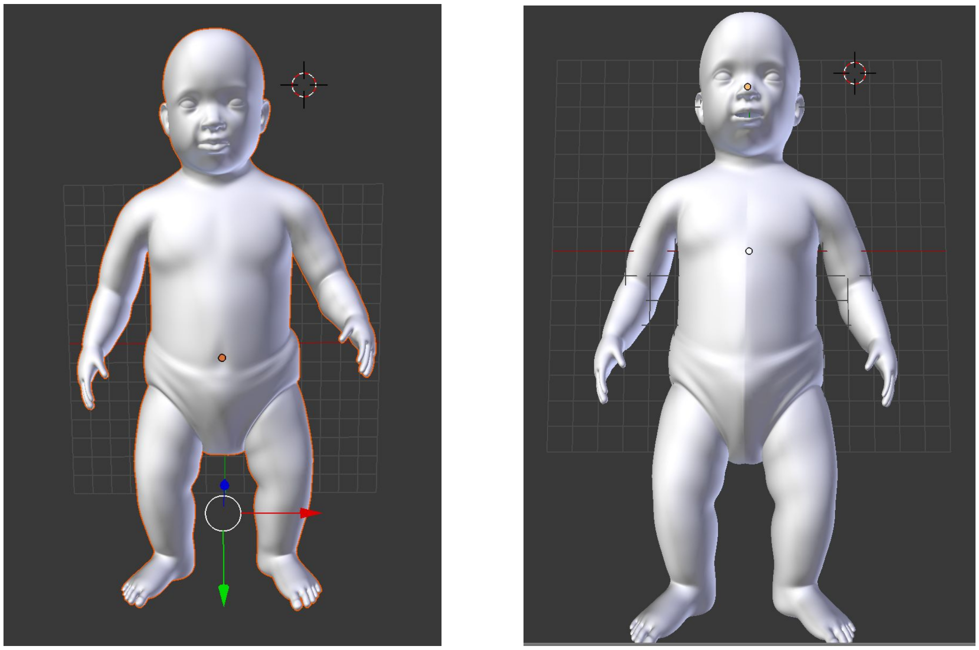

Figure 12: The figure to the right is the original baby. The figure on the left is our current neonate. Major alterations included making the baby symmetrical for better capability for later modifications, and creating an open mouth as intubation will be the focus of our simulation.

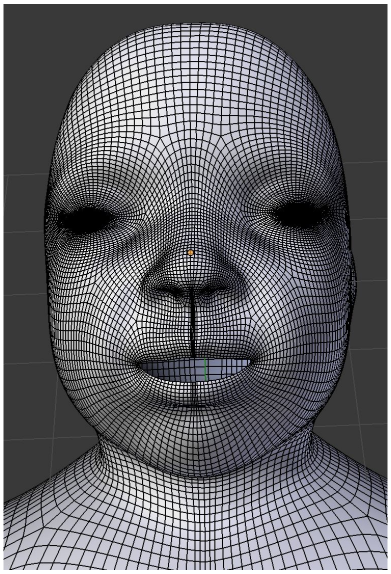

Figure 13: This figure shows the resulting mesh created after mirroring. Mesh lines were extended to ensure no discontinuities existed after integrating the two identical halves.

Other than the neonatal shell, we have also began to reconstruct the inner anatomy of the neonate. First, a CT scan of a neonate was imported into 3D Slicer, as shown in Figure 14. Next, the trachea, larynx, and vocal cords were segmented using a manual segmentation method in which the user outlines a region of interest. By utilizing a built-in thresholding functionality, which allows the user to segment pixels within a specified intensity range, a 3D model of the upper respiratory tract was isolated and subsequently exported to Blender as an .STL file.

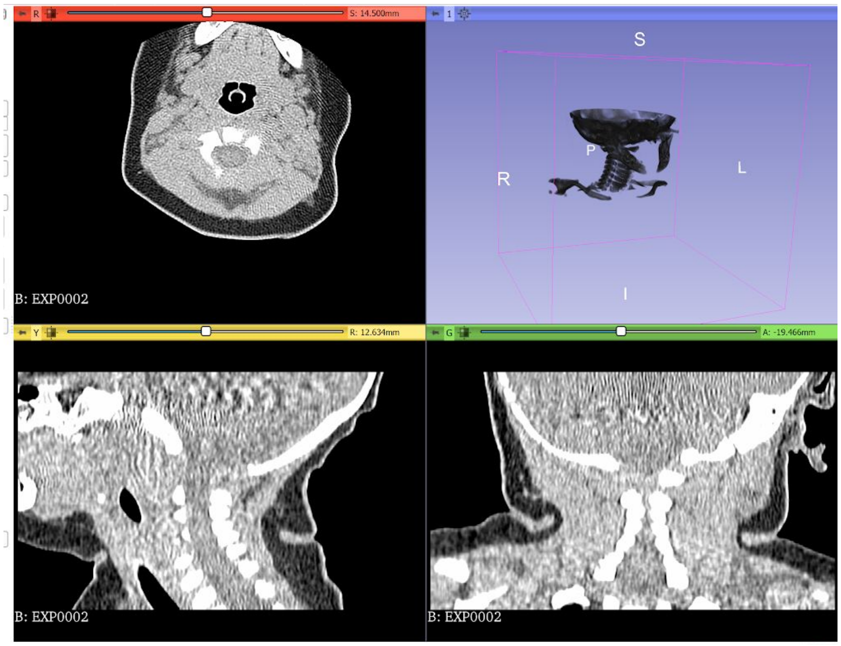

Figure 14: A screenshot of the 3D Slicer viewer, which shows the CT scan of the neonate.

Once in Blender, the model has been refined further. As depicted in Figure 15, upon the initial import into Blender, the 3D model was filled with holes and had a rough outer appearance. In order to give the upper respiratory tract a more realistic appearance, both the inner and outer surfaces were smoothed using texturing tools in Blender. Figure 16 depicts the smoothed surface, and while from the outside the object looks less realistic, the figure is shown to exemplify the capability of the smoothing tools in Blender. Further, during the actual simulation, the user will only see the inner anatomy, which is not depicted in any figures as it is not far enough along in its development to provide an accurate representation of the model.

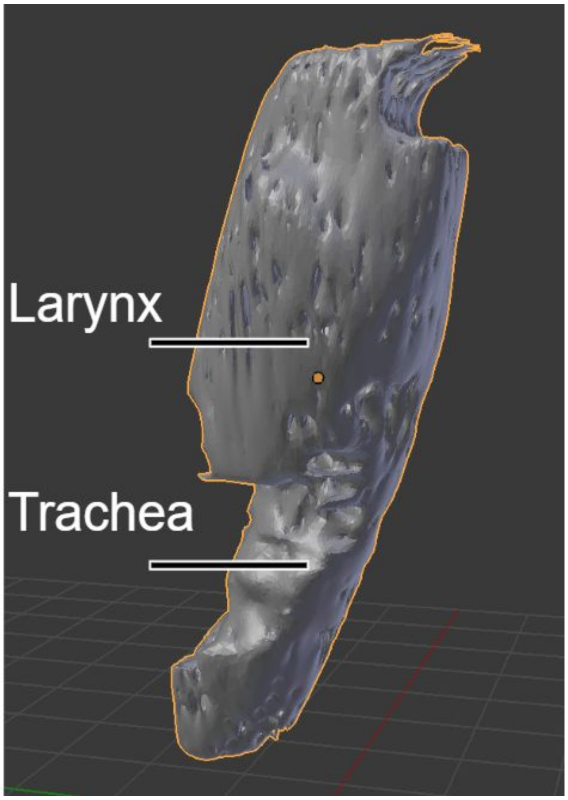

Figure 15: The upper respiratory tract upon the initial importation into Blender.

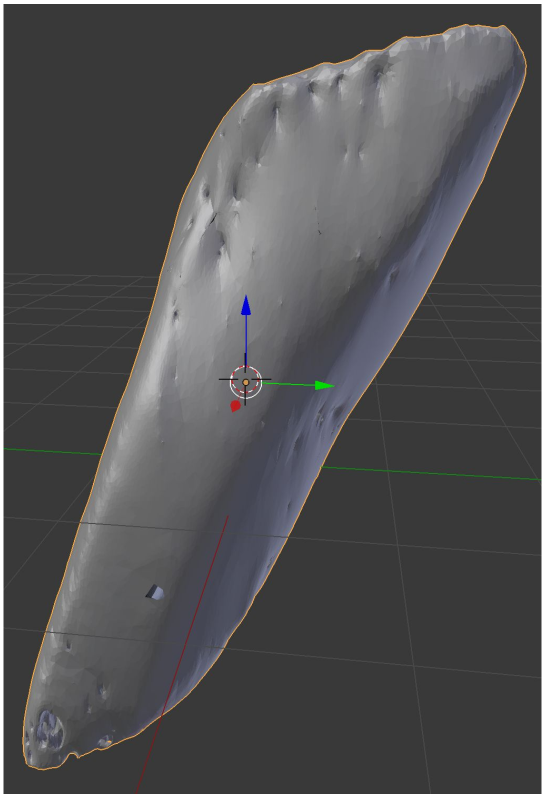

Figure 16: The upper respiratory tract once smoothed with Blender's texturing tools.

<u>Future Work</u>

The next steps in the modification of our 3D neonate will involve rigging the neonate's neck and jaw to move naturally within a VR environment. Additionally, the neonate's face, mouth and the upper respiratory tract will be segmented to allow different material properties to be implemented to each separate tissue area. For example, the cheeks will need to be more compliant than the jaw of the neonate. Separately segmenting these areas, and thus defining them as separate virtual objects, will allow different material properties to be assigned to each object in Unity. Oftentimes, neonatal models do not have accurate physical properties. Segmenting will help remedy this issue by allowing for various levels of stiffness in different areas. In order for the neonate to look realistic in the VR simulation, it will need to be textured. Texturing involves refining the surface’s shape as well as color, making the object more realistic.

Our prototype from Spring 2018 will be modified to more closely represent a neonatal OR. The arms will be updated to include realistic animations. Open source hand models from oculus (Figure 17) will be integrated into our existing first-person view using plugins available from Oculus and 3D Systems. These changes will increase the efficacy of the simulation by creating a more realistic training experience.

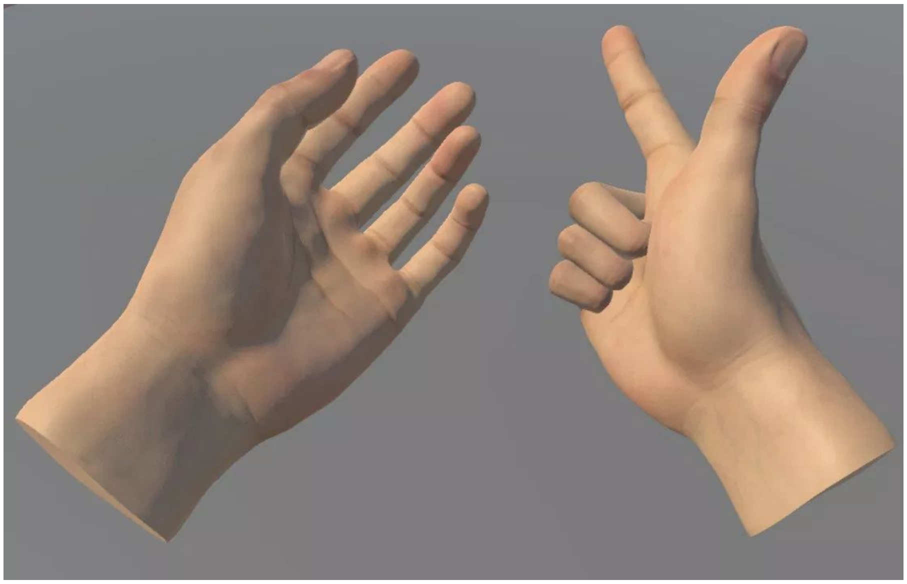

Figure 17: Textured versions of Oculus Hand Models 1.0 [38].

Testing

Due to time constraints and limited development we have not yet performed testing on the system. Further, evaluating the effectiveness of the final design will be extremely difficult. Proper testing would include finalizing the design and creating a study which compares success rates between residents that had underwent classical intubation training or had been trained using the new system. While this is a future goal, a more realistic form of testing would involve evaluating how well the different components of the design emulate a real procedure. Assessment such as this would need to be done subjectively, and would likely involve recruiting volunteer physicians who had previously performed the procedure to rate the realism of the various components of the simulation. For example, a physician would be asked to rate how well the anatomy of the neonate emulates a real model, and how realistically the tissues deform. Further, as the project progresses we plan on getting input from our clients, Drs. Tomlin and McAdams, about ways to improve the simulation. By repeatedly implementing changes and reevaluating, we will be able to fine-tune the simulation.

VI. Discussion

A successful implementation of the proposed design would drastically change neonatal intubation training and likely spur development of other simulated surgeries. Even if effective, however, accessibility to such advanced training would be limited. Initially, this project was proposed as a means of reducing training costs by avoiding incredibly expensive neonatal mannequins as well as the need for instructor supervision in hopes to provide more widespread accessibility to virtual training while also increasing effectiveness. Upon further investigation, however, access to a relatively high level facility would likely be necessary to run such an advanced simulation. The simulation would require the purchase of the devices outlined previously, such as the haptic feedback devices, VR headset, virtual reality software, and the simulation itself. Most importantly, however, the individual would need access to a powerful server to interface with the system. As mentioned in the background, realistic tissue physics is much more advanced than what conventional VR software is capable of simulating. According to VR specialists Ross Trednick and Kevin Ponto at the University of Wisconsin - Madison, in general, video game physics engines do not operate on lifelike physics models. The incorporation of non-affine transformation physics, in other words, deformable bodies, requires much more advanced physics engines which require extensive processing power. Thus, in order to simulate a high-resolution neonate with realistic physical properties in real time would require the incorporation of a highly advanced processor, most likely in the form of a server. The cost of a powerful server would greatly limit accessibility to VR medical simulations. While they could be accessible at most educational institutions, developing nations and rural areas would have limited access. Despite this, the simulation still has the potential to greatly increase medical training effectiveness and thus improve patient outcomes.

VII. Conclusion

Respiratory distress syndrome is a common disease experienced by neonates with remarkably poor clinical outcomes overall. High prevalence of RDS in neonates increases the need for more effective treatments, or alternatively, better training to increase success rates of widely used treatments. The development of a novel medical procedure simulation module which incorporates VR and haptic feedback could be highly beneficial for training effectiveness and thus, patient outcomes. It is also desirable that this system be inexpensive to increase training availability.

The final proposed system will incorporate a multitude of components including a VR headset, two haptic feedback devices, a Samsung phone, an external computer and likely, an external server. The Samsung phone will run the visual component of the virtual reality system and relay information to the computer. The haptic devices will operate in a similar fashion. The computer will subsequently rely on the external server to perform to bulk of the computer processing, and then respond to the haptic devices and phone. The virtual objects will be created using Solidworks, 3D Slicer and Blender, and imported into a scene created in Unity. Finally, virtual-physical properties of the neonatal model will be specified via a custom script in Unity, integrating haptic feedback with the final 3D product.

The complex nature of the proposed system presents an abundance of obstacles that must be overcome. While it is impossible to foresee every challenge that we may face in the creation of the design, it is worth highlighting some of the more obvious limitations and impediments. The first barrier to success lies in the possible compatibility issues between the various software elements. While through preliminary evaluation it seems as if each software will be compatible, it is quite possible that updates in any of the various components could present further obstacles down the road.

The more daunting hurdle will likely be designating realistic physical properties to the virtual objects to ensure that the haptic force feedback feels natural. Not only are there limitations in the motor arms themselves, such as only being able to provide force feedback from a single point at any given time, but the computer modeling of deformable bodies is an extremely challenging process. Given the team’s level of expertise, we will need to incorporate existing soft-body physics algorithms in our design, rather than build them ourselves. Further, to successfully assign physical properties to objects, we will need to create equations which explain how the tissue should deform when forces are applied to it. Extensive research and testing will need to be done to define those equations. Another long term goal is the introduction of multiple difficulty levels to the procedure. For example, by altering parameters such as the airway size, amount of neonatal head movement, or amount of fluid in the throat, the difficulty could be drastically altered.

Such a project is no easy task and will take time and effort. Moving forward we must conquer various aspects of the design in small increments. We will continue our progress on the 3D model of the neonate and the upper respiratory anatomy. Specifically, the 3D models will need to be rigged and textured to look and behave as they would in real-life. In addition, custom Unity scripts will need to be developed in order to incorporate the new hands into the simulation. In the future, we plan to develop viscoelastic models that accurately reflect neonates’ soft tissues, in addition to creating a realistic environment incorporating improved visuals and acoustics. The task at hand is tremendous, but represents the forefront of medical technology. In the coming years, it is likely that VR technology will become more prevalent, and will be more easily implementable to increase physician training, lower costs, and ultimately, improve clinical outcomes.

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X. Appendix

A. Problem Design Specifications

Function

The client wishes to develop a virtual simulation environment that accurately models a neonatal intubation procedure. Tentatively, the client desires that a virtual environment be created which mimics the upper respiratory tract, throat, and mouth of a neonate. The virtual system should precisely emulate a clinical environment in order to function as a novel neonatal intubation training method for physicians. Furthermore, the virtual components should be integrated with a haptic feedback motor arm which pairs physical traits to the virtual objects, thus mimicking a clinical procedure with only the use of virtual reality and a portable haptic feedback device. Ultimately, this device should serve as a virtual, but effective, surgery training method.

Client Requirements:

- The virtual environment must accurately emulate the physical and optical characteristics of an infant’s head, mouth, and upper respiratory tract.
- A haptic interface must register interactions between the user’s physical input and preprogrammed objects, and relay these interactions back to the user via a haptic motor arm.
- The system must include a user-friendly software allowing changes in procedural specifications.

Design requirements:

1. Physical and Operational Characteristics

a. Performance requirements:

- The system must be constructed for use in both clinical and rural settings, thus requiring portability and durability.
- The system must be capable of running up to 25 full simulations per day.
- A virtual environment must be capable of simulating neonates in the range of 1-10 lbs.

b. Safety: Any electronic components must be enclosed within appropriate housing to minimize the risk of injury due to electric shock.

c. Accuracy and Reliability: The system must be accurate to .02 mm to compete with current haptic feedback systems and provide a realistic surgical environment.

d. Life in Service: The system must last at least 5 years with minimal maintenance.

e. Shelf Life: The device will be stored inside and will not be exposed to extreme weather conditions. It should not need maintenance while not in use.

f. Operating Environment: The system should be capable of operating in a variety of environments, including clinical and outdoor settings. The virtual simulation will be perfected by using feedback from expert neonatologists to accurately emulate a neonatal intubation procedure.

g. Ergonomics: The device should be intuitive to use and feel very similar to tools used during neonatal intubation such as the laryngoscope and endotracheal tube.

h. Size: The device must be small enough be carried around in a backpack or other case.

i. Weight: The device must weigh less than 40 lbs, light enough to be easily transported in a backpack or other case.

j. Materials: The system will be comprised of a pair of virtual reality goggles, a haptic feedback motor arm, and any computer hardware required to render the environment and power the system.

k. Aesthetics, Appearance, and Finish: The virtual reality should not be blurry. The user should be able to interact with the environment without noticeable buffering.

2. Production Characteristics

a. Quantity: One functional prototype will suffice for BME 400. Ultimately, however, the aim is to provide worldwide accessibility.

b. Target Product Cost: The device should cost under $5000.

3. Miscellaneous

a. Standards and Specifications: If successful, the device would require IRB and FDA approval to serve as a credible source of medical training.

b. Customer: The system will be used by training physicians who are practicing neonatal intubation procedures. Consequently, they will demand a realistic virtual environment with physical characteristics which accurately model a neonates anatomy and physiology.

c. Patient-related concerns: No concerns should arise from the use of this device as it will serve as an additional form of medical training, not an alternative to current training.

d. Competition: Competition exists among virtual reality platforms, but to our knowledge, there only exists a single haptic feedback system on the market currently, and there are no integrative VR and haptic feedback systems which are used to simulate neonatal intubation procedures.

B. Downloaded Files

Prop	Website name	Author	Filename	Link
Laryngoscope Blade	3D Warehouse	ProviderOfRandomStargateStuff	Laryngoscope	https://3dwarehouse.sketchup.com/model/515e8861e0f3c2bfdcd154f0c7575f7f/Laryngoscope
DefKit asset	Unity Asset Store	Dr. Korzen	DefKit	https://assetstore.unity.com/packages/tools/physics/defkit-50767
Morgue scene	Unity Asset Store	Rokay3D	Morgue Room PBR	https://assetstore.unity.com/packages/3d/enviroents/morgue-room-pbr-65817nm
Arms	Sketchfab	DavidFischer	First Person Hands Rigged	https://sketchfab.com/models/547a45535f0c4fe787948f7a7a6a88db
Baby (modified by the team)	Free3D	printable_models	StandingBaby V2	https://free3d.com/3d-model/standingbaby-v2--119839.html

Table 2: Files that were downloaded and incorporated into the current prototype.

C. Estimated Costs

Material	Approximate Cost	Explanation	Link
Touch Haptic Device	$2200	This was purchased in order to visualize our simulation.	N/A
Unity Plugins	$200	In order to develop a life like simulation we may need to purchase more advanced Unity plugins than the ones provided for free. It is impossible to definitively say whether we will need additional plugins, but it is definitely possible that we require more advanced tools as we progress. Functionalities that we may need plugins for include more advance soft-body physics plugins or possibly texture plugins to give provide more realistic texture to the neonate. Finally, if we do end up purchasing such plugins we may also need to buy a monthly Unity subscription ($30/month). Once again, it's not clear whether this will be required but it's worth mentioning.	One advanced soft body physics plugin can be found here: https://assetstore.unity.com/packages/tools/truss-physics-41801
Total	$2400		

Table 3: Actual and Estimated costs for simulation development.