Redesigning the Radiological Positioning Board

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On my honor as a University Student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments.

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Abstract

In order to fight against clinical human error, we redesigned a specific medical device that could prevent such situations from occurring. When a patient either cannot move to the radiology department or movement would cause increased harm to the patient's condition, a portable X-ray is required to be transported to the patient's room. This machine is not a primary option for imaging due to its relatively lower quality of image generated. In order to generate a lateral image, the portable X-ray machine must be positioned along the patient's bedside with the technologist holding a portable background on the other side. However, the problem presented with this method was the cushions from the bed would cave upward under the weight of the patient. Twenty years ago, the leaders of the diagnostic radiology department presented a new use for the plastic code board used at the time to give a harder surface to perform chest compressions on when a patient needs resuscitation in the bed. Tragically, when using this device one Friday afternoon, the nurses forgot the board under the patient, which subsequently was left for the entirety of the weekend. The patient developed bed sores from this and later died during that stay. Since then, the radiology department took this code board to an upholstery shop to add a cushioned covering and a yellow flag to remind caretakers of its presence under the patient. This current design presents new problems however which we propose to fix with our capstone project. Through our work, we have faced many issues with the manufacturing of the new board, however we have found that our new design would be viable to continue development until it is hopefully refined enough for use within a healthcare setting.

Keywords: Diagnostic Imaging, Ergonomics, Computer Animated Design, Circuitry, Human Error, Radiology, Portable X-ray

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Introduction

Human error in the medical setting can be extremely detrimental to patients' experience and overall health. If it were officially a health condition, it would be the third leading cause of death in the United States[1]. This is a serious problem that warrants the attention of the engineers to design systems that not only help physicians and healthcare workers with their work efficiency, but also save patients unnecessary discomfort and/or fatalities. In many cases of human error in healthcare, it results in the loss of career or even criminal prosecution for their mistakes. A recent case of this scenario playing out was within the Vanderbilt University Medical Center in 2017[2]. Nurse RaDonda Vaught was charged with negligent homicide after she mistakenly administered vecuronium instead of the patient's prescribed midazolam. This resulted in the death of a 75-year-old which could have been easily avoided through a better design of the technology used in the case. Vaught used an emergency override on the floor's automatic dispensing cabinet which allows nurses to quickly take out medications in critical situations. This was also compounded with the two drugs having similar names in the system lack of distinction between the two. Although this is an extremely tragic situation and it was not due to malicious intent, the event led to the death of a patient which biomedical engineers must recognize as a call to action to design innovations that attack human error in healthcare.

We propose a new product to prevent such critical errors in specific situations. When a patient either cannot move to the radiology department or movement would cause increased harm to the patient's condition, a smaller portable X-ray is required to be transported to the patient's room. This machine is not a primary option for diagnostic imaging due to its relatively lower quality of image generated. In order to generate a lateral image, the portable X-ray machine must be positioned along the patient's bedside with the X-ray technologists holding a portable background on the other side of the bed. However, the problem presented with this method was the cushions from the bed would cave upward under the weight of the patient. This is harmful to the quality of care these patients receive because the bedding can distort the image that is generated since it obstructs the view that the portable X-ray can obtain of the body part in question. This is especially harmful in cases where the patient must be tested for fluid accumulation in the lungs. The bedding can obstruct the X-rays and cause misdiagnosis of such illnesses due to these distorted images received through this process. Twenty years ago, the leaders of the diagnostic radiology department presented a new use for the plastic code board used at the time to give a harder surface to perform chest compressions on when a patient needs resuscitation in the bed. This code board, a flat plastic slab, was repurposed to provide a firm, planar surface beneath the patient's body, thereby elevating them slightly and preventing mattress deformation. While functionally effective in improving image clarity, its use exposed a major design flaw: it was never intended to be used for this purpose, nor was it designed to be noticed or retrieved efficiently after the procedure. Tragically, when using this device one Friday afternoon, the nurses forgot the board under the patient, which subsequently was left for the entirety of the weekend. The patient developed severe bed sores from this experience and later died during that stay, although it is unknown whether it was directly linked to these injuries. Since that incident, several reactive measures have been implemented by the radiology department in an effort to ensure the board is not forgotten. Upholstery was added for patient comfort, and bright yellow flags were affixed to increase visibility (Figure 1). In one attempt to engage multiple senses, jingle bells were tied to the board so they would audibly alert caretakers to its presence (Figure 2). Yet none of these additions have sufficiently eliminated the risk. The bells are frequently forgotten, or worse, seen as bothersome; the yellow flag, though visible, is too often overlooked amidst the daily chaos of clinical care. These efforts have failed to solve the core problem: they still rely on humans to remember and act consistently in high-stress, multitasking environments.

Figure 1: Current design during a demonstration of its placement. *When placed, the board is seen providing a hard surface to raise the patient out of the hospital bed. This provides a clearer line of sight for portable X-ray hardware.*

In the case pertaining to our project, the outcome could have been easily avoided if there was a piece of technology that accounted for general human nature. A part of being human is making mistakes and learning from them to become better in the future. However, these mistakes can come with major consequences that in healthcare, the patients and workers cannot afford to take on. Therefore, the technology we create must be able to prevent just the consequences from occurring because there is no current logical way of preventing caretakers from forgetting about the board at the moment. Our task is to ensure that when these mistakes occur, that they are reminded in a timely and effective manner to correct their mistakes before it is too late. With this in mind, our project is to first and foremost create a new positioning board that can audibly alert the caretaker of its placement under the patient after the portable lateral X-ray is already performed. The new assisting board includes a pressure sensor and a speaker, which allows it to detect when the patient's body makes contact with the board when inserted, and alarm the nearby workers via speakers after a certain period of time.

At this time, there is no product that can accomplish our exact goals that is freely available on the market. Within the University of Virginia Medical Center, the Department of Diagnostic Imaging currently uses a plastic code board that has been wrapped with bright yellow upholstery and minimal cushioning. The upholstery that was added to the board over twenty years ago is also held together by Velcro which is incredibly unhygienic. On top of this, the board itself does not perfectly fit within the thin disposable plastic bag covering. The radiologic technologist is forced to cut open one side of this bag to fit the board within it which causes a small part to hang out which effectively defeats the purpose of the covering. There is also a large flap with a handle that is meant to hang off the side of the bed and alarm the caretaker of the board's presence under the patient. This has mostly failed at its intended purpose due to caretakers becoming used to the sight of the yellow flap, meaning the board is completely visible but often goes unnoticed. For this reason, the diagnostic imaging department experimented with audible alarms to make sure the caretaker heard that the board was under the patient. These efforts ended up producing a string with small jingle bells that were wrapped around the board shown in Figure 2. These were meant to be wrapped around the radiologic technologist whenever the board was in use so that upon hearing the jingle of these bells, the caretaker and those around them would be alarmed by the board. While this method worked in theory, in practice, it never made much of an impact. This was because radiologic technologists simply would forget to wrap the bells around their arm and/or would just leave them on the shelf and take the board with them to use. This ultimately added an extra level of possible human error that could occur when using this technology which could have a negative impact on the patient and/or the healthcare environment. This also adds an extra responsibility upon the radiologic technologists who already have many other aspects of the job to worry about other than tying jingle bells around their arm which can sometimes seem silly or embarrassing to wear.

Figure 2: Current Design with Jingle Bells. *Shown here is a design that attempted to prevent technologists from forgetting the board under a patient. Once the board is placed, these bells would be wrapped around the placer with string until its removal.*

Another piece of current technology used for this exact purpose is called a decubitus sponge[3]. As implied by its name, this is a board that is made of a soft spongy material and is used to lift patients out of the hospital bedding. This is a readily available product on the market and in many hospitals as explained by our advisors. However, the Diagnostic Imaging Department at the University of Virginia Medical Center found this product ineffective. They find that the decubitus sponge is not firm enough to effectively lift the patient out of the bedding. In turn, it defeats the purpose of the board because it caves under the weight of the patient too. The sponge is also incredibly hard to place under the patient in a balanced position. One of the most difficult spots to place the board is directly under the patient's thorax. This poses a great difficulty to the use of the decubitus sponge because it is not firm enough to push and slide under the patient while the yellow board currently can. Even though this design is comfortable to the patient and would prevent any bed sores associated with this positioning board, our clients have requested that the new design not include any cushioning on the board as to not make any intention that the board is to stay under the patient for extended periods of time.

The innovation of the new design lies in the automatic audible alarm. When analyzing the recent failed attempts at creating an alert to the board's presence under a patient, they either fell short in their ability to alert the caretaker effectively or in its ability to consistently set off this alert. Therefore, the new design will innovate the positioning board by attacking both of these problems. The board will include an integrated audible alarm that can alert caretakers of its presence or cause the patients themselves to call for the nurse if they are in a state of mind to do so. In the same design, there will be a feature that ensures that the timer that is set off after a certain amount of time is triggered by a consistent catalyst. The current options to do so would include either pressure sensor or a button that is automatically pressed when a patient is on it. This second approach would work similarly to a refrigerator light that is automatically pressed whenever the door is closed in order to shut off the bulb. The way in which we integrate this feature into our design will be further researched and evaluated. Another way that we hope to innovate this design is by creating the product with hygienic materials. The current yellow board includes Velcro to hold the upholstery together which is extremely problematic. Since the board does not fit perfectly into the protective plastic, some of this Velcro can have direct contact with the patient. This causes a health hazard because Velcro is extremely difficult to disinfect between uses. Especially within the context of the recent global pandemic, more hygienic medical equipment is a very big need in healthcare.

Our design objectives coalesced around three guiding pillars: enhanced usability, improved material design for durability and hygiene, and embedded electronics to autonomously remind staff of the board's presence. This included incorporating a pressure-sensitive timer circuit linked to a speaker system. Once activated, the timer would allow for the duration of a typical X-ray procedure, about five minutes on average, before sounding a loud alarm if the board remained in place. Such a feature ensures that, even if human memory lapses, the board itself will speak up.

In tandem, we revisited the physical form of the board. Instead of a flat, cumbersome slab that required awkward placement beneath the patient, our team designed a wedge-shaped profile with beveling for easier sliding. The structure was hollowed in CAD software to house electrical components and optimize weight distribution. We also ran simulations to identify stress points and ensure structural integrity under patient load.

Results

The development of the YellowBoard v2.0 involved iterative prototyping, through design simulations, and functionality testing. Throughout this process, our goal was to validate both the safety and practicality of the final design for use in a clinical setting. In this section, we present our process of development thus far. This includes direction received from our Diagnostic Imaging Department sponsors, iterative computer animated and hand-drawn designs, computer-based simulations, and physical manufacturing. While our efforts resulted in many lessons learned moving forward, there are still great findings from our research that deserve to be explored.

Obtaining Design Specifications

Due to the nature issue at hand, we worked closely with the leadership from the University of Virginia Medical Center Department of Diagnostic Imaging. This allowed us to follow the needs and wants of those who would be using this product once it is deemed suitable for utilization. Demonstrations of the utilization and faults of the current design were conducted in order that we might begin the design process in a way that closely follows the department's vision for what the board will turn out to be.

CAD Modeling

We used Autodesk Fusion 360 to create a computer animated design of our positioning board. We designed our product in a way that answered the three major concerns presented by the staff of the University of Virginia Medical Center. Firstly, we created the shape of the board in a way that provides for easier placement. This implied the inclusion of a blunt wedge at the front end of the board. This wedge shape will provide for easier placement without causing unnecessary harm to the patient such as pinching of the skin. In previous conversations with the client leadership team, an idea was pitched to have the board be two separate parts that would lock together underneath the patient. This would have allowed the user to insert the board only half the way under the patient's body for each part of the board. However this presented the problem of inability to align such pieces and especially the risk of pinching the skin of the patient. Therefore, moving forward, this simple design of a wedge shape was implemented to prevent such injuries from occurring but also providing any feature within the design that allows for this placement at all.

Another aim we kept in mind when designing our board was ensuring hygiene was not compromised when using this new design. The previous design had many flaws such as the inclusion of Velcro and the size of the board was too large to fit within the disposable plastic bags provided by the UVA Medical Center. Current procedures require technologists to slit open one side of the bag for the board to be placed into the corner of the two remaining sides. This leaves a large portion of the board exposed to the patient and does not provide the highest level of hygienic safety. Therefore to address these concerns, our computer animated design met specifications to fit within these disposable bags that allow for simpler sanitation practices. These bags had a length of 25 inches and a width of 18.5 inches when laid flat. Therefore, we designed the board with dimensions of 26” by 15” by 2” to fit these specifications. We were also advised to use materials that both allowed for easier cleaning and did not interfere with imaging results. We were advised to attempt to create the board using carbon fiber, however after further research, it was found that this material is relatively more brittle than readily available filaments like PLA or Polypropylene[4].

Figure 3: CAD model showcasing compartments for electrical components. *Shown here is a computer animated design model of our iteration of the radiological positioning board. Visible are compartments for all electrical components and the shape designed for placement. The blunt wedge and handle feature allows for a more efficient placement process.*

In order to address concerns of possible human error within this simple procedure of diagnostic imaging, we included key design elements that support technology that prevent such instances from occurring, showcased in Figure 3. Firstly, the way we implemented compartments within our design that favored the inclusion of electric circuitry. When planning this design model, we kept in mind the way in which we were to incorporate the electric components in a way that would both make the system run automatically after placement under a patient, and also not be muffled by the bedding when in position. Therefore the hole that spans the entirety of the thickness of the board is to house a button, similar to that found in refrigerator models to sense the opening of a door. Therefore, preliminary designs for this feature have been provided in Figure 4 for future fabrication and refinement. Once the board is placed and the button is pressed, as shown in Figure 5, a timer for 15 minutes will begin. Guidance from the Department of Diagnostic Imaging informed us that the procedure should not take longer than 5 minutes to complete. Therefore, 15 minutes should provide enough cushion to allow caretakers to remove the board without an alarm sounding. However, once this timer is up, an alarm will sound through 4 small speakers positioned along the handle side of the board. This should prevent the noise from being muffled under the patient and/or in the cushions of the bed. All of this will be controlled by an Arduino Uno breadboard and CPU that can be found in the largest compartment. This will be powered by a battery pack and all wiring will be fed through tunnels connecting each of these components of the circuit.

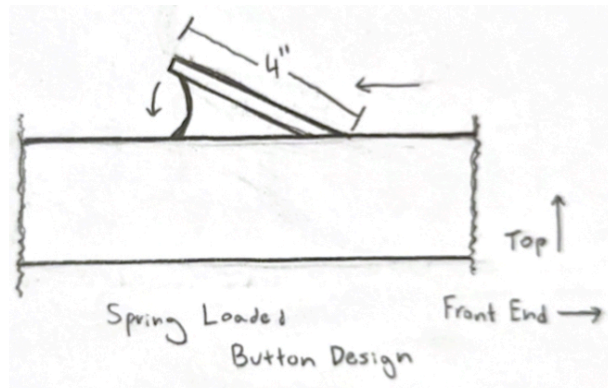

Figure 4: Drawing showing design of pressure-activated button incorporated into the board surface. *When the board is placed, the button will press down and start the timer coded on the Arduino Uno.*

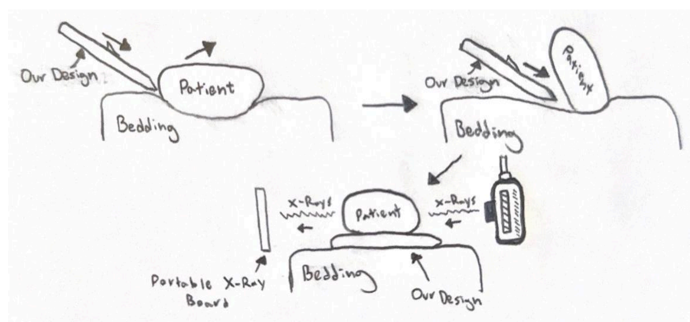

Figure 5: Drawing showing method of placement. *As shown, the board is placed by slightly tilting the patient and using the wedge-shape design to slide into place. Final stage of this process shows the result of a successful placement.*

Stress Testing Simulation

To assess the board's ability to perform under the pressure of placement, we performed a stress test within this same computer animated design software. Using the end at which the handle is placed as a locked surface, we placed 1000N of pressure on the wedge end of the board. This is meant to simulate the way in which the board might buckle under the stress of pushing the board under the patient. Because PLA was not an available material in this simulation, we only were able to use the similar and also popular filament of polypropylene[5]. Color-mapped stress analysis revealed the most significant deformation in the wedge tip region and battery housing channels, shown in

Figure 6. However, even under theoretical maximal stress, displacement did not exceed 15.0 mm, which is safely within clinical tolerances. This shows that the design in which we look to proceed with manufacturing is would be a suitable option. Because of the relative lack of structure on the bottom of the board due to the hollowed crevices, this is the direction the board is simulated to deform through placement. However, this simulation does not take into account the covers that would be placed over these electrical components. The current design includes rims around these hollowed out portions on which covers would be placed and secured through screws or plastic clips. Thes covers will sit flush with the outer surface of the board and will provide for further structural support. Therefore, the computer animated design of the board performed well under the stress of placement, even when important structural elements were not present.

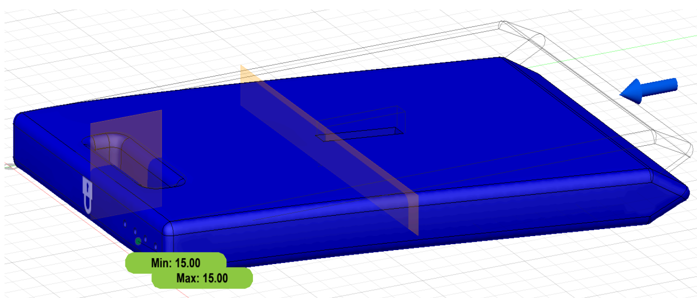

Figure 6: Point-stress simulation results of the board under 1000N of compression. *The results shown are promising, showcasing that even with hollowed electrical compartments, the board is structurally sound.*

Prototype Fabrication and Evaluation

Due to size constraints of available 3D printers, the full-size YellowBoard 2.0 could not be fabricated in a single piece. Therefore, we shifted our focus to printing the board in six separate pieces which would be assembled together post-printing. This would have been completed through plastic welding or some sort of glue that provided for cohesion and structural integrity. However, initial attempts to print the board in segments were met with challenges: warping at connector joints and structural weakness along split planes. This was due to several factors within the settings and limitations of the printers available. One such attempt, pictured in Figure 7, shows a visibly distorted edge that would have been incompatible with clinical use. This, along with multiple completely failed prints of the same settings and size allowed us to rule out the possibility of using 3D printing to fabricate a full-scaled version of the positioning board.

Figure 7: Failed 3D print of one-sixth of the full-sized board. *Due to time and equipment constraints, structural integrity was impossible to achieve within this print. Pictured here is the distorted and flimsy product of 3D printing, resulting in our disbelief in 3D printing as a viable method of producing the full-scale radiological positioning board.*

We therefore pivoted to scaled-down prototyping for physical validation. A scaled model was successfully printed using PLA, and its relative geometries confirmed our CAD assumptions. We first created a scaled version of the board that compromised on many structural components within the printer's settings. This board was produced with minimal shells and layers did not properly mend together as corners began to chip and fracture. From this, we increased the structural components to allow for a print that would take just under six hours to complete (the maximum time allotted for the available printers). These two boards were produced at a much higher quality but since they were made in different printers, there were massive discrepancies. One board, shown in Figure 8, was printed exactly how we had imagined it to, while the other became warped and deformed from uneven cooling of the extruded filament layers. This exemplified the inconsistency of this method of manufacturing, allowing us to shift focus to future research.

Figure 8: Successful scaled 3D print. *Shown here is the third and final print of the radiological imaging board. This is able to show relative size and shape of the board.*

Discussion

Throughout the development of the new design for the radiological positioning board, many lessons can be learned through the results we have obtained. Future research on this issue and the development of the new design should keep these results in mind for greatest success in these endeavors.

Inviability of 3D Printing

When considering the results that we have received through the physical fabrication of our design, it has been assumed that 3D printing is not the preferred method of construction moving forward. During our production process, we have found that the limitations and inconsistency of 3D printing has made it difficult to create a physical positioning board to evaluate and test in reality. When trying to print the full-scale version of the board in six pieces, we tried to print two pieces at a time using two machines of the same make and model. The failed print shown previously was actually the best result we received when trying to print. Other results were thrown away after they had been detached from the platform during printing, causing them to be pushed onto the floor by the extruder. The failed print picture is the best result we received and even that showed massive faults in structural integrity.

Furthermore, this inconsistent nature of the available 3D printer was increasingly exemplified through the prints of two replicate scaled boards. Each of these boards were given the same specifications for printing but were downloaded to two separate printers. These printers were the same make and model. The only variable that was inconsistent between these two were the color of PLA filament that was used to print the scaled model. Even with these similarities, there were major differences in the quality of print received. Due to rapid cooling on the 3D printer's platform, one of the prints' first layers were heavily warped upwards. This caused a chain effect for the subsequent layers of PLA laid by the extruder and made the entirety of the print's handle side disfigured and not fully representative of the design. This distortion also occurred on the corner at which the speaker compartment was placed in the design, making this feature unrecognizable.

Further Research

With these findings, we hope that future research is conducted in order to further this project closer to reality. Since we have established that 3D printing would not be the wisest choice for a manufacturing method, we hope that future researchers will use our design and concept and produce the product through different processes. This process would have to create the board in a way that allows it to be produced in one piece. When 3D printing, our plan due to limitations with size and time limits of the printer was to break the board into six distinct pieces. These pieces would have to be assembled in a way that provided structural integrity and a cohesive surface to prevent growth of bacteria and other maladies. Through our attempts, we have found that this was unsuccessful in the 3D printing process not only due to these limitations, but also because of the inconsistency of printer results. For our final print of the scaled version of the positioning board, we used the same specifications and settings on two separate printers of the same brand and model. One print came out exactly how we had planned for it to. However, the other print showed signs of disfiguring and warping due to uneven cooling. Although these problems could be fixed by exploring different 3D printer models, most printers would not support a full-scale print of the board.

Future research into the radiological positioning board should also advance the main feature in which our computer animated design was created to foster. The hole in the middle of the board that spans the entire thickness of the model should be filled with the automatically pressed button that starts the timer for the audible alarm. The initial concept of this design is to resemble commonly found automatic buttons, such as those utilized in refrigerator lightbulb designs. Another design aspect that must be further developed is the power source for the electric components. Currently, we have designed the compartments to fit a 4xAA battery pack. However, the leadership from the Department of Diagnostic Imaging have concerns about replaceable batteries being the source of electricity. These concerns include worries that technologists will not be able to know the status of the charge of these batteries. This would create the risk of the alarm not working properly if the batteries run out of power. Therefore, the preferred method of power moving forward should be a rechargeable battery that can be left on charge whenever the board is not in use. Therefore, if a technologist sees a positioning board that is not on the charger, they will opt for one that is and promptly plug in the board of unknown status.

Materials and Methods

In order to properly design a new version of the radiological positioning board that aligns with the needs of our sponsor, we first worked directly with the Department of Diagnostic Imaging at the University of Virginia Medical Center. These conversations informed all elements of our process, which can range from size and ergonomics to materials and circuitry integration. We began by evaluating the major concerns with the current board and identifying design criteria that would allow us to innovate both in usability and in reducing human error. Overall, the main objective was to create a patient-safety focused and durable device that improves upon the current standard.

All hygienic improvements were made to ensure compatibility with existing hospital protocols. Velcro, which was present on the original board and known to retain contaminants, was removed. External dimensions were constrained to allow full compatibility with the department's current 25 inch by 18.5 inch disposable sheaths, ensuring infection control could be maintained without additional accessories or procedural changes. Therefore, the design maintained a 26" by 15" by 2" dimension during CAD modeling.

To address the clinical issue of accidental patient overexposure to pressure, an internal electronic alert system was integrated into the board. A pressure-actuated switch is designed to be mounted inside a hollow cavity located centrally beneath the board surface. Activation of the switch is intended to initiate a 15 minute timer using an Arduino Uno based timer circuit, after which speakers embedded near the handle region emit a sound alert. The 15 minute time window was specifically advised by our sponsor. Upon timer completion, four speakers positioned near the handle would emit an audible alert. Speaker location was selected to minimize acoustic dampening from the patient or bedding. Power would be supplied by a 4xAA battery pack housed in a protected cavity within the board. Internal cable channels would be integrated into the CAD model to isolate wires from user handling areas.

Fusion 360 was used to develop the CAD model of the board. A wedge shaped profile was incorporated on the leading edge to improve ease of insertion under the patient. Although early iterations explored the possibility of a six piece design for easier handling and prototyping with limited resources, this concept was eliminated due to concerns over mechanical misalignment due to poor 3D printing results using PLA. As an alternative, scaled-down versions of the board were fabricated and assembled. Full-scale manufacturing is expected to proceed via CNC machining or vacuum forming to ensure dimensional stability and long-term performance. Mechanical viability was assessed using static load simulation in the software. A 1000 N force was applied at the wedge side with the handle region constrained as a fixed point, approximating worst-case insertion forces. Deformation remained below 15 mm, with localized stress concentrations at the wedge tip and battery housing channels. These values were deemed acceptable within clinical use tolerances and did not indicate structural failure.

The final design integrates structural geometry, embedded electronics, and hygienic considerations into the current positioning board. Modifications were continuously validated by our sponsor to ensure alignment with clinical needs to ensure on reducing preventable patient harm due to prolonged immobilization on imaging surfaces.

Within our design, we accounted for the size and shape of various electrical components. The main circuit board compartment is designed to fit an Arduino Uno, which the various parts included with this were used to test circuitry layouts. The battery pack is available on Amazon and is included within the QTEATAK 8-pack of AA battery holders. The speakers can also be found on Amazon in the Fielect 0.5W 8 ohm speaker 2-pack. To create our scaled prototypes and failed full-scale components, we used PLA filament in the Makerbot Replicator Plus. To convert our Fusion 360 design to the 3D Printers, we used the Makerbot Print software.

End Matter

Author Contributions and Notes

M.S.K. and J.B.K. designed research, performed research, 3D printed, analyzed results, and wrote the paper. M.S.K. produced code. J.B.K. created computer animated designs and produced drawings. A.J.C. provided guidance and advised research according to department needs. The authors declare no conflict of interest. This article contains supporting information online.

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