Patient Positioning Aid

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# Table of Contents:

Abstract ............................................................................................................................... 3

Introduction
  1.1 Background .............................................................................................................. 4
  1.2 Purpose of the Project ............................................................................................ 4
  1.3 Previous Work done by Others
    1.3.1 Products ........................................................................................................ 5
    1.3.2 Patent Search Results .................................................................................... 6
  1.4 Map for the rest of the report .................................................................................. 6

Project Design
  2.1 Design Alternatives
    2.1.1 Design 1 .......................................................................................................... 8
    2.1.2 Design 2 ........................................................................................................ 11
    2.1.3 Design 3 ........................................................................................................ 14
  2.2 Optimal Design
    2.2.1 Objective ....................................................................................................... 19
    2.2.2 Subunits ......................................................................................................... 19
    2.2.3 Force Analysis ............................................................................................... 38
  2.3 Prototype ................................................................................................................ 53

Realistic Constraints ....................................................................................................... 76

Safety Issues .................................................................................................................. 79

Impact of Engineering Solutions .................................................................................... 82

Life-Long Learning ........................................................................................................ 85

Budget ............................................................................................................................. 87

Team Members Contributions to the Project ................................................................. 88

Conclusion ...................................................................................................................... 90

References ....................................................................................................................... 91

Acknowledgements ......................................................................................................... 92

Appendix ......................................................................................................................... 92

Specifications .................................................................................................................. 95
Abstract:

There are many patients with disabilities whose needs are not met by positioning aids currently in hospitals. Overweight patients have to go through an open MRI and stay still for long periods of time. Patients with tremors are either immobilized by tape or Velcro causing them discomfort. Multiple components are needed in order to position the patient in the correct orientation. There is nothing in the market that can meet all the needs of imaging technicians and patients with disabilities. The patient positioning aid will be low-cost, versatile, easy-to-store, and easy-to-adjust as well as eliminate the need for purchasing multiple components in order to meet the needs of various patients. This device will incorporate an upper body and lower body-positioning device, and will be easily adjustable using a track system to accommodate different sizes, and heights of the patients. The positioning aid will be made very comfortable by the use of foam padding on the surface, a gel based headrest, and an arm stabilizer. It will be strong and sturdy so that the segment weight of patients weighing up to 500lbs can be supported. The device will better immobilize patients using arm and leg stabilizers, so that patients with diseases such as Parkinson’s can have an accurate image taken without having to worry about tremors. A handle bar above the patients head will be utilized in order to get the hands of the patient out of the imaging technologies way. It will be thin so once it is put on top of the imaging table patients with limited movement will not have to climb up very high. There will be 4 handles made for easy transfer of patients if needed. Foam padding placed underneath the device will allow for additional staff members to help out lifting heavier patients without hurting their hands. The positioning aid will be compatible with various imaging technologies including but not limited to MRI, CT, and x-rays.
Introduction:

1.1 Background:

A patient positioning aid is needed for individuals with disabilities. The disabilities create difficulties related to patient positioning. These difficulties include transferring the patient onto the medical devices and maintaining static positions during the procedure. The static positioning aids such as foam wedges and wrap around coils in use today for CT and MRI scan technologies are not very effective. The current options only satisfy the needs of specific patients. Therefore, a broader positioning aid with a wider range of capabilities is needed. The goal of this project is to create a versatile, low-cost, easy-to-adjust patient positioning aid that will work with a range of examination tables and imaging platforms and meet the needs of patients with disabilities.

1.2 Purpose of the project:

Patients need to undergo various medical examinations, which require them to remain static throughout the testing process. Currently, diagnostic imaging presents problems for patients with disabilities such as cerebral palsy and obesity. This problem in the medical field has led to the request for a better positioning aid which can be used by patients suffering from these disabilities among others. The current static positioning aids available for use are foam wedges and wrap around coils which can be used, however are ineffective for patients suffering from the disabilities described above and similar ailments. For example, a foam wedge would not be able to fully support body segments of larger weights and wrap around coils can cause discomfort as well as endanger patients that suffer from uncontrollable and/or involuntary movement. Wrap around coils come in sizes that cannot fit the leg or arm of an overweight patient through making them unusable. The general requirements of this project are to create a low-cost, versatile, easy-to-adjust patient positioning aid. The device should also able to work with a range of examination tables and imaging platforms and meets the special needs of patients with a wide variety of disabilities.

The positioning aid needs to be both functional for the medical professionals as well as comfortable for the patient. This limitation requires the design of the positioning aid to be durable and able to support a heavier body segment weight as well as be able to be operated by smaller, weaker hospital staff. Hospitals have little storage space for such positioning aids therefore, it is crucial that the device can be easily stored in the limited amount of space available. The material the device is made out of is also a limitation. The
positioning aid cannot be made out of metallic materials, and must be non-ferrous. The use of certain materials can cause interferences with the imaging technologies such as the CT, MRI and x-ray.

When designing the positioning aid both the hospital staffs’ and the patients’ needs were taken into consideration. For the technician the positioning aid needs to be light weight, easy to adjust, transfer, and store. For the patient the aid needs to be comfortable, sturdy, strong, and be able to immobilize patients. With these requirements in mind we came up with the design. A fairly light weight and strong material, PVC, was chosen for the base, with comfort coming from foam padding and a gel based headrest.

The major goal of a positioning aid is to get the arms out of the way when the images of the body are being taken. Therefore, a handle bar was designed for the patient with arm stabilizers to provide additional comfort to the patient’s upper arm while reaching backwards and gripping the arm bar. The arm stabilizers will also keep the elbows of the patient steady and not allow movement. The leg stabilizers were implemented to reduce movement in the lower extremities of the patient and are tall enough to be able to adjust a larger patient. Lastly, a track system is used to move the arm stabilizers and leg stabilizers so they can meet a wider range of patients. The track system also comes with stick on rulers so the doctors can quickly line up the attachments and ensure a good fit. The main goal was to make this device very user friendly as well as accommodate the different size patients that may be using the device.

1.3 Previous Work Done by Others
1.3.1 Products

Our research shows that there are positioning aids on the market that are designed for use with patients. These devices consist mainly of foam wedges, wraparound coils, and table mounted arm and leg positioners. Most common are the wedges, which come in sets and range in price from around $150 to $400. Wraparound coils can be quite expensive and a large range of them are required for imaging of the entire body. Arm and leg positioners were also found on the market by various companies but were still not as popular as the foam wedges. The arm and leg positioners were also expensive and needed to be purchased by the hospital individually. The products on the market were not able to provide the versatility needed for patient positioning during imaging.
### Table 1: Market Research Data

<table>
<thead>
<tr>
<th>Maker</th>
<th>Model</th>
<th>Price</th>
<th>Product Name</th>
<th>Type of aid</th>
</tr>
</thead>
<tbody>
<tr>
<td>BizChair</td>
<td>3004-HAUS</td>
<td>$331.99</td>
<td>Positioning Wedge system</td>
<td>Wedge</td>
</tr>
<tr>
<td>MedTek</td>
<td>MT-KC-01</td>
<td>Not listed</td>
<td>Knee crutch positioner</td>
<td>positioner</td>
</tr>
<tr>
<td>MedTek</td>
<td>MT-AP-01</td>
<td>Not listed</td>
<td>Arm Positioner</td>
<td>positioner</td>
</tr>
<tr>
<td>Fonar</td>
<td>N/A</td>
<td>Not listed</td>
<td>Solenoid coils</td>
<td>Wraparound coil</td>
</tr>
<tr>
<td>Newmatic</td>
<td>FSWG</td>
<td>$319.99</td>
<td>Standard wedge group</td>
<td>Wedge</td>
</tr>
<tr>
<td>Sound Systems</td>
<td>FRXG</td>
<td>$159.99</td>
<td>Routine X-ray group</td>
<td>Wedge</td>
</tr>
<tr>
<td>MedTek</td>
<td>MT-VL-FBB-01</td>
<td>$150</td>
<td>Vac-Lok</td>
<td>Wedge</td>
</tr>
</tbody>
</table>

### 1.3.2 Patent Search Results

Our search for patents for similar positioning aides came up with no results. The foam wedges and wrap around coils serve the same purpose as our device but do not share any resemblance to our design. The handle bar has a similar principle to an Overhead Arm Positioner found at the medtec website, but the design is different and our design incorporates arm stabilizers at the elbow. Positioning aids exist but do not take the same approach that we have taken.

### 1.4 Map for the rest of the report:

The discussion will follow the introduction. Brief descriptions of our first three designs are given there followed by a detailed description of our optimal design. The optimal design will include objectives and will be split up into subunits and explained more in depth in order to gain a better understanding for how the design works and functions. An in depth stress analysis will show that the design will work with the chosen materials. After the Optimal design has been fully explained there is a section which provides a description of the prototype and its operation with photographs. The testing of the prototype will also be included in this section of the report. Then there is a section that pertains to the realistic constraints which describes how engineering standards were incorporated into the design. The safety issues are also addressed in this part of the report which includes mechanical, decontaminations, biological hazards and
others. There is also a brief summary of the optimal designs impact of engineering solutions. The concept of life-long learning is talked about next regarding any new material learned, as well as, new techniques that were acquired during this class. The budget will be shown, breaking down the cost of the major components of our design, and the final cost of our prototype. Next is the section which describes the contributions that each team member made to the project throughout the semester. The conclusion will review and summarize the optimal design and prototype strengths. References and acknowledgements will be displayed thereafter. At the end of our report will be an appendix which will include the updated design specifications and material data sheets.
Project Design:

2.1 Design Alternatives:

2.1.1 Design 1:

The overall drawing of design 1 for the patient positioning aid can be seen in Fig A.1 above. Design one can be broken up into four major elements, the transfer board, foam padding, foam headrest, aluminum track system, and the knee crutch attachments. These components allow the positioning aid to meet the needs of various patients and be easy to use by hospital staff members. A polyethylene transfer board was selected as the base for design 1 with dimensions of 72”x 22”x 3/16”. This board is radiolucent and will not absorb any types of x-rays or cause any interference to the images. In addition the board will be lightweight at only 9 pounds allowing the use of minimal strength to lift. Narrow Economy Polyfoam with the dimensions of 72”x 19”x 1” will cover the patient transfer board to provide comfort to the patient. A nylon covering will ensure ease of cleaning and wiping off any type of residue or stains on the polyfoam cushion. Phat Pads, a donut shape headrest 8.5” in diameter, will be used to support and provide comfort to the head. Velcro straps are to be used on a patient-to-patient basis for patients that suffer from tremors to ensure immobilization.

There will be 4 aluminum tracks attached to the table to allow sliding of attachments with a tightening knob at the side. The locations of the tracks can be seen in fig A.1 above. Figure A.2 displays the shape and dimensions of the track.
system. Four bolts will be used to attach the track system through the polyethylene board to aluminum brackets underneath to eliminate cracking the polyethylene and prevent any loosening.

Figure A.2: Overall Track System

A square shaped base will slide inside the track and be secured to any location using the tightening knob. Attachments can be screwed into the square base. There will be a total of 4 bases with L-shaped attachment rods placed in them. Each base will go into a separate track, two on the topside of the positioning aid toward the head of the patient, and two on the bottom toward the patient's feet. The shape and dimensions of the square base can be seen in Figs A.3-4.
The L-shaped attachment rod can be seen in Fig. A.5. There will be different attachments that can be used for the various desired positions. The L-shaped rod can be used as a hand grip when a foam sleeve is placed over it for comfort. A knee crutch will be connected to the lower rods in order to provide knee support. The patient will place their legs over the knee crutch and be strapped in with Velcro if they need to be. Figure A.6 shows the knee crutch attachment.

We will be using aluminum alloy 6061-T6 for the L-shaped attachments rods. Calculating the maximum weight the attachment will have to endure and doing a force and moment analysis a conclusion was reached that the aluminum alloy would be more than sufficient in order to provide support and withstand bending from our maximum requirement.
The combination of these components and their specialty functions will help to aid in making the patient positioning aid both versatile and able to work with a wide range of examination tables and platforms. The total cost needed in order to make a prototype of the positioning aid is estimated to be about $900.

2.1.2 Design 2:

The objectives for Design 2 are to design a low-cost, versatile, easy-to-store, and easy-to-adjust patient positioning aid. This device will incorporate an upper body and lower body-positioning device, which will use Velcro to accommodate for the different sizes, heights and provide some additional comfort for the patient during the sometimes lengthy imaging procedures. Figure B.1 seen below is the overall drawing of Design 2, which can be broken up into its three main components. The components are the base, which will be made of a polyethylene board with a foam pad covering, and both an adjustable upper and lower body positioning aid. The combination of these three main components and their specialty functions will help to aid in making the patient positioning aid versatile, compatible with a large range of examination tables and platforms and lastly will provide additional comfort to the patient.

![Figure B.1: Design Two for the Patient Positioning Aid](image)

The board selected in particular for this design is the Gray Type I PVC sheet and will have the dimensions of 72"x 16"x 0.5". This board is also radiolucent so the x-rays will not be absorbed by the material and cause interference and in turn disrupts the images. This board was chosen because it is lightweight which will allow for medical staff to lift it on a daily basis. To ensure more patient comfort the PVC board will be covered by a piece of Narrow Economy Polyfoam. This piece of foam padding will be 72" long, 19" wide, and 1” thick. It will be in a nylon cover, which can be easily cleaned between examinations.
The upper body positioning aid will include a headrest, comfort supports for the arms and a plastic handle bar for gripping onto. The plastic bar will be located all the way at the top of the positioning aid and a high-density polyethylene will be used as the material for the handle bar. The rod will be 1 inch in diameter with the overall dimensions of the handle bar being 14 inches wide and 2.5 inches above of the positioning table. A thin layer of rubber will be put over the rod for more of a grip and comfort for the patient. Figure B.2 shows the overall dimensions and how the handle bar will look.

![Front View](image)

**Figure B.2: Front View of Handbar**

A radiolucent headrest, which utilizes a gel technology to distribute the pressure, equally is included in this design to provide further comfort for the patient during the procedure. The donut shape benefits the patient since it can allow them to be oriented on their backs or on their stomachs with their forehead resting on the pad. There will be arm wedges to the sides of the headrest to give more comfort and support to the patient as they lay on the positioning aid. The arm wedges are displayed in Figs B.3-4. The headrest with the wedges can be seen in Fig B.1.

![Arm Wedge](image)

**Figure B.3: Arm Wedge**

![Side View](image)

**Figure B.4: Side View of Arm Wedge**
The last major component is the lower body support, which consists of a knee wedge that will be made of PVC. It will be in the shape of a triangle which will be hollow in the center and then covered with thin foam padding on the outside. The foam will be there for added patient comfort. The PVC sheet will be cut into three pieces with one piece having the dimensions of 8”x 14”, and two pieces having dimensions 11” x14”. The three pieces will be attached together to form the triangle using non-ferrous PVC screws to secure them to one another. Figures B.5-6 shows how the knee wedge will look and what the dimensions will be.

![Knee Wedge](image1)

**Figure B.5: Knee Wedge**

![Side View Knee Wedge](image2)

**Figure B.6: Side View Knee Wedge**

Velcro will be used to attach the knee wedge to the board. The Velcro will allow the positioning triangle to be easily adjusted according to height from patient to patient. Lastly, there will be a Velcro strap going through the center of the triangle knee wedge. This Velcro strap will go around the patient’s legs and secure them tightly to the knee wedge. This was included to minimize movement in the lower legs during the examination especially for patients who have tremors or limited movement.
We performed a force analysis on all the components. The transfer board, foam wedges, and the handbar were looked at. The maximum patient weight on the board will be 500 pounds and this weight divided by the total area of the board (1152 in$^2$) will be 0.434 psi which the board will be able to easily support. The bending force created by the patient weight will be quite large, thus the board alone will not be able to support this load by itself. However, when the board is placed upon an examining table within a hospital or clinical setting the bending load created by the patient will be supported sufficiently by both the support board and the examining table. Analysis of the handle bar force system concluded that the weights of the patient’s body segments will create a normal stress, a shear stress and bending stresses. Using our maximum body segment weight bending stress applied to the horizontal portion of the bar is calculated to be 1145.92 psi, and the axial loading turns out to be 31.83 psi. In analysis of the knee wedge we calculated a shear stress calculated to be 572.96 psi, a horizontal bending calculated to be 1145.92 psi, and a total normal stress calculated to be 795.77 psi, as well as a normal stress on the knee crutch calculated to be 14.74 psi. Therefore, the material chosen must be able to support at least 1145.92 psi, which was the maximum calculated stress within the design. We decided to go with High Density Polyethylene. High Density Polyethylene has a minimum yield strength of 2180 psi, and according to our force analysis the material would be subjected to a maximum stress of about 1150 psi, therefore High Density Polyethylene will be able to support this stress without a problem. We estimated that this design will cost approximately $600 to make, but can be sold at a cheaper cost to consumers because of the lower prices on items when purchased in bulk quantities.

2.1.3 Design 3:
In our third design, the main objective was to keep the patient in a position, lying on the back, with the arms stably placed above the head, and the legs held stable and flat on the table. The overall design for design 3 is seen in figure C.1 above. This design, like the first two designs, utilizes a polymer board, which will act as the base, and central part of the positioning aid. All the other aspects of the design will be attached to this board through various methods. The material chosen for the board in this design is polypropylene sheet (dimensions 72”x19”x0.75”), for it is easily machined and welded, while having material properties suitable for the forces that will be applied to the board. The board will also have hand holes drilled at both ends and in the middle, allowing for the transport of patients from examination table to imaging platforms while on the board itself. Four slots, (two for the arm positioners and two for the leg positioners) are cut in the board as well, which allow for the arm and leg positioners to be slid up and down the board via a bolt system. This allows for a large range in the set up of the board for people of different heights. The track system is shown in Fig C.2.

On top of the board, a foam pad is installed that will keep the patient comfortable while on the board for long procedures. Along with this, a doughnut shaped pillow is added to the board to provide comfort to the patient’s head and neck, and also allows for the patient to lie face down if needed. The arm positioners, L-shaped high-density polyethylene pieces, are attached to the upper portion of the board via the bolt and sliding mechanism. The surface of the piece is coated in a comfortable foam pad so pressure is not put on the arm itself. These positioners allow the arm to be kept comfortably in a position above the head for extended periods of time. They will relieve the patient from any stress due to having their hands above their heads. Figure C.3 shows the shape of the arm stabilizer, while Fig C.3b displays the dimensions as viewed from the side.
On the top end of the board, the polypropylene arm bar will be welded. This bar is in place for the patient to hold onto while their arms are above their head. It will have a foam grip covering to give the patient comfort as they hold on to it. Figure C.4 shows how the arm bar will look.
Figure C.4: Hand Bar

On the lower portion of the board, the knee stabilizers are attached via the bolt and sliding mechanism similar to the arm stabilizers. The knee stabilizer consists of two high-density polyethylene bases on each side of the board, which attach to the board through the sliding mechanism. Two high-density polyethylene rods are attached to each base. Figure C.5 shows the attachment in detail. On top of these two knee stabilizers

Leg Stabilizer Base; Side

Figure C.5: Leg Stabilizer Base
HDPE bars slide up and down. The bars have holes, one on each side, for the rods to go through, so that they can slide down over the patient’s legs and can be held in place using pins that go through holes in the rods. Figure C.6 displays the leg stabilizer bars.

![Figure C.6: Leg Stabilizer Bar](image)

The undersides of the bars are covered with foam padding to keep the patient’s legs comfortable while being stabilized. This will prevent the patient from moving while at the same time allowing blood to circulate to their legs. Stress analysis on all portions of the positioning aid prove that the materials chosen will work safely under the given conditions. The estimated cost for design three of the patient positioning aid is $600.00.
2.2 Optimal Design:

**Optimal Design Objectives:**

The objectives for the Optimal Design are to design a low-cost, versatile, easy-to-store, and easy-to-adjust patient positioning aid. This positioning aid will eliminate the need for hospital staff members to purchase multiple components in order to position and meet the needs of various patients. This device will incorporate an upper body and lower body-positioning device, and both will be easily adjustable using a track system, which will help in accommodating for the different sizes, and heights of the patients. The foam padding on the surface of the devices was added to the design to provide some additional comfort for the patient during the often-lengthy imaging procedures. This positioning aid will be designed according to the specifications and will meet the needs of patients with disabilities. It will be strong so that the segment weight of overweight patients weighing up to 500lbs can be supported and transported. The device will better immobilize patients so that patients with diseases such as Parkinson’s can have an accurate image taken without having to worry about tremors. It will be thin so once it is put on top of the imaging table patients with limited movement will not have to climb up very high. It will be durable so that a new device does not need to be purchased very often and will save the hospital money in the long run. Lastly, the positioning aid will be compatible with various imaging technologies including but not limited to MRI, CT, and x-rays by using all non-ferrous materials as well as radiolucent materials.

**Subunits: Description of Optimal Design:**

In talking about the design it is very important to make note and give a quick introductory description of the imaging platforms the patient positioning aid will be used in – these include: x-ray, CT scan, and MRI. Both the x-ray and CT scan use very small and controlled amounts of x-ray radiation, which is passed through the body and different tissues which will absorb the radiation at different rates. CT stands for computed tomography and is sometimes also called CAT scan, and it uses computer processing of the information to show a cross-section of body tissues and organs. The CT scanner itself is a large, square machine with a hole in the center and the patient lies still on the table which can move up or down and slide into and out from the center of the hole. MRI scan stands for magnetic resonance imaging and it makes use of magnetic and radio waves which when sent through the body affects the body’s atoms, forcing the nuclei into a different position. As they move back into place they send out radio waves which the scanner picks up and a computer turns these signals into a picture. The MRI scanner is a rather large apparatus and the patient lies down on a bed which is then slid into a large, cylinder-shaped
magnet, and with an MRI scan it is possible to take pictures from almost every angle, whereas a CT scan only shows pictures horizontally.

**Figure 1** on page 18 is the overall drawing of the Optimal Design, which will be broken up into its five major elements and explained in greater detail as well as a rather detailed force analysis on this proposed patient positioning aid. The five main components of this design are the base, which will be laid on the table and made of a PVC board along with aluminum and PVC cross members with a foam pad covering it, a hand bar, an arm stabilizer, a knee fixation device and lastly the tracking system that will be used to easily adjust both the arm stabilizer and the knee fixation device. The combination of these five main components and their specialty functions will help to aid in making the patient positioning aid versatile, compatible with a large range of examination tables and platforms and lastly will provide additional comfort to the patient.

**Figure 1: Optimal Design for the Patient Positioning Aid**

**First Major Component: Base of the Positioning Aid**

The first major component of our design is the base for the patient positioning aid. This transfer board must be compatible with the various examination tables and imaging platforms. A PVC (polyvinyl chloride) board was selected as our design’s base. The board will have the dimensions 72”x 22”x
0.5". The tables and platforms at the hospital measure six feet long and twenty-two inches wide, therefore, the transfer board will be compatible and interchangeable with the various imaging device platforms since the 22" will be able to fit inside the MRI and CT scan. Physical properties of Type 1 PVC can be found in appendix A-2. Due to large the weight that needs to be lifted on this board during patient transfer from examination room to imaging platform, cross members are needed to ensure the structural integrity of the board. Two aluminum cross members (which are non ferrous and therefore safe in an MRI) that measure 1” x 0.5” x 72” will run the length of the board set 2.25” from the sides of the board. Physical properties for Aluminum alloy 6061 can be found in the appendix A-1. Along with these, three PVC cross members measuring 1” x 1” x 17” will run laterally across the board between the aluminum cross members. Physical properties of Type 1 PVC can be found in appendix A-2. The total cross member system can be seen in Fig. 2.

![Figure 2: Bottom view of positioning aid base showing cross member set up.](image)

Attached to the PVC board will be 4 aluminum handles which will be used to lift the board. The handles will be placed at the ends of the board, by the patients head and feet, allowing the board to be lifted by 4 people using handles. Also, foam will be attached to bottom of the board along the sides and top and bottom which allows the user to lift from the bottom side of the board as well. The board selected in particular for this design is gray PVC type 1 sheet and it runs about $175.00 for our size requirements and can purchased through the Modern Plastics website. This board is also radiolucent so the x-rays will not be absorbed by the material and cause interference and in turn disrupts the images. For the aluminum cross members, aluminum alloy 6061 was chosen because of
its superior strength and low weight. This aluminum can be purchased from the MSC catalog costing about $45.00 for the pair of rods. For the PVC cross members, gray PVC type 1 was chosen which can be purchased from the modern plastics website for about $34.00 for 10’. The price breakdown for this component and all the other components of the design can be found in the table on page 87, which is a quick budget summary for the design.

Since the MRI, CT scan and x-ray examinations can be quite lengthy, it is necessary for the medical staff to try to make the patient as comfortable as possible. The more comfortable the patient is, the less likely they will be to move during the examination. To ensure more patient comfort the polypropylene board will be covered by a foam pad which will run the length of the board. This piece of foam padding will be 70” long, 16” wide, and 1” thick. It will be in a nylon cover, which can be easily cleaned between examinations. The pad can be custom made and costs about $100.00. A complete drawing of the positioning aid base can be seen in figure 3.

![Figure 3: Positioning aid base](image-url)

**Second Major Component: Hand Bar**

The second major component of our design is the arm bar and head rest. The plastic bar will be located at the top of the positioning aid where the head will go. Gray type 1 PVC will be used as the material for the handle bar. The properties of the material are displayed in the Appendix A-2. The rod will be 1” in
diameter, and the handle bar will be 16.5 inches wide. It will be 2.5 inches above of the positioning table, having a total height of 3.5 inches. The handle bar will be made by cutting the rod at 45°, leaving two pieces that are 2.5 inches and one that is 14 inches. Then the pieces will be glued together on the 45° creating the handle which will be screwed to the base. Figures 4 – 8 display the dimensions of the hand bar followed by the complete component. A rod of Gray PVC type 1 10' in length will cost about $11.00 at Modern Plastics. A thin layer of rubber will be put over the rod for more of a grip and comfort for the patient.

**Figure 4:** Top View of Hand Bar

![Top View](image)

**Figure 5:** Bottom View of Hand Bar

![Bottom View](image)
Figure 6: Front View of Hand Bar

Front View

16.5"

3.5"

1"

1"

Figure 7: Side View of Hand Bar

Side View

1"

3.5"

1"
Brass screws will be used in order to secure the handle bar since brass is non magnetic and very strong. There will be two options for the patient to be positioned with respect to the table, either facing up away from the table, or facing down toward the table. When the patient is lying on their back they will reach behind their head in order to get their arms out of the imaging technologies way. The arms will be supported by stabilizers described later. While the patient is oriented with their stomach facing down, they can put their hands out toward the arm bar and grip on for comfort and support. This will be useful also for imaging of the wrist and parts of the arm.

**Headrest:**

A headrest was added to this design to provide further comfort for the patient during the procedure. The Phat Pads in the Alimed catalog seem ideal for our intended use. The headrest is a donut shape and is 8.5" in diameter for the adult size. The donut shape benefits the patient since it allows them to place both the back of their head and their forehead on it. This allows them to be oriented facing any direction they need to, with the necessary comfort in order to be immobile for about 45 minutes. The headrest will prevent any neck cramps or discomfort to the patients head. The pad utilizes a gel technology to distribute the pressure equally and is radiolucent. This product is extremely durable and
offers a lifetime guarantee so it would be a one-time investment of $80.00 for the hospital. The headrest can be seen in Fig. 9 and also with respect to the positioning aid in Fig. 1 on page 18.

![Head Rest](image)

**Figure 9:** Head rest

**Third Major Component: Arm Stabilizer**

Our design will include two arm stabilizers to provide comfort and stability to the upper arm of the patient as they reach back to grip the hand bar. The arm stabilizers will comprise of a base, a pivot, and linear bearing and an arm rest. The base will have dimensions of width 2 inches, length 7 inches, and thickness 1 inch. The base can be seen in Fig. 10. The base will be made of gray PVC type 1. Attached to the base is a 90° aluminum pivot, which allows a 1 ft piece of 1 in x 1 in aluminum extrusion to pivot 90° from horizontal to vertical which can be seen in Fig. 11.
Figure 10: Top and side views of the arm stabilizer base
This allows for a great range of arm stabilization. On this piece of extrusion is a linear bearing that can slide the length of the extrusion and be set to stay at a certain place via an aluminum knob. Attached to this is a piece of gray PVC type 1 which will be 3 inches x 6 inches x 1 inch on which the patient’s arm will rest. The bearing and arm rest can be seen in Figs 12-14 and the total arm stabilizer can be seen in Fig. 15.
Figure 13: Arm rest and bearing top view

Figure 14: Arm rest and bearing bottom view
A piece of non-adhesive T foam will be used to cover the part of the arm stabilizer facing the patient’s arm. This specialized foam eliminates pressure points, absorbs shock and vibration, recovers completely, is breathable, lightweight, and fire-retardant. The foam will provide full comfort to the patient’s arm, allowing them to relax by taking all tension out of their arms. The T foam will cost $32.00 for a big piece, which can be used in multiple areas of the positioning aid. The PVC used for the arm base and rest can be purchased from modern plastics and costs $25.00 for a sheet which can be used to make both arm stabilizer bases and rests. The aluminum pivot, extrusion, and bearing can be purchased from 80/20 Inc. and cost about $120 total for 2 of each. The arm stabilizer will utilize a track system, described next, in order to meet a wider range of patient arm lengths. The track for the stabilizer will start 14 inches from the top of the patient positioning table and will be 12 inches long. The arm stabilizer will be able to slide up and down the track and will be locked in at the desired location. Slots will be milled in the base allowing the base of the stabilizer to be attached to the base of the positioning aid via the bolts and knobs discussed in the track system. These slots allow for the arm stabilizer to be attached and removed while the patient is on the aid without the need of removing the knobs of the track system. When a patient reaches behind their head in a lying position, gravity will naturally pull their arms down. With the arm stabilizer in place their arms will lie comfortably on the stabilizers while their hands can grab the hand bar.

Figure 15: Total Arm stabilizer
Fourth Major Component: Knee Fixation Device

The fourth major component of the Optimal Design is referred to as the leg fixation device. This leg fixation device will be easily adjustable from patient to patient. It will be adjustable by sliding the device up and down the track system described later. The track will begin one foot from the end of the board on both the left and the right side of the transfer board. The slit will then be 14” in length to allow for 5” shift up or down depending on the height of the patient. The leg fixation device will be comprised of two bases, measuring 10 in x 2 in x 0.75 in made of gray PVC type 1. Material properties for this material can be found in appendix A-2. These bases will have slots so they can be attached to the aforementioned track system. The slots will allow for the fixation device to be attached and removed while the patient is on the aid. Attached to the bases will be two 10” pieces of aluminum extrusion with a 1 in x 1 in cross section. They will be placed vertically with respect to the base at each end of the base, 1.5” from the end as seen in Fig. 16. They will be attached using aluminum elbow brackets and aluminum and silicon bronze. Each base and corresponding extrusion will be attached to the board on opposing sides as seen in Fig. 1. Along with these two bases, there will be two leg stabilizer bars. The bars will consist of a piece of high density polyethylene (HDPE). A rectangular bar stock of HDPE (stock number KBS-737) can be purchased through k-mac-plastics online catalog at $16.00/ft but since four feet are needed for this design it will be a total cost of $65.00. The bar will be cut so it has a recess in it where the legs will be stabilized as seen in Fig. 20. The bar will have dimensions of 2.5 in x 1 in. On each side of the bar an aluminum linear bearing will be attached by aluminum bolts. These bearings will attach to one of the aluminum extrusions on one of the leg stabilizer bases, and the other bearing will attach to the aluminum extrusion on the opposite leg stabilizer base as seen in Fig. 1. This will allow the bars to slide from the top of the extrusion to the bottom, which will hold the legs in place between them and the board. The bearings will have a hand knob on them allowing the user to position at any position on the extrusion they want to. The aluminum L brackets, extrusions, and bearing can be purchased from 80/20 Inc. and cost about $160.00 for all needed. The dimensions and views of the whole leg stabilizer system can be seen in Figs 16 – 22. The part of the fixation bar that comes in contact with the patient will have a T-foam covering it to increase comfort. This T-foam will eliminate pressure points, absorb shock and vibration and recover completely after being used. The foam is also breathable and lightweight. It can be purchased through the Alimed online catalog for $32.00. This foam will ensure a comfortable, yet form fitted position of the lower extremities, which must remain very still during the imaging process. The leg fixation device will be effective in stabilizing the knee as well as keeping the patient comfortable during long examinations.
Leg Stabilizer Base

Figure 16: Base of the Knee/Leg Fixation Device

Figure 17: Top View of Knee/Leg Stabilizer Base
Figure 18: Side View of Knee/Leg Stabilizer Base
Figure 19: Knee/Leg Stabilizer Bar

Figure 20: Top View of Knee/Leg Stabilizer Bar
Figure 21: Front View of Knee/Leg Stabilizer Bar

Fifth Major Component: Track System

The track system that will be used in this design involves silicon bronze carriage bolts going through a slit in the positioning aid base and attaching to the arm stabilizer and knee fixation device. The bolt that will be used will be carriage bolts, seen in Fig. 23. There will be two bolts in each track with their heads facing down. The screws will be ¼ - 20 UNC threaded. Aluminum palm grip knobs threaded ¼ - 20 UNC will be screwed onto these bolts once in the slots of the board. The base of the arm stabilizer or leg fixation device can be slid onto the bolts below the knob via the slots that have been milled in them as seen in Fig. 25. The arms or leg stabilizer can be slid to a desired place, and then tightened down using the knob. The setup is shown in Figs 24 and 25. There will be a total of 4 tracks and slots, one for each of the two arm stabilizers, and one for each of the sides of the knee fixation device. There will be two bolts for
each attachment per slit which will keep the bases stable in all three planes. All the slots and tightening knobs are shown in Fig.1.

Figure 23: Bolt

Figure 24: Slot on Transfer Board
Figure 25: Top and Side views of base attachment via slots and bolts
**Force Analysis of Optimal Design:**

In order to design a safe and effective patient positioning aid it is important to analyze the forces that will be acting upon each separate part of the design. The first major part of the design that will be experiencing any significant load is the board and cross members and foam pad which the patient will be laying upon. In this situation the only forces in concern are the segment body weights of the patient, which will cause both a compressive force and a bending stress. Working from the bottom of the board to the top, the next system in concern is the leg stabilizer. Based on the design of this component and how it will be used the load applied to the component will be minimal, thus the stress on the component is negligible. Working upwards along the board the next system is the arm stabilizer. The weight of the patient’s arm will cause compressive and bending stresses within the extrusion. Finally, at the very top of the board there is the hand-bar which will experience a normal stress, a shear stress and bending stresses.

The weight of the patient on the transfer board will create both a compressive force and a bending stress. The compressive force is defined as a force per area and since the area of the board is rather large the compressive force will be rather small. The maximum patient weight on the board will be 500 pounds and this weight divided by the total area of the board (1584 in$^2$) will be 0.316 psi which is negligible and the board will be able to easily support. The bending stress in the board can then be calculated by breaking up the total weight of the patient into the weights of various main body segments as seen in the following figure:

![Figure 26: Distributed Load along Transfer Board](image)

In this figure the forces $W_f$, $W_l$, $W_t$, $W_{tr}$, and $W_{(h+a)}$ are the weights of the patient’s feet, legs, thighs, trunk, and head and arms respectively, all of which are calculated using the segment weight / body weight ration in Table 9.1:
Anthropomorphic Data of the textbook *Introduction to Biomedical Engineering*\(^1\). The overall lengths of the body segments were determined by using Figure 3.9: Body segment lengths expressed as proportion of body stature in the book *Occupational Biomechanics*\(^2\) and using a relative patient height of six feet (72 inches). The dimensions of the figure which show the relative location of the forces was determined by using the location of the center of masses of each body segment as described in Table 9.1: Anthropomorphic Data of the textbook *Introduction to Biomedical Engineering*\(^1\). The reactionary forces \(R_1\) and \(R_2\) can be determined using the following two moment equations:

\[
\sum R_1 = 0 = (1.4\text{''})(W_f) + (10.47\text{''})(W_t) + (28.15\text{''})(W_r) + (48.52\text{''})(W_{(r+a)}) - (72\text{''})(R_2)
\]

(Eq. 1)

\[
\sum R_2 = 0 = -(6.55\text{''})(W_{(r+a)}) - (23.47\text{''})(W_r) - (43.84\text{''})(W_t) - (61.52\text{''})(W_f) - (70.59\text{''})(W_f) + (72\text{''})(R_1)
\]

(Eq. 2)

By solving these two equations simultaneously, you find reaction force \(R_1 = 204.7\) lb and reactionary force \(R_2 = 295.3\) lb. Using these values of the reactionary forces and the values and locations of the forces due to the different body segment weights ultimate analysis on the system can be conducted by creating the shear and moment diagrams depicted in the following figure:

---


By analyzing the moment and shear diagrams the maximum moment is calculated to be 5441.6 lb\(^*\)in. The total bending stress applied to the board due to this moment can then be determined using the following equation:

\[
\sigma = \frac{Mc}{I}
\]  

(Eq. 3)

In this equation \(M\) is the maximum calculated moment, \(c\) is the distance from the neutral axis to the surface of the board and \(I\) pertains to the moment of inertia of the board. Because the cross section of the positioning base seen in Fig. 28 is comprised of two different materials, the dimensions of one of the materials must be changed so that that material will act like the other material.
To change the dimensions of the material you first need the modulus of elasticity for both materials. The modulus of elasticity for 6061 aluminum alloy and PVC are $10.1 \times 10^6$ psi and $0.45 \times 10^6$ respectively. Now, to change the dimension of the aluminum to what it would be if it were to have the same strength if it were pvc, you find the ratio:

$$n = \frac{E_{al}}{E_{PVC}}$$  \hspace{1cm} (Eq. 4)

This equation yield $n = 22.44$. Now, this number is multiplied by the horizontal dimension of the aluminum cross sections of the original total cross, yielding a new cross section of all PVC seen in Fig. 29.
\[ \bar{Y} = \frac{\sum (\bar{y} * A)}{\sum A} \]  

(Eq. 5)

Where \( \bar{Y} \) is the neutral axis, \( \bar{y} \) is the centroid of each piece, and \( A \) is the area of each piece. This equation yields the neutral axis at 1.1875" from the bottom of the cross section. The moment of inertia of a rod or beam’s cross-sectional area is a measure the rod or beam’s ability to resist bending. The larger the amount of moment of inertia the less the beam will bend and the moment of inertia is a geometrical property that depends upon a reference axis. In order to calculate \( I \) for the board the following equation for the moment of inertia of a set of rectangles is used:

\[ I = \sum \frac{1}{12} bh^3 + Ad^2 \]  

(Eq. 6)

Where \( b \) is the width of the rectangle, \( h \) is the height of the rectangle, \( A \) is the area of the rectangle and \( d \) is the vertical distance from the centroid of the rectangle to the neutral axis. Therefore, this is done for each rectangle, and each \( I \) is summed yielding the moment of inertia for the cross section. This equation yields a moment of inertia of 12.75 in\(^4\). Implementing equation 3, a moment \( M \) of 5441.6 lb*in, \( c = 1.1875 \) in, and \( I = 12.75 \) in\(^4\), the maximum bending stress in the board is \( \sigma = 506.81 \) psi.

Analysis of the arm stabilizer system shows that a bending stress and a compressive stress will be applied to the extrusion of the arm stabilizer. The bending stress is caused by a moment created from the weight of the arm trying to bend the extrusion as seen in Fig. 30.

![Figure 30: Arm Force in Stabilizer](image-url)
Figure 31: Compressive force in arm stabilizer

Figure 32: Cross-Section of arm stabilizer extrusion
Using Fig. 30 as a reference the moment $M$ can be calculated using the following equation:

$$M = F_{arm} \times d$$

(Eq. 7)

In this equation $F_{arm}$ can be calculated using Table 9.1: Anthropomorphic Data of the textbook Introduction to Biomedical Engineering$^3$ in which the segment weight / body weight for the total arm is 0.050. Assuming a maximum patient weight of 500 pounds $F_{arm}$ will then be 25 pounds and $d$ for this system will be 3 inches. Using these values the moment $M$ is calculated to be 300 lb*in. The bending stress to the arm stabilizer can then be calculated using equation 3; however this component will have a different $c$ (0.5 inches) and also will have a different moment of inertia $I$ which is given by 80/20 Inc. for model 1010 extrusion as 0.0323 in$^4$. Implementing this equation the bending stress in the arm stabilizer is calculated to be 4643 psi. The arm stabilizer will also experience a compressive stress. At a maximum, the most compressive force the extrusion will see is the total weight of the arm, $F_{arm} = 25$ lb. Taking this force over a cross sectional area of 0.5 in$^2$ which is much less than the actual area of the extrusion will yield a compressive strength stress of $\sigma = 50$ psi.

Analysis of the handle bar force system concluded that the weights of the patient’s body segments will create a normal stress, a shear stress and bending stresses. A general diagram of the handlebar system is depicted in the following figure:

---

In this figure the forces $F_1$ and $F_2$ depict the forces created by the weights of the patient’s two arms, and thus these forces are equivalent. The forces $R_1$ and $R_2$ are the reactionary forces on the hand bar and due to symmetry are also equivalent. Also due to symmetry of the hand bar analysis of the shear stresses, normal stresses, and bending stresses can then be conducted by splitting the bar into its two halves.

Shear stress is the *sliding* strain which is created by a torsion force and a shear stress will be applied to the hand bar due to the patient gripping the hand bar. A diagram of the shear stress is depicted in the following figure:
In this figure force $F_z$ is created by the weight of the patient's arm segment. Once again according to Table 9.1: Anthropomorphic Data of the textbook Introduction to Biomedical Engineering the segment weight / body weight for the total arm is 0.05. Thus in taking the maximum patient weight to be 500 pounds (as described in the project specifications) the force $F_z$ is 25 pounds. The general equation pertaining to shear stress in a rod or beam is:

$$
\tau = \frac{T \times c}{J}
$$

(Eq. 8)

The components of this equation are unique to the shape and setup of the member which the force is acting upon. Fig. 34 shows the forces causing torque in the hand bar.

---

Figure 35: Forces causing bending in arm bar

In our design the distance can be determined by looking at a cross section of the hand bar:

Cross Section

Figure 36: Cross-Section of Attachment Arm

From this cross-section it can be determined that the distance $c$ will simply be the radius of the arm which will be 0.5 inches. The $T$ in the general equation for shear stress in a rod is the torsion force created by the force $F_z$ and the equation for calculating $T$ is:

$$T = F_z \times d$$  \hspace{1cm} (Eq. 9)
The \( J \) in the general equation for shear stress in a rod pertains to the rod’s polar moment of inertia. The polar moment of inertia of a rod or beam’s cross-sectional area measures the rod or beam’s ability to resist torsion. The larger the polar moment of inertia the less the beam will twist. The polar moment of inertia of the rod can be calculated using:

\[
J = 2I = \frac{\pi}{2} \times r^4 \tag{Eq. 10}
\]

Thus the overall equation for calculating the shear stress in the rod of the hand bar is:

\[
\tau = \frac{F_z \times d \times r}{\frac{\pi}{2} \times r^4} = \frac{F_z \times d}{\frac{\pi}{2} \times r^3} \tag{Eq. 11}
\]

In the calculation of the shear stress \( F_z \) once again is the weight of the patient’s arm (25 pounds), \( d \) is the distance from the hand gripping the hand bar to the center of the vertical portion of the hand bar (assume 4.5 inches) and the radius \( r \) will be (0.5 inches). Using these values the maximum shear stress calculated will be 572.96 psi.

Due to the axial loading of the patient’s arm weights a bending stress is applied along the top (horizontal) portion of the hand bar. A diagram of this bending is depicted in the following figure:

![Figure 37: Horizontal Bending in Hand Bar](image)
This bending stress can be calculated using the equation:

\[ \sigma_{b1} = \frac{M_{\text{max}} \cdot c}{I} \]  
(Eq. 12)

In this equation the \( c \) is the radius of the bar as depicted in figure 36. The \( I \) in equation 12 once again pertains to the moment of inertia of the hand bar. In order to calculate \( I \) for the cylindrical hand bar the following equation is used:

\[ I = \frac{\pi \times r^4}{4} \]  
(Eq. 13)

The \( M_{\text{MAX}} \) in equation 12 is the maximum moment along the horizontal portion of the hand bar and this value (125.5 lb*in) was determined using the shear and moment diagrams depicted in the following figure:

![Shear and Moment Diagrams of Hand Bar](image)

Using these values the maximum bending stress applied to the horizontal portion of the bar is calculated to be 1278 psi.

The normal stress experienced by the hand bar will be created by two different methods: axial loading and bending. Figure 39 is a diagram depicting the force and dimensions involved in the creation of the normal stress in the rod due to axial loading:
Figure 39: Normal Stress and bending stress from Axial Loading
In Fig. 39 the force $F_y$ is a strictly downwards force created by the patient’s arm segment and the distance $d$ is measured from the center of the vertical portion of the hand bar to the center of the patient’s hand which is gripping the hand bar. The general equation for the normal stress in a rod or beam due to axial loading is:

$$\sigma_a = \frac{F_y}{A}$$

(Eq. 14)

In this equation $A$ is the cross-sectional area of the rod or beam, and since our attachment rods are going to be cylindrical the cross-sectional area of them will be $\pi r^2$. Thus the overall equation to calculate the normal stress in the rod from axial loading is:

$$\sigma_a = \frac{F_y}{\pi \times r^2}$$

(Eq. 15)

Once again using the patients arm segment weight to be 25 pounds and the radius to be 0.5 inches, the axial loading turns out to be 31.83 psi.
There is also a normal stress created due to bending in the hand bar. The general equation for the calculation of normal stress due to bending is:

$$\sigma_{b2} = \frac{M \times c}{I}$$  \hspace{1cm} (Eq. 16)

Two of the components of equation 16 have already been defined. $M$ is simply another bending force which can again be calculated in the same manner as the bending force in equation 12 however by using the force $F_a$ (25 pounds) and distance $d$ (3 inches). Also, similarly as in the calculation of the shear stress the distance $c$ will be the radius of the cross-section of the vertical arm of the attachment as depicted in Fig. 36, thus $c = r$. The $I$ in equation 16 once again pertains to the moment of inertia of the rod that makes up the hand bar and its calculation is shown in equation 13. Upon inputting the formulas for determining the various components of the normal stresses due to bending the overall equation for the normal stress due to bending in the hand bar becomes:

$$F_y \times d \times r \pi / 4 \times r^4 = F_y \times d \pi / 4 \times r^3$$  \hspace{1cm} (Eq. 17)

After determining the equations for the normal stress in the hand bar due to both axial loading and bending an equation for the total normal stress in the hand bar can be determined by adding the two equations, becoming:

$$\sigma_T = \frac{F_y}{\pi \times r^2} + \frac{F_y \times d}{\pi / 4 \times r^3}$$  \hspace{1cm} (Eq. 18)

Using equation 17 the normal stress due to bending is calculated to be 763.94 psi. The total normal stress is then this value plus the value of the stress due to axial loading (31.83 psi) which becomes 795.77 psi.

In the final determination of which material should be used in the design of the patient positioning aid all of the values of the above forces must be analyzed. In summary for a maximum patient weight of 500 pounds the board will experience a compressive stress of 0.316 psi and bending stress of 506.81 psi. The arm stabilizer will experience a bending stress of 4643 psi, and the handlebar will experience a shear stress of 572.96 psi, a horizontal bending of 1,278 psi, and a total normal stress calculated to be 795.77 psi. Therefore, two different materials were chosen. The material for the construction of the board must be able to withstand a much larger force than any of the other components, thus a PVC board with a tensile strength of 7,820 psi and aluminum cross members were chosen. For the remaining components the maximum stress which the material must be able to withstand is 1,145.92 psi, therefore PVC with
a tensile strength of 7,820 was chosen. Other qualifications of the materials must also be met such as it being light-weight, cost-effective, and able to go through both CT and MRI scanners, and the materials chosen satisfy these requirements as well.
2.3 Prototype

Subunit 1: Board

The first major component of our design is the base for the patient positioning aid. This transfer board must be compatible with the various examination tables and imaging platforms. It must also be fabricated using a relatively lightweight material to ensure that all hospital staff will be able to setup and store the device. Therefore, a PVC board was selected as our design’s base. The board has the dimensions 72” x 22” x 0.5”. The tables and platforms at the hospital measure six feet long and twenty-two inches wide, therefore, the transfer board will be compatible and interchangeable with the various imaging device platforms and will be able to fit inside the MRI and CT scan. This board is also radiolucent so the x-rays will not be absorbed by the material and cause interference and in turn disrupts the images. This board was chosen also because it is relatively lightweight. With all the components attached it is a little more than 1/10 of our maximum weight.

We attached side aluminum members underneath the board to prevent flexing. In addition PVC cross members were attached as reinforcement to prevent sagging of the base. The aluminum side members are placed 2 inches in from the sides and attached with brass screws. Each side member has a total of 13 screws securing it to the base. By placing them closer together they not only prevent flexing in one direction but also reduce it along with sagging in the other. The PVC cross members are attached using brass screws to the side members with one screw on each side. There are a total of 3 cross members measuring 15 inches, 39 inches, and 57 inches from the top of the transfer board. Figure 40 below displays the side members and the cross members.

Figure 40: Side and Cross Members
Figure 41 displays the cross member doing their job and preventing flexing while lifting heavy loads.

In addition to the cross and side members, aluminum handles are attached onto the base. There a total of four handles attached to the board, two toward the head and 2 toward the feet. They are placed 1.5” in from the side and 2.5” down from the top and up from the bottom. This will allow an even distribution of weight and allow hospital staff members to easy transfer patients to different locations. Figure 41 shows how patients will be transferred. The attachments however will be removed while transferring the patient since it would reduce the total weight endured by the staff and prevent any accidents from occurring. There are also foam pieces attached at various locations for when more than two people are lifting a patient. They are about 2” in width and vary in length depending on the space available at each location. One piece is attached near the top under the handbar, one is all the way on the bottom, and two are on the sides in the center of the board. They are shown in Figs 42-43. When a patient is being lifted by multiple people a person will grip one handle, and place the other hand underneath the board. Two other members can help by holding up from the sides near the stomach area. The board is simply placed on top of the imaging device’s table. It should be centered about the table in both directions.
Since the MRI, CT scan, and x-ray examinations can be quite lengthy, it is necessary for the medical staff to try to make the patient as comfortable as possible. The more comfortable the patient is, the less likely they will be to move during the examination. To ensure more patient comfort the PVC board is covered by a piece of foam. This piece of foam padding is 70" long, 16" wide, and 1" thick. It is in a nylon cover, which can be easily cleaned between examinations by wiping off any substance on it. To attach it to the board we used industrial strength Velcro. This will allow hospital staff member to remove the pad if they need to. Figure 44 shows the Velcro on the pad where it will attach to the board. Simply place the pad onto the board lining up the bottom section distinguished on the pad by the section that can be opened and closed.
by the use of Velcro. Once this section is lined up and the pad is centered it can be simply placed down onto the board and the Velcro will attach the pad securely.

Figure 44: Velcro on Foam Pad

A headrest was added to this design to provide further comfort for the patient during the procedure. The Phat Pads in the Alimed catalog are ideal for our intended use. The headrest is a donut shape and is 8.5” in diameter for the adult size. The donut shape benefits the patient since it allows them to place both the back of their head and their forehead on it. Allowing them to be oriented facing any direction they need to, with the necessary comfort in order to be immobile for about 45 minutes. The headrest prevents any neck cramps or discomfort to the patients head. The pad uses a gel technology to distribute the pressure equally and is radiolucent. This product is extremely durable and offers a lifetime guarantee so it is a one-time investment of $80.00 for the hospital. The Headrest can be placed centered above in between the arm stabilizers and can be adjusted to suit the needs of the patient.

Subunit 2: Handbar

To support the top half of the body our design includes a plastic handbar for gripping onto. The plastic bar will be located all the way at the top of the positioning aid. The handbar is made up of PVC. The rod is 1inch in diameter, and the handbar has a total length of 16.5 inches. It is be 4.5 inches above of the positioning table. The handle bar was made by cutting the rod into a
segment of 16.5 inches with 45 degree angles on each side, and two segments of 4.5 inches having a flat side and a side with a 45 degree angle. The pieces were glued together using PVC primer and glue. The handbar has a rubber grip covering that gives the patient comfort while holding on and prevents their hand from slipping off. The handbar is attached to the transfer table by bronze screws. Figure 45 shows how the handbar is used. In addition Velcro will be provided for use with patient with certain disabilities. The Velcro will secure a patient’s arm to the handbar who has limited reach movement and is not able to keep their arm using their own strength. The handbar is already attached to the positioning table and no further assembly is needed.

Figure 45: Use of Handbar
To prevent anyone from lifting the board using the handbar a laminated caution sign is used. The sign saying “DO NOT LIFT BY BAR” is glued right underneath the handbar so that it can be seen in plain sight to anyone about to lift the board using the handbar. Figure 46 shows the signs location and how it looks on the board.

Subunit 3: Arm Stabilizer Attachment

Our design includes two arm stabilizers to provide comfort to the upper arm of the patient as they reach back to grip the handbar. They each weight 3lbs. It is made up of a base attached to the transfer board using the track system. The base is 7” by 2 1/16” by 1”. It has two knobs located at 0.75” in from the top and bottom and 0.75” from the inside. They allow securing the arm stabilizer to the base at the desired location using the track system described later. The base has two slots that face the inside of the board for easy attachment and removal, each with a length of 0.75”. Figure 47 displays the arm stabilizer. The base of the stabilizer can be easily slid onto the carriage bolts and under the knobs then secured by tightening the knobs.
The base has a 90 degree pivot bracket attached to it using aluminum bolts. To the pivot bracket there is an extrusion that adjusts at the desired angle and can be secured using a knob. This extrusion is 1 foot in length. To the extrusion is the PVC block that supports the arm. This block has the dimensions of 6” x 3.5” by 1”. It is attached to the extrusion using a linear bearing that can slide up and down the extrusion and be secured using a knob. It is also attached using aluminum bolts. A piece of non adhesive T foam covering covers the component which supports the patient’s arm. It was attached using gorilla glue which has excellent adhesive properties. The foam is used to provide comfort to the patient’s arms and prevent any injuries from occurring if the patient bumps their head into the attachment. We will be covering the foam using waterproof fabric to give it a more finished look and prevent wear and tear allowing it a longer lifetime. This will also make it easier to clean since it would be hard to clean foam. To place the linear bearing onto the extrusion, line it up to the extrusion with the foam cushion on the arm rest facing up and simply slide in. Then tighten it at the desired location using the knob. Figure 48 shows how the patient will rest their elbow on the arm stabilizer.
The arm stabilizer is one of the most versatile components of our design. It can be adjusting in multiple ways. It can slide on the track system, set to a particular angle using the pivot bracket, and be slid up and down on the extrusion using the linear bearing. All of these allow the hospital staff members to accurately position the patient’s arms so they do not receive any stress during the imaging procedure. It also allows the staff members to take care of patients with limited arm movement. Using the handbar and arm stabilizer together, the staff member can orient the patients arm so it is locked into the aid and cannot move and will not require any stress from the patient. The Velcro straps can also be used to secure the patients arm to the arm stabilizer for patients with limited arm movement.

**Subunit 4: Leg Stabilizer Attachment**

The Leg stabilizer was added to the design to limit the movement of the lower extremities during the often-lengthy imaging exams. The base of the leg stabilizer is made of PVC and is 12” long and 2” wide. The base has two, 1 ¼” slits that are used to easily slide the attachment off of the board when the patient is being moved onto the board. There are two aluminum knobs that are used to tighten this base to the board once the final position has been achieved. The leg stabilizer base can be seen in Fig. 49 below:
The next part of the leg stabilizer attachment are the four-10 ½” aluminum extrusions, which were purchased from 80/20 Air Inc. These extrusions are attached 1” in from the each edge of the base. They are held vertically on the base by a 1”x 1” L-shaped bracket on each side of the extrusion. The L-brackets are bolted into the base with aluminum bolts as well as attached to the side of the extrusion by an aluminum bolt as well. The extrusions are then capped at the top to prevent any injury that may of occurred when the staff was adjusted or removing the attachment. Figure 50 below is the leg stabilizer base with the attached 80/20 extrusions.
Figure 50: Leg Stabilizer Base with 80/20 extrusions

The last component of the leg stabilizer consists of the two-18 ¼" x 1 ¼" High Density Polyethylene bars (HDPE). These join the 2 leg stabilizer bases on each side of the positioning aid. The HDPE bars are used to adjust the stabilizer in the Y-direction as much as 10" depending on the size of the patient’s lower body. Loosening the aluminum knob and then sliding it to the desired position and retightening the knob again can make the adjustments and ensure a proper fit for the patient. The aluminum handles are held into the aluminum extrusion by silicon bronze carriage bolts, which are able to slide up and down the extrusion with relative ease. The sliding mechanism for the HDPE bars is a single flange linear bearing, which cups the extrusion and then has the HDPE bars attached to the extra aluminum component. The HDPE bars are connected to the single flange liner bearing by two aluminum bolts on each side.

The HDPE bars also are not connected to one another so they can be adjusted appropriately. This was done because the thighs of a patient are larger and taller than the upper shin of the patient. This concept can be seen in Fig. 51 below.
Figure 51: Adjusted Leg Stabilizer Attachment on Patient

This specialized fit is necessary to limit the movement of the patient while undergoing the imaging procedure. The HDPE bars also have foam padding underneath where the bar comes in contact with the patient. This provides additional comfort and allows for an even greater fit. The foam is then covered with a fabric and secured with double sided tape for a more pleasing look aesthetically. It also allows for easy cleaning between each of the patients, which is highly desired by the staff. The Fig. 52 below is a front view of the entire lower leg stabilizer attachment of the final prototype.
Subunit 5: Track System

The next subunit of the prototype is the track system, which the arm and leg stabilizers slide up and down the positioning board. The two aluminum handles in each of the bases of the arm and leg stabilizers have a silicon bronze carriage bolt which slides with relative ease up and down the slit. Each of the four slits is 1/4” wide and the carriage bolt is ¼”x 20. The length of the slits is not the same though for the arm and leg bases. The length of the two arm stabilizer slits is 12”, whereas the length of the two leg stabilizer slits is 14”. The distance they are from the edge of the board differs slightly as well. The two slits for the arm stabilizer base are 1 ½” in from each side of the board. The slits are in slightly further due to the function of the arm stabilizer, which, needs to provide support to the upper arms/elbows and must be in closer to the board to provide this necessary support. The two slits for the leg stabilizer base are 1” in from each side of the board. The slits for the legs at 1” are sufficient for this part of the design and therefore there was no need to drill closer to the center of the center because the more room for the patient on the board the better. The Fig. 53 below is the slit in the board for one of the arm stabilizer bases. The other side of the
board has an identical slit for the arm stabilizer base. The leg stabilizer slits look identical however, they are slightly longer as mentioned earlier in the report.

Figure 53: Track System for Arm Stabilizer Base

The last addition to the track system was using self-stick rulers underneath each of the four slits on the side of positioning aid. The rulers included as a part of the prototype to help the staff position the patient. They can simply choose the location that they would like to position the patient and the staff on the other side of the board can pick the same location on the ruler to ensure that the base is lined up. The addition of these rulers will help to lessen the amount of time it takes to get the patient set-up for the imaging procedure.

Subunit 6: Storage of the Prototype

The last subunit of our prototype is an important aspect of the overall design. One of the goals of the project was to make the device easy to be stored. The hospitals are often limited in the amount of space they have to devote to pieces of equipment when they are not being used all the time. Therefore, the prototype will come with two wall hooks that will hold just the positioning board with all the attachments removed to lighten the weight of the board. The two wall hooks just need to be mounted on a wall near the in or near
the operating room. They are to hold the board in the horizontal position. One of
the hooks should be above the above and the other below it to hold it up so the
board can just be slid in between the hooks and held up against the wall. The
maximum weight the hooks can be hold is fifty pounds and the board weighs 56
pounds but will be supported by two hooks, so it will be able to support the
weight of the board. A picture of the hook can be seen in the Fig. 54 below.

Figure 54: Hook that will be used to hold Positioning Board

The second component to the storage of the device is an aluminum
carrying case. This aluminum case contains a foam padding that was
customized to fit each of our attachments in an organized manner. The case also
comes with a handle for easy carrying for the hospital staff. The case and the
attachments together weigh approximately 20 pounds, which is not too heavy for
staff to lift short distances. The aluminum material is a good case material
because it is non-ferrous and can be brought into the operating room without any
problems.

This aluminum case is the following dimensions 36” L x 13-3/8” W x 4-1/2”
H. The separate case for all of the attachments and any extra parts was added
to the prototype to decrease the chance of the components being misplaced by
the staff. Since all of the attachments for this prototype are in one place the staff
just needs to get the box and take out the necessary attachments for the
patient’s procedure, as some patients may not need both the legs and arms
stabilized. This storage box also makes it easy to put back all the parts after the
staff has cleaned them and they can make sure that all of the parts are present
upon completion of each exam. If there are no empty spaced then all of the
components are there, if any spots are vacant the staff must try to locate them
are reorder that component of the prototype. This moderately sized case can be
easily put into a storage closet, as it is not very deep and can be easily located
by staff when it is needed. The Fig. 55 below is the case being used to hold the
various attachments of the prototype.
Operation of Device and Step by Step Instructions to Operate the Device

The first step to operating the Positioning aid is to remove it from the wall by sliding the board out from between the two hooks, which are currently holding it in the horizontal position. After the board has been removed, it can be placed on the table where the patient will be for their pre-operative procedure. The patient will then lay on the board, which should only have the foam pad, four handles, arm bar and headrest currently attached to it. Note that the arm and/or leg attachments should not be put on the board until the patient is on the imaging table and does not need to be moved anymore. Also, it should be mentioned that patients with limited leg movement or that are fragile may need the staff’s support in sitting on the bench and assuming the required position on the board which is lying on their back. The patient may then get comfortable and place their head in the headrest.

Once this is done the staff may lift the patient and carry them a short distance to the imaging table. The number of staff required to lift the patient is dependent on many factors and the staff prior to moving the patient should use their best judgment. For a lightweight patient less than 150lbs, two relatively in shape staff members, could move the patient by using the top two handles and the other staff member at the bottom gripping the two handles. However, it is recommended that since the board has four handles, four staff can move the patient by placing both hands in the handle. There is also the option for the staff to use one hand in the handle and the other on the under side of the board which has foam there to minimize any injury or discomfort to the staff. There are also two pieces of foam in the center of the board, which can be used for a fifth and
sixth member to help lift a heavy patient. The staff can simply use their palms to grip the under side of the board which has the foam there to also decrease discomfort.

It should also be noted that the board should never be lifted via the arm bar, as it was not designed for that function. It is also not recommended that the staff try to lift the patient and move them long distances (i.e. down the hall to another room), as the board is able to support the weight, the added bouncing from moving increases the risk that the board may fail.

Once the patient is on the imaging platform the aluminum storage case may be removed from the closet that it has been stored. This setup of the attachments can be easily done with two staff members, one on each side of the patient. The two horizontal arm stabilizer components should be removed from the box and attached to the arm stabilizer bases. The horizontal component can be slide onto the extrusion and then tightened using the aluminum handle. The handle should be facing the staff, and the foam part should be facing upwards with the foam end closest to the patient head. The bases can then be slid onto the board by the two slits drilled into each base. Next, after the bases have been placed on the board, the angle of the 90-degree pivot brackets on the attachments can be adjusted so that the patient’s upper arms/elbows rest comfortably on them. The location of the base on the track system can also be set at this time using the rulers that are on each side of the board. The two staff members just need to select a designated distance that the patient is comfortable and make sure both sides are even. It is at this time that the patient should assume the overhead position and grip the arm bar with both hands with their palms facing the ceiling. This desired position is necessary to remove the arms from the images that are going to be taken. Any minor adjustments either to the position of the base or the angle can be made at this time by loosening the aluminum handles and then tightening them.

If the patient has limited arm function, the case contains two Velcro straps that can help the patient hold the arm bar. If only the upper body needs to be stabilized the patient is now ready to undergo their examination. However, if the patient’s lower body needs to be stabilized as well during the procedure, continue the operation procedure below.

The next step to setting up the patient is for each of the staff members to remove one of the leg stabilizer bases from the storage case. The leg stabilizer base is U-shaped. The base may then be slid onto the lower part of the board using the pre-drilled slits. Once the base is on the board it can be temporarily tightened using the two aluminum handles. The bases should be positioned so that the patient’s knee lies between the two extrusions. The rulers on each side of the board should help the staff in making sure the two bases are lined up evenly so that the HDPE bars can be easily slid onto the extrusions. The staff members should each take out one of the HDPE bars from the storage case.
The HDPE bars should be slid onto the extrusion with the bar to the left of the extrusion and will slide up and down the extrusion by the silicon bronze carriage bolts. The foam side should be in contact with the patient and the aluminum handles should be facing outward toward the staff member so they can adjust the height of the height appropriately. The second HDPE bar can then be placed onto the board using the same technique as described above. Once the two HDPE bars are both secured and provide a tight fit for the patient and they cannot move their lower extremities without putting forth a huge effort, the prototype setup has been completed. Note that the lower body stabilizer should not cut off the patient’s circulation or serious complications may occur. The Fig. 56 below is a picture of the Prototype and its various components to help with determining where parts may go in case there is any confusion.

**Figure 56:** Final Prototype and its attachments

Upon completion of the examination the patient should lie on the table. The patient may release their arms from the arm bar and place them by their side. The staff should then loosen the aluminum knob on the horizontal arm stabilizer component and remove it from the arm stabilizer base. This should then be placed it its designated place in the storage case. The next part of disassembly is to loosen the arm stabilizer base so that it may be removed from
the board as well. After it has been removed the staff should store it in the case. It will be necessary to loosen the aluminum handle slightly to get it back to a 0 degree angle. If the patient only had their upper body stabilized they would be ready to get off of the table and walk out of the room. If however they cannot walk and must be moved to another bed, that may now occur since all of the attachments have been removed. If the patient had the lower body stabilized as well for their examination, continue reading with the disassembly of the prototype.

The next step to disassemble is to loosen one of the HDPE bars on each side and simply pull up and disconnect the bar from the leg stabilizer base. This can be done for the other HDPE bar as well. These two bars can then be placed into the storage case in their designated areas. The last step to the disassembly of the prototype involves loosening the two aluminum handles securing the base and sliding the base off of the board by the pre-drilled slits. These two leg stabilizer bases can then be placed in their designated places in the storage case. Note that each of the attachments should be cleaned prior to their return to the storage case. This is necessary for any device that is used in the hospital in order to avoid contamination. Once all the attachments have been accounted for, the storage case may be closed and latched and then returned to its designated place in the hospital. Lastly, the patient can sit up and get off of the board, or if they need to be transferred to another bed, they may be lifted at this time by the staff. After they have been removed from the board, the staff should wipe down the pad and clean the handles and board. Once the board has been sanitized it can be placed back on the wall. The board will just slide horizontally between the two hooks and remain there until it is needed for another procedure.

Prototype testing with clients:

This prototype was designed to accommodate patients with various disabilities. The six patients described below are the “theoretical” patients in which our design should be fully functional for. A brief description of each patient has been stated and how the prototype was tested for each of these patients will be described later in the report.

Bruce. Bruce was born in 1960. He is an aerospace engineer and vehicle enthusiast who lives with his wife and one cat. In 1999, he was involved in a serious motorcycle accident, which resulted in the paralysis of his legs, and now he uses a manual wheelchair. He experienced renal failure in 2003 and takes a large number of medications daily.

Joan. Born in 1919, Joan has raised 5 children and has many grandchildren and great-grandchildren. Now a widow and living in a convalescent home with heart failure, she is relatively sedentary and is fragile and weak. She is also hard of hearing.
Lloyd. Lloyd, a retired pharmacist, was born in 1926. Diagnosed with Type 2 Diabetes in 1989, Lloyd has some hearing loss and, due to poor diet and lack of exercise, is very overweight (400lbs).

Sophia. Sophia was born in 1970 and emigrated to the U.S. from Poland in 1987. In relatively good health, Sophia had several small strokes in 2003, and now takes heparin as a precautionary measure. Sophia has limited right arm function and walks using a cane, but she continues her job as a social worker and is very active in the community.

Arnold. Arnold was born in 1952 and since his heart attack in 1999 has worked in the mailroom of a large manufacturing company. He has diabetes and Parkinson’s disease, and experiences slight to moderate tremors. He lives alone.

Dave. Now 22, Dave was diagnosed with diabetes in 2000. He has limited use of his right arm and leg due to a head injury he sustained while playing football in college. Dave uses a cane and sometimes an electric scooter.

There was valiant attempt to get actual patients with conditions similar to those listed above by placing flyers all around campus to recruit volunteers to test our prototype on. However, we did not get any responses from these flyers, as we were not able to provide students or staff with any compensation for their time. Therefore, team members mimicked the patient’s conditions.

The team member that was simulating Bruce’s conditions had their legs tied together to simulate lower body paralysis and thus they were unable to use their legs to get onto the board. This lower body paralysis was not a huge problem because the staff was able to assist the patient by lifting their legs and gently placing them onto the positioning board. Once the legs were on the board with the knees facing the ceiling the team member was able to continue with the prototype setup with no problems recorded by the staff. The patient just needed the same help when getting off of the board upon completion of the exam. Once the lower body stabilizer components were removed from the board the patient could sit up right and with a staff member on each side of the patient the legs could be moved to hang over the edge and then help was used to help place him into his wheelchair. The fact that Bruce takes a large number of medications cause not pertain to our particular project and was not simulated by a team member.
The individual that was simulating Joan was skinny and had limited lifting strength. These characteristics were not a problem for our positioning aid. The individual just required a little assistance in getting onto the board and she had no trouble fitting into the device since she was relatively lightweight. She only required two staff members to lift her onto the imaging table. The individual also was wearing earplugs to simulate the fact that Joan is hard of hearing. However, this too did not pose any major problems since the staff was able to easily motion to her what was required of her. The easy set up and design was very helpful in accommodating patients that may be hard of hearing. The individual just needed additional help from a staff member when getting off of the imaging table once her exam was complete.

The team member that simulated Lloyd weighs 225 pounds plus the 25 pounds the attachments weigh and the other team members were able to lift him and there was minimal flexion in the board. The main reason for the excellent support of this weight was the addition of the aluminum bars that run down each side of the positioning aid and the three PVC bars that are attached horizontally on the board. These minimize greatly the flexion and bending of the PVC base for heavier patients. Although it is recommended that this board should not be used to move patients room to room, only from one table to another table.
relatively close by. Figure 58 below is picture of 250 pounds on the board being lifted with relative ease by two members of our team.

![Figure 58: Testing the Flexion of the board with 250 pounds](image)

The 400 pounds were simulated using the calculated body segment weights of a person this size and placed on the board. This required much more staff to help in the lifting but it proved successful. The two additional staff in the middle of each side of the board helped to alleviate some of the bending that may have been present when briefly lifting the weight.

The team member that simulated Sophia was not able to use their right arm at all during the testing of the prototype. This person required help from the staff to get on the board and once on the board the staff had to put the patients right hand in the overhead arm position and then use one of the Velcro straps in the storage case to help secure the hand around the arm bar. This Velcro strap was added to the design during the testing process when the group realized limited arm movement could pose a problem in the current design, but with this Velcro strap the problem has been solved.

The team member that simulated Arnold was required to shake slightly during the testing process. Although it took a slightly longer time for the subject to get situated in the device, the lower body stabilizer did an excellent job in minimizing any movement in the lower limbs. The upper body also was limited in
its movement when the Velcro straps were attached around the upper arm around the horizontal arm stabilizer and they would ensure minimal movement during the imaging procedure. These straps were very convenient for this situation as well. Figure 59 below shows the Velcro strap on the test subject to ensure the arm did not move.

Figure 59. Velcro Strap used to stabilize Upper arm/Elbow

A team member also simulated Dave by not using their right arm or right leg at all during the testing session. This was not hard for our design to accommodate, all that was needed was assistance from two staff members to help the subject get onto the board. It required a slightly longer amount of time for the setup to occur but was a success. The right arm of the subject had to be placed around the arm bar with the help of a staff member and the Velcro strap was used again to hold the upper arm/elbow in place. The Velcro was secured around the horizontal arm stabilizer base and did not provide any discomfort to the subject. Once the examination was complete the subject just needed some assistance from the staff in getting off of the board and once the subject had his cane he was no longer in need of additional assistance. Figure 60 below shows the patient in the optimal position required during the imaging examination.
Figure 60: Optimal Position desired when in the Positioning Aid
3. Design Constraints

The new patient-positioning aid is limited by several constraints which could fall under two categories: engineering standard constraints and realistic constraints. In order to fully comply with any sort of constraint based on engineering standards a search was performed on the FDA website for any sort of positioning aid in the radiology review panel. The only positioning aid found was one pertaining to holding the head, however this search and other searches for positioning aids under various review panels declare that this type of device falls under the category of a Class I – General Controls device. The FDA has exempted almost all class I devices from the premarket notification requirement based on the exempt status declared in 21 CFR Parts 862-892. This device is also exempt from the GMP regulation as long as the device is not labeled or otherwise represented as sterile – which it is not. Further searches of engineering standards using the recognized FDA databases revealed no further standards for this type of device. However, this device is for use by humans with disabilities thus it must also adhere to other special medical constraints.

Further engineering standards for the design of devices is set by the “NSPE Code of Ethics for Engineers”. This code states that engineers are expected to exhibit the highest standard of honesty and integrity and must be dedicated to the protection of public health, safety, and welfare. A full review of the fundamental canons, rules of practice, and professional obligations can be found at The National Society of Professional Engineers ® website (http://www.nspe.org/ethics/eh1-code.asp).

The new patient positioning aid is also limited by several realistic constraints including economic, environmental, sustainability, manufacturability, ethical, health and safety, social, and political. All of these constraints will affect the different areas of the design and thus affect the overall design process.

Economic constraints play a huge role in affecting the design process for the economy of the intended market as well as the demand or need for this type of product will set the value or price of the product. The demand for any product greatly influences the cost of that product; cost being what the consumer is actually willing to pay for the product. There does exist an average cost or equilibrium market price for the product; however this cost could fluctuate based on demand. If the consumer demand for the product is high then the cost of the product will rise, conversely if the demand is low then the cost will be lowered.

This discussion of cost and demand fluctuations influences the profit of a company obtained from the product. This is a design constraint because a product is designed to ensure the highest demand possible, which will therefore create the most profit. There are many patient positioning aids on the market however none of which incorporate all of the same desired versatility and adaptations which results in an increased demand for such a device as this one.
Environmental constraints are based on the environmental concerns of consumers. If it is known that a product harms the environment then consumers are much less likely to purchase or use that product. Environment concerns are also included in the manufacturing process of the device as well as its disposal. This new positioning aid does not harm the environment from the manufacturing process through its disposal. The manufacturing process for the positioning aid uses common cutting and drilling techniques which do not harm the environment and its intended use does not harm the environment either. Upon disposal of the device all of the parts could be broken down and recycled.

Another realistic design constraint is sustainability. A well-made product has to be sustainable for any consumer is not likely to buy a product which is expensive to maintain. Maintenance can range from expensive parts to having to pay for expensive technicians to fix a problem. This new patient positioning aid does not require any major expensive parts and all of the parts are easily accessible. Also, no major technician was required to machine the parts or put them together, thus the product is projected to not be expensive to maintain.

The manufacturability of a product is also a realistic design constraint, for if the product is difficult to manufacture this will in turn drive up manufacturing costs. Manufacturing costs can include labor hours which are paid in wages, the cost to buy or rent certain machinery, as well as the raw material which goes into the manufacturing process of the product. In this new patient positioning aid the manufacturability was taken into great consideration. All of the parts of the project are easily accessible as well as easy to work with. The product is made mostly out of PVC or HDPE both of which are plastics which can be cut by any normal saw, and the rest is made of aluminum which is a soft and easily machined metal.

Ethical constraints are important to the design process, for a product which is viewed by society as being unethical will be less likely to sell. Ethical constraints are particularly important to biomedical engineers because biomedical engineering is a part of the medical field which is constantly the center for ethical debates. Working as a biomedical engineer one is much more likely to run into ethical issues when compared to other engineering professions. However, for the new patient positioning aid ethical constraints are not much of a concern. The positioning aid requires minimal body intrusion, and is to be used in both CT and MRI scanners both of which are widely used across the world without opposition.

Health and safety constraints are major concerns while designing a new product, especially for engineers as stated in the NSPE code of ethics for engineers. If a device is found to be unsafe or unhealthy as to cause injury the device will for one most likely not sell well, and will also most likely run into legal action. A company will experience lawsuits if one of their devices causes injury,
therefore companies concentrate highly on the health and safety of their products. Also, even one unsafe product could be detrimental to a company’s profits and success, for this could limit the amount of customers who buy other products with the same company’s name. The new patient positioning aid poses little threat to the user’s health, and a discussion of the safety issues contained in the device will be discussed in the **Safety Issues** section.

The social and political design constraints are similar because they help form the society’s views of the product. These constraints are also similar to the ethical constraints because just as if a product is viewed to be unethical, if a product is viewed to not be socially acceptable or not politically correct then the device will be unlikely to sell. The positioning aid is both socially acceptable as well as politically correct because it is not invasive on the subject in any way nor does it violate any person’s with disabilities regulations.

The success of the product is based on all of the above issues and constraints. Therefore, in designing the product close attention must be paid to all of these areas.
4. Safety Issues

As described in the **Design Constraints** section the overall safety of a product greatly influences the success of that product. Based on the new positioning aid the major safety issues addressed in the design of the product pertained to mechanical, biological hazards, radiation, host reaction to biomaterials.

One of the major safety issues of the design of the device was mechanical safety. The device needs to be both functional and not harmful to the subject or technicians using the device. The first major mechanical safety issue was that the device must hold a patient body weight of up to 500 pounds without breaking or bending which would harm the patient. To overcome this issue we designed a PVC and aluminum framework to attach to the underside of the board that would add more support as well as reduce flexion. The following figure is a digital image of this framework attached to the bottom of the board:

![Figure 61: Framework To Reduce Flexion](image)

Another mechanical safety issue was the presence of sharp edges which could harm both the patient and technician. In order to reduce this risk we used a router on the corners of the transfer board as well as the arm and leg stabilizer components. In testing the device it was noticed that the corners of the arm stabilizer were close to the head of the patient, so the whole arm stabilizer was covered in polyfoam. Further testing proved that if a technician were to lift by the bottom of the transfer board at the ends of middle of the board the pressure on the fingers could be harmful. Therefore, blue polyfoam was attached to the underside at these locations (also depicted in fig. 61). One other mechanical safety issue that was addressed was the fact that the foam pad could slip on the
smooth surface of the transfer board. To correct this problem Velcro strips were attached to the surface of the transfer board and the bottom of the foam pad as depicted in the following figures:

![Figure 62: Velcro On Foam Pad](image)

![Figure 63: Velcro On Transfer Board](image)

Other safety issues that were addressed were ones that pertained to biological hazards and host reaction to biomaterials. Pertaining to biological hazards all components of the design can either be washed themselves or are covered with a material that can be washed. The Velcro on the transfer board and foam pad are 100% percent waterproof and the foam pad is covered with a material that is moisture proof and can be taken off further and washed. Also, the
polyfoam on the arm and leg stabilizers are being covered with a moisture proof material and a material case is fitted to the headrest. Concerning host to biomaterials no part of the design is invasive to the body or will be entering the body in any manner, however that patient will be resting upon the device thus allergic reactions was taken into account. Searches for common allergies on the materials used came up negative, for the human body comes into contact with each of the materials on a daily basis. The only other concern would be the introduction of large amounts of the aluminum, brass, or bronze entering the body and through proper use of the device the patient will not come into contact with any of these metals. In this manner careful consideration was taken into the selection of rounded handles, and end caps were placed on the 80/20 material to prevent cuts or scratches.

The device is designed to go through CT and MRI scanners therefore all of the materials are radiolucent. Being that they are radiolucent this will ensure that parts of the device will not interfere with the imaging platforms nor will they cause any further radiation to be magnified onto the body of the patients or the technicians.
5. Impact of Engineering Solutions

Engineers are molded into becoming very good problem solvers, thus when a team of engineers come together to design a product it is most often being designed as a solution to a specific problem. This is the case with this new patient positioning aid, for it was designed to solve general problems as well as for the needs of specific clients. The specifications of the design called for a versatile and easy-to-use patient positioning aid that did not use items such as common foam wedges. The specifications also called for it to be able to hold a patient body weight of up to 500 pounds as well as be used as a sort of transfer board. In order to obtain more specific needs the team visited the radiology department of Hartford Hospital located in Hartford, Connecticut, and questions the technicians as to what they would want in a new positioning aid. The technicians responded with a want for a positioning aid that would elongate the patient’s body as well as hold the arms and legs in place so that proper imaging could be obtained.

This new positioning aid has an impact on engineering solutions in a global, economic, and societal context. Concerning the impact on societal context much of the positioning was designed with the needs of the technicians located in the radiology department of Hartford Hospital in mind. The technicians explained that in order to elongate the patient’s body they would have to stretch out the patient’s arms and then tie them to the end of CT or MRI table. This process not only comes off as being unprofessional but it also puts the patient in a great deal of discomfort and could instigate emotional trauma to the patient. However, this new patient positioning aid has a hand bar at the end of the transfer board for the patient to be able to hold onto, and then the arm stabilizers hold the arms in a more natural position. The following figure is a digital image of this position:
This new patient positioning aid also proves to be an engineering solution in the economic context. Before this product radiology technicians were required to use a whole array of products ranging from different shaped and sized foam wedges to wrap-around coils. Due to the fact that each foam wedge and wrap-around coil was only a specific size many of them were required in order to have the capability of being able to image various patients of different builds. This could prove to be very costly because the radiology department had to buy many different pieces and from doing market research it was found that packages of foam wedges and pieces could cost upwards of eight-hundred dollars. However, this new patient positioning aid is designed to be versatile therefore it can support patients of various builds. The sliding track system of both the arm and leg stabilizers as well as the movement in them due to the 80/20 material virtually eliminates the need for different sized foam wedges or pieces. Therefore this new patient positioning aid is an engineering solution in the economic context because now radiology department can buy one low-cost product that will do the functions of many different foam pieces and wrap-around coils. This also aids in the planning of the radiology department’s budget because before they were not able to accurately plan for just how many different sized foam wedges they would need, whereas now due to this design it is versatile enough that they can be ensured it will work with any real patient.
This new patient positioning aid is also an engineering solution in a global context because it can be assumed that since the only real positioning aids used in radiology departments were the foam wedges and wrap-around coils, that if one department (like the one in Hartford Hospital) has a problem with them, then the others will also. With this in mind this new patient positioning aid will solve the problems of many other radiology departments. Also, since the product was designed to accommodate patients of various builds it can also be used globally on all different types of patients. Furthermore, research has shown that this one of the only patient positioning aids that can be used in both CT and MRI scanners as well as be used as a carrying/transfer board. This distinct characteristic will also greatly add to its global impact.
6. Life-Long Learning

The entire layout of Biomedical Engineering Senior Design at The University of Connecticut has most definitely added a great deal of new material learned and techniques acquired that will be used throughout the student’s careers. The entire senior design process was broken down into Senior Design I and Senior Design II which were taken over a period of two semesters.

The first course taken was Senior Design I and this course taught students about the beginning basics of the design process. In Senior Design I the students were broken into groups and were given a list of possible projects, thus right from the beginning the team members had to work together to make a very important decision – which project to try and tackle. This first decision was extremely difficult because already the team members had to work together and brainstorm different methods of how to complete the projects. This is pertinent to life-long learning because there are going to be many instances in an engineer’s career where they are going to have to commit to a task or project without even being able to try it out first. This could be a very stressful decision and it was a good exercise to practice without having to try it out first in a job setting.

Once the teams had selected a project or were assigned one to do this started the next aspect of the design process which was the actual planning of the design prototype. This part of the design process was also very influential to acquiring new techniques pertinent to life-long learning because it required the teams to come up with at least three different design prototypes that would meet all of the project specifications. For many groups it proved difficult to come up with a thorough plan of three very different prototypes that would actually work and fulfill all of the project specifications. This part of the design process was also another great exercise to prepare students for a career setting. Out in the engineering industry the first solution to a problem is rarely the best solution, thus by requiring the teams to come up with three different design prototypes it required them to think long and hard about the problem and attack it at different angles in order to come up with the different solutions.

On top of having to brainstorm three different prototypes, the teams were also required to write formal engineering reports on all three designs. This once again aids in life-long learning for it is practice in writing formal engineering reports. The reports had to be thorough enough with diagrams and figures so that the person reading the report could see exactly how the design was going to work and also more importantly if it in fact was going to work. From these three engineering reports the teams then had to pick an optimal design which ranged from being one of the three designs, a compilation of all three designs, or a design which went about a totally different angle.
The second half of the course was Senior Design II, and this part of the course taught about the actual construction process of the design prototype. In this part of the course students learned everything from budget and timeline planning, to learning new skills such as becoming machine shop certified. Each team was required to do their own parts ordering and was given a strict budget, thus teaching students about budget planning. This is very important out in industry for if two products are going on the market and they perform the same exact functions, the one that costs the less is going to be the one that consumers buy and thus the company that made them will receive the highest profit.

Also in this part of the design process students acquired new techniques such as learning how to machine their own parts in the machine shop, or even just using the correct general tool for the task at hand. Actually constructing a design prototype is greatly influential to life-long learning because it is a hands-on process in which the students are assembling their own project. The teammates had work together to complete each part of their prototype, and learn to depend on each other to finish their own tasks.

This second part of the senior design course was an insight to how actual engineering companies operate, because it was run similar to how an engineering company would be. The overall organization of the course was broken down into three different levels: the design teams, a teacher’s assistant (TA), and then the professor. As far as a real engineering company is concerned the design team is still the design team whereas the TA functioned as a manager, and the professor functioned as the overall boss or owner of the company. The design teams were required to work together on their own under the supervision of the manager. The manager made sure that there was no “shirking” by any of the team members by making each team break the construction of the prototypes into various tasks which were then personally assigned to each team member. There was a weekly staff meeting in which the design team and manager would all meet with the business owner, and the business owner would then comment on the progress thus far. This is a perfect exercise for life-long learning because it mirrors the design process of an actual engineering company.

Thus, Senior Design I and II were both influential in life-long learning because the students learned new material and acquired new techniques. The students were introduced to an actual design process starting from the very beginning planning stages and then following it all the way through to the conclusion which is the construction of a working design prototype. For the students this was an excellent life-long learning experience because it was a hands-on experience.
7. Budget

<table>
<thead>
<tr>
<th>Description</th>
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<tr>
<td>Base for Position Table</td>
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<tr>
<td>Foam Headrest</td>
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</tr>
<tr>
<td>T-foam</td>
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<tr>
<td>HDPE rectangular bars</td>
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<td>PVC 1&quot; Rod</td>
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<td>PVC 1&quot; sheet</td>
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<td>PVC .75&quot; sheet</td>
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<tr>
<td>Palm Grip Aluminum Knobs</td>
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<tr>
<td>80/20 Materials for Arm/Leg Stabilizer</td>
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</tr>
<tr>
<td>Aluminum 6061 Aluminum Material</td>
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<tr>
<td>PVC 1&quot; Square Rod</td>
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<tr>
<td>Velcro</td>
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<tr>
<td>MSC Hardware</td>
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<tr>
<td>Foam Pad for Patient Positioning Aid</td>
<td>$141.81</td>
</tr>
<tr>
<td>4 Aluminum Handles</td>
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<tr>
<td>Aluminum Carrying Case</td>
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</tr>
<tr>
<td>Two wall hooks</td>
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</tr>
<tr>
<td>Sticky Rulers</td>
<td>$20.00</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>$1133.92</strong></td>
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</table>
8. Team Members Contributions to the Project

**Christen Thomsen:**

Christen’s track is Biomechanics so any questions concerning the force analysis of the different designs were directed towards him. In the first part of senior design, which was the planning stage, Christen either knew all of the force and moment of inertia equations, or had the literature from his courses to find them. Christen was also very knowledgeable in overall general machining and construction so he helped greatly in creating the sliding track system which makes the optimal design versatile. In writing the reports for Senior Design I it was Christen’s task to concentrate mostly on thoroughly describing the movements of each component and the force analysis that accompanied them.

In Senior Design II Christen also performed half of the machining. Over winter break Christen attended the machine shop certification course so throughout the construction of the design prototype he did a lot of the cutting and drilling to create the different pieces. Christen was in charge of milling the slots in the transfer board for the arm stabilizers as well as creating the arm stabilizers. To create the arm stabilizers he had to cut down the PVC pieces as well as 80/20 material, and assemble them using aluminum bolts and bronze carriage bolts. Christen is very knowledgeable on different construction materials so he found all of the radiolucent hardware that we needed. Christen also aided in creating the antiflexion-frame for the bottom of the transfer board by drilling and tapping the aluminum rods and overall assembly of the device.

**Bhavin Patel:**

Bhavin’s track is Bioinstrumentation, however since there is no circuit present in our design is specialty was not utilized. However, Bhavin was also very knowledgeable in mechanics and the overall aesthetics of the designs, therefore in Senior Design I he played an important role in brainstorming new design ideas. In writing the reports for Senior Design I Bhavin was in charge of describing the overall parts of the design. Bhavin was however able to use his computer specialty, for he was mostly in charge of posting all of our work on our website.

In Senior Design II Bhavin also performed half of the machining. Over winter break Bhavin also attended the machine shop certification course and in the actual construction of the design he was given the task of creating the leg stabilizers. Bhavin had to mill the slots for the leg stabilizer in the transfer board as well as cut the PVC and 80/20 material and assemble the leg stabilizer supports using the radiolucent hardware. Bhavin also had to cut the HDPE which serves as the leg-locking portion of the leg stabilizer. Bhavin also aided in creating the antiflexion-frame for the bottom of the transfer board by drilling and tapping the PVC cross members and the overall assembly of this portion of the device.
Ashley Reeners:
Ashley’s track is Biomaterials, however in our design there are no real components that have to interact directly with the human body as to require them to be biocompatible. Ashley however was extremely helpful in the overall aesthetics of the designs as well as making sure each design fulfilled all of the project and patient specifications. In Senior Design I Ashley was also in charge of describing the overall function of the designs as well as how each design fulfilled the project and patient specifications.

In Senior Design II Ashley was extremely helpful in the construction of the design prototype even though she was not machine shop certified. Before Bhavin and Christen took many of the parts into the machine shop Ashley performed much of the measuring on the different components. This measuring and planning was very important because many aspects of our design fit into each other or work together, thus precise measurements were necessary. Ashley also glued most of the polyfoam to the arm and leg stabilizers as well as was given the task to order a custom foam pad for the transfer board. Once all of the parts were machine Ashley also aided in switching out the stainless steel with the radiolucent hardware as well as aiding in the construction of the antiflexion-frame. Ashley was also given the task of determining a method to store the device in which she came up with the steel hooks to hang on the wall as well as the carrying case for the components.

Andrew Harris
Andrew’s track is Biochemistry, however in our design there are no chemicals or interactions with the inside of the human body thus he was not able to use his specialty. Andrew was also very knowledgeable in general machining and construction as well as mechanics. Due to this in Senior Design I he worked alongside with Christen to work out all of the force equations to ensure that the transfer board and all of the components would fulfill all of the project and patient specifications. Also for the reports in Senior Design I Andrew concentrated on writing out the force equations and demonstrating how the designs worked and also showing that they actually would work.

In Senior Design II Andrew was extremely helpful in the construction of the overall device. Even though he was machine shop certified many of the components required two people in the machine shop to machine, thus when Bhavin and Christen's schedules did not coincide Andrew helped out both of them in the machine shop. Andrew was also in charge finding a grip for the hand bar as well as handles to be used to carry the device with a patient on it. Andrew ended up receiving a free grip for the hand bar as well coming up with many different handle ideas. Andrew also aided in the overall design of the prototype by switching out hardware, cutting and filing bolts, and aiding in testing the device.
9. Conclusion

This new patient positioning aid will be versatile and not only fulfill the project and patient specifications but also fulfill the real world specifications of actual radiology technicians. The device will completely elongate the patient’s body making it easy to pinpoint both CT and MRI scanners on the desired body segment. While elongating the patient’s body it will also hold the patient in place thus creating a more comfortable scanning process for the patient.

The transfer board will fit directly on top of modern existing CT and MRI imaging tables and the custom foam pad will give the patient a comfortable surface to lie on. There is a headrest which also serves for patient comfort and the hand bar gives the patient something to hold onto in order to elongate the body. The arm stabilizers make the patient more comfortable as well because it ensures that they do not have to hold their arms up for the whole imaging process. The arm stabilizers will instead hold the patients arms in position for them. The leg stabilizers are versatile because they slide side to side along the board as well as in height on the 80/20 material and this movement allows them to lock in a patient comfortably. The antiflexion-frame attached to the underside of the transfer board as well as the handles attached to the top will also ensure that a patient could be carried on the board. Most importantly, the whole apparatus is radiolucent thus it is safe to use in CT and MRI scanners.
10. References

1. Food And Drug Administration: www.fda.gov
2. The National Society of Professional Engineers: www.nspe.org/ethics/eh1-code.asp
11. Acknowledgements

Rehabilitation Engineering Research Center (RERC) - Funding
Dr. John Enderle – Client/Advisor
Chris Liebler – Advisor
Keith Crosby – Uconn Medical Center Technician
Dave Kaputa – Teaching Assistant
Quing Zhu – BME Faculty (Imaging Consulting)
Mrs. Thomsen – Christen’s Mom (Sewing)
Surge- Machine Shop
Rich-Machine Shop
Appendix:

Tables:

Table A-1

<table>
<thead>
<tr>
<th>HDPE: Physical Properties</th>
<th>English</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density</td>
<td>0.0338 - 0.0348 lb/in³</td>
</tr>
<tr>
<td>Apparent Bulk Density</td>
<td>0.021 - 0.022 lb/in³</td>
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<tr>
<td>Water Absorption</td>
<td>0.01 %</td>
</tr>
<tr>
<td>Moisture Vapor Transmission</td>
<td>0.965 cc-mil/100 in²·24hr-atm</td>
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<tr>
<td>Environmental Stress Crack Resistance</td>
<td>10 - 5000 hour</td>
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<table>
<thead>
<tr>
<th>Mechanical Properties</th>
<th></th>
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</thead>
<tbody>
<tr>
<td>Hardness, Shore D</td>
<td>58 - 65</td>
</tr>
<tr>
<td>Tensile Strength, Ultimate</td>
<td>3480 - 6530 psi</td>
</tr>
<tr>
<td>Tensile Strength, Yield</td>
<td>2180 - 4350 psi</td>
</tr>
<tr>
<td>Elongation at Break</td>
<td>500 - 1000 %</td>
</tr>
<tr>
<td>Tensile Modulus</td>
<td>116 - 144 ksi</td>
</tr>
<tr>
<td>Flexural Modulus</td>
<td>72.5 - 220 ksi</td>
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<tr>
<td>Izod Impact, Notched</td>
<td>1.5 - 14.1 ft-lb/in</td>
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<tr>
<td>Tensile Impact Strength</td>
<td>152 - 228 ft-lb/in²</td>
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<tr>
<td>Coefficient of Friction</td>
<td>0.28</td>
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<table>
<thead>
<tr>
<th>Electrical Properties</th>
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</thead>
<tbody>
<tr>
<td>Electrical Resistivity</td>
<td>1e+017 ohm-cm</td>
</tr>
<tr>
<td>Surface Resistance</td>
<td>1e+017 ohm</td>
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<tr>
<td>Dielectric Constant</td>
<td>2.3</td>
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<tr>
<td>Dissipation Factor</td>
<td>0.0001 - 0.0005</td>
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<table>
<thead>
<tr>
<th>Thermal Properties</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>CTE, linear 20°C</td>
<td>77.8 μin/in·°F</td>
</tr>
<tr>
<td>Melting Point</td>
<td>255 - 268 °F</td>
</tr>
<tr>
<td>Vicat Softening Point</td>
<td>226 - 264 °F</td>
</tr>
<tr>
<td>Brittleness Temperature</td>
<td>-148 - -94 °F</td>
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</table>

93
# Table A-2

## PVC Type I

**Technical Data SIMONA® VERSADUR® PVC Type I – 150 Series**

<table>
<thead>
<tr>
<th>Property</th>
<th>Test Method</th>
<th>Unit</th>
<th>Typical Value</th>
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</thead>
<tbody>
<tr>
<td><strong>Physical</strong></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Density</td>
<td>D-792</td>
<td>g/cc</td>
<td>1.45</td>
</tr>
<tr>
<td>Water Absorption</td>
<td></td>
<td></td>
<td>(24 hrs @ 73 °F) D-570 % 0.04</td>
</tr>
<tr>
<td><strong>Mechanical</strong></td>
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<td></td>
</tr>
<tr>
<td>Tensile Strength</td>
<td>D-638</td>
<td>PSI</td>
<td>7,820</td>
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<tr>
<td>Tensile Modulus</td>
<td>D-638</td>
<td>PSI</td>
<td>496,000</td>
</tr>
<tr>
<td>Elongation</td>
<td>D-638 %</td>
<td></td>
<td>150</td>
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<tr>
<td>Izod Impact</td>
<td>D-256</td>
<td>ft. lbs./in.</td>
<td>0.8</td>
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<tr>
<td>Rockwell Hardness</td>
<td>D-785</td>
<td>“R”</td>
<td>113</td>
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<tr>
<td><strong>Thermal</strong></td>
<td></td>
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</tr>
<tr>
<td>Heat Distortion Temperature</td>
<td>D-648</td>
<td></td>
<td>66 psi at 172 °F</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>264 psi at 162 °F</td>
</tr>
<tr>
<td>Vicat Softening Temperature</td>
<td>D-1525</td>
<td>°F</td>
<td>109</td>
</tr>
<tr>
<td>Coefficient of Thermal Expansion</td>
<td>D-696</td>
<td>in./in.</td>
<td>°C 7 x 10-5</td>
</tr>
<tr>
<td><strong>Electrical</strong></td>
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<td></td>
<td></td>
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<tr>
<td>Volume Resistivity</td>
<td>D-257</td>
<td>ohm-cm</td>
<td>&gt;6.2 x 1016</td>
</tr>
<tr>
<td><strong>Flammability</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flammability</td>
<td>D-635</td>
<td></td>
<td>self-extinguishing</td>
</tr>
<tr>
<td>UL 94V-0, 94-5V</td>
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</tr>
</tbody>
</table>
Technical Specifications:

**General Parameters:**

Number of required operators: 2-6  
Imaging Compatibility: MRI, CT-Scan, X-ray

**Mechanical Parameters**

Weight of Device:  
- Without Attachments: 54 pounds  
- With Attachments: 68 pounds  
Maximum Load: 500 lb  
Operational Dimensions: 72” x 22” x 13”  
Storage Dimensions:  
  - On Wall Mount: 72” x 22” x 5”  
  - Storage Case: 36” x 13-3/8” x 4-1/2”

Durability: Impact Resistant, Abrasion Resistant, Corrosion Resistant

Range of Movement:  
- Upper body: 12” horizontally  
- Lower body: 20” horizontally  
- 10” vertically

**Environmental Parameters**

Humidity: 0-100%  
Operating Temp: Room Temperature  
Storage Temp: Room Temperature  
Dust: Easily cleaned

Operating Location: Clinical Setting  
Storage Location: Wall

**Health Specifications**

Toxicity: None  
Carcinogenicity: None  
HMIS Ratings (0-4):  
- Flammability: 1  
- Reactivity: 0

Health: 1