Patient Positioning Aid
Design 2

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**Design Two Objectives:**

The objectives for Design 2 are to design a low-cost, versatile, easy-to-store, and easy-to-adjust patient positioning aid. With this positioning aid there will be no need for hospital staff members to purchase multiple components in order to provide a variety of positions and meet the needs of various patients. 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. The positioning aid will be able to 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. 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.

**Design Two:**

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 special x-ray equipment to obtain image data from different angles around
the body and then 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 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 of their own 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 seen below is the overall drawing of Design 2, which will be broken up into its three major elements and explained in greater detail as well as a rather detailed force analysis on this proposed patient positioning aid. The three main components of this design are the base, which will be laid on the table and 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.

**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. 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 will have the dimensions 72”x 16”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 only 16” will be able to fit inside the MRI and CT scan. The board selected in particular for this design is the Gray Type I PVC sheet and its run about $90.00 for our size requirements and can purchased through the USPlastics 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. This board was chosen also because it is lightweight. This is a reasonably lightweight for medical staff to lift on a daily basis. The price breakdown for this component of the design can be found in Table 1, 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 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. This foam padding will have to be cut down to 16” wide to be compatible with our design, since the width of our positioning aid is only 16”, the maximum size that can easily fit in and out of the imaging systems.
**Figure 1:** Design Two for the Patient Positioning Aid

**Second Major Component: Upper Body Positioning Aid**

To support the top half of the body our design will include a head rest, foam pads for arm comfort and a plastic handle bar for gripping onto. The plastic bar will be located all the way at the top of the positioning aid. High density polyethylene will be used as the material for the handle bar. The properties of the material are displayed in Table 1.

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Resistance

Mechanical Properties

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Electrical Properties

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Thermal Properties

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The rod will be 1 inch in diameter, and the handle bar will be 14 inches wide. It will be 2.5 inches above of the positioning table. The handle bar will be made by cutting the rod into a segment of 14 inches and two segments of 2.5 inches. Then the smaller segments will be attached to the 14 inch handle on one side and to the table on the other. Figures 2 through 5 display the dimensions of the hand bar followed by the complete component. A rod of high density
polyethylene 2 feet in length will cost about $10.00 at K-Mac Plastics. A thin layer of rubber will be put over the rod for more of a grip and comfort for the patient.

Figure 2: Top View

Figure 3: Bottom View

Figure 4: Front View
Plastic screws will be used in order to secure the handle bar instead of the conventional metal ones in order to make the positioning aid 100% compatible with all imaging devices such as the MRI. The use of PVC plastic screws will be proficient since PVC is lightweight, non-corrosive, vibration resistant, and antimagnetic. There will be two options for the patient to be positioned with respect to the table, either facing up away from the table, or down facing 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 foam wedges 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.
Two foam wedges will be supplied along with the positioning aid to provide comfort the patient as they reach behind their head for the handle bar. The set of arm wedges will be placed on either side of the patients head, one on the left and the other on the right. The position can be seen in figure 1. The arm wedges will be 3.5 inches wide with a length of 1 foot. The height of the wedges will be 5 inches. Figures 8 through 10 display the different views and the dimensions of the arm wedge. A piece of foam can be obtained for about $65.00 from which we can cut out the desired shape for the arm supports then encapsulate the wedge with a protective coating. The patient will grip on to the handle bar and rest their arms on the foam wedge. Since the arms are naturally being pulled forward not much force will be exerted on either the handle bar or the foam wedge therefore high segment weight is not an issue in this case. When the patient is oriented face down on the positioning table the foam wedges will be taken off for more comfort to the patient.

Arm Wedge

Figure 7: Arm Wedge
Figure 8: Wedge Side View

Figure 9: Wedge Front View
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. Allowing them to be oriented facing any direction they need to with the necessary comfort in order for them to be able to be immobile for about 45 minutes without any neck cramps or discomfort to their 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.

In order to make the components of this design as versatile as possible Velcro will be incorporated underneath them. On the foam padding across the positioning table there will be attached a piece of Velcro with dimensions 15 inches wide and 30 inches long. This will be placed on the same side as the handle bar. This Velcro piece will cost about $35 dollars and will be the loop end which is very soft. This way there will be no discomfort to the patient due to the
Velcro. The headrest will have Velcro hooks underneath it this way once it is placed down in the desired location, it will be secure and not move. The arm wedges that will support the arms will also have Velcro hooks attached underneath. The Velcro will allow the most versatility possible to the positioning of the components allowing the patient to have maximum comfort according to their body. The location of the Velcro with the headrest and arm wedges attached to it is shown in figure 1.

**Third Major Component: Lower Body Positioning Device**

The last major component of design two will be used to position the lower extremities of the body. The design from the bottom up will include two Velcro strips applied on top of the foam-padding base. These Velcro strips will be 4” wide and 2’ long. Velcro of this size can be purchased at [www.textol.com](http://www.textol.com) and usually runs about $3.90 a yard for the loop portion and $3.90 a yard for the hook portion. The loop side will be placed on the foam padding so that the patient does not feel any discomfort or scratching from the Velcro during the procedure. The hook part of the Velcro will be placed on the bottom and one side of the triangular knee support. This knee support will be made of PVC and the triangle will be hollow in the center and then covered with thin foam padding which can be seen in Figure 14. The PVC sheet used for the triangular frame will be ordered from USPlastic’s online catalog. Part #45088 is a Gray PVC sheet with the dimensions (.39”x 24”x 48”) and will cost around $35.00. This PVC sheet has excellent corrosion resistance and weather resistance. The working temp is 33 deg F to 160 deg F. and the forming temperatures of 245 deg F. It is good electrical and thermal insulator and has a self-extinguishing per UL Test 94. PVC applications are almost unlimited. It's the most widely used member of the vinyl family. It is excellent when used for corrosion-resistant tanks, ducts, fume hoods, and pipe and would is ideal for self-supporting tanks, fabricated parts, tank linings, and
spacers. Therefore we will make three pieces from this sheet with the dimensions 8”x 14”, 11” x 14” and 11” x 14”. The side view of the knee wedge can be seen in Figure 12 and the top view in Figure 13. These three pieces will then be attached using non-ferrous screws such as PVC screws. The outer layer of this knee frame will consist of a thin blue foam pad with the dimensions (3/8”x 24”x 56”) that will be cut to 30”long by 14”wide and wrapped around the PVC knee frame and bonded using a glue. This foam pad can be found at www.rei.com and is part number 374053 and will cost only $13.50. The hook portion of the Velcro will be placed on each side of this positioning triangle so that its position on the board can easily adjusted from patient to patient. The last part of this lower body-positioning device is the use of a Velcro strap to minimize movement in the lower legs during the examination. In the Alimed catalog, part number JS91-278, is a Universal Strap that is strong, versatile, reusable and has one closure. It should also be noted that it is radiolucent and therefore will not interfere with the imaging process. The strap is 3” wide and 76” long and cost $32.00, but for our purposes the length can be shortened to around 40”since it will only be going through the knee triangle and around the shins of the patient.
Figure 11: Knee Wedge

Figure 12: Side View of Knee Wedge
Figure 13: Top View of Knee Wedge

Figure 14: Front View of Knee Wedge
**Force Analysis of Design Two:**

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 foam pad which the patient will be laying upon. In this situation there will only be one force of concern which will be a downward force located in the very center of the board caused by the weight of the patient. This downward force will create both a compressive force and a bending force within the board. 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 (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. The major force analysis of the design needs to be concentrated on both the handle on the one end of the board and the knee crutch attachment on the other side of the board.

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:
Figure 15: Hand Bar Force System

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:
Figure 16: Shear Stress in the Hand Bar

In this figure force $F_z$ is created by the weight of the patient’s arm segment. 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. 1)**

The components of this equation are unique to the shape and setup of the member which the force is acting upon. In our design the distance can be determined by looking at a cross section of the hand bar:

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Figure 17: 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:

$$T = F_z \times d \quad \text{(Eq. 2)}$$

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:

$$J = 2I = \frac{\pi}{2} \times r^4 \quad \text{(Eq. 3)}$$

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

$$\tau = \frac{F_z \times d \times r}{\frac{\pi}{2} \times r^4} = \frac{F_z \times d}{\frac{\pi}{2} \times r^3} \quad \text{(Eq. 4)}$$

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 (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:

![Horizontal Bending in Hand Bar](image)

**Figure 18: Horizontal Bending in Hand Bar**

This bending stress can be calculated using the equation:

$$\sigma_{pl} = \frac{M_{\text{MAX}} \times d \times c}{I}$$

(Eq. 5)

In this equation the $d$ is the same distance (4.5 inches) as in the previous calculations and the $c$ is the radius of the bar as depicted in figure 17. The $I$ in equation 5 pertains to the moment of inertia of the hand bar. 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 cylindrical hand bar the following equation is used:

$$I = \frac{\pi \times r^4}{4}$$

(Eq. 6)
The $M_{\text{MAX}}$ in equation 5 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)

**Figure 19: Shear and Moment Diagrams of Hand Bar**

Using these values the maximum bending stress applied to the horizontal portion of the bar is calculated to be 1145.92 psi.

The normal stress experienced by the hand bar will be created by two different methods: axial loading and bending. **Figure 20** is a diagram depicting the force and dimensions involved in the creation of the normal stress in the rod due to axial loading:
Figure 20: Normal Stress from Axial Loading

In figure 20 the force $F_y$ is a strictly vertically 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:

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

(Eq. 7)

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:

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

(Eq. 8)

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 and it is depicted in the following figure:

**Figure 21: Normal Stress due to Bending**

The general equation for the calculation of normal stress due to bending is:

$$\sigma_{b2} = \frac{T \times c}{I}$$  \hspace{1cm} (Eq. 9)

Two of the components of equation 9 have already been defined. $T$ is simply another torsion force which can again be calculated in the same manner as the torsion force in equation 2 however by using the force $F_y$ (25 pounds) and distance $d$ (3 inches) depicted in figure 21. 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 figure 17, thus $c = r$. The $I$ in equation 9 once again pertains to the moment of inertia of the rod that makes up the hand bar and its calculation is shown in equation 6. 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:
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:

$$\sigma_t = \frac{F_y \times d}{\pi \times r^2} + \frac{F_y \times d}{\pi / 4 \times r^3}$$  \hspace{1cm} \text{(Eq. 11)}$$

Using \textbf{equation 10} 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.

Analysis of the knee crutch portion of the design concluded there only to be a relevant force due to axial loading. The forces acting on the knee wedge are depicted in the following figure:

![Figure 22: Forces Acting on Knee Crutch](image-url)
In this figure the force $F_L$ is the force of the patients legs acting upon the knee crutch and the force $R_L$ is the reactionary force. The force $F_L$ can be determined by once again using Table 9.1: Anthropomorphic Data of the textbook Introduction to Biomedical Engineering\textsuperscript{2} in which the segment weight / body weight for the total leg is 0.161. $F_L$ is then calculated (using the maximum patient weight is 500 pounds) to be 80.5 pounds, however the crutch needs to be designed so that both legs can be on the crutch at the same time thus $F_L$ will be 161 pounds. The amount of axial loading can then be calculated using \textbf{equation 7} in which it is the force ($F_L$) divided by area. The area used to calculate the axial loading can be seen easier by cutting off the portion of the knee crutch above axis-a in \textbf{figure 22}; as depicted in the following figure:

\begin{center}
\includegraphics[width=0.5\textwidth]{knee_crutch.png}
\end{center}

\textbf{Figure 23: Top View of Knee Crutch After Being Cut Above Axis-A}

As seen in \textbf{figure 23} the area needed to calculate the axial loading is simply two rectangles with dimensions 0.39”x14”. Using \textbf{equation 7} the axial loading in the knee crutch is calculated to be 14.74 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 the maximum patient weight of 500 pounds the forces acting on the handle bar include: 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. Other qualifications of the material must also be met such as it being light-weight, cost-effective, and able to go through both CT and MRI scanners. The material chosen was 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. High Density Polyethylene is also a sufficient material for it is both lightweight and able to pass through CT and MRI scanners.

**Budget Summary:**

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Conclusion:

Patients need to undergo various medical examinations (i.e. CT scan, MRI, X-ray), which require them to remain static throughout the testing process. However, certain disabilities can lead to patient discomfort during the test or may even prevent the patient from partaking in the examination. Foam padding and a comfortable headrest will provide comfort to these patients and allow them to go through with the examination. A handle bar with arm wedges will allow the patient to take their arms out of the way without discomfort. The knee wedge will be strong enough to support large segment weights and will have a Velcro belt to immobilize any patients suffering from tremors. The positioning aid will be mostly made of plastic materials, allowing it to be used in the MRI imaging system. It will be relatively lightweight and the hospital staff will not have any problems lifting the device onto the examination table or imaging platform. The components will be versatile allowing the hospital staff to position the components at any desired location and secure it there using Velcro. All of these modifications to the current patient positioning aids will greatly benefit both the patient and the lab technician. In addition to fulfilling all of the patients needs, this device will also be cost-effective for the hospital and their number one choice when selecting a patient positioning aid.