Patient Positioning Aid
Design 1

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Design One Objectives:

The objectives for Design 1 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 multiple attachments that can be positioned and set in the desired location in order to adjust the patient in numerous positions. 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 One:

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 1, which will be broken up into its four major elements and explained in greater detail as well as a rather detailed force analysis on this proposed patient positioning aid. The four main components of this design are the patient transfer board, the foam padding and foam headrest that cover the patient transfer board, the aluminum track system complete with four aluminum L-shaped rod components and the knee crutch attachment. The top two L-shaped rod components will be used as arm supports during the imaging process and the bottom two L-shaped rods will have the knee crutch attached to them as needed. The combination of these four components and their specialty functions will help to aid in making the patient positioning aid both versatile and able to work with a range of examination tables and platforms.
Figure 1: Design One for the Patient Positioning Aid

1st Component of Design 1: Patient Transfer 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 polyethylene transfer board was selected as our design’s base. The board will have the dimensions 72”x 22”x 3/16”. 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. The patient transfer board selected in particular for this design is the JS9-719 Standard Antistat white transfer board.
found in the Alimed catalog, Issue 1, 2005. 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 at only 9 pounds. 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. Although, it should be noted that it is much cheaper to buy these boards in large bulk quantities than just one at a time. ($199.00 each vs. $99.00 each)

2nd Component of Design One: Foam Padding and Patient Headrest

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 polyethylene patient transfer 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. When speaking to various hospital staff and technicians, an easily cleanable and durable foam padding cover was mentioned various times and it was brought to our attention that many patients undergoing these examinations are trauma patients. The 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 pad utilizes a gel technology to distribute the pressure equally and is radiolucent as
well as easy to clean. This product is extremely durable and offers a lifetime guarantee so it would be a one-time investment of $80.00 for the hospital.

Another component of the design that can be used on a patient-to-patient basis is the Velcro straps. Velcro straps are often necessary when the patient suffers from tremors to ensure their movement is greatly reduced to obtain the best images possible. The Velcro straps selected for this design can be found in the Alimed catalog. They are rolls of disposable, latex-free, non-irritating, and non adhesive Velcro. The lab technician could cut a piece of proper length when it is needed for the patient undergoing the examination. A thirty-foot roll of 3” width Velcro runs about $78.00 a roll but can be purchased at a much cheaper rate when bought in bulk quantities.

**3rd Component of Design One: Aluminum Track System**

There will be 4 aluminum tracks attached to the table to allow sliding of attachments. The front view of the track is shown in figure 2 with the dimensions. The base of the track will be 3 inches wide and 2.5 feet long with a height of 2 inches. This will be made by taking a sheet of Aluminum .25” thick and bending it to correspond to figure 2. The side of the track facing away from the patient will have a little gap for a tightening knob. The dimensions of the gap can be seen with respect to the side in figure 3. The track will be attached to the transfer board with four bolts, 2 for each end of the track. The top view of the track is displayed in figure 4 and shows the positioning of the ½ inch bolts. The track will be attached through the polyethylene board to aluminum brackets placed underneath for support. The aluminum support bracket will be used to eliminate the possibility of the bolts cracking the polyethylene and prevent any loosening.
Once the track is made it will look like figure 5 and have corresponding dimensions. There will be 4 tracks each placed at the ends of the table shown in figure 6.

**Figure 2:** Front Track

**Figure 3:** Side Track
Figure 4: Top view of Track

Figure 5: Track

Figure 6: Position of Tracks
Inside of the track will be the square shaped base which will do all the sliding. The base will be made with a square bottom with a rod placed onto it, and a knob to tighten at the desired location. The dimensions will be 2.4” by 2.4” with a height of 1.4”, while the knob will have a diameter of 3/8 of an inch. The square base will be a little narrower then the track in order to permit swift motion on the track. The rod will have a diameter of 0.875 inches which will allow enough room for it to slide through the 1 inch gap on top of the track. The base will weigh about a pound making it easy to handle for whoever is going to set up the imaging device. There will be a total of 4 bases with attachment rods placed in them. Each one 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.

![Figure 7: Base](image1)

![Figure 8: Base Side](image2)
The rod will be positioned into the square base of the track. The bottom of the rod will be threaded in order to screw into the base. The vertical part of the rod will be 16 inches and the horizontal top will be 7 inches for attachments. The base end of the rod will have a diameter of 0.875", as will the uniform top where attachments will go. The
two top attachment aluminum rods on the positioning aid are going to be used as hand grips. Foam sleeves will be provided to simply slide over the rod making it comfortable for the patient to hold on to. The aluminum rods will provide support and positioning when needed, and will be able to get the patient’s hands and arms out of the way for imaging of other parts of the body such as the abdomen or chest. And if they are not needed they can be simply removed from the track and put aside.

**4th Component of Design One: Knee Crutch Attachment**

![Knee Crutch](image_url)

**Figure 12: Knee Crutch**

A lot of times it is necessary for patients to have an MRI or CT image taken with their knee bent. In order to support that position, the knee crutch will be an attachment included with the positioning aid. Figure 12 shows the whole knee crutch. Instead of buying the attachment, a pair will be made so they can attach and function correctly with the design of the positioning aid. The knee crutch will be made from a sheet of aluminum which will be cut to the desired dimensions. The dimensions of the device will be a width of 7 inches, a total length of 14 inches, and will have a thickness of 0.25 inches which can be seen in figures 13 and 14 displaying a top and front view of the attachment. It will then be bent to an angle of 45 degrees at the center of the aluminum
sheet in order to have an equal amount of area on each side of the pivot point. A hollow rod shaped aluminum sleeve with a diameter of .95 inches will be attached to the bottom of the pivot point on the knee crutch. The aluminum sleeve can be seen in figures 15 and 16 where the side and bottom views of the knee crutch are being displayed. Once all the pieces are in the correct shape and connected, all the sharp edges will be smoothed out for safety so that no one gets any injuries or cuts from sharp edges. The knee crutch will then be enclosed completely with a layer of foam about 1 inch thick. The foam will be able to provide comfort for the patients while the aluminum will be able to provide support.

![Top of Knee Crutch](image1)

**Figure 13:** Top knee Crutch

![Front of Knee Crutch](image2)

**Figure 14:** Front Knee Crutch
The finished knee crutches will be attachable to the two lower aluminum rods of the positioning aid when needed. This will allow the hospital staff members to only attach the segment when desired and keep it off to conserve space when not needed. The aluminum sleeve will have a slightly higher diameter than the attachment rod in order for the sleeve to be able to slide over the rod completely. Then, a screw type of knob will be used to tighten the sleeve to the rod. The knob will be able to secure the knee crutch and prevent it from falling off thereby preventing possible injuries to the patient. The position of the knob relative to the aluminum sleeve can be seen in figure 16. Once the knee crutch is attached and secured it is ready to be used by a patient. The hospital staff
member can adjust the height and position of the knee crutch for ideal imaging after which the patient can place their knee over it. This will not be difficult for the hospital staff member since the knee crutch will weigh an estimated 2.5lb according to a weight of 0.098lb per cubed inch. There will be Velcro also provided so that a patient's thigh and calf can be secured to the knee crutch in order to immobilize the patient. The attached and secured knee crutch is presented in figure 17.

![Attached Knee Crutch](image)

**Figure 17:** Attached Knee Crutch

**Force Analysis of Design One:**

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. The polyethylene board alone will not be able to support this load by itself; however when it is placed upon an examining table within a hospital or clinical setting the load created by the patient will be supported sufficiently by both the polyethylene board and the examining table.

The major force analysis needs to be concentrated on the four attachment arms which will have to support the load created by the weights of the patient’s various body segments. Analysis of this system concluded that the weights of the patient’s various body segments upon the attachment arms will create two different types of stresses. These two different types of stresses include a shear stress and a normal stress. Shear stress is a *sliding* strain which is created by a torsion force and a normal stress is created by axial loading which is a compressive force.

A shear stress will be applied to the four attachment arms due to the manner in which the patient’s various body segments will be placed upon them. The design calls for the attachment arms to function as either a type of arm grip or also as a knee crutch when the proper attachments are connected to the attachment arms. A shear stress will be applied to the attachment arm when it is being used as an arm grip because as a patient has his/her arm raised and hand closed around the attachment arm a natural *push* forward or down will be created in such a manner as to apply a shear stress. A shear stress will also be created in a similar manner when the knee crutch attachment is being utilized. In this application the patient’s leg will be resting upon the knee crutch; however due to the force of gravity as well as due to natural alignment of both the hip and knee joints in the human body a natural push will be created upon the attachment arm thus creating a shear stress. A diagram of the shear stress is depicted in the following figure:
Figure 18: Shear Stress in the Rod

In this figure force $F_z$ is created by the weights of the patient's various body segments.

The general equation pertaining to shear stress in a rod is:

$$\tau = \frac{T \times C}{J} \quad \text{(Eq. 1)}$$

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 support arm rod:

Figure 19: 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 0.4375 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} \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:

$$J = 2I = \frac{\pi}{2} \times r^4$$  \hspace{1cm} \text{(Eq. 3)}

Thus the overall equation for calculating the shear stress in the rod of the attachment arm is:

$$\tau = \frac{F_z \times d \times r}{\frac{\pi}{2} \times r^4} = \frac{F_z \times d}{\frac{\pi}{2} \times r^3}$$  \hspace{1cm} \text{(Eq. 4)}

However, upon analysis of this shear stress it can be concluded that the shear stress in the attachment arms created by the weights of patient’s various body segments is not the limiting factor in the determination of which material can be used to construct the attachment arms. The limiting factor in the choice of which material should be used is the value of the normal stress in the attachment arms.

The normal stress experienced by the attachment arms 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 body segment and the distance $d$ is measured from the center of the vertical portion of the rod to the center of the horizontal portion of the rod. The general equation for the normal stress in a rod or beam due to axial loading is:

$$\sigma = \frac{F_y}{A}$$  \hspace{1cm} (Eq. 5)

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:

$$\sigma = \frac{F_y}{\pi \times r^2}$$  \hspace{1cm} (Eq. 6)

There also exists a normal stress due to bending in the rod which is depicted in figure 21:
Figure 21: Normal Stress due to Bending

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

\[
\sigma_y = \frac{Mc}{I}
\]  
(Eq. 7)

Two of the components of eq. 7 have already been defined. \( M \) is simply another torsion force which can again be calculated in the same manner as the torsion force in eq. 2 however by using the force \( F_y \) and distance \( d \) 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 19, thus \( c = r \). The \( I \) in eq. 7 pertains to the moment of inertia of the attachment rod. 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 four cylindrical attachment arms the following equation is used:

$$I = \frac{\pi \times r^4}{4}$$  \hspace{1cm} (Eq. 8)

Upon inputting the formulas for determining the various components of the normal stress due to bending the overall equation for the normal stress due to bending in each of the four attachment rods becomes:

$$\sigma_b = \frac{F_y \times d \times r}{\pi \times 4 \times r^4} = \frac{F_y \times d}{\pi \times 4 \times r^3}$$ \hspace{1cm} (Eq. 9)

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

$$\sigma_t = \frac{F_y}{\pi \times r^2} + \frac{F_y \times d}{\pi \times 4 \times r^3}$$ \hspace{1cm} (Eq. 10)

In order to successfully choose a sufficient material for the construction of the attachment arms and sliding tracks one other force-strain system had to be analyzed. This last force-strain system pertains to the load which acts upon the track system when the attachment arms with the patient’s body segments are attached to it. This system is depicted in the following figure:
Figure 22: Applied Load to Track System

This figure depicts the forces which occur when a patient’s body segment is positioned on the attachment arm and the attachment arm is slid into position within the sliding track. Force $F$ is the load applied to the system by the weight of the patient’s body segment and force $P$ is the resulting force which pushes up on the track due to force $F$. The value of force $P$ can be determined by taking a moment at the center of the vertical rod which will be called point $c$. The moment equation will then be:

$$\sum M_c = (F \times d1) - (P \times d2) \quad (\text{Eq. 11})$$

All of the components of this equation are known except for the value of the force $P$. Force $F$ is the patient’s segment weight and the distance $d1$ is the distance the center of the horizontal portion of the attachment rod to far edge of the vertical portion of the attachment rod (3.875 inches). Distance $d2$ is the distance from the center of the top portion of the sliding track to closest edge of the vertical portion of the attachment rod (0.625 inches). By setting the moment equation equal to zero so that the system is in static equilibrium the force $P$ can be calculated by:
\[ P = \frac{F \times d_1}{d_2} \quad \text{(Eq. 12)} \]

In the final determination of which material should be used in order to sufficiently support the weights of the patient’s body segments the limiting factor is the total normal stress within the attachment rod. Recall that the equation for determining the total normal stress in the attachment rod is depicted in eq. 10:

\[ \sigma = \frac{F_y}{\pi \times r^2} + \frac{F_y \times d}{\frac{\pi}{4} \times r^3} \]

All of the values of the components of this equation are known values. The distance \( d \) is the distance from the center of the horizontal portion of the attachment rod to the center of the vertical portion of the attachment arm (3.4375 inches). The distance \( r \) is the radius of the attachment rods (0.4375 inches). The force \( F_y \) is the weight of the patient’s respected body segment. The segment weights of any human body can be determined by using a table of anthropomorphic data which relates the weights of body segments to the overall weight of the person. In order to determine which material will be sufficient for our design our calculations were done using the weight of the largest segment the attachment rods would be holding which would be the total leg and the maximum overall human weight would be 500 pounds (as depicted in the specifications of the needed patient positioning aid). According to Table 9.1: Anthropomorphic Data of the textbook Introduction to Biomedical Engineering\(^1\) the segment weight / body weight for the total leg is 0.161. Using this information the total leg weight of a 500 pound person would be 80.5 pounds. Upon inputting these values into eq. 10 and converting to ksi (kip per

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square inch) the total normal stress in the attachment rod is about $3.015 \times 10^{-2}$ ksi. Therefore the chosen material must be able to support/resist this load and also must be able to go through both a CT and MRI scanner. With respect to being able to go through both a CT and MRI scanner aluminum seems to be the best candidate and most grades of aluminum are able to very easily resist a load of $3.015 \times 10^{-2}$ ksi. With price in mind the chosen material is aluminum alloy 6061-T6. This grade of aluminum is one of the cheapest that we found and also has ultimate strengths of 38 ksi in tension and 24 ksi in shear; as well as yield strengths of 35 ksi in tension and 20 ksi in shear. Therefore, aluminum alloy 6061-T6 is a sufficient material for our patient positioning aid because it can easily support the predicted loads of the force analysis and is cost-effective.

**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.
The positioning aid will be mostly made of an aluminum alloy which is a non-ferrous material, 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 and attachments will also be reasonably lightweight. The use of a track system for the arm and knee attachments will allow for an easier and faster patient set-up time for the lab technician. The design shows promise and will work since the maximum possible stresses that it will encounter are compensated by the strength of the aluminum alloy. 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 patient’s needs, this device will also be cost-effective for the hospital and their number one choice when selecting a patient positioning aid.