Arm Holder for a CT Scanner

Preliminary Design Report

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ABSTRACT

Cardiac computer tomography scanning is an imaging technique that is becoming more widely used. The process involves emission and detection of x-rays sent through the patient to image internal organs and arteries to aid in diagnosis. To produce the best image with minimal motion artifact, the patient's heart rate needs to be low by keeping the patient comfortable and relaxed. One factor currently contributing to patient discomfort is the lack of support and positioning of the arms, which must be held above the patient's head throughout the procedure. To do this, our client would like us to construct an adjustable arm rest with sufficient forearm support for the user. Based on our client's requirements, we formulated three designs based on a common wedge frame. The design we will continue to develop has wedge angle adjustment and handlebars with rotational and distance adjustment options. Our next steps include obtaining materials, constructing and testing the prototype, and creating an alternate design recently requested by our client that can be used in conjunction with the currently used wedge.

BACKGROUND

Problem Statement

In computer tomography (CT) scanning, digital geometry processing is used to generate 3D images. The digital data is collected by a series of x-ray plates that rotate around the patient at high speeds, allowing the device to complete a chest scan, for example, within 15 seconds. However, to produce the best quality images using the CT scanner, the patient must be restrained to minimize movements. Respiration, cardiac motion, and patient restlessness produce blurring, doubling, and distortion artifacts in the reconstructed images and may lead to misdiagnosis [3]. In one study, images of anesthetized patients still resulted in a 0.1mm error and 0.6-1.4mm error for non-anesthetized patients [6]. For cardio and respiratory applications of CT scanning, beta blockers are given to the patient to help keep his or her heart rate below 60 beats per minute. A low heart rate prevents the patient's internal organs from excessive motion that can cause blurring in the final image.

To help maintain the patient's low heart rate and to restrict body movement, the arms must be comfortably secured out of the scanning area (the patient's chest) during the fifteen minute procedure. Since the scanning bed does not have a way of accomplishing this arm support, our client would like a device that can comfortably support and restrict movement of the patient's arms throughout the procedure. To prevent IV pinching, the inner elbow must remain unbent and accessible. Most of the patients are between 40 and 80 years of age and the device must accommodate individuals with restricted shoulder rotary motion. The device should be adjustable to accommodate all body sizes. The device must remain stable on the scanner table, have customizable height and grip angle adjustments, and provide support to the patient's forearms.

Problem Overview

The arm holder design must be comfortable for the patient and adjustable to suit a wide range of patients, particularly elderly patients that may or may not have rotary movement limitations in their shoulder and elbow joints. The device should be manageable by a single nurse and easy to store. The device should also be sturdy and fit on the bed of a CT scanner such as those produced by General Electric (GE), Phillips, and Siemens.

Problem Motivation

The device would enhance patient comfort during the twenty minute scanning procedure, keep the IV connected to the patient's arm easily accessible, and reduce unnecessary arm movements. This would subsequently help the patient maintain a low heart rate and thus reduce the amount of image artifact in the cardiac tomography output image.

Cardiac Computed Tomography (CT)

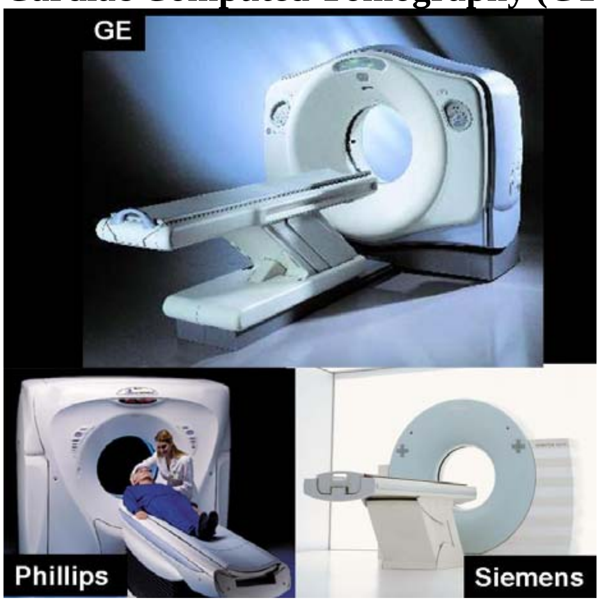

Figure 1. Ct Scanners produced by GE, Phillips, and Siemens.

CT is a medical imaging method that uses digital imaging processing to construct a three-dimensional image of an object using a series of two-dimensional X-ray images around one axis [1]. For cardiac CT scans, the final image construction can visualize arteries and detect plaque buildup or blockage within them.

During a cardiac CT scan, the patient must lie down on their back on the scanning bed (Fig. 1). An IV is hooked up to their arm to administer beta blockers to lower the patient's heart rate to 60 beats per minute. This heart rate reduction is necessary in order to reduce image artifact and allow the arteries to be detected clearly in the image. The patient is then asked to stretch their arms back behind their head in order to keep their arms out of the scanning area.

Setting up the patient and the equipment may take approximately fifteen minutes, but the actual data collection process takes roughly 7-10 seconds. The CT scanning bed slowly slides the patient through the CT scanner's open circular frame at a steady rate. It collects thousands of data points along a single rotary axis around the patient which are then reconstructed into a three dimensional image by a computer. When the scan is complete, the scanning bed slides back out. The patient is then detached from the IV and can return home between one and two hours.

Range of Motion (ROM)

Most of the patients undergoing a cardiac CT scan are elderly and may have rotary problems in their joints. Studies have shown that older adults have less ROM of the extremities than younger adults, including less elbow motion and decreased shoulder rotation [7]. Shoulder joint motion studies typically examine a variety of shoulder movements including elevation, extension, medial rotation, lateral rotation, and abduction. Normal ranges of motion for these measurement categories for a group of healthy young males are 167°, 62°, 69°, 104°, and 184° respectively [4]. From adolescence to adults over 61 years of age, these ROM measurements tend to decrease 7-15°, 39-49°, 7-25°, 42-58°, and 22-32°, respectively [7]. These rotational restrictions limit how far a patient can reach back behind their head and rotate their shoulders outwards in order to keep their arms away from the cardiac scanning field.

Design Constraints

A variety of constraints are instrumented to ensure high design quality and pateint safety. The two CT scanning tables used at UW-Health in Madison, WI are GE Lightspeed VCT 64-slice scanners. Since there are two scanners available, our client has requested two prototypes. The scanner table's width is 16.5 inches with a concave table surface to cradle the patients' body. However, the final prototype should be developed to accommodate many different scanner brands (i.e. Toshiba, Phillips, and Siemens).

Most importantly, we must assure the patient's safety. The device must be reusable, up to twenty procedures per day. Selected materials must withstand recurrent patient contact and regular cleaning by ethanol-based or antibacterial cleaners. The design should also minimize sharp edges.

During the scanning period of approximately fifteen to twenty minutes, the patient's comfort is the main concern. Each patient may require different angles and/or distances to remain comfortable. Therefore, the client has requested as many degrees of freedom as possible. Many of the elderly patients have restricted joint rotation and may require special consideration.

For the convenience of the nurses and in order to expedite the procedure, the device must be maneuverable by one staff member during set up and weigh less than thirty pounds. Storage of the device should be simple. It should be light and small enough to hang on the wall or conveniently stow in an alternate location. The device must be capable of sustaining up to a four foot drop with no damage.

Competition & Current Devices

A series of web searches and communication with the client revealed that there are no arm rests on the market specifically designed for CT scanners. Since there were no available products, a wedge shaped padded device provided by GE is commonly used (Fig. 2). The patient simply rests his or her arms on the wedge during the procedure.

Figure 2. Padded wedge currently used for arm positioning and support.

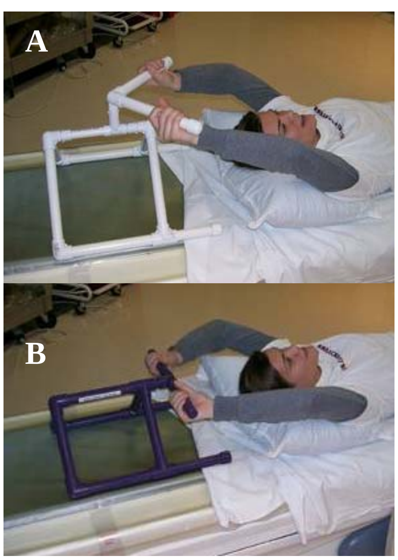

Figure 3: Team member demonstrates versions one (A) and two (B) made by client.

Based on a device used by some of his colleagues in Germany, our client built two versions of an armrest that are currently in use at UW-Health. Version 1 of the armrest is made from PVC tubing and is a simplistic design with an angled handle bar (Fig. 3a). Similarly, version 2 is also made from PVC tubing, but has a straight handle bar (Fig. 3b)

Since both versions of the device are not adjustable, problems may arise for individuals with limited range of motion needing to use the device. Our client informed us that most of his patients are above the age of 40, hence it is imperative to develop a device that comfortably accommodates patients with various ranges of motion. Furthermore, neither version provides sufficient support in the forearms, which increases patient discomfort. The only differences between the two versions are the orientation of the handle and the rigidity of the device. Both armrests are secured onto the CT scanning table using Velcro straps purchased with the scanner. Unlike version 1 where the handle is offset from the base at a certain height, the handle bar on the second version is directly attached to the base of the unit. The direct attachment of the handle to the base improves the rigidity of the device, which allows fewer movements during the procedure and consequently aids in producing better quality images.

MATERIALS

Since CT scanners are essentially X-ray machines that send several X-ray waves at different angles, there are very minimal restrictions on the type of materials used for the armrest [1]. Unlike with MRI machines, ferrous materials may be used with CT scanners, which further alleviate restrictions on the possible materials to use for the device. Moreover, the armrest will not be used in the field of the CT scanner since the device will remain outside the CT gantry. While materials used in the device do not have many material concerns, they must be rigid, sturdy enough to support patients' arms, durable for repeated use, and be able to withstand hospital disinfectants. Material density should be considered, as it will directly affect the weight and stability of the device.

Expanded rigid polyvinyl chloride (PVC) sheets are sturdy, but are also easy to machine, which make them ideal candidates for the device. Hence, PVC will be the major component of the device and will be used to form the frame [2]. Aluminum or other metals are other alternative materials that could be used for construction of the device's frame. Vinyl grips will be used to cover the handlebars to for comfort and easy cleaning between uses (Fig. 4).

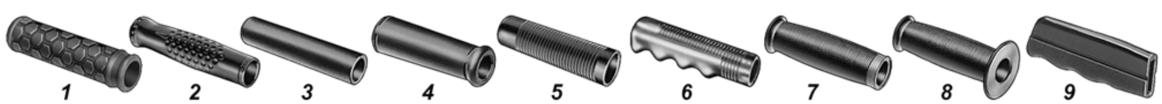

Figure 4. Vinyl handlebar grips [2].

To provide support for the forearms, padding using Tempur-Pedic® material will be attached to the top side of the PVC wedge. By conforming to the specific shape of the arms of each individual, the padding will allow the patient to comfortably rest the arms. Materials used can not be absorbent in order to prevent spread of infection from other patient's open wounds or sores. To properly disinfect the device between uses, the padding will be covered with a vinyl material.

FUTURE RESEARCH

Further research will be conducted to learn more about ergonomics pertaining to elbow and shoulder motions to help with the handlebar placements and the design of the angular adjustment ranges. Additionally, more research is necessary to learn more about materials that can feasibly be used to construct our designs while remaining under budget and adhering to previously specified client requirements and design constraints.

ALTERNATE DESIGNS

The three designs are all variations of one general design. The general design combines the padded wedge currently used in positioning the patient with the addition of an adjustable handle. The wedge is designed to be angle and height adjustable and uses a reclining mechanism much like that of a beach chair (Fig. 5). Two parts of the frame are attached at one end through a pivot point allowing them to rotate freely. The bottom section of the frame has three indents in which a hinged vertical support attached to the top frame may fit. By changing which slot the support sits in, the angle and consequently the height of the wedge can be adjusted. The wedge frame is also designed to fold flat (approximately 3.5 inches) as in the bottom of figure 5. The frame will be constructed of rectangular PVC stock of varying widths and secured by screws, PVC cement, and bolts. A padded surface is attached to the top frame. This will consist of foam padding on top of a thin board. An easy to clean material such as vinyl will be used to cover the foam padding. The padded top will have arm indentations to aid in restricting patent movement. A small padded flap (not shown in Fig. 5) will be added to the front of the wedge to protect the patient's back when lying against the front edge of the frame and continue the wedge shape to the table top. The three designs arise by varying handle adjustment mechanisms. Each variation is discussed in the following sections.

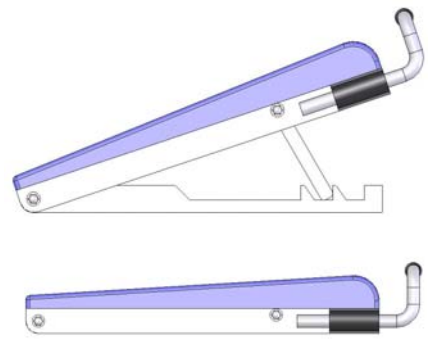

Figure 5. (Above) Sliding handlebar design in unfolded position. Vertical support is sitting in middle position. (Below) Sliding handlebar design in flat storage position.

There are several benefits to this general design. First, the design incorporates several positioning mechanisms making it easy for a staff member to handle and set up. It folds flat and is convenient for out of the way storage on a wall or in a cabinet. The angle adjustable wedge allows greater ranges of positioning than the current padded wedge. Padded arm indentations help support and restrict the patient's forearms which previously had no support. The handlebar also allows the patient to comfortably rest and steady their hands. There are a few disadvantages to this design. It assumes all patients will have their shoulders just before the wedge with their head resting at the base of the wedge. This position does not work for all patients who are not comfortable lying completely horizontal since it cannot be used as a back support like the current wedge. This is because the handlebar would interfere with the patient's placement on the device.

Design 1: Rotational Handlebar

The first variation is the rotational handle design which uses two hinges that can be locked at any angle **(**Fig. 6). These hinges are attached to the back side of the top frame and handlebar support. The handlebar is bent into a long U-shape and placed in two holes in the handlebar support. A long vinyl grip or grip tape covers the handlebar for extra comfort.

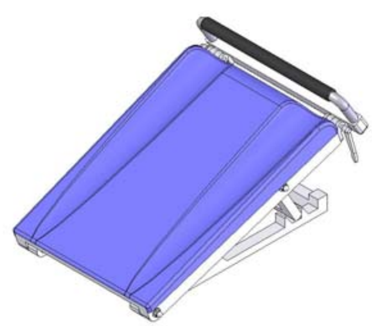

Figure 6. Rotational handlebar design with locking hinges.

A benefit of this design is that the handlebar has some distance and height adjustment. The hinges can be locked within a 90 degree range. The easy lock hinges are also simple to use and quickly set up. However, since the handlebar is constrained to rotation about the hinges, only a single height is available for a certain distance and vice versa. This design also requires the locking of two hinges instead of one as with the sliding handlebar design. Pinching may also be a concern while adjusting the hinges.

Design 2: Sliding Handlebar

The second design is the sliding handlebar design (Fig. 7). The handlebar is constrained so that it may slide and adjust to a desired distance. The two ends of the handlebar fit into round clamps on both sides of the top frame. These clamps squeeze the handlebar when tightened much like a bicycle seat mechanism. Again a vinyl grip or grip tape will be used on the handlebar to ensure patient comfort.

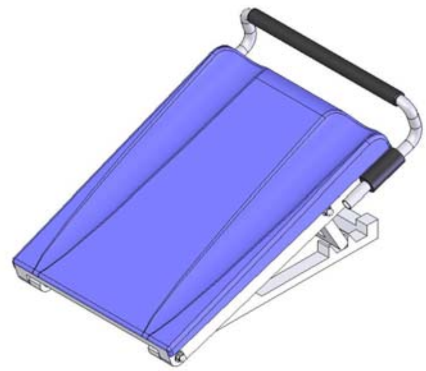

Figure 7. Sliding handlebar design with circular clamps.

This design has several advantages. The handlebar distance can be adjusted up to three inches parallel to the top of the wedge, allowing the patient to find his or her most comfortable setting. This design also requires only one side of the clamps to be tightened. This would be more convenient for the worker by simplifying the set up procedure. This design also has some drawbacks. The handlebar is only distance adjustable along the top frame of the wedge and cannot adjust to height.

Design 3: Rotational & Sliding Handles

The last variation is the rotational and sliding handles design (Fig. 8). This uses the same clamping mechanism as the sliding handlebar design but has two separate handles. Dividing the handlebar allows rotation and permits the patient to supinate and pronate their arms. The distance could also be adjusted by sliding the bar through the clamp. Clamps on both sides need to be tightened to lock them into place. Alternatively, the handles may be angled forward to accommodate slightly bent elbows. Each handle would have a grip for maximum comfort.

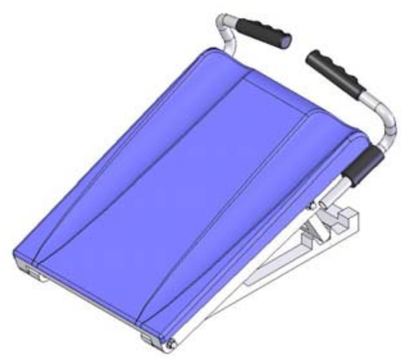

Figure 8. Rotational and sliding handles design with circular clamps.

There are several benefits to this design. Of the three designs, this design has the greatest degree of adjustability. It allows arm rotation, distance adjustment, and is the only design with the option to angle the handle to accommodate slightly bent elbows. However since the handles are separate each locking mechanism must be tightened.

DESIGN MATRIX/PROPOSED DESIGN

All three proposed designs were judged on four categories: comfort, adjustability, portability and ease of manufacturing. Since our client was most interested in maximizing patient comfort and the ability to adjust to patients with varying ranges of motion, those two categories were weighted more than others (Fig. 9).

	DS1	DS2	DS3
Comfort (30)	20	25	28
Adjustability (30)	20	25	30
Portability (20)	20	20	19
Ease of Manufacturing (20)	13	15	18
Total (100)	**73**	**85**	**95**

Figure 9. Design matrix.

Design 3, which has handles that rotate as well as vary in distance, would be the most adjustable and most comfortable of all the designs. The other two only have a single handle that can either rotate or change in distance. Further, the hinges in design 1 may pose a risk of pinching during use and hence was awarded the lowest score. Although all three designs can fold flat and be carried easily, the first two designs will be less compact when folded due to the nature of their handles. Since design 3 has two separate handles, it might be slightly more difficult to carry and transport it from one room to another. Finally, design 1 with the angle adjustable handlebar would be the most difficult to manufacture due to the two lockable hinges. Since design 3 has two separate bars that are free to rotate about the plane of the arm rest, it requires fewer nuts, bolts and other parts that are necessary in the first two designs. Overall, design 3 has the highest score, and consequently is the design that we will pursue during the semester.

FUTURE WORK

To ensure that the device will accommodate patients with limited ranges of motion, we need to research the ergonomics of arm and wrist positions. We hope to incorporate our findings in an alternate design our client requested which works in conjunction with the current wedge. This new device would allow us to accommodate patients with severe shoulder restrictions who need higher vertical positioning to remain comfortable. We will order materials and build a prototype of design 3 while concurrently formulating the specifications for the alternate design. We will also need to test the prototype and make any necessary alterations to ensure that all components are functioning properly. Finally, we will begin paper work on filing for a patent through the Wisconsin Alumni Research Foundation (WARF).

APPENDIX A - References

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