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Research paper

Deformation and Stress Analysis of Angiography Hand Rest

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Abstract

Angiography is a test to observe the arteries in the limb using x-ray and a special dye. For this research, the angiography will be focusing on arms and hands. The patient's arms and hands need to be still, to ease the process. Therefore, a device is needed to assist in holding the arms of the patient. Many of the medical personnel facing similar problems during an angiogram. The most common is the patients won't stop moving and flinching while the tube entering the blood vessels. This can cause serious injury which can be fatal. They require the design to hold the patient's arm and limiting their movement. This research will focus on the development of a device to address the above mentioned issues. The main objective of the project is to build a prototype of hand rest that will be able to hold the patient's hand. The design will be suitable for the different age and physical build of the patients. It will be developed by using computer-aided design software; Solidworks. The device needs to be easy to use and adjustable for different patient size. With new invention, the problem can be reduced and shortened the queue time. The design will be an improvement to all angiogram facilities throughout the nation.

Keywords: *arm board, radial cardiac catheterization, angiography, Solidworks*

1. Introduction

Coronary artery disease is the leading cause of death in developed countries [1]. It happens when a blood vessel or the artery, which carry rich-oxygen blood to the heart and other parts of the body become narrowed and hardened. This is due to the plaque that is build up on the wall of blood vessels. As it grow, it prevent the blood to flow efficiently through the artery and even block the blood stream that cuts off the blood supply which will cause chest pain or heart attack.

In order to treat this coronary artery disease, there are two possible ways. The first one is treated by doing bypass surgical and the second method is through a coronary angiography procedure. Basically bypass surgical is the main choice to treat patients, but due to recent technology advancement, coronary angiography is the better choice to treat this coronary artery disease [2]. Coronary angiography is a procedure where the doctor or physician uses a set of fluoroscopy camera and a special dye to view the coronary artery system of the patients. The special dye is inserted into the bloodstream and because of its radiopaque characteristic, the fluoroscopy camera gets the image of the artery system accurately. In addition, the doctor also uses a thin tube called a catheter that is placed into the blood vessel through radial (hand) or femoral (leg) artery and guided to the area to be studied, mostly to the patient's heart. Then through this catheter, the special dye is injected into the vessel in order to make the area shows clearly in the x-ray picture. Sometimes, the catheter is placed together with a balloon or stent to open up the narrowed blood vessels. This procedure, called cardiac catheterization [3].

There are many instruments required in order to carry out an angiography procedure like catheters, wire, balloons, stents and arm board. The arm board is important as it is where the patient's arm will be located during long period of angiography procedure. It is important to keep the patient's arm immobilize as it will disturb the operation. Besides, patients need to be comfortable during the operation as this angiography procedure can be very time consuming. Right now, the current angiography procedure is using a simple flat board where the patient's arm is located. The design has no ability to hold the patient's arm firmly. The nurses put a towel to adjust the patient's arm to a specific height and wrap around a patient's arm with bandage to prevent it from moving. This makes the patient feels uncomfortable during the operation as it consumes time to be carried out. The objectives of this project is to study and understand the current radial arm board and design an improvement angiography arm board using Solidworks. The new design will be analyzed using Solidworks. This project concentrates on the design of the angiography arm board where it gives the ability to elevate the patient's arm for the doctor to easily access to the wrist area.

Besides, the size of the arm board is too big for storage capability. Most angiography arm board is thin, but the shape is wide for its size. This gives the problem for staffs to store it properly as when it is not being used, the board is stored in the operating room which has limited spaces. Due to that, the staffs just put it anywhere without proper storage place. In addition, because of its size, these staffs have a handling problem to assemble and disassemble it. Sometimes it disturbs the operation procedure as the c-arm of x-ray machine needs to rotate during the imaging process and it interferes with the board. One of the solution is purchasing the existing arm board from abroad. The existing arm board priced as shown in figure 1 goes as high as $1,450.00 (RM 5,684.72) without postage and tax cost. Beside the high cost, the features of the existing arm board in Malaysia is not a lot of a difference from the abroad arm board beside the arm straps and the curve for arm placement [4]. In order to solve this issue, a new arm board design needs to be created as compact as possible to accommodate the angiography procedure.

Figure 1: Angiography Armboard with reusable pad. [4]

2. Literature Review

During angiography procedure, the x-ray machine that has an arm like C-shape is used to for imaging process. It has the ability to rotate in variety of axes as it needs to be directed to the patient's coronary system for accurate imaging around the heart and chest cavity [5]. Basically, the patient is prepared in a supine position on a supporting table, then imaging is being carried out by a C-arm by rotating about the patient so that the patient's coronary system may be viewed from all different angles [6]. Most of the hospitals using standard flat board to hold the patient's arm during angiogram operation. This rigid arm board is attached to the operating table by some part of arm board is inserted under the table and the rest extended laterally from the side of the table where the arm is positioned. This is where the extending arm boards often physically interfere with the C-arm because of the relatively limited space provided for the patient and supporting table [6]. Figure 2 shows the existing radial arm board used in the hospital.

Figure 2: Current radial arm board.

The existing radial arm board is too big for its size. Thus, its storage capability is not efficient as the nurses need to clean and store it properly. Besides, for the size, it is not easy to handle as nurses need to attach the board on the supporting table and adjust it at substantially horizontal and planar support on which the arm is stabilized. Sometimes, the spaces offer from the radial arm board is not enough. The board need to have a supportive space upon which to place the medical instruments [7].

Current arm board is made up with radiolucent material. The term "radiolucent," as used herein, means a material that substantially permits the penetration and passage of x-rays or other forms of radiation through the material [7]. Thus, this radiolucent type material is suitable for angiography procedure as it does not interfere with the radiation from the x-ray during the imaging process. Sometimes it is not good for the doctor as for most radial cardiac catheterization, which happen in the patient's arm, it requires the doctor to stand closer the x-ray machine.

Anthropometry is a field about the scientific study of the measurements and proportions of the human body and their applications that establishes the physical geometry, mass properties, and strength capabilities [8]. With all the anthropometry measurements and dimensions, descriptive statistics data is produced like mean, standard deviation, standard error of mean, coefficient of variation, minimum, maximum, 5th percentile, 50th percentile and 95th percentile [8]. The anthropometry information will be used for product or equipment and workplace design. This utilization of the anthropometry data will enable designers to accommodate the desired portion of the potential user population in their design. The uses of anthropometry in the workplace can help designers in evaluating proper postures and distances to reach controls, specify certain clearances separating the body from hazards of surrounding equipment and identify certain elements that constrict movements. Figure 3 and table 1 below shows the list of anthropometry measurement based on their position.

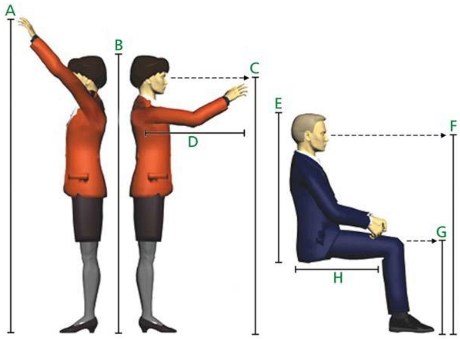


Figure 3: The illustrations of the measured anthropometry dimensions [8].

Table 1: List of anthropometrical positions [8].

Anthropometric Measurement	Practical Application
Height	Height of panel wall
Weight	Weight limits for seating
Standing Eye Height	Visual obstructions/displays
Standing Overhead Reach	Accessibility of high shelves
Standing Forward Reach	Reach conditions
Sitting Height Overhead	Overhead clearance; sitting panel height
Sitting Eye Height	Height of top of monitor
Buttock-to-Popliteal	Seat depth
Buttock-to-Knee	Knee clearance
Sitting Popliteal Height	Seat height
Sitting Knee Height	Knee clearance under work surface
Thigh Clearance	Clearance between thighs and bottom of work surface
Waist Depth	Clearance between backrest and workstation edge
Elbow Rest Height	Armrest, keyboard, or writing surface height
Sitting Hip Breadth	Seat widths
Forearm-to-Forearm Breadth	Seat and armrest widths
Hand Thickness at Metacarpal	Hand clearance in a handle, slot

Table 2: List of anthropometrical measured position [8].

Measurement	Letter	Female (mm)	Male (mm)
Standing Overhead Reach	A	1902.50 – 2204.72	2062.48– 2379.98
Standing Height	B	1529.09 – 1737.36	1645.92 – 1866.9
Standing Eye Height	C	1445.26 – 1651	1559.56 – 1772.92
Standing Forward Reach	D	782.32 – 916.94	858.52– 1003.3
Sitting Height	E	795.02 – 909.32	853.44 – 972.82
Sitting Eye Height	F	1082.04– 1239.52	1176.02– 1336.04
Sitting Knee Height	G	502.92– 589.28	543.56– 635
Seat Depth	H	429.26– 518.16	449.58 – 535.94

3. Radial Arm Design

Table 3: Product Design Requirement.

Performance	Able to be fixable position for arm within one minute.	**Ergonomics**	Follow guidance standard for good ergonomics position
Design	Withstand average human's arm weight.	**Weight**	5kg or less
Material	Lightweight Material – Can see through by X-ray vision	**Market/ Patent**	Catheterization facility, Malaysia.
Size	Should be less than 200mm height and 500mm length. (Easy storage)	**Product Life**	10 Years
Cost	RM1000 including manufacturing	**Customer**	Angiography patients and medical personnel
Maintenance	Minimal	**Safety**	No sharp edges/components

A new model design of radial arm has been proposed. The model of the design was made using Solidworks software. All the components or parts of the model were combined using mechanical assemblies to generate the final completed product with requirement in table 3 above. Figure 4 shows the modelling of the new radial arm board.

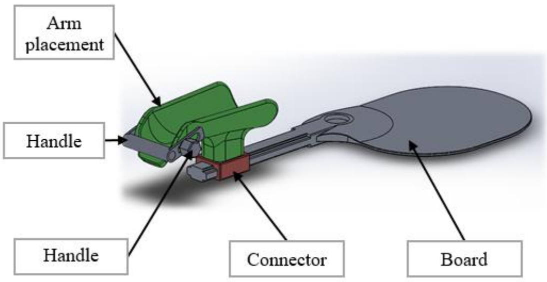


Figure 4: Model of the new radial arm board.

The design mainly consists of five components that are arm placement, handle, handle knob, connector and board. Arm placement is a place where the patient's arm will be located for angiogram procedure. The semi cylindrical shape with enlargement of the radius of the wall from the front to the back will provide comfort for the patient during the procedure as the procedure usually takes a longer time. The existing radial arm board is only a flat board where the patient's arm cannot be positioned properly and provide comfort to the patient. Besides, the front of the arm placement is designed to accommodate the procedure by providing a condition where the wrist of the patient will be in approximately 60º hyperextension [9]. This will ease the doctor or surgeon to conduct the procedure as the wrist access area is larger. A towel is needed in order to make the patient's wrist in 60º hyperextension for the existing radial arm board. Figure 5 shows the feature of the design that provide 60º hyperextension on the patient's wrist.

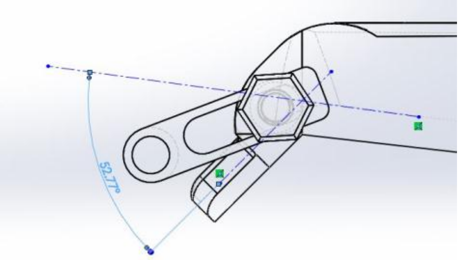


Figure 5: Wrist area that provides approximately 60º hyperextension of the patient's arm.

4. Analysis

In material selection, a suitable material for the new design concept of the radial arm board is chosen. At first, the carbon fiber reinforced plastic is chosen for all the components of the product because it has high strength to body ratio and also durability compare to standard plastic like PLA or polylactic acid/ polylactide. After some consideration has been made, the chosen material which is the carbon fiber reinforced plastic is cancelled because of the price and other several factors like machining process and material resources readiness. Table 4 shows the type of material chosen for each of the components of the new design concept of the radial arm board for prototype fabrication.

Table 4: List of components and their type of material selected.

Component	Type of Material Selected
Arm placement	Polylactic acid, PLA
Handle	Polylactic acid, PLA
Handle knob	Polylactic acid, PLA
Connector	Aluminium
Board	Aluminium

Different components are made from different types of material. For arm placement, handle and its knob, 3D printing is being used to fabricate them. Polylactic acid is a type of plastic that used in 3D printing. It offers good durability of the product and also better surface finish and aesthetic value of the product. While for connector and the board, aluminium is chosen. This is because of the strength that the material provides to withstand the weight of the patient's hand without external support required. In addition, aluminium also has good corrosion resistance and offers easiness for machining processes.

Analysis

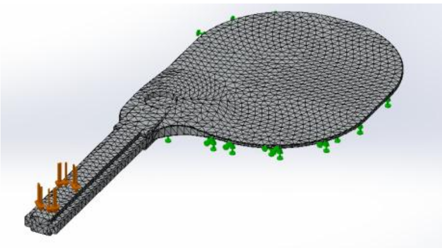
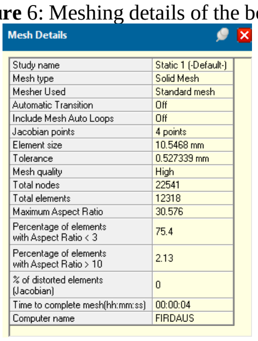


Figure 6: Meshing details of the board



Mesh Details

Study name	Static 1 (-Default-)
Mesh type	Solid Mesh
Mesher Used	Standard mesh
Automatic Transition	Off
Include Mesh Auto Loops	Off
Jacobian points	4 points
Element size	10.5468 mm
Tolerance	0.527339 mm
Mesh quality	High
Total nodes	22541
Total elements	12318
Maximum Aspect Ratio	30.576
Percentage of elements with Aspect Ratio < 3	75.4
Percentage of elements with Aspect Ratio > 10	2.13
% of distorted elements (Jacobian)	0
Time to complete mesh(hh;mm;ss)	00:00:04
Computer name	FIRDAUS

Figure 7: Meshing details of the board.

Static structural analysis of the new design concept of the radial arm board is being done by simulation in the Solidworks. It can determine the maximum deformation, stress, strain and factor of safety of the model. All the analysis is determined by putting several boundaries like external load or weight and fixed support. Then, the software will run the test with the specific mesh size suitable for the model. The smaller the mesh size, the larger the element number, the better the simulation. All the result of the analysis will show in color contour in each specific area. Figure 6 and 7 above shows the meshing details of the board. The load applied at the end of the board is set to 150N. This load is equivalent to the weight which is about 15 kg. Although most of the patient's arm usually weighted less than 10 kg, for this simulation, it is suggested to apply the load a little bit higher. Deformation is the changing of the shape of an elastic object because of the reaction of external force. The deformation is determined by using static structural analysis in the Solidworks. Figure 8 shows the deformation of the board.

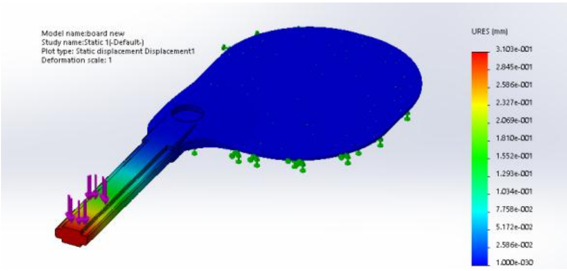


Figure 8: Deformation of the board.

The board is one of the components of the radial arm board. It will placed under the mattress and patient on the bed to withhold the weight of the patient's arm at the other end. The highest deformation of the radial arm board which indicated in red color is located at the end of the board where the patient's hand will be located and it's only 0.3103 mm.
Stress is the force per unit area and it shows how the model design being affected by the weight or load given. Figure 9 shows the contour of the von Mises stress.

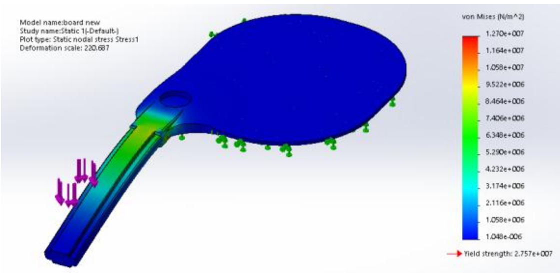


Figure 9: von Mises stress of the board.

When a patient's arm is being placed on arm placement where it will attach at the end of the board, the load will affect the board and produced stress. Most of the stress concentration happened in the middle of the board and the maximum value of the simulation is 12.7 MPa. The material of the model design is aluminium so the yield strength is 27.5 MPa. Based from the simulation analysis, the maximum stress in the model below is the design the yield strength of the material and the elastic deformation of the board will not occur.
Strain is defined as the amount of deformation of the solid due to stress. When a material is loaded with a force, it produces a stress, which then causes a material to deform. If the stress is small, the material may only strain a small amount and the material will return to its original size after the stress is released. This is called elastic deformation, because, like elastic it returns to its unstressed state. Elastic deformation only occurs in a material when stresses are lower than a critical stress called the yield strength. If a material is loaded beyond its elastic limit, the material will remain in a deformed condition after the load is removed. This is called plastic deformation. Figure 10 shows the contour of strain on the board.

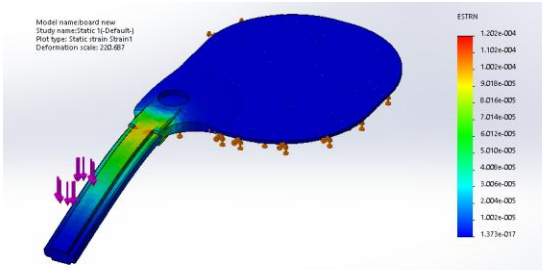


Figure 10: Strain of the board.

The strain analysis of the board showed that the most strain occurred in the middle of the board between the support and the load situated. The elastic deformation highly unlikely to occur because the stresses are lower than the critical stress or yield strength.

5. Final Product

Figure 11: Prototype of the radial arm board.

Figure 12: Demonstration on how to use the prototype.

From the figure 11 and 12 above, Handle and handle knob are two things that working together to provide support during the angiogram procedure. The handle will be gripped by the patient and the knob will be used to lock the handle after some adjustment has been made. The handle will provide comfortability for the patient during the procedure as the patient will have something to hold during the long period of procedure. They can grip or release it during the procedure compared to the existing radial arm board where the patient's arm will be tied to the board. When the final suitable position of the handle is determined, the knob will lock the handle and prevent it from moving. This will help to prevent the patient's arm from moving during the procedure.
Lastly, the connector and the board are two more other components to complete this new design of the radial arm board. The connector is where the arm placement will be attached and then the connector will be attached to the board in sliding system. It enables the doctor or surgeon to adjust the position of the board that is suitable for the

arm. This will help the procedure to be performed more effectively and also give comfortability to the patients.

6. Conclusion

In conclusion, this project was developed in order to improve the existing radial arm board to improve and accommodate the angiography procedure. All the objectives stated are achieved successfully. The first objective is to understand current radial arm board by studying the angiography procedure and current radial arm board. Understanding the design and looking the disadvantages or drawbacks for improvement through literature review and discussion meeting with the staffs. Then, the second objective is to design and develop a new concept of the radial arm board where most the drawbacks of the current radial arm board are being improved. The last objective is to analyze the designed radial arm board using Solidworks where the structure is being analyzed to meet the specifications required for the angiogram procedure.

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