Designing a Modified Armboard for Cardiovascular Medicine

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Abstract

The armboard is used in a variety of surgical practices for proper positioning and restraint of the patient's arm. The division of cardiovascular medicine at the University of Virginia (UVA) hospital primarily uses two models: the Banjo armboard and the Siemens armboard. However, the responses of interviewed medical professionals highlight that these models are hindered by their strength, stability, durability, and range of applicable surgical procedures. Therefore, we designed a modified universal armboard that improves upon the major limitations associated with each current model, whilst maintaining their strengths. Its novel three-piece ergonomic design allows for application to a wider range of procedures, while facilitating ease of workflow. In addition, geometrical and material modifications further enhance its overall strength and stability.

Keywords: Armboard, Cardiovascular Medicine, Medical Device

Introduction

An ideal armboard should support and position the patient's arm, while being comfortable and atraumatic for the patient and nonobstructive to the operating area. In the division of cardiovascular medicine at UVA, there are two armboard models primarily used: the Siemens armboard and the Banjo armboard (**Figure 1**). The catheterization (Cath) lab, which consists of an examination room with diagnostic imaging equipment used to visualize the interior structures of the heart and treat any stenosis or abnormality found, mostly uses the Banjo model. On the other hand, the electrophysiology (EP) lab utilizes various interventions for the diagnosis and treatment of heart rhythm disorders and uses both models depending on the procedure being performed. According to 25 medical professionals interviewed from UVA's Cath and EP labs, each model has its own associated pros and cons.

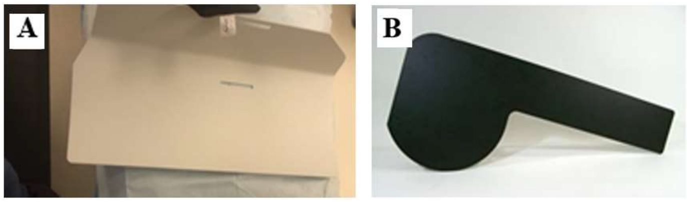

Figure 1: Most Common Armboard Models Used in Cardiovascular at UVA. A) The Siemens armboard is primarily used in the EP lab, and is used to position the patient's arm parallel to the body. **B)** The Banjo armboard is primarily used in the Cath lab, and the circular region can be rotated under the patient to position the arm at an angle.

The Siemens model is used when the patient's arm needs to be placed parallel to his or her body. This armboard slides under the patient's body and features a rising cusp that allows for proper support of the arm. The ABS-polycarbonate (ABS/PC) material and simple design allow the board to be cleaned easily with a bleach wipe, the common mode of disinfection used in the hospital. That said, the flexibility of the material and dimensions of this armboard hinder its stability. This is especially problematic with overweight patients with heavier arms as it causes the board to bend down, fall out of place, or even break. Also, because the armboard is inserted under the patient once they have already laid on the operating table it can be difficult to position and disrupt workflow. Many technologists interviewed claimed that a longer and wider model might mitigate some of the constraints associated with heavier and taller patients, and they expressed no concern for potential drawbacks associated with modifying the armboard's geometry.

The Banjo model consists of a semicircular head fitted under the patient and an arm stretched out for situating the patient's arm. Its geometry allows for a wider range of application compared to the Siemens model as it can be rotated under the patient to accommodate any needed angle of the patient's arm. Additionally, it is constructed of a carbon fiber backbone with foam cushioning, which leads to greater stability, strength, and comfort. While this model is superior to the Siemens design in respect to stability and range of application, there are drawbacks to the material composition. The Banjo armboard is priced around $1500 and suffers from durability issues. Many of the registered nurses (RNs) interviewed cited that the foam material occasionally splintered becoming difficult and a hazard to clean. Consequently, they must dispose of the armboard to avoid any potential injury due to risks of laceration and infection the splintered material poses.

Our device aims to address the limitations of current models using geometric and material modifications to improve upon the previous designs' stability, comfort, and functionality. Our hopes are that this model will eliminate the need for two models in UVA's department of cardiovascular medicine, while reducing significant constraints.

Results

Identification of Constraints

Feedback from the first round of interviews highlighted the significant limitations associated with each model. Furthermore, it was used to solidify the desired functions and constraints of the new model, and to guide the design of the modified prototype in CAD. The results from these 25 interviews are summarized in Table S1. The results imply that the most important functions of an armboard are to provide stability, support, and comfort. During interviews, we asked medical professionals if there were any added features that would enhance the functionality of current models. Some ideas included a hinge mechanism that would allow for easier rotation of the armboard, a cusp on the outer side to store electrical wiring or surgical instruments, and a mechanism to raise or lower the patient's elbow and wrist to improve comfort and feasibility of the right radial access procedure. Such suggestions helped allude to the primary constraint of our design being the need to keep the device as simple as possible. Simplicity allows for the armboard to be easily configured for operation, safe and easy cleaning, and allows space for additional padding or restraints if needed. Another constraint introduced was the need for a radiolucent material, which allows x-rays to pass through; this limited the available material options for our design.

While the majority of respondents were members of the Cath and EP labs, we additionally sought feedback from other departments for a more diverse perspective. Three members from the OR were additionally interviewed to gain insight into the different models used in their department. In general, their models feature less limitations because they do not have to be radiolucent, and the hospital beds in the OR feature railings that allow for armboard attachment. That said, their use of a hinge mechanism that allows for the armboard to be rotated and locked into place inspired the inclusion of the rotational aspect in our designs. In addition, a design proposed by the chief imaging technologist at UVA is the STARBoard from Adept Medical *source*. The ergonomics of this design also allow for rotation of the armboard, and it features a larger area under the patient for greater stability. However, it is specific for right radial access procedures and is very high cost.

Prototype Design Specifications

Given the constraints and required functions of armboards, a modified armboard prototype in CAD was designed that accommodates both arms of the patient at any angle of indication through a rotational mechanism. Its characteristics and features are shown in Figure 2. This universal design can be used in a greater range of procedures, ideally eliminating the need for multiple armboard models. While it would be ideal to include the majority of the suggestions for additional functions, some could not be feasibly implemented with a simple design, and were thus not included in the design. The model consists of three main pieces: a centerboard, a right armboard, and a left armboard. In practice, the centerboard is placed under the hospital bed mattress prior to the patient lying down. Subsequently, the pegs of the right and left armboards are placed in the "cupholder" of the centerboard, and rotated to the angle required by the procedure.

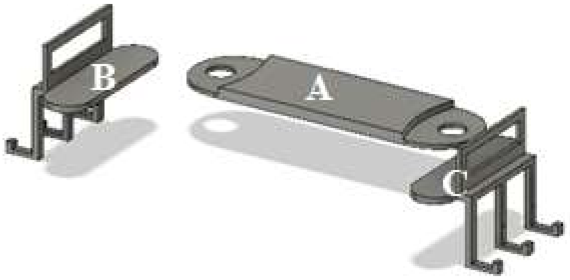

Figure 2: Initial Universal Armboard Prototype. The model features a (**A**) centerboard that is placed under the patient prior to surgery. On each side of the centerboard, there are two "cupholders" that allow for pegs on the underside of each of the (**B**) right and (**C**) left armboards to be positioned in. Each armboard features hooks used to hold medical device wires, and slits for applying restraints to the patient's arm.

This eliminates the problem with fitting the armboard under heavier patients as indicated by many interview respondents. Inclusion of the rotational aspect was influenced by interview suggestions and the hinge mechanism featured in many OR armboard models. In addition, the size and width of each armboard was increased to better accommodate larger and heavier patients.

Design Iteration

The prototype was scaled down 10x and 3D printed for use in 9 more interviews with medical professionals. Their responses highlighted the pros and cons of the model, as well as recommendations for future designs. None expressed concerns about it interfering with the workflow of setting up the armboard and positioning the arm for the procedure. In fact, two respondents believed that the three-piece design and preliminary placement of the centerboard would speed up the overall process. In addition, all responses positively viewed the rotational mechanism, although some gave suggestions on how to improve it. On the other hand, 5 respondents expressed concern regarding the size of the hooks and the height of the opening above the armboards. They suggested that it may interfere with access of X-ray imaging devices above and below the armboard, as well as physician access to the arm.

Final Design Specifications

The second round of interview responses were used to guide the construction of the final design (Figure 3). The sharp edges were smoothed out to eliminate any discomfort or potential injury to the patient. The size of the centerboard was increased to enhance the overall stability under the patient, and the length and width of each armboard was increased to accommodate larger patients. The modifications to each constituent piece are depicted in Figure 4. By making the hooks smaller and removable, they can now be added or removed depending on the procedure. They are fed through the holes on the outside of each armboard, and have winged extensions on the top that function as a stopping mechanism, preventing the hooks from falling through the holes. Therefore, they can be feasibly removed if imaging access below the armboard is needed. In addition, the geometry of the rotational mechanism was modified. The peg under the armboard is fitted perpendicular to the bed into the hole of the centerboard, and subsequently rotated to the desired angle, which locks it into place.

Figure 4: Components of Final Armboard Design. **A)** The size of the centerboard was increased to enhance overall stability. **B)** The geometry of the openings on each side of the centerboard was modified to fit the new geometry of the pegs under each armboard. **C)** The hooks were removed replaced with holes that allow for placement of removable and smaller hooks. **D)** The size of the openings on each armboard were reduced due to concerns over a patient's arm or wrist falling through them. **E)** An additional peg was added to the opposite side under each armboard, which allows for them to be used on the right or left side of the centerboard.

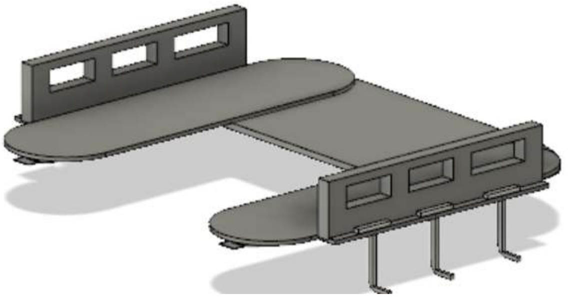

Figure 3: Assembled Final Armboard Design. Fully assembled armboard with removable hooks.

Determining the Optimal Material

Static loading tests were performed in CAD to find the optimal material for the armboard (Figure S1). The applied forces simulate the loading experienced by the armboard subjected to a 350-pound patient. The materials tested, their mechanical properties, and the maximum displacement results are shown in Table 1. The maximum force experienced in each material was 20 MPa, and occurred at the interface of the outer edge of the centerboard and the armboard. However, given that each material has a significantly higher yield strength, none are at risk of failure. Defined in Table 1, the maximum displacement was lowest for the carbon fiber material. Therefore, we determined that carbon fiber is optimal for the base material of our armboard. Since polycarbonate is more flexible due to its lower Young's modulus, it may be ideal for the hook material, facilitating easier hook placement through the holes of the armboard. However, these results may not be fully realized in practice. Unforeseen higher loading events may demonstrate that the weaker materials are not suitable for use. Furthermore, patient feedback on the design might suggest that the stiffer carbon fiber material is less comfortable. Future research and armboard designs should address these limitations.

Table 1: Mechanical Properties of the Materials Tested and Static Loading Test Results. Maximum displacement is defined as the distance the distal tip of the armboard flexed downward from its initial angle parallel to the ground.

	Carbon fiber	**Polycarbonate**	**ABS/PC**
Young's Modulus:	133 GPa	2.275 GPa	2.78 GPa
Yield Strength:	300 MPa	62 MPa	54.4 MPa
Maximum Displacement:	0.11 mm	6.7 mm	5.3 mm

Discussion

The proposed universal armboard will eliminate the necessity of having different models for different procedures in cardiovascular medicine, while maintaining the strengths and improving the limitations of the Siemens and Banjo models. The model retains simplicity in design so that it is easy to maneuver and clean, and maximizes the operating space for the physician and nurses. Through geometry optimization, the inclusion of the centerboard component, and designed rotational mechanism, the modified armboard allows for easier manipulation and a more universal accommodation. This moves beyond current models of the armboard used at the UVA hospital, as each of the models has a narrow niche of procedures for which they fill. Each design only supports the patient's arm in a small range of positions and requires additional tools to properly secure the patient.

Future work will involve constructing the full-scale model to be used in surgery simulations. This will elucidate how feasible the model is used in practice, providing a better understanding as to how it impacts the setup and workflow. Furthermore, volunteer patients in these simulations can provide a new dimension of feedback regarding the comfort of the design, which addresses some of the limitations expressed in the static loading tests. Ultimately, this will provide feedback on the overall comfort of the design and any unforeseen problems to guide future design iterations. Unfortunately, complications arising from the COVID-19 pandemic hindered our ability to obtain the full-sized model and to perform these simulations at the hospital. The mechanical and aerospace engineering (MAE) machine shop at UVA briefly accepted the task of constructing the model before re-evaluating and informing us that they must focus on MAE projects and therefore would not be able to complete our model in time. Subsequent attempts to find other local options to complete our model failed. Nevertheless, this opens up the opportunity for future capstone groups to finish what we started. Given the promising feedback on our final design and outlined steps to improve it in the future, we hope that it can eventually be submitted for IRB approval to be used for testing in clinical trials.

Materials and Methods

Interviews

Questionnaires consisting of ten questions were used to guide each set of interviews. In the first set of interviews, a total of 25 medical professionals were interviewed; their positions, years of experience, and relevant responses are summarized in Table S1. The majority of respondents were interviewed at their convenience in the cardiac transition unit (CTU) break room and were selected at random. Furthermore, most respondents were members of the EP and Cath labs, but others from Radiology and the OR were interviewed. Factors influencing the inclusion of functions in our design were the frequency of the response and how well the function could be implemented using a simple design. The second set of interview questions focused on obtaining feedback for our initial prototype, comparing it to the Banjo and Siemens models, and recommendations for future iterations. While 4 interviews were randomly conducted in the CTU break room, the remaining 5 were scheduled with members of the EP lab who have significant experience using the Banjo and Siemens armboard. Their feedback was similarly analyzed and used to guide alterations made in the final design.

CAD Modeling

Autodesk Fusion 360 was used for designing the initial small-scale models and the final full-scale model. The dimensions of the EP lab beds were measured and used to scale each model. The decision to include some of the desired modifications, while excluding others, was primarily made at our discretion. The complex designs mandated by some of the desired modifications, such as adjustable padding to support the elbow and wrist joints, could not be feasibly made in CAD with a simple design. However, others such as removable hooks and the rotational locking mechanism were achieved with a simple design. The small models were scaled to 1/10th of the size of the full-scale model. We 3D printed the small-scale model using an M3 Mini 3D printer. The 3D printed model was assembled and showcased to medical staff during the second set of interviews. Upon reaching the final design, it was scaled up to fit the dimensions of the EP lab bed. Engineering drawings were made for this design so that it could be assembled using UVA's machine shops.

Static Loading Simulations

The static loading tests were performed in Autodesk Fusion 360, simulating the loading experienced by a 350-pound patient. The loads applied to the centerboard and armboard were 192.5 pounds and 21 pounds, respectively, which corresponds to the approximate total body weight of the torso (~55%) and arm (~6%) for the 350-pound patient. The loads were uniformly applied to the centerboard and armboard. The bottom of the centerboard was constrained to prevent its movement, as it would be in practice due to the hospital bed. The radiolucent materials tested were ABS/PC, PC, and carbon fiber. Since no materials were at risk of failing, flexibility was determined to be the deciding factor for ideal material.

End Matter

Author Contributions and Notes

N.B., R.S., J.W., N.M., and K.M. designed research and analyzed data;
N.B., R.S., and J.W. performed research and wrote the paper.
The authors declare no conflict of interest.

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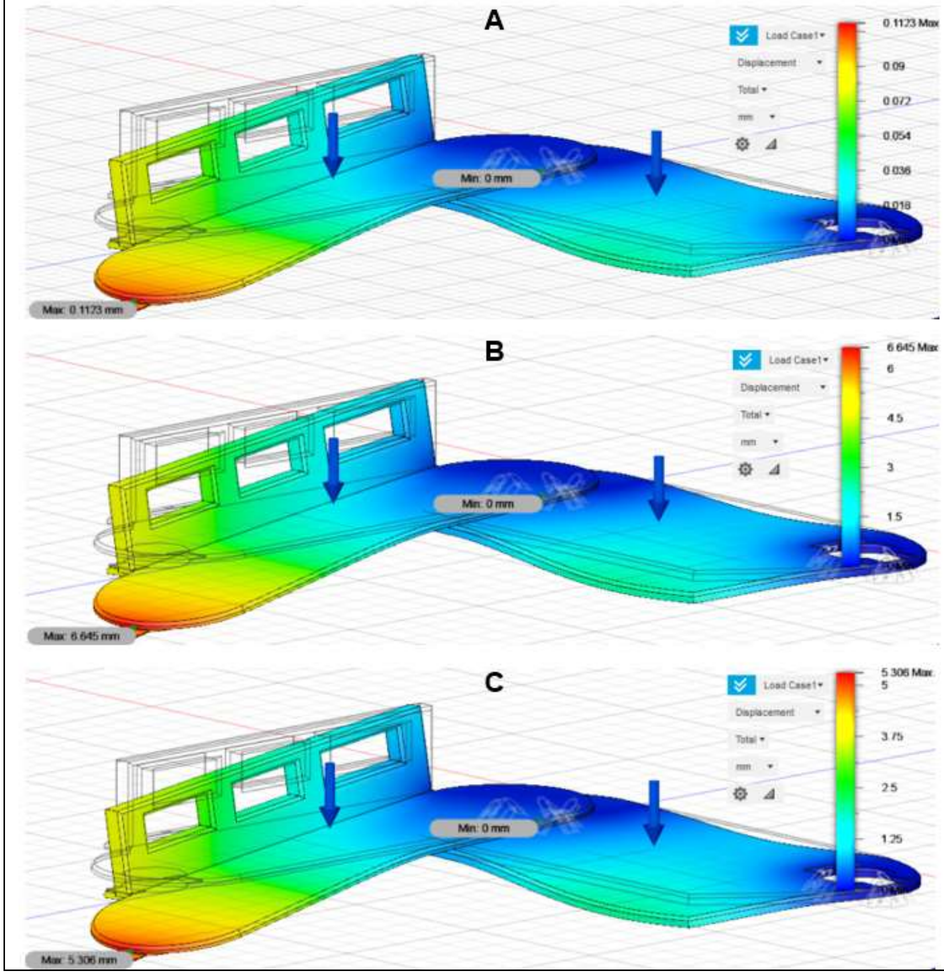
Supplementary Material

Supplementary Table 1: Summary of Interview Responses.

Total Respondents:	25	**Additional features desired:** *(most common responses are included)*	(*9*) Adjustable angle, (*5*) Adjustable padding, (*3*) Longer/wider, (*4*) Better arm constraint, (*2*) Support surgical wires, (*2*) Radiation protection, (*4*) No additional features desired
Labs Represented:	(*11*) EP, (*7*) Cath, (*4*) Radiology, (*3*) OR, (*1*) Echo		
Position:	(*16*) RN, (*4*) Imaging Tech, (*1*) Fellow, (*1*) Physician, (*3*) Other		
Years of Experience:	*Range:* 2mo – 40yr *Average:* 9 +/- 10yrs	**Ideal material(s):**	(*6*) ABS-PC, (*6*) Plexiglass, (*4*) Carbon fiber, (*4*) Padding
Armboards Used:	(*23*) Banjo, (*22*) Siemens, (*4*) Plexiglass, (*3*) OR Models, (*10*) Other (not specified)	**Most negative experiences:**	(*8*) Armboard fell from the bed, (*5*) Fitting the armboard under heavier patients, (*4*) None
Required Functions: *(most common responses are included)*	(*17*) Stability/support, (*8*) Comfort, (*3*) Easy to clean, (*3*) Security, (*2*) Easy to fit under patients		



Supplementary Figure 1: Results from Static Loading Tests Performed on Different Materials.

A) The carbon fiber material has a maximum displacement is 0.11 mm when loaded.

B) The Polycarbonate material has a maximum displacement of 6.7 mm when loaded.

C) The ABS/ Polycarbonate material has a maximum displacement of 5.3 mm when loaded.