Expanding Armrest Module for Electric Bariatric Chair

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Abstract

Bariatric surgery is a critical part of the fight against severe obesity in America. Current medical equipment in the bariatric field does not accommodate patients on the larger end of the spectrum. This affects the quality of care they can receive and can impact the outcomes of their treatments. The aim of this study was to design an expanding armrest module for a bariatric chair to allow customization of armrest width up to 50 inches to provide optimal comfort. First, materials and mechanisms were evaluated to determine the strongest method of moving the components. Then, a novel design was created incorporating a gear system to move the armrests of the chair using computer-aided design (CAD) and simulation techniques. Further iterations and testing must be done on this design before prototyping can begin. The current design does not provide enough strength and support to hold the armrests up when at maximum width. The development of this design serves as a first step in the process of designing and prototyping an expandable armrest attachment for a bariatric chair.

Keywords: bariatric chair, expanding armrest, gear system, optimal comfort

Introduction

Significance

Bariatric care refers to a variety of treatments and procedures aimed at assisting with weight loss in patients with severe obesity. As of August 2023, about 9.7% of adults in America were classified as severely obese[1]. As the obesity epidemic continues to worsen, this number will only get higher. Patients with obesity are at an increased risk of developing diabetes, high blood pressure, heart disease, and many other problems[2]. It is estimated that severe obesity can shorten life expectancy by up to 14 years[3]. Bariatric care is critical in helping patients avoid these deadly diseases and extend their lives. Although the first bariatric treatments were developed around the mid-1900s, the treatment remained largely in obscurity until the 1990s when the obesity epidemic was officially recognized in the medical community[4].

Innovation

In response to the increasing number of bariatric procedures, specialized equipment had to be developed to accommodate larger patients inside hospitals. As patients have continued to get larger, the equipment has not been adapted to fit these needs. Current bariatric chairs used in hospitals have a maximum armrest width of about 32 inches. This allows the chair to be moved through standard width door frames. Unfortunately, this is not wide enough for the largest patients. These armrests can cause injuries to patients that cannot fit comfortably in the chair, which can impact the patient health-wise and economically. These injuries can lead to complications before and after surgery which endanger the patient. It will interfere with the ability for patients to get the best help possible and can also greatly impact the critical recovery period. Technology exists that allows bariatric beds to have expandable armrests, however, it has yet to be integrated into a chair. Incorporating this functionality into a chair can enhance patients' ability to recover dynamically by supporting them from the supine to sitting position. It is unhealthy for recovering patients to spend much of the time lying supine before and after their surgery, as this can cause issues with fluid buildup. An electric chair that can support patients of size is better for physical activity as it allows for more movement, independence, and can support the patient's ability to switch positions. Having an electric chair would allow them to move around and stop them from having a completely sedentary lifestyle, as well as supporting a more robust recovery period.

Aims

The first aim of our project was to prepare and design an attachment to an existing bariatric chair that will allow the armrests to be expanded up to 50 inches so that the width can be adjusted to accommodate the largest patients. This includes research that was done to determine optimal materials and expansion mechanisms to accomplish these goals. The acquisition of a bariatric chair that is in use within hospital systems is a critical component of this process. A basic model of the existing Shuttle A Bariatric chair from Agiliti was created and a design was fabricated around it using computer aided design (CAD). Limitations with both the chair itself and the underestimation of the time required to complete multiple objectives led to multiple reevaluations of these aims.

The second aim of our project was to evaluate the integration of the design module into the existing bariatric chair designs and prepare the design for future work. A potential functional design was developed in a computer-simulated environment, the chair was unable to be disassembled to perform real-life testing. Further plans for the accomplishment of this aim are outlined in the Next Steps section of this study.

Results

Materials Analysis

After some preliminary research, we came to 6 primary materials designated for use within the project. The materials identified were medical grade aluminum, titanium alloy, stainless steel, medical grade PEEK (polyetheretherketone, a semi-crystalline thermoplastic), carbon fiber, and medical grade ABS (Acrylonitrile butadiene styrene, a common thermoplastic polymer). Each material was evaluated using seven key criteria on a scale of 0-100: cost effectiveness, strength-to-weight ratio, durability, ease of fabrication, biocompatibility, corrosion resistance, and weight. While the score we would give each material was based on the research conducted and the criteria for each factor. Cost effectiveness was based on relative material cost per unit volume/weight and the score reflects both acquisition costs and lifecycle value. Strength-to-weight ratio was calculated by comparing tensile strength divided by density. Durability score focused on fatigue resistance, impact strength, and long-term performance. Ease of fabrication score evaluated machinability, forming capabilities, joining methods, and potential tooling costs. Biocompatibility score was based on normal standards for medical devices. Corrosion resistance score was based on resistance to cleaning agents, bodily fluids, and general hospital environments. Finally, the higher the weight score, the material is lighter which is better for handling and portability. Table 1 shows all of the materials, criteria, and their respective color-coded scores. This table is visualized in radar plots in Supplementary Figure 1.

Realistically most of the mechanism will have to be made of metal, with aluminum or steel being the ideal materials. The strength of plastics will not be enough to support any of the custom designed mechanism components or the armrests apparatuses of the chair. The expanding portion of the design as is, is not strong enough to support the armrests. The gear racks used to expand the chair are too small or weak in proportion to the weight they need to hold. In both simulations and the physical prints of the design, this is the case showing room for improvement in these areas. While metals will be costlier to work with and acquire, they are necessary for the constraints of the project.

Expansion Mechanism Analysis

A preliminary survey of existing mechanisms was conducted to determine potential methods of expanding the armrests in our design. The most common mechanisms identified were belt, gear, and chain systems. Each mechanism was graded using seven important factors: smoothness of motion, noise level, maintenance, durability, cost, and load handling. The grades were determined based on research of each mechanism's performance in other medical devices. Table 2 shows each of the systems and the grades for each of the criteria. Load handling and durability were deemed to be the most important criteria due to the need for high load tolerance in the constraints of our project. Therefore, we identified the gear system as the ideal choice for our design. It was the only system that had good

Table 1. Materials Comparison Analysis. Each material was graded on a scale of 0-100 on the 7 key criteria. Aluminum or steel was chosen due to superior weight capacity. Color gradient was added, with green indicating positive and red indicating negative.

Score out of 100	Cost-Effectiveness	Strength to Weight Ratio	Durability	Ease of Fabrication	Biocompatibility	Corrosion	Weight
Medical Grade Aluminum	75	70	75	85	70	65	80
Titanium Alloy	45	90	95	60	95	95	85
Stainless Steel	65	60	90	70	85	85	40
Medical Grade PEEK	35	65	70	65	90	95	90
Carbon Fiber	30	95	80	55	80	90	95
Medical Grade ABS	85	50	55	90	75	75	85

durability and load handling while also being quiet and low maintenance. The only concern with the gear system could be the cost of buying gears or machining custom ones, however, we believe that the potential for this system outweighs these costs. This led to the decision to use as many pre-made components as possible in the design. This will allow us to highlight both reproducibility and ease of access when attempting to integrate the design. This area is one of the most critical spots of future innovation within the design. Finding a way to properly support the armrests, expansion gearbox, electronics, and the expanding arms is the most constraining aspect of the design process.

Table 2. Comparison of expansion mechanisms. Belt, gear, and chain systems were ranked from 1-5 based on 7 different criteria. The gear system had the highest average rating and was chosen for the design.

Feature	Belt System	Gear System	Chain System
Smoothness of Motion	4	5	3
Noise Level	5	5	2
Maintenance	5	5	1
Durability	2	5	5
Cost	4	3	3
Load Handling	3	5	5

Design Development

Before the acquisition of the Shuttle A Bariatric chair, we had attempted to make some preliminary designs for a gearbox and expansion mechanism. This design was a simple gear-based expansion design. Using real gears and gear racks from the McMaster-Carr catalog that is integrated with Autodesk Fusion 360, a computer aided design software, we created a simple mechanism where a central gear would turn clockwise and send the gear racks outward in opposite directions while in parallel (Figure 1). This included two 48 pitch rectangular gear racks 18 inches in length (6832K74) and one 20-degree pressure angle, roundbore, 48 pitch, 48 teeth metal gear (7880K24). The component number in McMaster-Carr follows each respective component. While this exact gearbox could not be transferred into the final product, it was used as a basis for the future expanding mechanism.

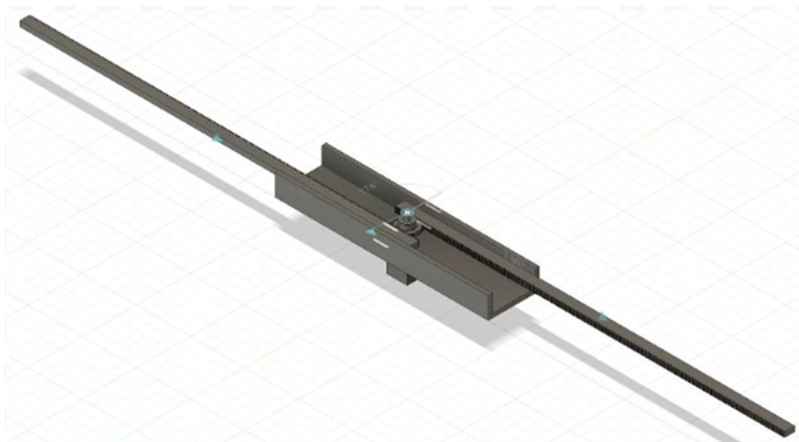

Fig. 1. Preliminary gear design in expanded position.

Following the acquisition of the bariatric chair, a preliminary CAD model of the Shuttle A Bariatric chair by Agiliti was created. This model only included the frame, armrests, and electronics box of the chair. These were identified as the main constraints that would interfere with how we originally saw the mechanism working. Secondary components like the seat, backrest, and leg rests were left out as they were not essential constraints to our design. This skeleton model laid the foundation for the space that our design had to fit to avoid interference with the ground or other components of the chair (Figure 2).

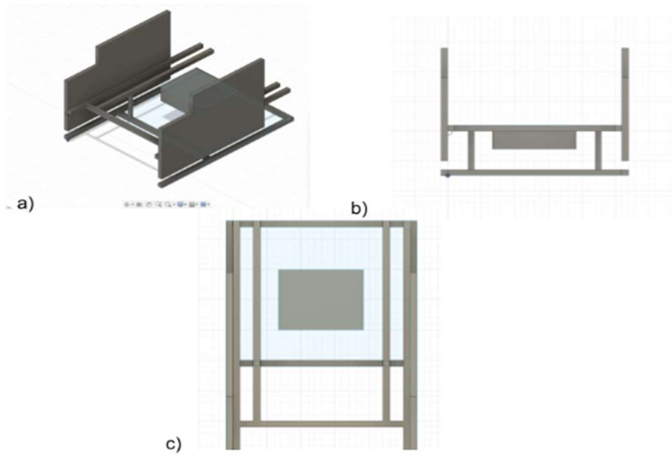

Fig. 2. Basic diagram of chair frame and components. The box in the center represents battery and electronics box that is connected to the seat. The seat was not included to visualize the space that our module will go in underneath. a) Isometric view, b) front view, c) top view

The iterative process followed how we navigated through each of the constraints and features of the design. This started with highlighting similar McMaster-Carr components that could be used from the initial design phase. After determining which components to use, we then would design around the skeleton model of the chair and the components as restraints. We used: one 18-inch long 5/8-inch diameter 1566 carbon steel rotary shaft (1346K513), six 12 pitch 18 teeth high-power metal miter gears (7655K3), two 20-degree pressure angle round bore 16 pitch 48 teeth metal gears (5172T24), and two 20-degree pressure angle rectangular 16 pitch 2 feet long metal gear racks (5174T2). These were determined after some iteration with various types of these components, but these fit the constraints the best. The rest of the developed components would have to be custom made in order to fit the previously mentioned constraints. These gear-racks would allow the chair to expand up to the required 50 inches. The gearbox was designed to be attached to the bottom of the electronic box that was already a part of the chair. It would then attach to the custom designed supports and gear-rack rails to allow for the mechanism to expand. Since all these parts were already made to work with each other, the gear mechanisms themselves should work without issues (Figure 3).

The largest problem with the current design regarding the proposed mechanism is that it may be too heavy and cause the structure of the chair itself to fail. Even with the support structures we have designed, at the current point in the design, we cannot simulate real-life use cases. This means that a lot of the prototyping process and continuation of the design process must start to take more actionable, reality-based constraints into account. Whilst we believe this iteration could work, we know that if it were to be applied as is, it would most likely fail to complete all the intended use cases.

Fig. 3. Final CAD model of design. Isometric frontal point of view of final mechanism in retracted and expanded positions.

Discussion

The results of this project provide a starting point for the development of an expandable armrest attachment for a bariatric chair. The design fits within the existing components of the chair and allows for expansion of the armrests up to 50 inches. Further testing is required to verify that the materials and gear system that we identified as optimal can support the weight of the armrests when expanded as well as a patient sitting in the chair.

Next Steps

The accomplished design is limited in its capability and requires further testing and iteration to become viable. The model was 3D printed to demonstrate the functionality of our design (Figure 4). The armrests snapped at the attachment point under their own weight showing that further strength and tensile testing are required before a prototype can be manufactured. Once extra supports are added and sufficient strength is demonstrated in a computer simulated environment, preliminary prototyping on the chair itself may begin. Due to the size of the device, costs of the materials, and specialized tools needed to implement the design, the computer model must be perfected before real-life testing can begin.

Fig. 4. Failed 3D model of design. First attempt at 3D printing the proposed design. Armrests snapped at attachment point due to excessive loading.

If a design cannot be perfected using the materials and gear system we identified, future work could include analysis of other materials and mechanisms. There are many other metals that could be utilized beyond the ones we identified. Another potential mechanism for expanding the chair that we did not fully investigate is a hydraulic system. Hydraulic systems are also common in various medical devices, especially when precise movement and high strength is required. We believed this system was too complex and expensive to consider at this phase of the design, however, further research could reveal that it may be viable.

The normal timeline for medical devices of this caliber is usually on the magnitude of decades. We understand that our work has only just scratched the surface as to what is possible, and the constantly changing scope and nature of the project has led to less progress than we had initially hoped for. After the acquisition of the chair, the constraints were much more complex than anticipated, and it would require more experience in mechanical engineering to take the chair apart. This hopefully can be fulfilled by a future group that can take our work as a basis and jumping point for beginning to work on a prototype involving the chair.

There are a few key directions that a future group can take regarding this project. They can improve the model of the bariatric chair in CAD in order to allow for better simulations and more realistic design. They can continue to better modify our final design (Supplementary Figure 2) and make it more robust, dynamic, and realistic. Finally, they can take apart the chair and then design based on how they want to constrain the design after taking apart certain pieces. We hope to have eliminated a large part of the research and time-consuming non-design work needed to progress (materials and mechanism research). This project in the future should be advertised as a hands-on device design project. There is a lot more mechanical, electrical, and materials engineering put into this project than initially thought, so there should be a pivot to finding potential future groups that are strong in these areas. Those who have more experience in CAD and mechanical physics, rather than biology and data science are ideal for this type of project and can greatly enhance progress. We believe that this is only a starting point in terms of a much larger project, and hope that more groups will be able to not only make this product a reality but keep innovating and improving so that the design can achieve an ideal result for what is intended.

Future Work

Once these steps are completed, the finalized design will be ready to be integrated into an existing bariatric chair. After the design is completed and integrated, FDA approval will be required for the commercial application of the device. The device would be classified as an accessory to a Class II medical device meaning it would likely require either an Accessory Classification request with a 510k Premarket Notification or a De Novo classification request so that the FDA could evaluate the risk of the device[5-7]. In addition to FDA approval, the device would need to be compliant with standards and regulations from other organizations such as the International Organization for Standardization (ISO) and International Electrotechnical Commission (IEC)[8-10]. Both of these organizations also set regulations for safety surrounding medical devices. Further research into these specific organizations and their regulations will be required when getting approval for this device to be used in clinical settings.

Challenges and Limitations

The delays with acquiring the Shuttle A Bariatric chair presented the main challenges of this project. Despite starting the ordering process in early November, the chair was not delivered until late January. During this time, it was very difficult to begin designing the attachment due to uncertainty around the dimensions of the chair. No designs or blueprints were available online so CAD drawings were not able to be started until the chair could be measured manually. During this time, the group focused on identifying potential materials and mechanisms to be used in the design.

Once the chair was delivered, further challenges and limitations with the design were identified. We had originally thought that the chair could be easily disassembled so that an attachment could be integrated without the use of specialized tools. However, after surveying the chair, we discovered that major components of the armrests were welded to the frame of the chair. This limited our ability to fabricate a design as it would now require the detachment of the armrests from the frame. Due to the difficulties required to detach the armrests, as well as the risks it poses to the integrity of the chair, the CAD model is the only part of the design process we were able to develop. The constraints of the chair itself when translating it to CAD was difficult and time-consuming. There was a lot of time spent researching the background information as well. As discussed in the Next Steps section, we hope a future group can perfect our design and begin prototyping a real-life model with the chair we were able to acquire.

Materials and Methods

Materials

The Shuttle A Bariatric Chair by Agiliti was used as a base for the design of our device. A refurbished version of the chair was purchased from CeviMed, a medical equipment and supply website. The chair and shipping totaled to $1350, which is about 10% of the cost for a new version of the chair. This chair has existing movement mechanisms incorporated into it that allow for adjustments to the height, seat angle, and reclining position.

Each of the McMaster-Carr parts has a corresponding price that could be used to identify a potential cost for the current design. The rotary shaft (1346K513) is $21.89. The high-power metal miter gears (7655K3) come in pairs for $348.16 per pair, so $1044.48 in total. The 2 metal gears (5172T24) are $ 98.52 each or $197.04 total. Lastly are the 2 metal gear racks (5174T2) that are $36.86 each or $73.72 in total. All the premade components combined would cost $1337.13, so we highly recommend validating and finalizing specific premade components before purchasing as they can end up being costly.[11-16]

Methods

Mechanical Modeling and 3D Printing

All iterations of the device were modeled in the CAD software Autodesk Fusion 360. The Shuttle A Bariatric Chair was measured using a tape measure and recreated in the software. Parts used in the design were imported from the McMaster Carr catalog[11-16]. Basic functionality of the device was tested using assembly simulations in Fusion. Changes to the CAD model were made based on the results of these simulations. A 3D model was printed using a Ultimaker s5 3D printer.

End Matter

Author Contributions and Notes

Parsia, D. completed the initial skeleton model of the chair in CAD and advised on the expanding mechanism CAD. Wisoky, J. completed the iterations regarding the expanding mechanism and gearbox. Parsia, D. and Wisoky, J. completed analysis and mechanism/materials research and wrote the final report.

The authors declare no conflict of interest.

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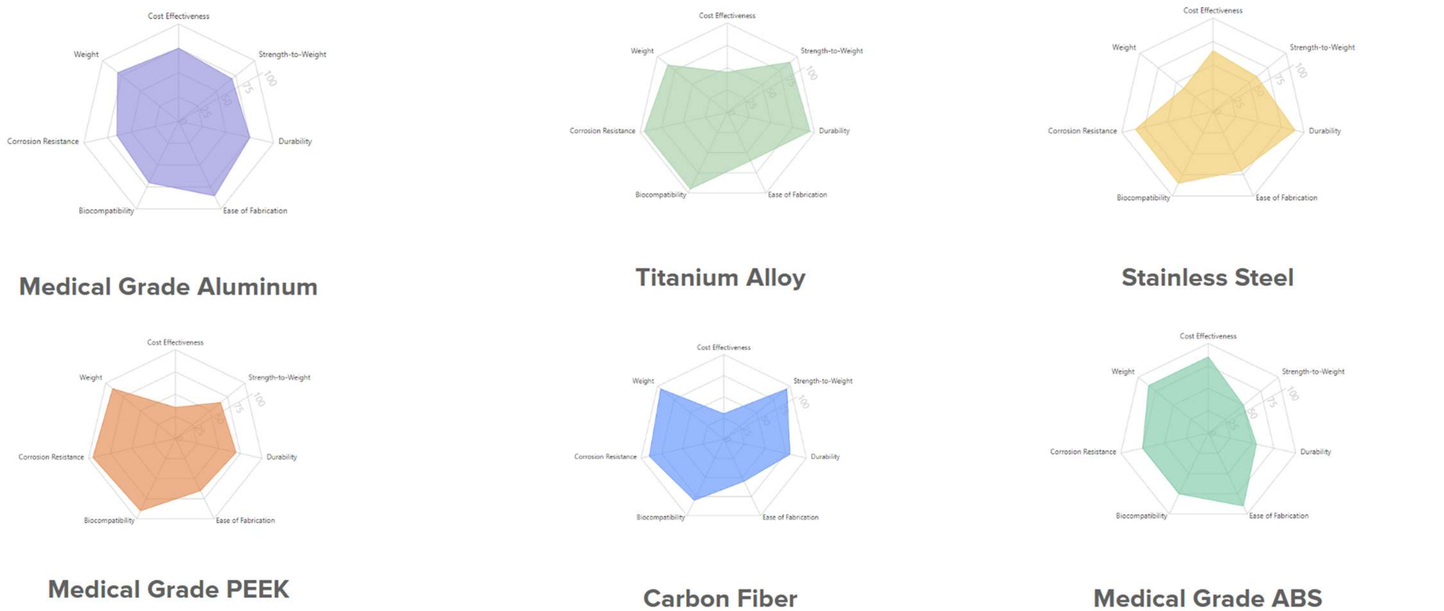
Supplementary Figures



Supplementary Figure 1. Radar plots for visualization of materials analysis. *Using the data from Table 1, radar plots were generated for each material analyzed. The radar plots help visualize how well rounded each material is and can help identify points of weakness.*

Supplementary Figure 2. Final design of supports and mechanisms without the armrests. *This is the Final CAD design of the proposed mechanism with the custom supports and gearbox. The armrest panels are removed to highlight the design isometrically and from the top down.*