DESIGN AND DEVELOPMENT OF A LIGHTWEIGHT DURABLE ADJUSTABLE COMPOSITE BACKREST MOUNTING

by

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Eun-Kyoung Hong, M.S.

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As prevalence of wheelchair usage has increased, wheelchair manufactures are required to provide more and better wheelchairs because of secondary injuries such as pressure sores and repetitive strain injuries. Better qualified wheelchairs provide more adjustment, so wheelchair components have been developed to provide that adjustment. Among the wheelchair components, a backrest is one of critical components of the wheelchair due to the importance of seating position and appropriate trunk support.

The Lightweight Durable Adjustable Composite (LWDAC) Backrest Mounting project consisted of three design iterations, prototypes, durability testing, and user evaluation. The backrest mounting is adaptable to most ultralight manual wheelchairs. The backrest is designed with features including height, width and backrest angle adjustment. The angle adjustment adds adjustability and flexibility to a rigid backrest and can be operated with only one hand, without high strength or dexterous manipulation.

The LWDAC was tested with ANSI/RESNA durability and fatigue test standards and passed impact test, static stability test and durability test, but not fatigue test. This study also included focus groups to gather user and clinician feedback regarding backrest characteristics. The backrest had overall positive response from participants. The participants agreed the backrest mounting can be operated with one hand, felt comfort when seated, and wheelchair

users were interested in purchasing the backrest and clinicians indicated they would recommend the LWDAC backrest.

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PREFACE

I have appreciated the opportunity to broaden my education and expand my horizons, at the Human Engineering Research Laboratories and the Department of Rehabilitation Science and Technology. I would like to thank Dr. Rory Cooper and especially Dr. Jon Pearlman, whose door was always open to answer my questions and offer his encouraging support throughout my project. I must also extend my gratitude to the member of my thesis committee, Todd Hargroder for his assistance and guidance. I would also like to thank my academic advisor, Dr. Diane Collins, for her support. Additionally, I would like to thank all the students and staff at HERL for support, patience and friendship, especially Mark McCartney and Jeremy Puhlman for their patient education in the machine shop.

Finally, I also appreciate my parents and my brother's family for all the love, support and patience they have given me during my master's program. To my family, you have been my rock and a role model of an attitude toward life. I would also like to extend my thanks to my friends for making my time in Pittsburgh truly special.

1.0 BACKGROUND

1.1 WHEELCHAIR USAGE

In the United States, roughly 21.2 million people currently have limitations in basic physical activities, such as walking, climbing stairs, carrying, or lifting. [1] World-wide, over 100 million people with physical disabilities use wheelchairs for their primary means of mobility. The use of wheelchairs has increased for several reasons: birth defects, accidents, debilitating diseases, and advanced age. Based on the report from the World Health Organization, more than 29,000 people annually have unexpected injuries. Advances in healthcare have helped individuals with serious injuries and severe disabilities live longer. Current estimates of persons with spinal cord injury range between 250,000 and 400,000. [2] As a result, experts anticipate that the need for wheelchairs worldwide will continue to increase, up to 22 percent, over the next 10 years. [1, 2]

As the rate of wheelchair usage increases so has the demand for wheelchairs, which has led to an expanded market that continually demands providing better wheelchairs and seating systems. Based on innovations in technology, people are living longer, and are participating in the community at higher rates. Like individuals without disabilities, the demand to maintain an active lifestyle is also present among people with disabilities and wheelchair technology is integral to maintaining an active life style for individuals with a disability. Wheelchairs allow

people with disabilities to enhance function, to increase independence, and to have greater accessibility to the home and community. [3, 4] The lack of a wheelchair is the main cause of limited participation to people with spinal cord injuries. As a result, the wheelchair is most important mobility component for this population [3, 4] and as the individual begins to adapt to their disability, they consider a wheelchair as an extension of their body. Any wheelchair is a critical component to meet users' expectations, preferences, physical needs, and functional requirements. [5]

Different types of wheelchairs have different comfort and ergonomic ratings, due to the varying qualities of different wheelchairs. A wheelchair that had more adjustability received higher ratings on comfort and ergonomics compared to a wheelchair with minimal adjustability. [6] As the supply of manual wheelchairs increases, the demand of making them safer, more effective, and more readily available is necessary. [7]

1.2 IMPORTANCE OF A BACKREST

It is a challenge to recommend a particular wheelchair because wheelchair configurations are determined by the wheelchair users' comfort, possibilities of transfer, and efficient propulsion.[8] Many wheelchairs have adjustable axle position, seat depth, footrest height, and tilting angle and reclining angle. [9] Among adjustability features, changing the height of the footrests, changing the height of the axle and changing backrest angles are the only adjustments to that can be made to shift peak pressure or provide pressure relief. According to a study on the effect of changing tilt and seat-to-backrest angles during wheelchair propulsion, seat angle could be determined by a combination of user comfort and clinical pressure modulation that would

minimize the risk of overuse shoulder injuries that may be caused from pressure relieving activities. [10] As the backrest provides pressure relief and postural support, it is an essential part of wheelchair configuration. [8]

Differences in postural alignment and shoulder flexion range are observed between wheelchairs with standard configurations and wheelchairs with posterior seat inclination and a low backrest which was set perpendicular to the floor. The wheelchairs with posterior seat inclination and low backrest set perpendicular to the floor give significantly more active upper extremities' flexion while the backrest supports the lumbar spine to maintain anterior pelvic tilting. Additionally, the angle of the backrest provides the wheelchair user space for posterior tilting. [11] In another study, balance control and postural muscle use were tested in various seating conditions. The researchers compared a standard chair (10 degree reclining) to an adjustable chair that tilted 7 degree, 12 degree and reclined 22 degree to provide a more stable sitting posture. They found the configurations from the adjustable chair provided increases in reaching distance and in individual pressure distribution by decreasing peak pressure. The researchers also found that these adjustments have a positive impact on transfers and wheelchair propulsion. [8] Thus, the type and configuration of the backrest has a significant impact on the safety and function of the wheelchair user.

In addition to postural support, the backrest protects and supports the spine which is one of the most important structural parts in the body. Because the weight of the upper body is sustained through the spine, it is an imperative structural component; therefore, the protection or support of the spine is essential. Boninger et al. conducted a study in which a group of individuals with tetraplegia was radiographically measured kyphosis and scoliosis. According to this study, people with tetraplegia have a higher incidence of kyphosis and scoliosis than people

without paralysis. [12] In many cases, wheelchair users have insufficient muscle strength to support and control the spine, so the spine tends to be become bent and deformities of the spine are caused by the forces of gravity. When the wheelchair backrest does not provide proper postural supports to a wheelchair user, combinations of lordosis, kyphosis, and/or scoliosis postural deformities may develop. [13]

According to a seating and positioning specialist, [14] pelvic stability affects shoulder mobility which is crucial to wheelchair users weight-bearing and movement. Wheelchair users have to perform tasks during the day in a seated posture and the seating for each task performance is not consistent throughout the day. It has been suggested that the seating system allow for changes in posture. The seating and positioning specialist also emphasized the use of a tilt-in-space function during the individual activities. [14] As an analog to the wheelchair, the office chair design is a critical factor to determine the comfort and health related to sitting throughout the day. Typical sitting for about 2 hours in an office chair could facilitate the development of pain even if the office chair is well-designed and ergonomic. Therefore, frequent repositioning while sitting is recommended in an able-bodied population. [15, 16] Likewise, frequent changes of position in a person's wheelchair are also highly recommended. Therefore, adjustability of wheelchairs is useful.

An adjustable backrest is an important feature to provide appropriate trunk support in several different circumstances. For example, while propelling a wheelchair uphill or downhill on a ramp, the wheelchair user should lean into the ramp to minimize the risks of injury or feelings of instability; adjusting the backrest angle to provide trunk support would help with this activity. Also, the adjustment of backrest angle could help make it easier for users to dress and perform other activities of daily living. Also, wheelchair users have individual preferences for

their postures in daily activities, making adjustability an important feature. [17-20] Because of the increasing number of wheelchair users, providing an adjustable backrest is necessary due to the importance of seating position and appropriate trunk support and the variability of wheelchair users needs and back problems.

1.3 COMPARISON OF COMMERCIAL BACKRESTS

Backrests have different characteristics such as height, shape, stiffness, weight, and adjustability. Based on the height of the backrest, wheelchair users are provided different support and functions. Lower backrests provide freedom of movement with less stability while higher backrests provide more support, but may limit mobility for propulsion. The rest of characteristics are unique depending on the specific type of backrest. Manual wheelchairs are commonly fitted with one of three types of backrest: sling upholstery, rigid, or custom molded. Most manual wheelchairs come standard with sling upholstery for the backrest and are typically made of fabric or leather. The rigid backrest is one of the most recommended backrest to support the user's posture as a combination of a back cushion on a rigid frame. The custom molded backrest is an individualized backrest for a person who has particular deformity. Each has different perspectives which could be advantages or disadvantages.

The sling upholstery backrest has a rectangular shape based of frames of wheelchairs' tubes. The materials of sling backrest stretch out to create the wheelchair backrest. Because of the extensibility of the material, it has 'give' and the backrest contours to the shape of spine. An advantage of this type of backrest is that it can be used by a wide range of people because it conforms based on the back shape and posture, and thus it is common and useful especially for a

folding wheelchair. The flexibility of this backrest also makes it ideal for folding wheelchairs which are easily transportable. A primary drawback to the sling backrest is that it does not provide a stable base of support for posture.[18, 21, 22] Consequently, lack of postural support may cause back pain, [23] and /or postural deformity.

Figure 1. Linear nylon upholstery backrest

The rigid backrest has different features compared to the sling backrest. The rigid frame is designed to form a trapezoid shape that more closely resembles the shape of the back. Even though there is cushion on the backrest, the frame is firm. Therefore, it is generally not adjustable and is sensitive to the user's body size. However, it provides a solid base of support for appropriate posture, so it is most appropriate for users without a postural deformity.

Figure 2. Rigid backrest

The custom contour backrest is shaped individually, and is big and bulky. This type of backrest covers the entire spine and fills spaces to support deformity of spine. It is very individualized product, so it requires intensive labor. The quality of the custom molded backrest depends on clinicians' skills. [18, 21, 22]

Figure 3. Custom molded backrest

Table 1. Advantages and Disadvantages of Different Types of Backrest

Backrest	Advantages	Disadvantages
Linear nylon upholstery backrest	- Adjustability - contours to shape of spine - lightweight	- less stable - clinical backgrounds
Rigid backrest	- good stability - comfort	- less adjustable - sensitive to fit - weight added
Custom molded backrest	- individualized - specific to a particular deformity	- weight added - intensive labor - affected by clinicians' skills

Among the three types of the backrests, the standard sling upholstery for the backrest has been used by most wheelchair manufacturers and wheelchair users. As mentioned earlier, the sling upholstery has flexibility. Additionally, some of those sling backrests have adjustable tension, so wheelchair users can periodically use the adjustability of tension to assist in pressure relief activity. However, it provides less postural support. In addition, it provides little back support while the user participates in dynamic activities such as propelling up and down ramps, over various surfaces and over obstacles. [18, 21, 22]

A backrest comparison study with people with recent spinal cord injuries compared three different back supports while performing 4 functional tasks. The 4 functional tasks included timed forward wheeling, forward vertical reach, ramp ascent, and 1-stroke push. The three back supports were standard sling upholstery, Jay J2 back (rigid backrest), and Pindot Pax-Bac. The reaching activity of the functional performance was significantly greater when the J2 was used. Also, people were more satisfied with the J2. [18, 21, 22]

1.4 SIGNIFICANCE OF STUDY

As previously mentioned, the prevalence of wheelchair usage has increased. Accordingly, wheelchair manufactures are required to provide more and better wheelchairs because of secondary injuries such as pressure sores and repetitive strain injuries. The better wheelchair provides more adjustment, so wheelchair components have been developed to provide that adjustment. Among the wheelchair components, a backrest is one of important parts due to the importance of seating position and appropriate trunk support. A manual wheelchair usually comes with a sling backrest and the standard sling upholstery backrest has been used by most wheelchair users. This type of backrest offers wheelchair users some advantages such as periodical adjustability of tension to assist in pressure relief from sling backrest. However, it does not have appropriate postural supports. Accordingly, wheelchair users commonly have back pain and neck pain [24] due which the seating system may contribute to. For improvement of postural support and comfort, rigid backrests have been used. [25] However, it has difficulties of some functional limitations because they are not adjustable by the user and hard to reposition in a chair. As a result, an adjustable backrest design with the benefits of a rigid backrest would be appropriate and useful.

2.0 STATEMENT OF PROBLEM

Based on the above significance, the goal of this project was to design and construct a lightweight, durable, adjustable, composite (LWDAC) backrest for ultralight manual wheelchairs based on benefits of rigid backrest for promotion of healthier and more functional mobility. The starting point of this work was a first-generation LWDAC design which met ANSI/RESNA standards and was evaluated by a focus group. This original design included angle adjustment from -5 degree to 55 degrees (i.e. 85 degrees to 145 degree w.r.t. horizontal). No tools were necessary for any of the angle adjustments. The backrest has horizontal adjustment (fore-aft) ranged 25.4mm (1 inch) and the height selection according to wheelchair frame tubes. Those adjustments were appropriate and useful for most of the users, allowing them to adjust the backrest angle easily and safely.

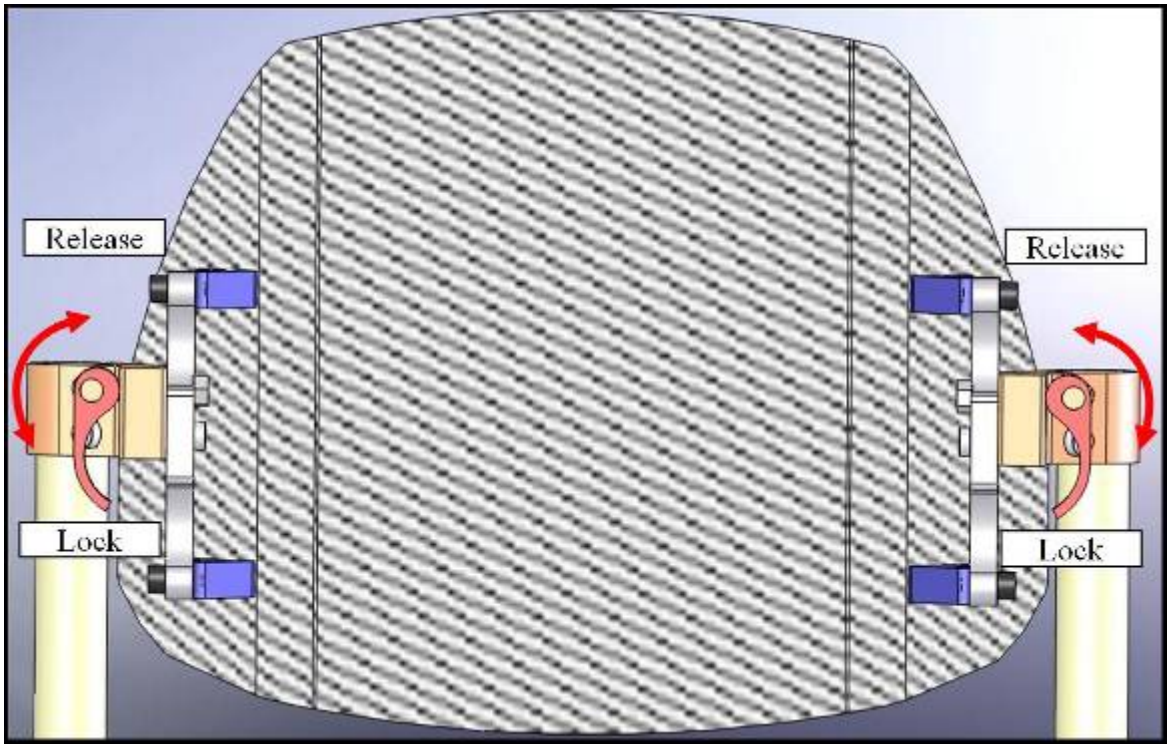


Figure 4. Method of angle adjustment of the previous prototype

However, the previous prototype created a demand for the wheelchair users' to have a high degree of upper extremity strength and dexterity due to need to tighten and loosen the backrest cam-lock adjustment mechanism. Also, the previous prototype required using two hands or one after the other for adjustment. Therefore, it was not easily adjusted by wheelchair users who lacked upper extremity strength and dexterity. The specific improvements required from the previous design were angle adjustment with only one hand, with less strength or complicated procedures.

3.0 AIMS

The overall purpose of this study was to redesign a lightweight, sturdy, user-adjustable, easily set-up and ergonomic backrest support for ultralight wheelchairs to satisfy the needs of wheelchair users. The aim of this project was to improve the previously tested backrest design to maximize functionality and ease of use. The angle adjustable backrest provides necessary postural support and a variety of positions to ease dressing, propulsion, and seated comfort.

Objective #1: Develop a commercially ready prototype of the Light weight, Durable, and Adjustable Composite (LWDAC) Backrest that meets the following design criteria.

Design Criterion #1a:

Improve the ease and simplicity of adjusting the LWDAC backrest by or for the user.

Hypothesis #1a:

Participants will rate the LWDAC as superior on overall performance related to strength, simplicity, arm position, body position, and feeling safe or secure while they operate the recline adjustment by a visual analog scale.

Design Criterion #1b:

Enhance the aesthetic appearance and add features necessary for achieving commercial readiness.

Hypothesis #1b:

The LWDAC backrest will receive favorable overall ratings as measured by a visual analog scale.

Design Criterion #1c:

Expand the accommodation and fit of the LWDAC backrest to a wider range for ultralight wheelchairs.

Design Criterion #1d:

Design for manufacturability and create documentation for commercial production sourcing.

4.0 BACKREST DESIGN

The backrest mounting design has evolved several times. The initial design was improved based on the feedback from an initial focus group. This section includes several design iterations with advantages and disadvantages of each change discussed. This section will start with a detailed description of the initial design of the backrest mounting prototype and continue with a discussion of its advantages and disadvantages. Based on feedback from clinicians, potential users and engineers, performance improvements were requested. Each associated design change was based on information from previous design and feedback from professionals.

4.1 INITIAL DESIGN

4.1.1 Concept description

The initial prototype of the LWDAC consisted of several aluminum parts and a cam-lock device. The cam-lock connects a pivot bar to a bracket which is connected to the wheelchair. The brackets are attached to the vertical tubes of the wheelchair frame with clamps. There are four brackets which are triangular in shape. These were attached to the backrest to provide the connection between the backrest itself and adjustment mounting. Two brackets on each side are attached vertically to the backrest, and one pivot bar was also vertically connected. (Figure 5)

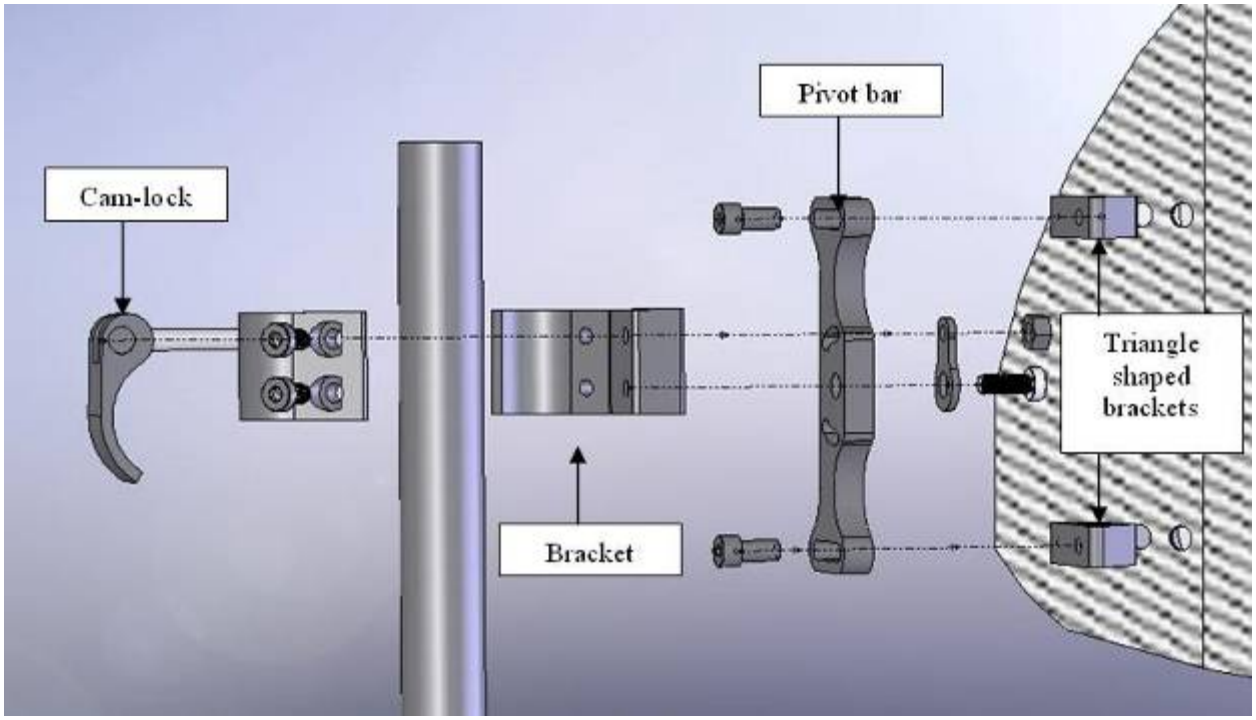


Figure 5. Explosion view of previous design

The pivot bar has several slots and holes for different purposes. Around the center of the pivot bar, there are two symmetrical slots at the each end for screws to attach to the triangle shaped brackets. There is one hole in the center for the pivot point which provides the angle adjustment of the backrest. There are two arc shaped slots near the center hole to limit the angle of recline. (Figure 6) The bracket, which is permanently attached to the vertical tubes of wheelchair frame, has two holes. One hole is for the cam-lock and the other hole is for the straddle, which limits the angle of recline.

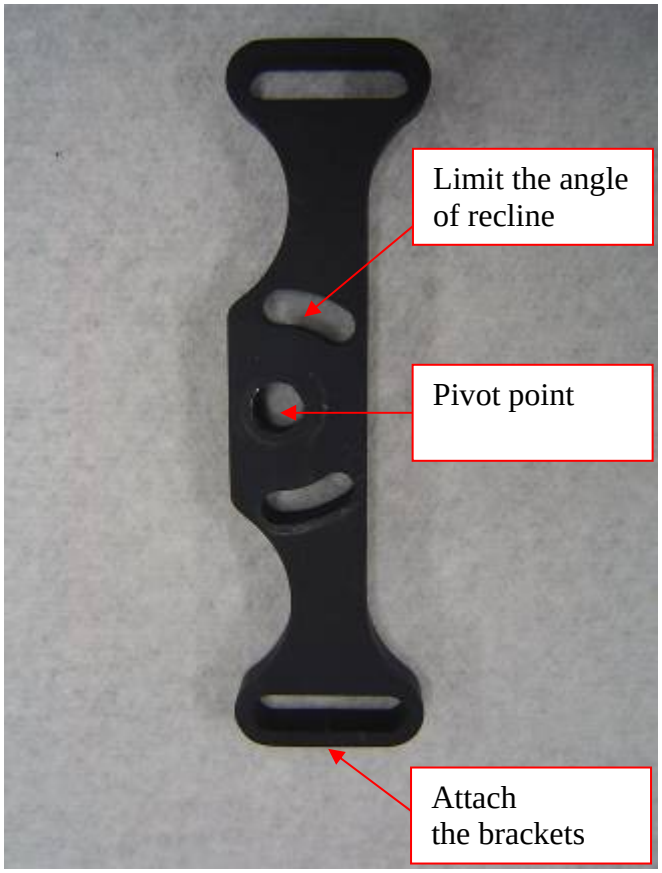


Figure 6. Pivot bar with description

The cam-lock mechanism is a connection for the pivot bar and the bracket that houses all the pieces of the backrest mounting. When it is released, it allows the backrest to recline/incline and fixes the position when it is tightened. As mentioned before, the two arc shaped slots allow the backrest to incline to -5° and 55° based on a vertical reference line. (Figure 7)

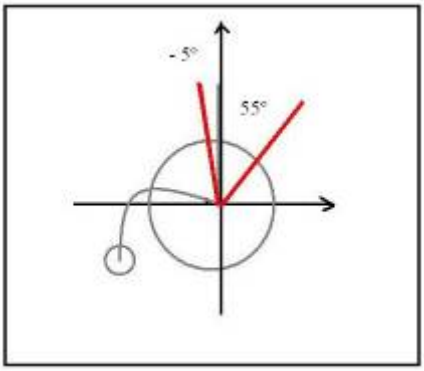


Figure 7. Range of incline -5º to recline 55º

It is possible to adjust the height of the backrest attachment bracket where it clamps onto the vertical frame tubes of the wheelchair. To adjust the height of the backrest, it is necessary to untighten the bolts holding the clamp together; therefore, it is not adjustable by hand. However, it can be adjusted by anyone without the need for special training. It also has a horizontal adjustment (fore-aft). This adjustment comes from the pivot bar slots which are connected to the triangle-shaped brackets. The slots are 25.4mm (1 inch) long, which gives 25.4mm (1 inch) of horizontal adjustment. (Figure 8)

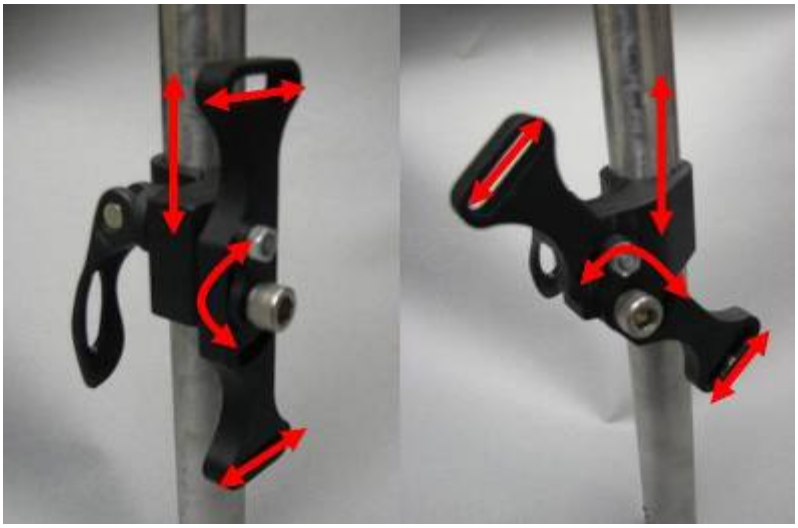


Figure 8. Adjustments of previous design

The components were designed using the 3D modeling software SolidWorks and prototyped using a Stereo Lithography Apparatus (SLA) machine (3D Systems, Inc) to verify operation. The final components were made from aluminum, which made them durable. The cam-lock was strong enough to fix the backrest position and connect all the components.

4.1.2 Concept advantage

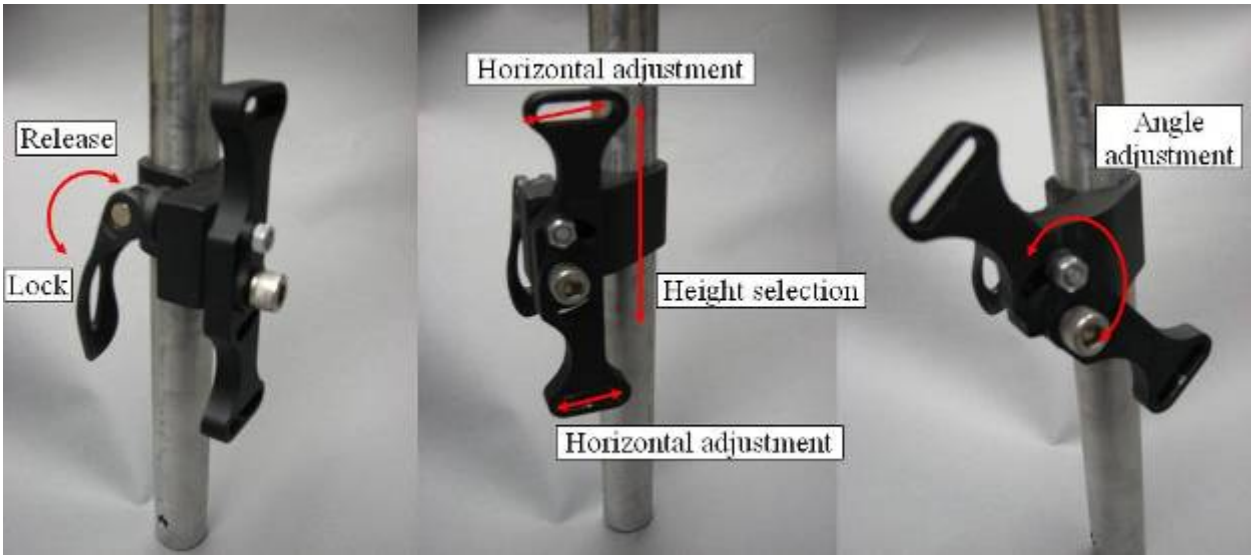


Figure 9. Method of angle adjustment (left), adjustments (middle) and angle adjustment (right)

There is continuous angle adjustments from -5° to 55°, a horizontal adjustment (fore-aft) of 25.4mm (1 inch), and height selection. The backrest can also be used on any wheelchair if there are two vertical bars on the frame. (Figure 9)

4.1.3 Concept disadvantage

As there are merits, this design also has several demerits. Even though the cam-lock works well on the backrest mounting, it requires a high level of strength and dexterity to fix the backrest in one position. Also, there is one cam-lock on each side. The wheelchair user must use two hands simultaneously to operate the cam-locks, or one hand following the other. While proceeding separately, there is a possibility of angle variance on each side. The system works well to allow the user to recline easily. However, when bringing the backrest forward, the wheelchair user needs to lean their trunk forward while pulling the backrest forward, and then

they need to tighten the cam-locks to secure the position. While wheelchair users are going through these procedures, their position can be awkward and uncomfortable.

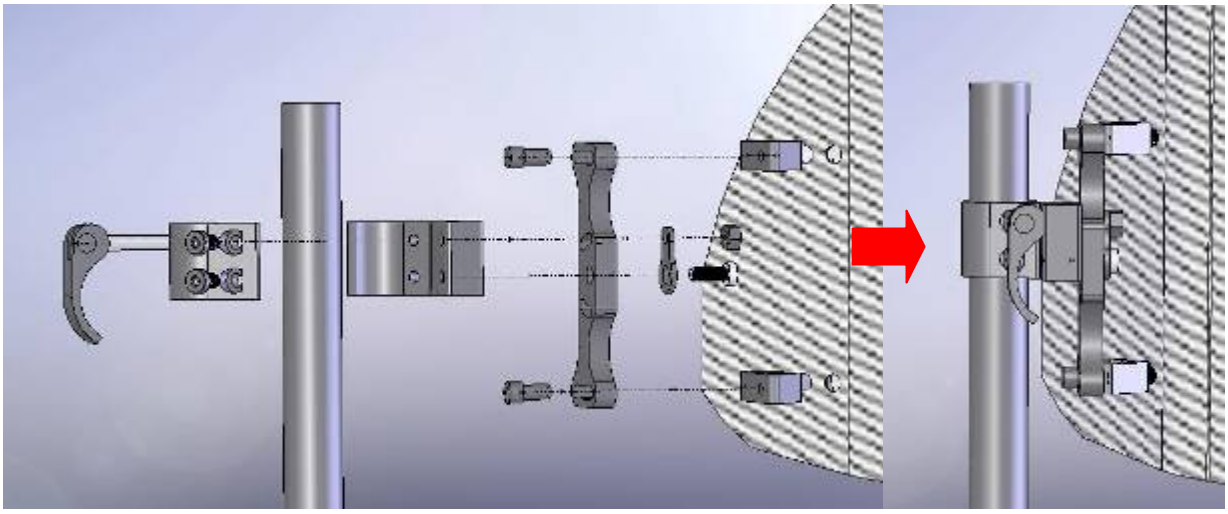
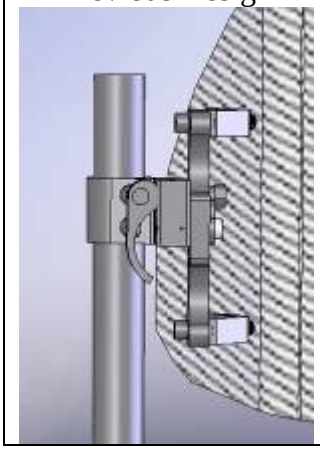


Figure 10. Assembly (left) and fully assembled (right) device

Table 2. Advantages and Disadvantages of Previous Design

	Advantages	Disadvantages
Previous Design 	*Horizontal adjustment (fore-aft) of 25.4mm (1 inch)	*Two hands operation
	*Height selection of 254mm (10 inches) and 355.6mm (14 inches)	*Required a high strength and dexterity
	*Cam-lock mechanism to lock the backrest at various angles – continuous angle adjustment	*Required uncomfortable position, with trunk forward during adjustment
		*Possibility of angle differences on each side

4.2 USER NEEDS FROM CLINICAL PERSPECTIVES

Based on disadvantages of the previous design, specific improvements were planned for the next prototype. The required improvements included angle adjustment using only one hand with minimal force required or complicated procedures. The spinal cord can be injured in different regions. According to the purpose from the previous design, the clinical guidelines offer some precautions and recommendations regarding the operation of a backrest mounting. According to the level of spinal cord injury, there are various arrangements of movements or limitations. The lumbar level of injury causes limitations in leg movement while injury to the thoracic level may result in decreases in the strength of trunk movement and sitting stability is also weakened. The levels, cervical 8 to thoracic 1, are related to grasping strength and fine finger movements; therefore, grasping strength and finger manipulation movement diminishes when these areas are injured. The injury of cervical 7 decreases strength of elbow extension. People with a higher level injury often have decreased ability for extension and flexion of the upper extremities. Based on this information about the limitations in functioning depending upon spinal cord injury level, pulling actions are better than pushing. [26]

Based upon the previous design and clinical perspectives, the backrest adjustment should be operated by pulling. It also needs to eliminate the requirement for fine dexterity so that gross muscle movements can be used so its operation is not difficult for individuals with higher level injuries. The operating procedures should be simple and only require one hand to operate. The maintenance of sitting stability is important for the safety of users. Consequently, decreased upper extremity strength must be kept in mind.

4.3 DESIGN IMPROVEMENTS / PROPOSED SOLUTION FOR THE DESIGN – CONCEPT 1

Based on the previous design and clinical perspectives, a method of quick and easy release was the focus for the new backrest mounting design. A primary goal was to allow users to disengage the system with one hand. As a result, the design of a single cord or bar to release the pivot system was the focus of consideration. The cord method comes from the design of folding backrests on some manual wheelchairs where when a cord is pulled, one pin on each side of the backrest pulls inside and unlocks the backrest. The bar method is similar to the cord method but uses hooks and a bar. Accordingly, the backrest is folded when the bar is pulled and the hooks disengage. Power wheelchairs and automobiles use a different method called the teeth method which is the interlocking of teeth in a pair of gears. Pulling a lever allows the gear teeth to move together, so it can control the backrest angle. The problem with using the teeth method is not only size, but also the installation of gears that cause difficulty. Using a combination of methods to solve the problem, the new prototype incorporated toothed gears with a cord for quick release. (Figure 11)

Figure 11. Concepts of methods - Bar method (left), Cord method (middle) and teeth method (right)

4.3.1 Concept description

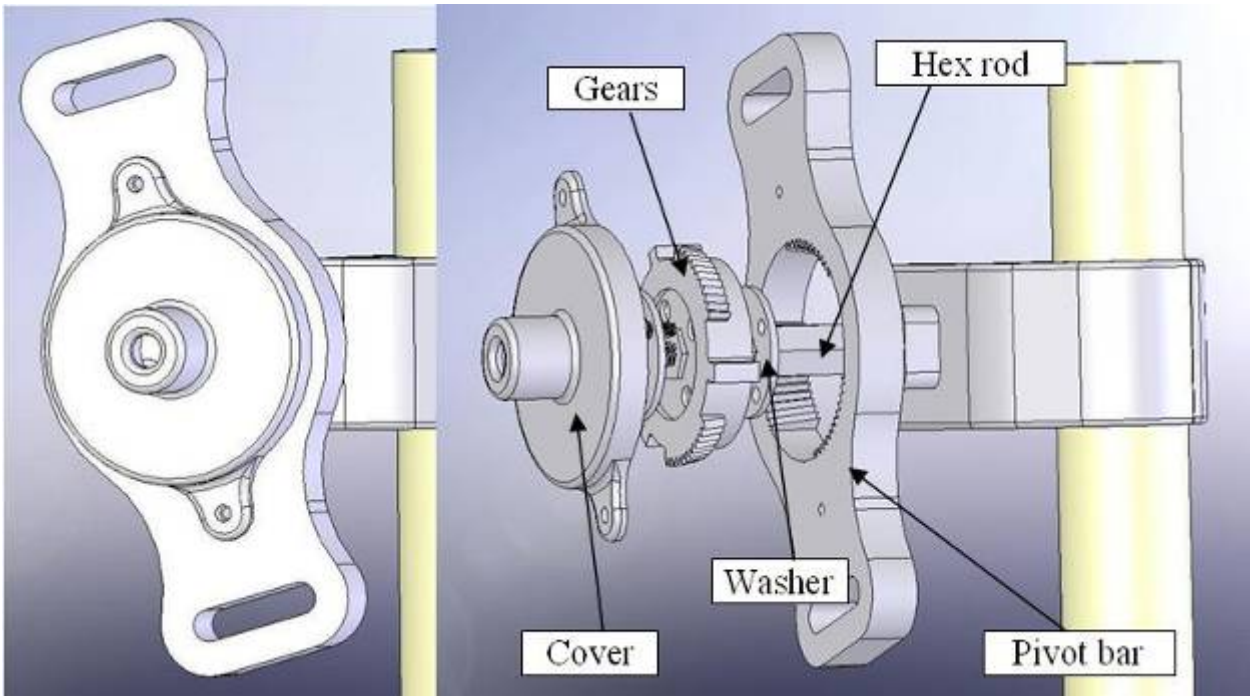


Figure 12. Explosion view of Concept 1 Design

The cam-lock mechanism was replaced with a cord and gear. All the parts except the cam-lock mechanism are the same as the previous design. The holes of some of the parts for the cam-lock were used in the tooth gear design. Engagement of gears is performed as same as locking the cam-lock mechanism and also disengagement of gears is equivalent to loosening the cam-lock mechanism. In addition, the gears are angled slightly which makes them a tapered spline. The gears can be adjusted with half of gear engaging them. There are four triangle-shaped brackets attached to the backrest for connection between the backrest itself and the adjustable mounting which is identical to the previous design. For the function of horizontal adjustment (fore-aft), the pivot bar slots which connect to the triangle-shaped brackets are kept in this concept. (Figure 13) However, the center of pivot bar was changed since the use of a cam-lock was replaced by a tapered spline.

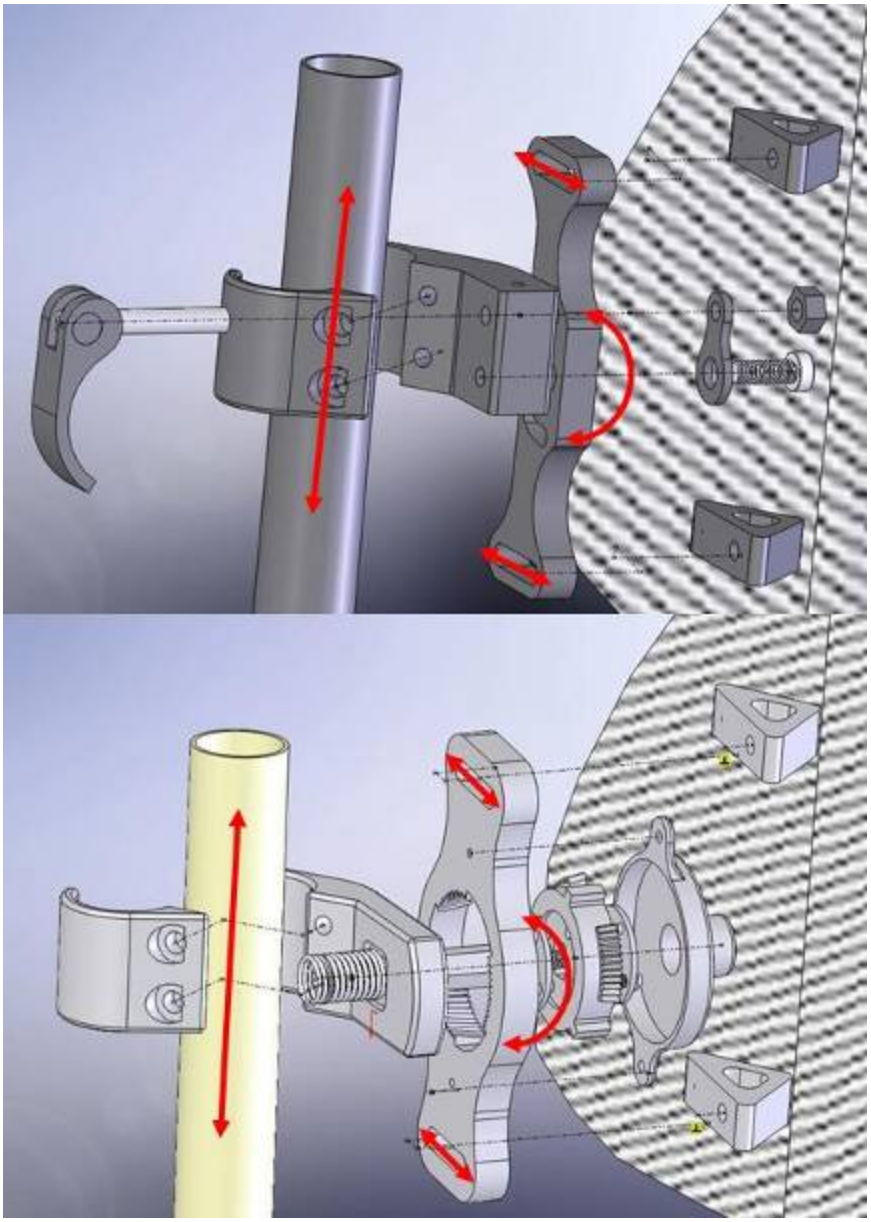


Figure 13. Adjustment of Previous design (top) and Adjustment of Concept 1(bottom)

The female part of the gear is part of the pivot bar, therefore, the center part of the pivot bar became thicker and round-shaped for the male part of the gear insert. Sliding the male gear part along the center post makes it engage or disengage. (Figure 12) The male part of the gear has two profiles. The inside half of the male part consists of a flat round and the other side is comprised with tooth gears, flat space and open segments. The flat round surface of the inside gear makes the pivot bar rotate and stay concentric with the opposing gear system. Similarly, the

outside gear includes flats, open segments, and teeth that have a taper angle. Five degree of the taper angle makes disengagement and engagement much easier. There are 12 teeth at 3 sections with 5 degree increments on each tooth. The flats and open segment spaces support limitation of angle rotation. The open segments spaces are 60 degrees at 3 sections which give angle rotation same as the previous design gives -5 to 55 angle rotation. (Figure 14)

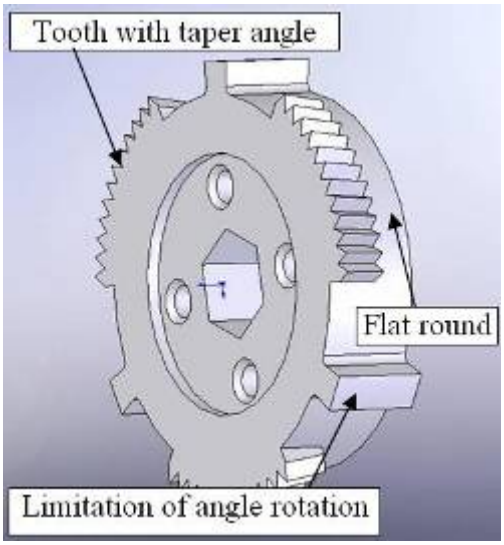


Figure 14. Male part of gears with explanation of composition

When the gears disengage, the cover restricts the male portion of the gear from displacing too far. For one handed operation, the male portion of the gear is spring-loaded to normally be engaged. The cover also hides the spring and protects the mechanism. (Figure 15) The path for the cam-lock going through is changed to the path for a hex rod. Thus, the hex rod is crossed the adjustment mounting parts. The hex rod is connected to the male gear and they are moved together by pulling on the cord. By pulling and releasing the cord, the gears are disengaged and engaged. Again, the springs makes the gears engage at the same time when releasing the cord, which allows the user to adjust the backrest.

The components were designed using the 3D modeling software Solid Works and prototyped using a SLA machine to check how they operate. The final components were made from SLA, aluminum and steel, which made them durable.

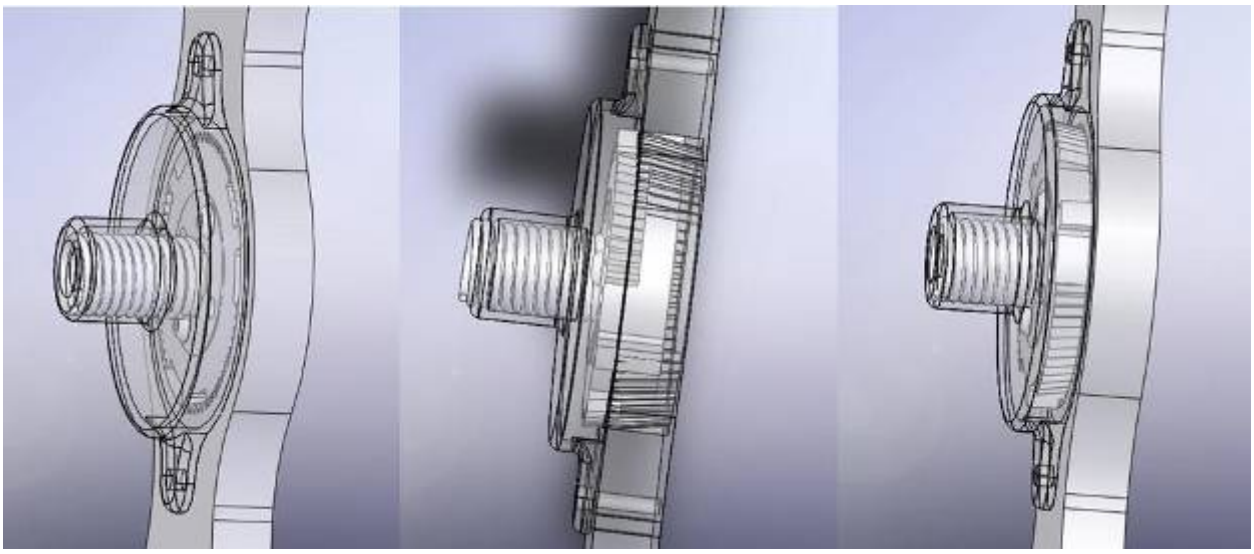


Figure 15. Engaged gears(left), Partly engaged gears (middle) and Disengaged gears (right)

4.3.2 Concept advantage

Some of the advantages of this concept are horizontal adjustment, height selection, and angle adjustment which are similar to the previous design. Depending on the placement of chair bracket, the height is changeable. Slots in the pivot bars make backrest adjustable horizontally, so that it can shift fore or aft. (Figure 16) This concept meets the criteria of easy adjustment, since the angle adjustment is activated by one hand by pulling a cord, and does not require precise movement or dexterity. Due to the spline taper, the gears are easily aligned when engaging together.

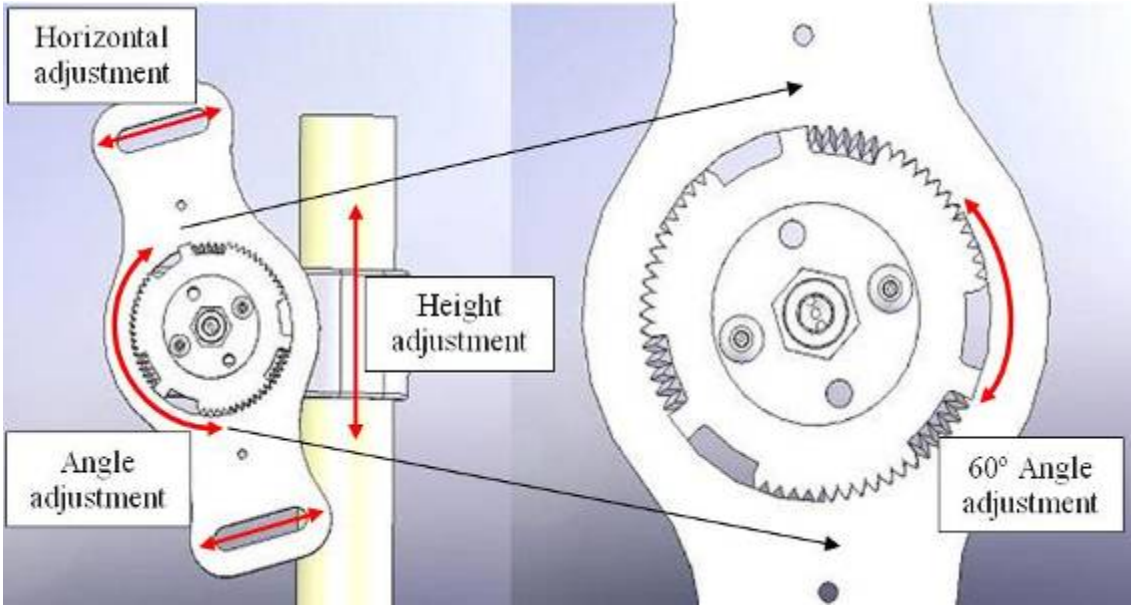


Figure 16. The Pivot bar of concept 1

4.3.3 Concept disadvantages

Several disadvantages exist with this prototype. This prototype requires more strength to engage the gears and it is more secure when the gears are correctly engaged. If the gears are not strongly engaged, the backrest is not entirely stable, and thus becomes unstable during adjustment. Therefore, the spline taper should be engaged securely for safety. The gear mechanism depends on a spring hold the gears in the engaged position. Disengaging the system is more difficult because it requires strength to overcome the spring tension. Figure 17 shows an example of an unstable position due to half engagement of gears with lack spring load. Also, the placement of the spring protrudes from the part. It does not have a clean finish even though there is a cover.

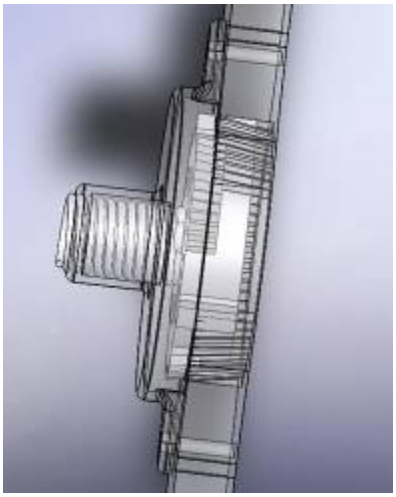


Figure 17. Half engagement of gears causing lack of strength

The strength is limited due to the minimal number of gear teeth engaged, even when the gears are engaged in a locked position. Also, the gears are locked and released by the sliding of the hex rod. There is friction in the sliding mechanism whenever the wheelchair user pulls the cord to change the backrest angle since user's residual weight passes through the center hex rod. When the male parts are sliding to release the gears, they have only three bearing surfaces (Figure 18) to sustain the center position of the gears. Due to the limited support, it is difficult to keep the gears centered.

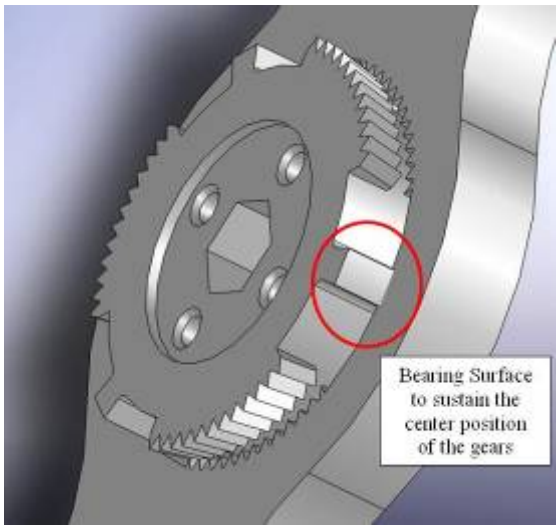
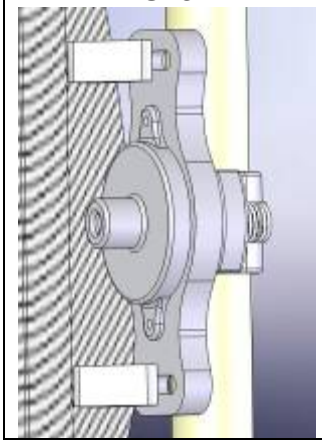


Figure 18. Bearing surface

Table 3. Advantages and Disadvantages of Design concept 1

	Advantages	Disadvantages
Concept One 	*Horizontal adjustment (fore-aft) of 25.4mm (1 inch)	*Required high strength to disengage
	*Height selection of 254mm (10 inches) and 355.6mm (14 inches)	*Protrusion of the spring area made it bulky
	*One hand manipulation	*Limited strength due to gear surface contact
	*No fine movement or dexterity required	*Sliding mechanism is high friction
	*Easily aligned with spline taper	*Difficult to stay centered while disengaging gears

4.4 DESIGN IMPROVEMENTS / PROPOSED SOLUTION FOR THE DESIGN – CONCEPT 2

The following design uses a similar concept to the first one. Instead of pulling out the tapered spline from the pivot bars for disengagement, the pivot bar and the taper spline are one piece and a female-splined cover is used for locking the system.

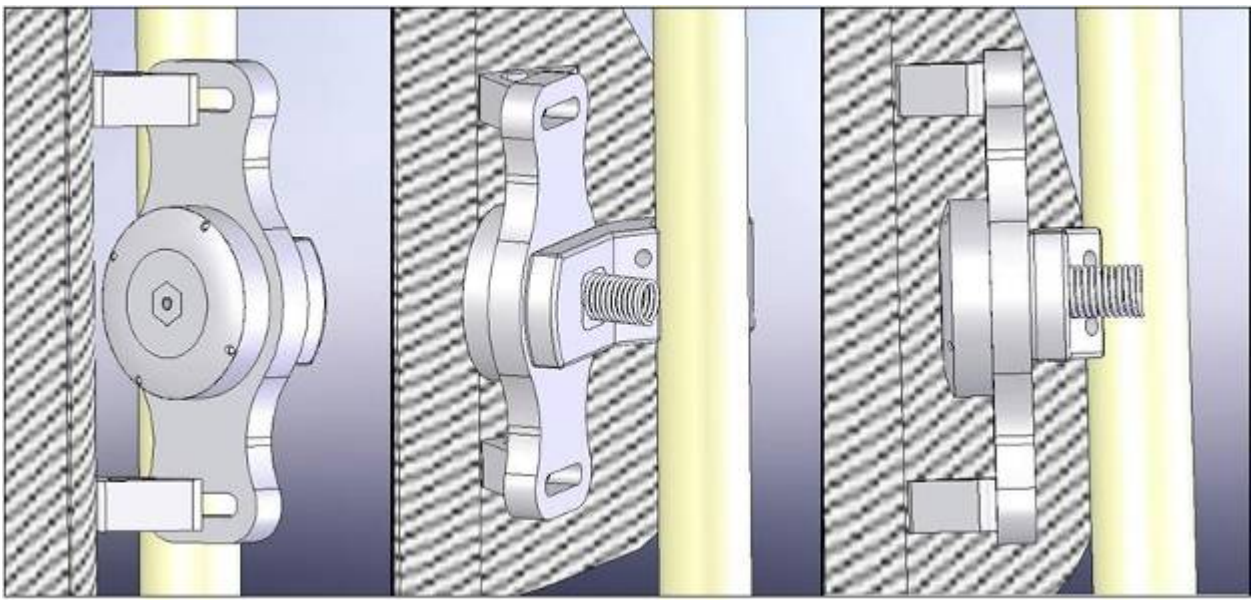


Figure 19. Design of Concept 2

4.4.1 Concept description

Four triangle-shaped brackets are attached to the backrest as a linkage to adjust the mounting. The pivot bar slots for the function of horizontal adjustment (fore-aft) are kept in this concept. The slots are also connected to the triangle-shaped brackets. The center of the pivot bar was changed to combine with the tapered spline. This replaced the insertion of the tapered spline into the pivot bar. The second concept is locked with covering gears, while the first concept is locked with sliding insertion of taper spline into the pivot bar. (Figure 20)

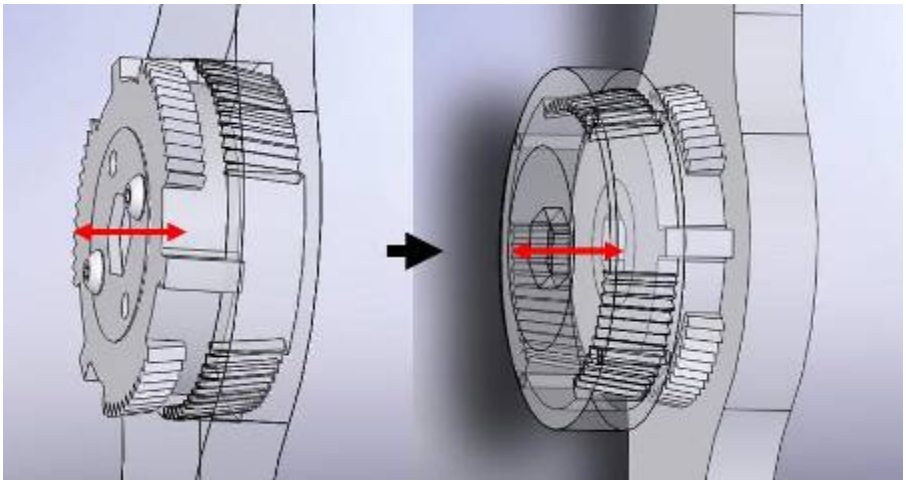


Figure 20. Insertion of taper spline(left) and cover of taper spline(right)

The male part of the gear is on the pivot bar. Therefore, the center of the pivot bar is thicker and round-shaped to maintain the balance of the tapered spline attachment. The sliding of the female gear part along the center makes the cover engage or disengage. (Figure 21)

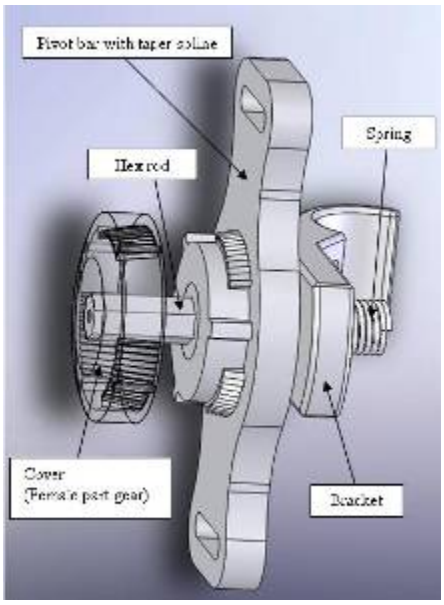


Figure 21. Explosion view of concept 2

As with the previous design, the male part of the gear was separated into two parts. The half side of the male part, which is close to the cover, consists of flat spaces and open segments.

The other side attached to the pivot bar consists of tooth gears, flat spaces and open segments. (Figure 22)

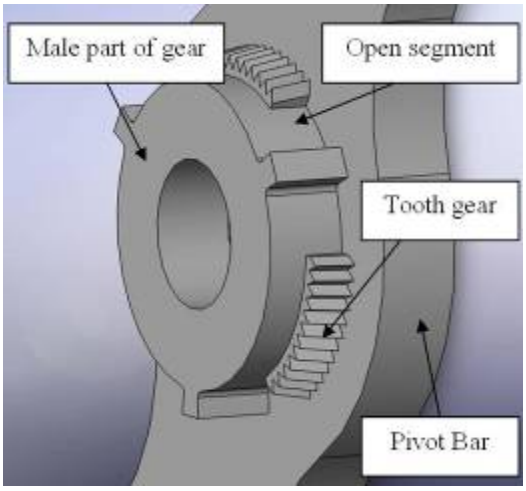


Figure 22. Male part of gear on the pivot bar

In this concept, some mechanisms are identical to the last generation. The gears have 5 degree angled taper which eases the engaging and disengaging. There are 12 teeth at 3 sections with 5 degree increments on each tooth as same as the first concept. Also, the limitation of the angle rotation is caused by the flat and open segments. Sixty degrees of the open segments spaces at 3 sections for angle rotation are kept in this concept as well. The flat spaces of the gear assist the cover in staying in the center, during adjustment. The cover is fixed with a hex rod which is also connected to the backrest brackets. Therefore, the cover which has the female part of the gears is moved with the hex rod for disengagement and engagement. When the gears are disengaged, the pivot bar and male gear freely rotate together. When the cord is released, the hex rod and cover slide back and the gears automatically engage due to the spring force.

The components also were designed using the 3D modeling software Solid Works and prototyped using a SLA machine to check how they operate. During transition to prototyping, the third concept was immediately suggested. The SLA prototyping was the final components.

4.4.2 Concept advantage

Identical to the last concept, only one hand is required to pull the wire/cord to release the backrest which allows for easy adjustment. Some advantages of this concept such as horizontal adjustment, height selection, and angle adjustment are the same as the first concept because this one is identical except for the gear engagement direction. The placement of the chair bracket gives adjustable height and the slots in the pivot bar give horizontal (fore and aft) adjustment to the backrest. (Figure 23)

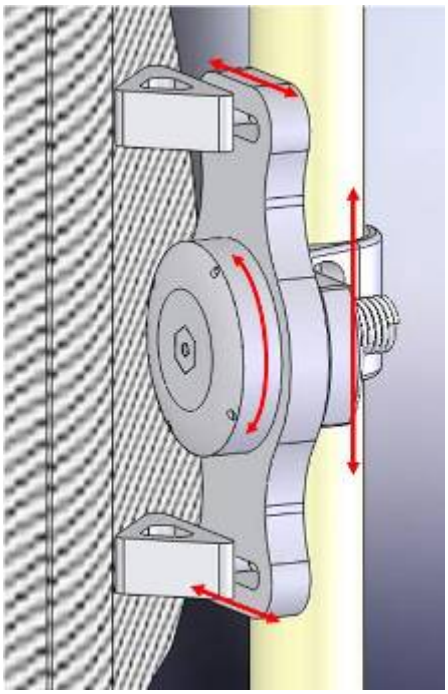


Figure 23. Movement of Concept 2 Prototype

Because the cover of the female gear plays the role of engaging and disengaging via the sliding hexagon rod, less strength is required for release, compared to the first concept. (Figure 24) The hex rod is covered by round shaped parts, so that it can be supported inside of the pivot bar center hole. This concept provides a stronger and more stable system to keep the female gear cover in the center. Based on the first concept, the spline taper helps the gears easily align.

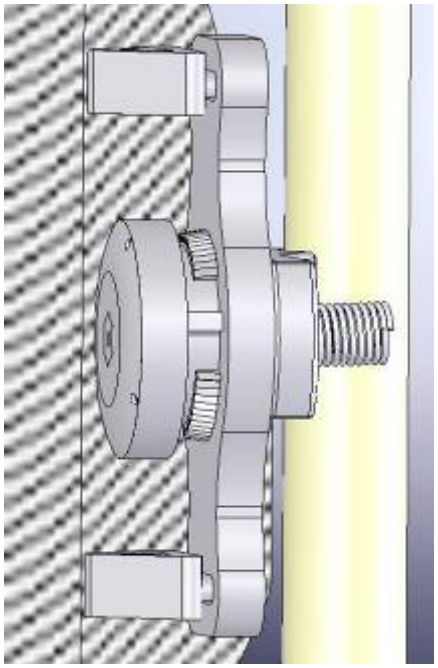


Figure 24. Disengagement of gears with pulled cover

4.4.3 Concept disadvantage

Due to changing direction of the gears, the disadvantages of this concept are identical to the first concept prototype except this concept allows for a few improvements related to strength. This concept also uses a spring to automatically reengage the gears after adjustment but the spring is placed outside of the mounting, which makes the system bulky. The sliding of the female gear/hex rod is also difficult due to the friction which is caused by the user's body weight against the system during backrest adjustments. Due to the limitation of angle adjustments, there are open segments which make the gears partially engage. (Figure 25)

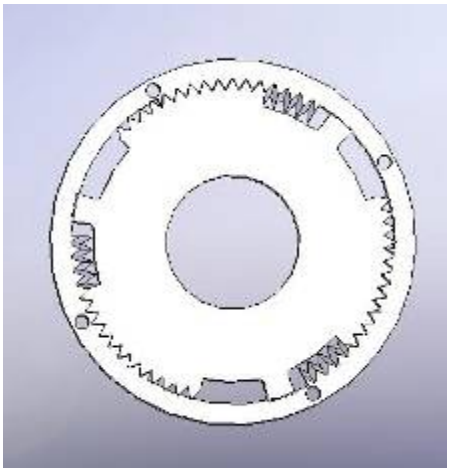
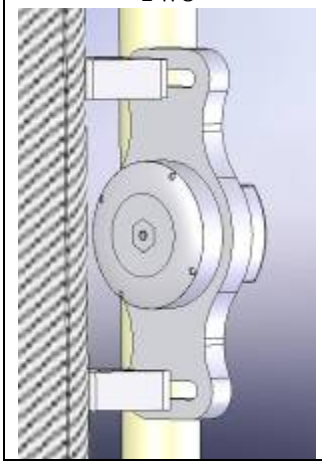


Figure 25. Partial overlap of gears

Table 4. Advantages and Disadvantages of Design concept 2

	Advantages	Disadvantages
Concept Two 	*Horizontal adjustment (fore-aft) of 25.4mm (1 inch)	* Protrusion of the spring area
	*Height selection of 254mm (10 inches) and 355.6mm (14 inches)	*Sliding mechanism gives friction
	*One hand manipulation	*Required strength
	*No fine movement or dexterity required	*Limited strength due to gear surface contact
	*Stable to stay center	
	*Less strength to release	
	*Easily aligned with spline taper	

4.5 DESIGN IMPROVEMENTS / PROPOSED SOLUTION FOR THE DESIGN – CONCEPT 3

4.5.1 Concept description

Through several design changes, the last concept was derived. In the previous concepts, there were triangle-shaped attachments which were vertically connected to backrest in the previous design. This attachment design was changed to a J-shaped bracket design for more adjustment. The J-shaped brackets have slots, so that they can be attached to the backrest itself while offering an adjustment so it can fit on wheelchairs with slightly different widths. This J-bracket has a tapped hole for attaching to the backrest mount which is the pivot bar. (Figure 26)

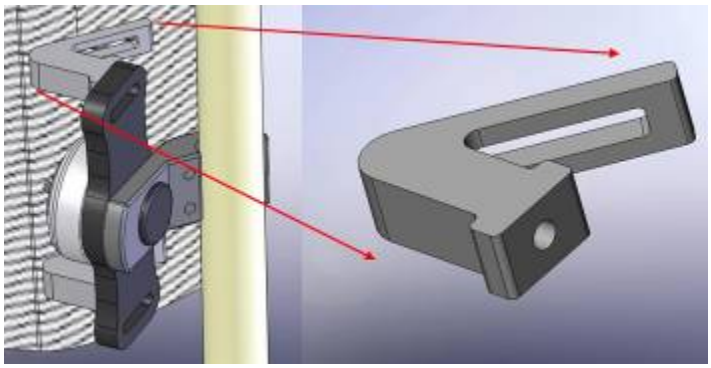


Figure 26. J-shaped bracket

The pivot bar is fixed between the two J-shaped brackets and the wheelchair frame bracket. The pivot bar has two slots at the end of each side for fore/aft adjustment and a 17.78mm hole at the center of the pivot bar for placement of the 12.70mm hex rod. Four 3.175mm holes are positioned around the center hole. Those small holes receive the screws that hold the gears. The shape of the pivot bar is curved according to the shape of the gears and cover. The curved-shape is an aesthetic decoration and it protects the gear from dust. (Figure 27)

Figure 27. Concept 3 pivot bar

Gears have continuously 72 teeth which allow 5 degree increment adjustment (360/5=72 teeth). Two gears attach to one side of the pivot bar. One of the teethed gears has a 17.78mm hole at its center to support a 12.70mm hex rod passing through it. There are four more 3.175mm holes around the center hole for screws to fix to the pivot bar and to hold the other teeth gear. The other one has a 12.55mm hex hole at its center to pressed-fit a 12.70mm hex rod through it. There are two fan-shaped slots which have 60 degree angles for limitation of angle rotation as same as previous designs. One gear with hex hole is connected to the hex rod held by a wheelchair backrest frame mounting bracket. Therefore, the inside gear rotates with the pivot bar and the outside gear remains stationary constrained by the wheelchair backrest frame mounting bracket. To fix the backrest shell position, female gear covers slide over both males gears when all are aligned and locks them relative to each other. (Figure 28)

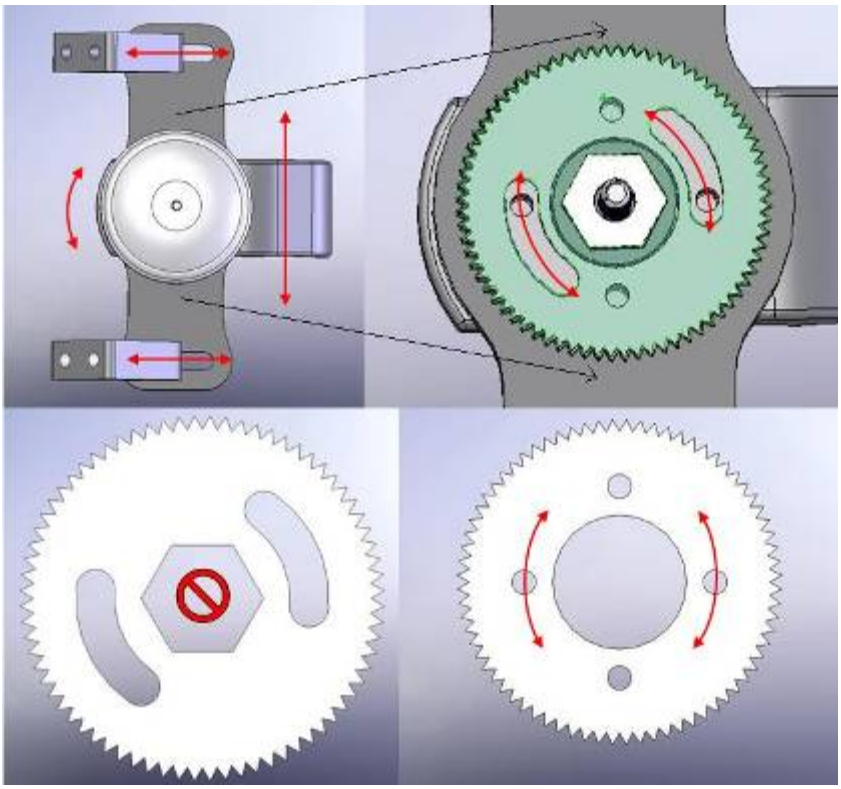


Figure 28. Movements of gears

Figure 29. Concept 3 prototype – fixed position

As the female gear slides off of the male gear fixed to the pivot bar (as the cord is pulled) it allows the two male gears to rotate relative to each other. (Figure 29) For one hand operation,

the female gear covers are spring-loaded to normally be engaged, and also connected to one another by a cord. When the cord is pulled or released, the gears disengage and engage, respectfully. (Figure 30)

Figure 30. Concept 3 prototype – available angle adjustment with released cover

The components were designed using the 3D modeling software SolidWorks and prototyped using a SLA machine to test their operation. The final components were made from SLA, aluminum and steel, which made them durable. Only the hex rod and the connector between the hex rod and aluminum brackets were made from steel, and only the cover was made from SLA.

4.5.2 Concept advantage

The two slots in the pivot bar and wheelchair bracket provide continuous horizontal adjustment (fore-aft) and vertical adjustment (height). Based on changing to the J-shaped brackets, there is a width adjustment which allows for some variance in width between wheelchair tubes. (Figure 31)

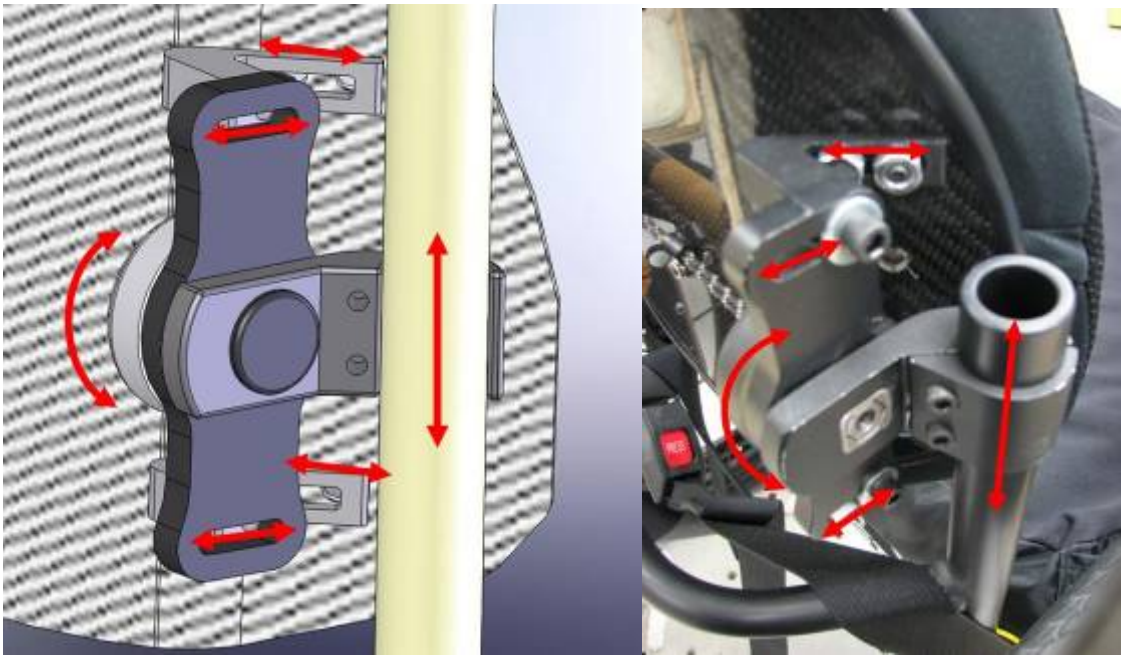


Figure 31. Movement of concept 3

Only one hand needs to be used for quick release, which does not require much strength, and pulling the cord only requires minimal gross movement of the arm. As a result, the dexterity required to adjust the angle is minimal and the position of the wheelchair user's body will be more stable when reclining. The springs which pull the cover back to its original place are located inside of the hex rod, so that the system is compact and self-contained. (Figure 32)

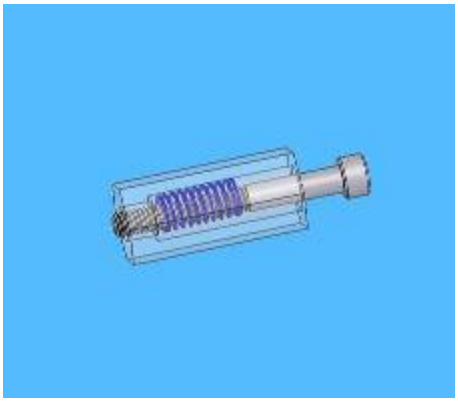
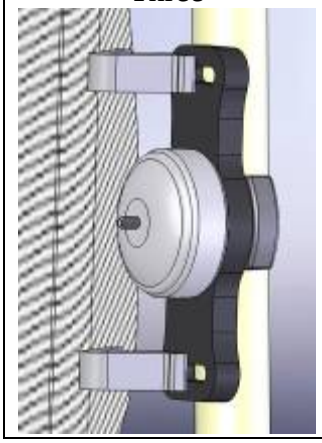


Figure 32. Spring inside of hex rod

4.5.3 Concept disadvantage

All the pieces are press-fit together with interference of 0.15mm and some pieces move together while changing angles. This concept uses two male gears and one female gear. Thus, it requires a more complicated process to build than the other concepts, which use only one male and female gear. To work smoothly, the two male gears should be precisely built and aligned.

Table 5. Advantages and Disadvantages of Design concept 3

	Advantages	Disadvantages
Concept Three 	*Horizontal adjustment (fore-aft) of 25.4mm (1 inch)	*Requires precisely aligned gears
	*Height selection of 254mm (10 inches) and 355.6mm (14 inches)	
	*Width adjustment	
	*One hand manipulation	
	*No fine movement with dexterity required	
	*Strongest engagement all tooth gears	
	*Easily aligned with camber	

5.0 TESTING

The last prototype design was tested with ANSI/RESNA durability and fatigue test standards. Wheelchairs are generally evaluated through ANSI/RESNA standards test, so the backrest prototype should pass the standards for the safety of wheelchair users. [27]

5.1 METHODS

ANSI/RESNA wheelchair standards testing was completed at the Human Engineering Research Laboratories. It was tested with a 406.4mm (16 inch) width low height carbon fiber backrest and Quickie GP wheelchair. For the purpose of simulating a wheelchair user, a 100 kilogram wheelchair test dummy was used. Two parts of the ANSI/RESNA tests are related to the safety and operation of the wheelchairs; static stability and strength. Static stability test evaluates to see whether or not the wheelchair will tip backward or forward. Instead of changing configurations of the wheelchairs, the max forward and max backward positions of the backrest were tested for the LWDAC in a neutral configuration. Another safety test is a determination of static strength, impact strength, and fatigue strength. The static strength tests apply a constant force to some parts of the wheelchair. The impact strength testing uses dynamic forces to some parts of the wheelchair and also includes dropping a wheelchair approximately five centimeters from the ground. Also included in the dynamic strength test is the double-drum test which

consists of two rollers that roll at a speed of one meter per second, with one roller turning slightly faster. The test cycles are the double-drum test for 200,000 cycles and the curb-drop test for 6,666 drops which simulate a wheelchair that is used for about three to five years. The LWDAC backrest was tested under the ANSI/RESNA wheelchair tests which involve backrests. Accordingly, the tested wheelchair was in a neutral configuration and the angles of backrest were changed max forward to max backward when changes were needed.

5.2 RESULTS

The static stability testing was performed for the forward and backward positions of the backrest. The tipping angles for the LWDAC were similar even though backrest angles were changed. The similarity of tipping angles means that the LWDAC provides angle adjustment without affecting the stability of the wheelchair.

Table 6. Results of static stability test

Direction		Tipping angle (Degrees)	
		Backrest Forward (46 º vertically)	Backrest Backward (-16 º vertically)
Forward	Front wheels locked	20.6º	20.0º
	Front wheels unlocked	23.4º	20.9º
Rearward	Rear wheels locked	8.2º	9.9º
	Rear wheels unlocked	14.1º	18.4º
Sideways	Left	22.4º	22.5º
	Right	23.3º	21.7º

The impact test evaluates the strength of the wheelchair structure according to the ANSI/RESNA standards test. The impact test of the new prototype was performed by using a

pendulum on the center of backrest. After the backrest was hit with a 13.6kg (30lbs) pendulum, there was no failure. (Figure 33)

Figure 33. Impact test of the Backrest

The double-drum and curb-drop tests were followed as the last tests because they are often destructive. The LWDAC was tested by running the double-drum test for 200,000 cycles and completed without failure. For the curb-drop, the test was stopped after roughly 2,000 out of 6,666 cycles with a class II failure. Class II failure requires the break to be repaired by a trained technician.

6.0 FOCUS GROUP EVALUATION

6.1 FOCUS GROUP METHODS

Two focus groups were held with the purpose of evaluating the backrest prototype according to design criteria.

6.1.1 Device

Among the three concept prototypes which were previously mentioned, our design team decided that the third concept prototype is the best design with a strong and clean mechanism.

6.1.2 Recruitment

The focus groups included both manual wheelchair users and rehabilitation professionals. The manual wheelchair users all self-propelled ultralight weight wheelchairs as their primary means of mobility and were able to transfer independently. The users that participated in the focus group were representative of individuals with spinal cord injury and osteogenesis imperfect. The rehabilitation professionals included RESNA certified Assistive Technology Practitioner (ATP) RESNA certified Assistive Technology Supplier (ATS), Occupational Therapist, Physical Therapist, Rehabilitation Engineer, and Rehabilitation Tech Supplier. All

participations were ethnically diverse (Hispanic/Latino, African American, Caucasian, and Asian) and over the age of 18. The Human Engineering Research Laboratories registry system was used for recruitment efforts, which involved flyers mailed to qualified people in the registry. Our participants were asked to contact study investigators if they were interested in this study.

6.1.3 Protocol

Prior to any data collection, the focus group protocol was approved by the University of Pittsburgh Institutional Review Board. Participants consented to participate in this focus group and received an oral introduction to the LWDAC backrest prototype. The demonstration covered the functions, adjustments and operation of the release mechanism. Following the demonstration, the focus group participants were asked to test the prototype while performing three tasks: 1) recline the backrest angle through its entire range (-5° ~55° vertically), 2) observe backrest adjustment and 3) consider how the backrest looks from an aesthetic point of view. The participants were allowed time to freely recline and experience the backrest angle changes. The participants were encouraged to try to transfer into the wheelchair mounted with the LWDAC backrest, but not required. After becoming familiar with the prototype, the participants were asked to fill out a questionnaire and were asked to elaborate on what modification would be done to improve the prototype, including operation.

6.1.4 Questionnaire

The questionnaire was designed to ask participants to discuss their reaction to release mechanism function, adjustment function, appearance of the LWDAC. The questionnaire used a

visual analog scale of 10cm in length. Participants were asked to mark an X anywhere on the line to indicate their opinion. The scale ranged from strongly agree, extremely comfortable, or extremely easy (100mm) on the left to strongly disagree, extremely uncomfortable, or extremely difficult (0mm) on the right. In addition, participations' opinions on the next prototype of the backrest were assessed by using open-ended questions. Below is an example of a visual analog scale in questionnaire and the entire questionnaire is in Appendix A.

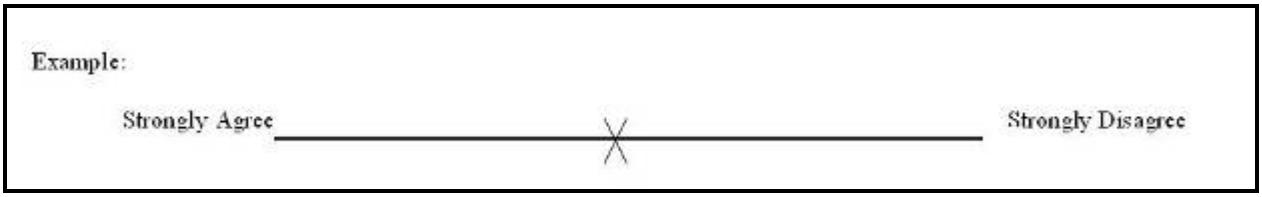


Figure 34. Example of a Visual analog scale

6.1.5 Statistical analysis

The questions using the visual analog scale of 100mm in length were measured with a ruler using the distance from the left edge of the scale to the nearest millimeter. For consistency, some categories' scores were reversed so that all of the results reflected responses to positively phrased questions. Higher scores indicate more positive responses. The 100 millimeters reflect a perfect score of 100 (i.e. most strongly agree). Ten backrest features were evaluated. The mean scores of each of the ten features were calculated as well as summing the features scores to created and overall mean score of the LDWAC. The scores were analyzed using SPSS 16.0 (Chicago, IL). Frequency distributions and measures of central tendency were used to describe the data.

6.2 EVALUATION

The purpose of this study was to evaluate the prototype of the LWDAC Backrest. According to inclusive criteria of wheelchair users for the focus group, about seventy people who were using an ultralight manual wheelchair as their primary means of mobility, self-propelling and transferring independently were eligible to participate in the study from the Human Engineering Research Laboratories registry system and received an invitation letter to participate. From the invitees in the Human Engineering Research Laboratories registry and the clinicians from the Center for Assistive Technology, eight wheelchair users and nine clinicians volunteered to participate in this focus group.

6.2.1 Participants

A total of seventeen individuals participated in this study. The mean age of all participants was 38.2±11.8 years. Fifty nine percent of the population were Caucasian (n = 10), 24% were other (n= 4), 12% were African-American (n = 2), and 6% were Hispanic (n=1). Seventy seven percent of the population were male (n=13). Table 7 presents the descriptive statistics of demographic data for all participants.

Table 7. Demographic information

Demographic measure	%(n) or mean (standard deviation)
Age	38.2 (11.8)
Race	
African-American	11.8 (2)
Hispanic	5.9 (1)
Caucasian	58.8 (10)
Other	23.5 (4)
Gender	
Male	76.5 (13)
Female	23.5 (4)

On average, the wheelchair user participants have been using a wheelchair as their primary means of mobility for 19.6 ± 6.2 years and 62.5% of wheelchair users (n = 5) were using sling backrests. (Table 8)

Table 8. Information of Wheelchair users from Participants

ID	Disability	Years with injury	Type of WC	Type of backrest
1	T 10	27	Tilite – EVO	Sling
2	C 7	15	Tilite – TR	Rigid
6	T 4	13	Quickie – 2	Rigid
10	T12	13	Quickie – revolution	Sling
11	T5	23	Quickie – Ti	Sling
12	T4	15	Invacare – crossfire	Sling
13	Osteogenesis imperfecta	26	Quickie – Ti	Rigid
17	T11	25	Quickie – HP2	Sling

The clinicians group was comprised of five physical therapists, two occupational therapists, one ATP, and one ATS. Forty four percent of clinicians (n= 5) had been working for more than 10 years. (Table 9)

Table 9. Information of Clinicians from Participants

ID	Professional	Years with experience
3	Physical Therapist	4-6 years
4	Occupational Therapist	10 year or more
5	Physical Therapist	7-9 years
7	Physical Therapist	7-9 years
8	Occupational Therapist	10 year or more
9	Physical Therapist	1-3 years
14	Physical Therapist	1-3 years
15	Assistive Technology Practitioner	10 years or more
16	Assistive Technology Supplier	10 years or more

6.2.2 Evaluation of Light Weight Durable Adjustable Composite Backrest

Table 10 displays descriptive statistics with higher being better for the questionnaire ratings. All average scores are arranged 0 to 100. Only three categories of one hand operation (81.41 ± 22.86), overall comfort (76.53 ± 18.11), and willing to purchase (70.41 ± 23.47) received ratings greater than 70 which represents a strong rating. There are two categories that roughly received a score of 50, which were comfort of arm position (52.12 ± 22.86) and comfort of body position (58.58 ± 23.63), indicating neutral responses.

Table 10. Descriptive Statistics of Questionnaire by Categories

Ratings	N	Lowest	Highest	Mean	SD
Mounting looks	17	19	98	62.53	28.91
Strength	17	4	97	63.59	26.01
Simplicity	17	12	99	62.94	28.00
One hand operation	17	25	100	81.41	22.86
Comfort of arm position	17	19	96	52.12	22.86
Comfort of body position	17	9	96	58.58	23.63
Feel safe or secure	17	15	99	68.82	28.53
Overall comfort	17	11	97	76.53	18.11
Overall appearance	17	26	96	62.12	25.06
Willing to purchase	17	8	98	70.41	23.47

Table 11 shows descriptive statistics questionnaire ratings by participants. Forty seven percent (n=8) of participants rated overall greater than 70. The LWDAC received ratings greater than 70 from only twenty five percent of wheelchair users (n=2). On the other hand, sixty six percent of clinicians (n=6) rated the backrest greater than 70 overall.

Table 11. Descriptive Statistics of Questionnaire by Participants

Participants	Group (Wheelchair user = w, Clinician = s)	Minimum	Maximum	Overall mean score
1	W	31	97	62.10
2	W	86	98	89.70
3	S	46	97	68.90
4	S	30	100	71.40
5	S	4	72	44.20
6	W	87	97	93.70
7	S	46	97	77.70
8	S	73	98	88.00
9	S	45	95	79.90
10	W	25	46	35.90
11	W	21	93	60.00
12	W	36	98	62.90
13	W	25	98	58.10
14	S	22	87	49.00
15	S	53	83	70.40
16	S	54	92	72.40
17	W	8	79	35.40

Table 12 presents descriptive statistics of total ratings by the wheelchair user and clinician groups. The overall ratings of wheelchair users were relatively lower and had a larger variability, when compared to those of clinicians.

Table 12. Descriptive Statistics of Total Ratings by Group

Ratings	N	Minimum	Maximum	Mean	SD
Wheelchair users	8	354	937	622.25	213.16
Clinicians	9	442	888	691.00	140.97
Total	17	354	937	658.65	176.25

Figure 35 shows the average of ratings of each category by grouping wheelchair users and clinicians. The clinicians rated Mounting looks, Strength, Simplicity, One hand operation, Overall comfort, Overall appearance, and Willingness to Purchase higher. Mounting looks (34), Overall appearance (15), and One hand operation (14) have more than 10 magnitude differences between two groups. However, Mann-Whitney was run for comparing two independent groups (users and clinicians) and there were no significant differences between the two groups on any of the backrest features.

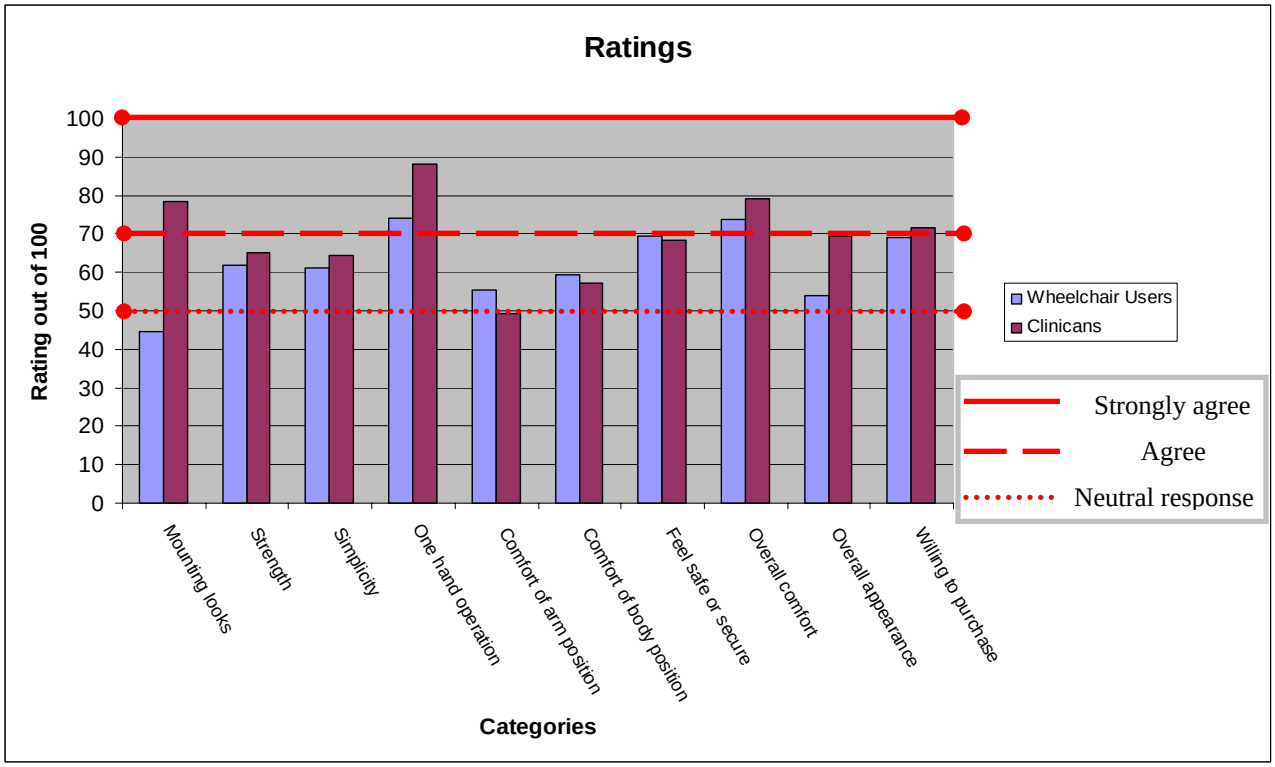
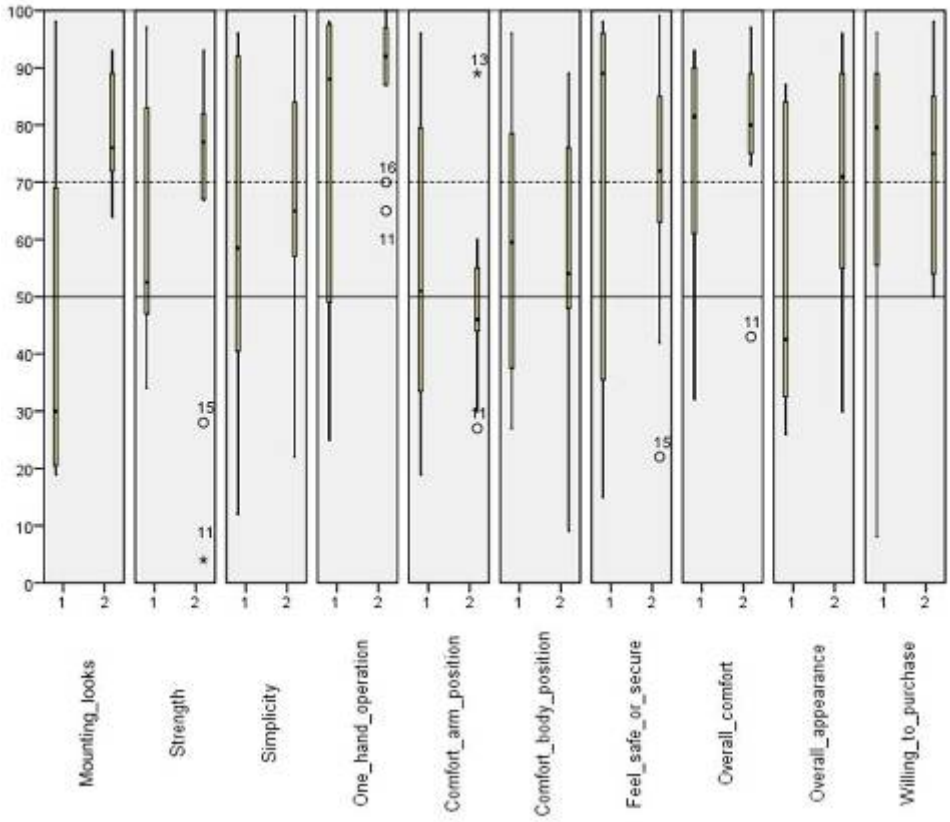


Figure 35. Average of ratings by Group



Group 1 = Wheelchair user / Group 2 = Clinician

Figure 36. Median of ratings by group

The mean of ratings about range of recline or backrest angle range (-5º to 55º) is 46.41 ± 18.91. Wheelchair users (49.63 ± 18.07) rates higher than clinicians (43.56 ± 20.24). Fifty three percent (n=9) of overall participants choose the $100 ~$150 as a reasonable price for the adjustable backrest accessory.

Table 13. Information of Clinicians from Participants

Price	%(n)
$50~$100	17.6(3)
$100~$150	52.9(9)
$150~$250	17.6(3)
More than 250	5.9(1)
Missing	5.9(1)

Participants were asked to choose the three features that the wheelchair users consider to be the most important when they purchase a backrest or wheelchair. Participants were asked to choose from the following features: dimension, weight, adjustments, safety, durability, easy to use, comfort, and effectiveness. All participants from the wheelchair users group chose comfort as an important point when they choose a backrest or wheelchair. Safety and easy to use were considered as the other important items. Only clinicians chose the safety item as the most important item.

Table 14. The Most Important Items

Items	Total Frequency	Wheelchair users	Clinicians
Comfort	14	7	7
Weight	7	4	3
Easy to use	6	2	4
Safety	6	0	6
Durability	5	3	2
Adjustment	4	1	3
Effectiveness	4	3	1
Dimensions	1	1	0

6.2.3 Comments for next prototype from focus group participants

- Quick-release for entire backrest mounting

  A quick-release mechanism for taking a part of backrest is needed for next prototype for folding wheelchair users. The folding wheelchairs are typically fitted with sling backrests, so the users are not required to take them on and off to fold. To allow the LWDAC backrest to work with these types of wheelchairs, a quick-release attachment is necessary.

- Remote Control or Push Buttons for angle adjustment

For some subjects it was difficult to reach the release cord and there were concerns that it could cause harm to the shoulder. Also, it can interfere with the backrest and push handles when users try to reach back behind their chair. Instead of placing on the back, the remote control and push buttons were raised up for preventing shoulder injuries.

- Pre-sets

  Some participants suggested that they would prefer to have three or five pre-sets angles instead of having options at a 5 degree increment. The pre-sets would be in a “perfect” position for usual, reclined position for rest or dressing, forward position for working on tables and so on.

- Range of angle adjustment

  There were mixed demands, as the rating for range of angle adjustment was 46.41 ± 18.91.

- Usability in clinic

  Most clinicians thought the system would be useful in a clinical setting as a tool for fitting individuals with backrest and identifying ideal fixed angles for non-adjustable backrests. For this to be useful, the clinicians suggested adding an angle gauge to measure the selected backrest angle.

- Pressure relief

  For some clinicians there was a concern that during recline, the user may slide forward, causing shear, peak forces on the sacrum. Therefore, education or precaution should be performed before using it.

- Durability of cord and spring

The cord is polyester cord with 2mm (3/32 inch) diameter and the spring is inside of a 19.05mm (0.75 inch) hex rod. The thin cord and tiny springs may easily break. Currently, there are no specific standards for durability test of mechanism for engagement and disengagement. Accordingly, it requires manual checking durability of spring and cord separately.

- Aesthetics

  Additional various colors were mentioned.

7.0 DISCUSSION

While many rigid backrests are commercially available, adding user-controlled adjustability would provide several additional and beneficial features. The primary competition comes from Jay Division, Invacare, and Varilite. Nothing among those offers the extreme light weight and angle adjustment while seated in a wheelchair. Only three backrest mounting systems have been patented with adjustable angle. One system has a detachable mount which allows the user to adjust the height, tilting angle and width. However, the backrest angle is fixed with screws making adjustment difficult. [28] Another product available is a wheelchair back seat angle adjustment mechanism and related devices. This product has features to enable width adjustment, horizontal adjustment (fore-aft), and height adjustment. The design uses slots and several screws to adjust horizontal adjustment and seat width adjustment with screws tightening. [29] The last design allows the backrest angle to 'float' around a pivot point, but does not provide a way to fix the backrest angle. Instead this design is stabilized by using a spring system, which tends to keep the backrest at a neutral angle. [30] Therefore, based on our patent search, our design is unique and has promise to augment currently rigid backrest systems.

Table 15. Comparison of The Primary competition

	Jay Division	Invacare	Varilite	ADI
Weight	1.8~2.3kg (4~5 lbs.) without mounting hardware	*	1.9kg (4.2 lbs.) includes all hardware	Less than 0.7kg (1.5 lbs) / about 1.4kg (3 lbs.) includes LWDAC mounting
Capacity	136.4 kg (300 lbs.)	*	113.6 kg (250 lbs.)	113.6 kg (250 lbs.)
Size	165.1mm to 609.6mm (6.5 inches to 24 inches)	419.1mm (16.5 inches)	355.6mm (14 inches)	254mm / 419.1mm (10 inches / 16.5 inches)
Price	$ 510.00	$ 438.00	$ 350.00	

Our initial focus while designing the adjustable backrest was solely for the use of ultralight wheelchair users, however, based upon the feedback and results from our focus group, we found that it may be a useful tool for fitting individuals in a seating clinic. At the seating clinics, as the clients are selecting the suitable chair, clinicians would have a tool that will allow them to decide on an appropriate angle for the backrest. For special features in clinical setting, the LWDAC backrest could be added some angle indicators or clinicians could measure angles after finding a comfortable spot for a wheelchair user.

Prior to these current design changes, there was also a focus group to gather feedback on a previous design. The questionnaire from the previous focus group was different from the current questionnaire, results and improvements between previous prototype and current prototype are not comparable. However, it was clear to see improvements through summaries of focus group. The previous design used a cam-lock mechanism to lock the backrest at various angles selected by user. Based on comments from the focus group with the previous design, some people who sated they would only infrequently adjust the backrest angle were satisfied

with cam-lock. In contrast, people who indicated they would like to adjust the backrest angle daily or more frequently described interest for an easier locking mechanism. The primary complaint of the cam-lock was the strength and dexterity required and the awkward hand/arm posture. Also, difficulty of fitting various ranges of wheelchairs was addressed because wheelchairs have variations in tolerances and manufacturer dimensioning. Conversely, the focus group with the current prototype was happy with one hand operation. The participants thought that this prototype would provide comfort (relaxation), weight shift (pressure relief, pain management), propulsion efficiency, space for ease of dressing, and more activities such as reaching back as benefits. In addition, they would like to apply the LWDAC in the clinic as an evaluation tool for fitting backrest angle. Attachments between backrest and wheelchair have slots, so the current prototype is able to fit to a wider range for wheelchairs. Accordingly, there were improvements from previous prototype.

Table 16. Improvements from previous prototype

Previous Focus Group	Design Changes	Current Focus Group
- Strength and dexterity required - Awkward hand/arm posture	- Cam-lock mechanism to combination of tooth gears and cord	- Single hand operation - Low force - Low dexterity - Simple procedures for adjustment
- Difficulty of fitting various ranges of wheelchairs	- Brackets with slots	- Width adjustment for fitting different dimensions of wheelchairs

The unique feature of the LWDAC backrest led us to assume that 70% (score 700) was a standard percentage of a favorable response. Overall, the mean of ratings (658.65 ± 176.25) are less than 70%. However, the participants rated that they are willing to recommend it as a clinician or use it as a wheelchair user if the LWDAC was available for purchase higher than 70% (70.41 ± 23.47). Prior to the focus group, the participants had no experience with changing the backrest angle while in seated in a wheelchair because there are no products that provide

angle adjustments with ease of use. The overall comfort ratings were also higher than 70% by all participants. The reason could be that angle adjustment provides comfort and pressure relief without having to transfers.

During the focus group, there were different points of view between wheelchair users and clinicians. Overall, the clinicians and wheelchair users had different mean ratings. In addition, the characteristics considered for choosing a wheelchair or a backrest were also different. The clinicians gave higher ratings on most categories than the wheelchair users, except on comfort of arm position, comfort of body position, and feeling safe or secure. Mounting appearance, overall appearance, and one hand operation received greatly higher ratings from clinicians as compared to wheelchair users. According to the wheelchair users, the LWDAC backrest looked bulky and big and the addition of mounting to rigid backrest could be much heavier and bulkier compared to sling backrest. Wheelchairs usually come with sling backrests which are lightweight and require no additional attachments. Therefore, the additional weight of the adjustable backrest may negatively impact an individual's ability to independently use transportation. Comfort, weight, durability, and effectiveness are important items to consider when choosing a wheelchair or a backrest for wheelchair users. Wheelchair users need to consider the weight or dimensions of the wheelchair more than the clinicians do. Wheelchair users did not choose safety for weighted items, while clinicians indicated safety as an important feature. The clinicians stated the need to educate wheelchair users about the consequences of recline. Changing the angle of the backrest for dressing, comfort or pressure relief could result in a pressure point at the edge of the backrest. In addition, there is the possibility of sliding out of the chair and the risk of shearing. To reduce this risk education about the usage of backrest angle adjustment should be done in clinic at the same wheelchair users were trained.

The clinicians expressed concern that reaching back to release the backrest hardware would cause a shoulder injury. However, reaching straight back behind the body is a recommended movement to prevent shoulder pain. [31] The cam-lock mechanism requires an at least 103.64 N force to release and lock for angle adjustment. However, a 6.67 N force to pull a cord for angle adjustment is required while the backrest does not have any loads and a 19.57 N force is required while someone is leaning toward to the backrest, so angle adjustment is a low force task. Also, adding foam or a grab bar around the cord would be helpful for the reduction of hand function. In a result, movement for angle adjustment could be simply same as reaching straight back behind the body. Shoulder pain in individuals who use manual wheelchairs is a common secondary problem and is caused by increased loading and the repetitive and nearly exclusive use of the upper limbs for transfer, self-propulsion, and pressure relief. [32-34] Pressure relief and transfer must be performed periodically through the day to prevent pressure sores. During the performance of the aforementioned tasks, the scapula is in a position of increased anterior tipping, decreased upward rotation, and increased internal rotation and the position of humerus is decreased external rotation.[34] When reaching straight back, the position of scapula would rotate downward with internal rotation and the humerus would externally rotate. As a result, reaching back could result in stretching exercises on certain muscles of the shoulder contradictory to expectation of shoulder injury from focus group. [31] In short, wheelchair users could achieve two advantages with angle adjustment of backrest. While reaching back for the angle adjustment, wheelchair users could stretch and perform pressure relief.

The feature of the LWDAC backrest would provide trunk support to minimize the risk of injuries or feelings of instability while propelling a wheelchair uphill or downhill on a ramp. Also, the feature could make dressing and performing other activities of daily living easier for

wheelchair users. Accordingly, wheelchair users would use the feature of the LWDAC backrest whenever they need to perform those activities. People without disabilities require frequent changes of position while sitting, because sitting for about 2 hours in an office chair may facilitate the development of pain. Frequent repositioning in a person's wheelchair is also strongly recommended as well. When wheelchair users change their positions with the LWDAC for prevention of back pain, the feature of the LWDAC backrest would be used at least every 2 hours.

There were several limitations with the LWDAC backrest. First, only three wheelchairs with the LWDAC were available - two 406.4mm (16 inch) width wheelchairs and one 457.2mm (18 inch) width wheelchair. The subjects' wheelchairs were not individually fitted, so wheelchair users could potentially feel less comfortable during testing in our chairs compared to their own wheelchair. Second, the pre-production prototypes did not operate as smoothly as the production models should, due to the prototyping method used. Thus, the outcome of the focus group may be biased slightly by the operation of the device. Third, the LWDAC backrest is solely designed for attachment of ultralight wheelchair, so it is independently operated by wheelchair users while seated in their wheelchair. However, angle adjustment also could be performed by the others. People with high level injuries could use this feature with assistance, but this feature is not comparable to power seat functions because this only has the recline feature and creates a risk of sliding out and recline angle is ranged from -5 to 55 degree which is not enough to provide equal functions same as power wheelchair. Fourth, based on the cost analysis conducted, the LWDAC backrest is expensive in terms of money and labor. Materials used in making the backrest consist of SLA, aluminum and steel. Working with the materials using the Electrical Discharge Machining (EDM) machine and Computer Numerical Control (CNC) machine, requires

intensive labor. For the next design iteration, using a standard spline gear, punching holes into aluminum pieces or using injection molding would reduce manufacture costs.

8.0 FUTURE DIRECTIONS

8.1 DESIGN CHANGES FOR NEXT PROTOTYPE

Based on feedback from consumers and clinicians during the focus group and discussion of the design team at Human Engineering Research Laboratories, design issues that need to be addressed before commercial production are listed below.

- A quick-release mechanism for the entire backrest mounting system

  For application of the LWDAC to a folding MWC a quick-release system is required. ADI has developed such a mechanism for its current, non-adjustable mounting hardware. In future design iterations, this quick-release mechanism should be integrated into the LWDAC.

- Remote Control or Push Buttons for angle adjustment

  A remote push-button was suggested by some of the subjects due to concern of arm discomfort. Because this is a low-force task, we believe arm discomfort will not be a critical design issue; in fact, we believe reaching back may improve flexibility for some users. In the near-term we will not pursue any remote button options, until we address the other higher-priority design changes discussed here. However, using a cord for angle adjustment still requires dexterous hand function. A handle or grip bar could be adapted to replace/augment the cord to reduce

required hand function. Instead of gripping and pulling a cord, sliding or pushing a bar with gross movement may reduce hand function.

- Durability of cord and spring

  Using a tension spring could have a risk through extending it to exceed the maximum of compromising the durability. However, the LWDAC uses a compression spring which does not have the risk of compromising the durability. Future designs will incorporate a thicker (4.5mm) cord to ensure long-term durable use.

- Aesthetics

  Based on various colors were mentioned, it will have options for choosing a color. In future designs, several color options will be available.

- Pre-set and range of angle adjustment (Figure 37)

  Currently, there are 72 teeth in the gears with 5 degree increments, which gives 12 different angle options ranging from -5 to 55 degree. Instead of having infinite options, pre-set would give several positions such as perfect position for usual, reclined position for rest or dressing, forward position for working on table and so on. However, it would be complicated to have pre-sets due to individually various preferences. Modifying the gears to enable angle options to 6 with 10 degree increments would be better in order to comments of fine angle adjustment.

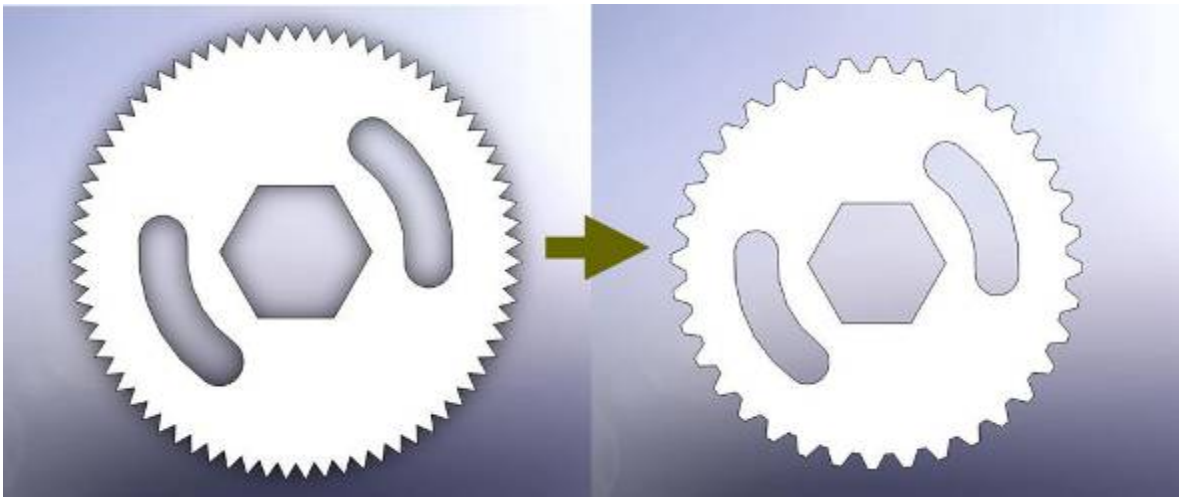


Figure 37. Design change of range of angle adjustment

- Hex rod with spring inside (Figure 38)

  Based on ANSI/RESNA testing failure, design changes should come with next prototype to make it stronger. The last concept design used press-fits for assembling parts which may not be strong enough to hold together, so next design should have a flange to be help to prevent it from coming a part.

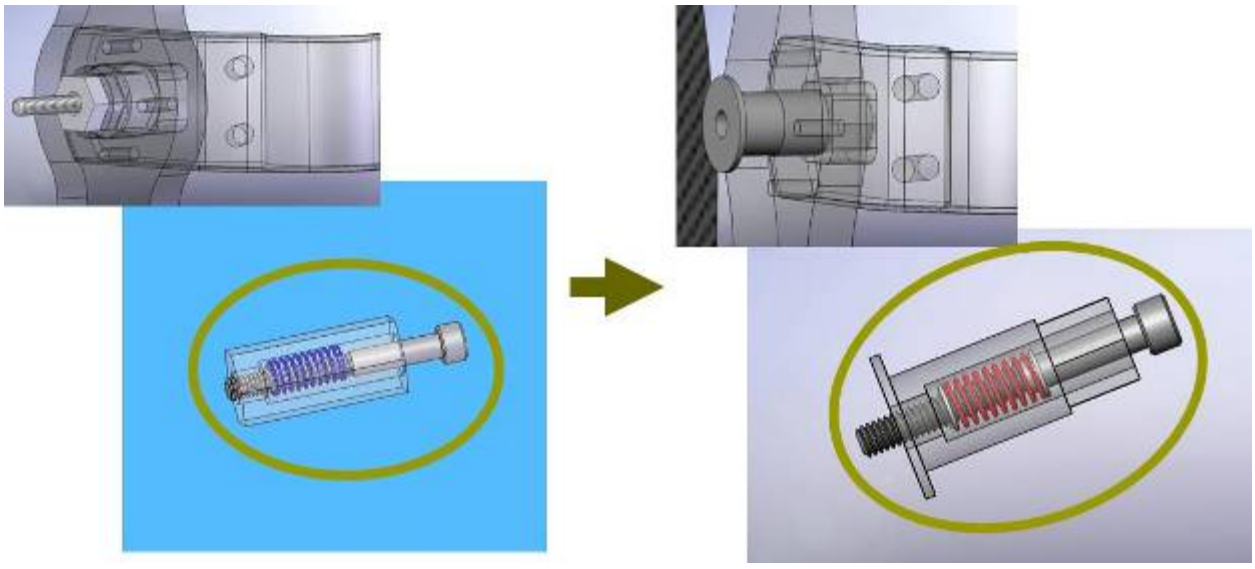


Figure 38. Design change of Hex rod

8.2 TEST OF NEXT PROTOTYPE

A second generation design should be developed based on the feedback from the focus group. Once a new and improved prototype is created, it should be tested according to ANSI/RESNA durability and fatigue test standards to ensure it is durable for reliable and safe use. There are also tests which involve mounting the postural support devices (PSD) to simulate mounting on a wheelchair. The PSD are additional components to wheelchair seating or wheelchair seating and the test for PSD is from a part of International Standard Organization (ISO). Through the test, static, impact and repetitive load strengths are determined as well as disclosure requirements for PSD with associated attachment hardware intended for usage with wheelchairs. [35] As the prototype appropriately meets needs of wheelchair users, it should be tested and meet all sections of the standards. The backrest mounting is new prototype to be attached to wheelchairs. Accordingly, the ANSI/RESNA standards and ISO standards do not verify specific parts yet. Even though the test would follow those standards, durability of the mechanism for engagement and disengagement such as spring and cord might not be tested.

8.3 USER TRIALS

8.3.1 Measure pressure

Changes of positions are helpful for pressure relief, so using the LWDAC would hypothetically assist preventing of pressure sores. In future work, we will measure interface pressure to determine the influence the LWDAC may have on pressure sore risk.

8.3.2 Kinematics

Although positions for angle adjustment are visible, using a “Vicon” which is capturing postures would provide detailed information of movements while users try adjusting the LWDAC angles. The biomechanical analysis will provide a more in depth understanding of positions of the joints of the arm while the user is adjusting the system.

8.3.3 Activities of Daily Living course and Home Trials

Although the focus group provided perspectives from both wheelchair users and clinicians, user trials are necessary for a broader evaluation. Future studies should propose protocols that consist of an Activities of Daily Living (ADL) course and a trial period where the participants can take the LWDAC home for continued use. Conducting such a study will provide a more in depth understanding of the use of the adjustable backrest.

9.0 CONCLUSION

The prevalence of wheelchair usage has increased and wheelchair manufactures are providing more and better wheelchairs because of secondary injuries such as pressure sores and repetitive strain injuries. Among the wheelchair components, a backrest is one of the most important parts due to the importance of seating position and appropriate trunk support. Accordingly, the LWDAC backrest has angle adjustment by single hand operation while in a chair that also provide the benefits of rigid backrests. However, there are no commercially available products which are comparable.

From this study, we found that most subjects believed the LWDAC could provide valuable features when added to their rigid backrest systems. Additional improves that were suggested include a quick release mechanism, fewer possible angle selections, and additional colors. Despite these suggested changes, many of the subjects indicated that they would purchase the LWDAC backrest as existing prototype without any changes. As a result, we established that the LWDAC would have a reasonable chance at succeeding in the market depending on the final price point.

Future studies should consist of an ADL course and trial period where the participants can take the LWDAC home to try during continued use. Future studies may provide a more in depth understanding of the use of the adjustable backrest. The LWDAC is a good alternative to commercially available backrests that provide unique options and benefits to the user.

APPENDIX A

FOCUS GROUP QUESTIONNAIRE

The following questionnaire was made for the evaluation of the LWDAC backrest. The questionnaire is for both of wheelchair users and clinicians.

Lightweight, durable, adjustable composite (LWDAC) backrest: Focus Group Questionnaire

Date: ____/____/____

Age: _____

Gender: ☐ Female ☐ Male

Veteran: ☐ Yes ☐ No

Ethnicity:

☐ African -American

☐ Asian -American

☐ Hispanic

☐ Caucasian

☐ Other: Please specify: _____

<u>If you are a wheelchair user:</u>

Injury Level or Disability: _____

Date of Injury or Onset of Disability: ____/____/____

What is the make and model of your primary wheelchair?

Make: _____ Model:_____

What is the make and model of your current backrest used on your primary wheelchair?

Make: _____ Model:_____

What do you like most about your current backrest? Please explain your answer.

_____

What do you like least about your current backrest? Please explain your answer.

_____

What is your reason to use the current backrest?

_____

If you are a rehabilitation professional:

What is your professional background? Please check all that apply.

- ☐ Assistive Technology Practitioner (RESNA certification)
- ☐ Assistive Technology Supplier (RESNA certification)
- ☐ Occupational Therapist
- ☐ Certified Occupational Therapy Assistant
- ☐ Physical Therapist
- ☐ Physical Therapy Assistant
- ☐ Physiatrist
- ☐ Rehabilitation Engineer
- ☐ Rehabilitation Tech Supplier
- ☐ Other: _____

How many years of experience as a rehabilitation professional do you have?

- ☐ Less than 1 year
- ☐ 1-3 years
- ☐ 4-6 years
- ☐ 7-9 years
- ☐ 10 years or more

We are interested to know the range of backrests you provide and the relative proportion. Please, fill in the column to the right with the percentage of the backrests you provide for manual wheelchair users, and add any style(s) that we have not listed in the 'other' row. The total percentage should add up to 100.

Rigid	
Sling	
Adjustable –Tension Sling	
Custom-molded	
Other:_____	
Total Percentage	100%

We are interested in learning about any concerns or complaints you have heard from wheelchair users about currently available backrests?

_____

If yes, which style of backrests are most concerns/complaints related to? (rigid, sling, etc.)?

_____

Please tell it like it is – we want your honest opinion of the LWDAC. Only through your forthright responses can we make it better. For each statement below please mark an X anywhere on the line to indicate your answer.

Example:

Strongly Agree ——X—— Strongly Disagree

****

1) Does the backrest mounting look big and bulky?

Strongly Agree _____ Strongly Disagree

2) How would you rate the required strength to operate the recline mechanism?

Extremely Easy _____ Extremely Difficult

3) How would you rate the simplicity of operation of the recline mechanism?

Extremely Easy _____ Extremely Difficult

4) Do you agree/disagree with the statement that the recline mechanism can be operated with one hand?

Strongly Agree _____ Strongly Disagree

5) How would you rate the comfort of arm position when operating the recline mechanism?

Extremely Comfortable _____ Extremely Uncomfortable

6) How would you rate the comfort of body position to operate the recline mechanism?

Extremely Comfortable _____ Extremely Uncomfortable

7) Do you feel safe or secure while operating the recline adjustment?

Very Safe _____ Very Dangerous

8) How would you rate the overall comfort when sitting in the LWDAC backrest?

Extremely Comfortable _____ Extremely Uncomfortable

9) How would you rate the available range of recline or backrest angle (-5 to 55)?

Too Large _____ Too Small

10) How would you rate the overall appearance of the LWDAC backrest and hardware?

Very Attractive _____ Very Unattractive

11) If the LWDAC was available for purchase, would you recommend it (clinicians) or use it (consumers)?

Strongly Agree _____ Strongly Disagree

12) What price would be reasonable for this adjustable backrest accessory?

1) $10~$50
2) $50~$100
3) $100~$150
4) $150~$200
5) $200~$250
6) More than $250

We are interested to learn about the potential impact that our adjustable backrest system will have on those who use or could use rigid backrests.

Based on your expert opinion, what portion of the total number of people who **already use rigid backrests** would benefit from the adjustability that our system provides?

1) A Few
2) Less than 50%
3) More than 50%
4) All

What kinds of benefits would people get from the adjustability? Please explain your answer.

_____

Based on your expert opinion, what portion of the total number of people who **do not currently use rigid backrests** would be able to use them with the addition of our adjustable hardware.

5) A Few
6) Less than 50%
7) More than 50%
8) All

Are the adjustments sufficient fore-aft/up-down?

_____

What are the three things that you like best? Please explain your answer.

_____

What are the three things that you most dislike? Please explain your answer.

_____

PLEASE SELECT THE THREE ITEMS that you consider to be the most important to you when you choose a backrest or wheelchair.
Please check the 3 boxes of your choice.

☐1) Dimensions
☐2) Weight
☐3) Adjustments
☐4) Safety
☐5) Durability
☐6) Easy to use
☐7) Comfort
☐8) Effectiveness

If you were in charge of redesigning the LWDAC, what would you do differently? Please explain your answer.

Thank you very much for your time!!

APPENDIX B

FOCUS GROUP TRANSCRIPTION

The following transcriptions were recorded during two focus groups dated February 5th and 12th 2009 as part of evaluation with the LWDAC backrest. Those are included here as evidence of the focus group.

LWDAC focus group transcription
Thursday February 5, 2009

C = focus group coordinator speaking
S = clinician subject speaking
W = wheelchair user subject speaking

C we want to discuss a little bit more pointing out those kinds of issue.
I think there are all good points we also pull one of some how heavy hardware is you guys can tense of whether or not because we can also decide to make out other materials that might be lighter and just strong so weight you know we back on weight whether or not too heavier it's okay has there that is good piece of information for us
we were really not as much as we like compliments but we are not looking for compliment here we really want to get… you know the one of questions in questionnaire for instance, what would you focus on if you were designing for the next generation we really want to focus on what change what thing should've change from here
so that is the idea in terms of adjustability
S do you have one and backrest without this pack that is like come with just then can compare to that too much added.
C in terms of aesthetics or weight
S the aesthetics
C you know what we might…
W look at mine…
C yeah you have this backrest right
S oh did you
C the other thing is I am sure you know in the CAT they have one also…

(Inaudible)

C if you wouldn't mind I do not mind showing people the backrest
S how much the weight of backrest
C the weight of actual backrest or hardware I don't…
do you know weight is the backrest
S it's not too heavy.
W it's not heavy. 2 pounds pound and half
C yeah very light what we are going to do we want once everybody play with that we going to take one we take hardware off of it you can feel of hardware of feel the backrest
is there any questions about it
S is that impact test done all by the all test or one side…
C the impact test is only from the front but it's also because of way of the system design it couldn't be done on the back because of it's the symmetric system of pivot then almost it doesn't matter the idea is the people are going to throw away back into the backrest so that's why the test is they providing that way but we wouldn't…
S I am concerning I am thinking side…
C mechanism
S impacting upper impacting still works..
C there are all other impact tests that they do on their wheelchair usually what you do is impact whatever furthest away from the person impact on the wheel or those kinds of thing it's not

typical there is not a test say impact the hardware of backrest because wheels which is too further the assumption wheel is going to be happen before the backrest but that's another

S you thing situation is very common so I don't know but

C good point

W I don't know how many times gone have backwards ran over pushing handle is it's the normal point of impact

C no that's good point we haven't tested yet that type of impact

W it look like it clear of kinds of pushing handle put in on spread bar but I guess you can also push angle as well because of so push angle

(Inaudible)

W so it push handle remove

C yeah

W two kinds of cane you drop down in the hall you kinds of one cross the spread bar clamp on it come out and either one out of function with that

C lets a play with you want to bring a couple more let's just you guys break out go out split out…

(Inaudible)

<Remote release>

S why would you do this

C why you tilt it now change cloth far back that is one of reason forward is going to be going up hill it's necessary…

W I think it would be really really good idea but in clinic someone already too much stable accommodate too much

C just seat over here so we can caption some of the…
what are you thought about the backrest you don't use the rigid backrest right

W I will tell you what I got this chair a year ago
I had a chair before leave time what but not yet I didn't realize how well sling back is block glove okay and then it also aluminum plain bent it this over year analyze either after that I haven't done I figured in this chair light back then I tried way different right back assemble I tried them in half dozen configuration each time trying different things and essentially as you can do find a position good for a sitting or something just like you said you go to get dress going thing and it doesn't work that fact you know you back up get on sling in it up and river you realize how important things to getting dress for you like jeans up

W once I had rigid back I realize… wow I can't jeans up
anyway second things was the bracket tree not kick it hung up those thing and dress get in do whatever I didn't like that either so you guys cleaned up pretty good
there are a lot of snag one died pull snag right you know angle edge sticking out corner is thing out adjustability wasn't too tight like this snag thing this is pop-up this back I don't know I mean

I never thought about gear things but I would thought we really need was thing pushing you know in mounting couple inches gap may

(Inaudible)

C your thought was maybe…
W just don't make so rigid

W did you get it pull it out some other way
if you want it between this all lock
C yeah actually we have some small changes all cleansed up actually it will constrain it basically this one that's this is prototype so it doesn't smart as
W you might even rather than the cable of power on it… like a little bar what you know get the bar of it it release use different type of mechanism It wouldn't better yet
C do you like the idea might be might be unlock variable
W I never tried that idea but I just the reason I rejected the rigid was I couldn't be happy with it also situation that I adjusted one thing and another situation was in the wet and it seems natural of sling giving I didn't realize how good when I wasn't good without it. you know what I mean
C Right
W it sling gave little only the other rigid you can't do that I don't know which one back should I why this chair that's going to be why

(Inaudible)

C do you want to transfer here
you want some help

(Inaudible)

S how did you decide in terms of anterior posterior I mean range of angle
C I think it was a
W you know what I would not like about this actual backrest bone in the backrest itself is too soft okay it way too much give in it that is something we could adjust by… thinner or high density foam the other thing is bring this up you know
C can I adjust for you
W sure

(Inaudible)

C so was the hardware catching on stuff it also back you know you could adjust if you want it to

(Inaudible)

C did you state rigid allomen for a while
W yeah actually we can figuring out every where with thinking of you know I just couldn't come up anything when I was happy with I wouldn't back to sling back I gave up rigid idea so I think so
C you adjusted you going to lay off half of it just like that try again

(Inaudible)

<Shoulder issue>

C do you think remote release for the backrest
W I mean reach down here I mean I don't have any problem with that that's not a big issues because you got complicated it then get involve something like
C cable around it
W it is over complicated you know

S how do you feel
W I don't think I don't want release I mean you could put it you know off the one side a little
C dominate side
W yeah you know you could have either side pull it here release for both sides you could do something like that grabbing in center is not completely awkward

(Inaudible)

W okay I am watching TV I think that is kinds of cool you know I haven't recline seat say again I can say that tilting one you can sit back and do it stretching like this relax change personally back for time being some like that would be nice too you are not getting out of sling in it you are not get out of fixed right

(Inaudible)

S very good

W proper pre-set might be better because infinite adjustability like this is too far come back it's far again
C there is 5 degree inclement right now we could change 10 or 15
W you will know really obvious you have three spots lock just okay this is my primary spot this is middle spot this it…

(Inaudible)

C that is only adjustment you make strong whatever put it position and then when you're dressing you can find other reasons
W I don't know about like center of gravity things I may used to do that try grab handrim couple degree forward when you go to upper ramp you got a choice between back-off back good strong a little bit push against back a little bit
once you have talked people suggested it might have function of allowing you climb the hill pushing against backrest

sling back off I just curious it would help

(Inaudible)

C he might put it forward when he go up so he can really against to backrest still
W it's not comfortable, but I can really straight against lean gravity
W I think I wouldn't use… cold out
W I don't want to change simple ease

(Inaudible)

C you saw the previous design right

W there are a lot of little things hassle
don't take time it has to be slick(sleek) and simple
it's not going to be used

<u>*<Safety issue>*</u>

W more comfort stretch my arm
I can get angle
it makes my muscle fatigue relaxing my muscle
C do you think your backrest adjust incorrectly or because of angle differently
W I can adjust angle here that doesn't give me comfort
C would you use for things like getting dress change going up hill
W I wouldn't be actually it wouldn't make difference for changing dress it would make difference being in all day give comfort to me for long time
W I like I am doing right now I will do this while I am sitting little while
you push my lumbar it is kinds of weight shift
W I have fatigue after all moves 7 hours in same position fatigue would be lesser than this
C what is the clinician's thought about
you said you back a little bit more comfortable that actually means more shear on your back
what would you guys suggest
S I just look into moving
when you recline you can move forward how long will you stay you will get sit edge pressure back when you go position back I don't know how hard would be

C migrate this room relief

(Inaudible)

W as long as user understand what they are doing I am sitting vertical so my pressure is my U.C.
when I switch to recline to put it on my sacrum that's good my weight shift balance of time between of
C we need to train in there understanding consequence of using shear and shift

W here is more important to me
I would everything around here be cleaned and snag for equal reaching around it it probably some sorts of… rounded plugs put in here nice and smooth pushing handle around here keep in it tight

<u>*<Snag and clothing>*</u>

C what about handling cane

W I don't like this at all it is on my way
I want this all clean here that's why I like it and also solve my back pain I know some people would be that the cane is there happy about it for me I don't want it here I want back it grabbing this you can grab here push this side and this side push again here that's kinds of engineering

C that's more tricks we need to think about

W that would be much cleaned a little bit push something here or here either side a button 1/4inch push this side ¼ inch push that side are connected with a shaft through okay

C will you take on off so we can pass it around

(Inaudible/questionnaire)

C tool accessories purchase besides of backrest itself

S only the mechanism

C three pounds for total with mounting and backrest

S when I see people in the wheelchair games most people use rigid backrest

W pushing in here center pushing is really needs

W I like fore-aft where you can get it I like you can flip around actually do you have it can you actually have it

C it won't go all the way that you want, yes we can invert it

W you could get it off flip around get it on. Then you got a lot of fore then that might be too much

C how much are you looking forward fore

W I like little bit more than you got, not a lot

C how about adjustment

W I don't care about adjustment I need I am going to use one spot personally I like further forward but the other people like further back so I need you put some adjustment we can either we can have different length

W everyone has different balance points I don't want being wheelie leaning backward

C respect of center of gravity when you do recline
obvious your torso going to back because of the pivot point your legs also move forward so there is a little bit of balance

W the pivot is on lumbar
I would be in a list of getting one of these I would get it definitely it takes about one year to find the backrest I like you would go with rigid backrest I would go with rigid backrest even the way it is right now is good

<Angle>

C why we choose -5 to 55 degree for change angle

S I think the negative 5 is like eating writing or doing something on table

S I consider posterior angle
C do you think 55 degree is too far
S no its not too far
S but you shouldn't have more because of increase of shear
I don think so

C 1.5 pound is for only backrest itself 3 pound is together
W so it was doubled

C do you think we need to decrease range of angle
it needs to educate consequence of using it
W it depends on people activities

C so what do you think it is worthy
W it is accustomed education use what you need understand what you are doing

C you understand that consequence of reclining
it works while add some features to the we could adjust maybe to maintenance
some people we don't want go back -5 back to 40
W that might be and more related prescription wouldn't matter at me
I will just you know I am going use just full function and then
C that is going to people refuse use around it active user
they are going to decide it too far back
W it is problem open it up too much kinds of out of the position it become it depends on functional capabilities
W I think it is good idea as well as promising
C we brought up this issue of a the thing catching um… the type of things um… that… so released aesthesis those kinds of things how is looking it what would you guys change about these to improve them
S I actually like them
W pretty good
S I like to look at W's it should be I do not think
W you already rounded it corner off sufficiently more snag many be make any difference round a little bit more or not but it looks pretty good
C in terms of release function grabbing gross… sounds like everyone was pretty comfortable
How much force… um is it everyone
Pretty agree those…
W I think um… nothing looks fine side more reach people has spinal cord issue sensory issue I mean should be reaching them… so maybe they are not required
C much button either side or remote type of system or
S I mean I rather button… cheaper option
W I think that is adequate pulling a cord on center almost seems like cheap mechanism or something like that you know easy to things to snag whatever I like button on the side is better than reaching all the way of the middle of the back I guess I have to apply to have sit with long cord one button I am going to choose a button to recline
C the quick release we talk initially validate having pop-up backrest pretty quick how important is that look the consequence we had like this it means everybody seems think looks good not..
right now…

I have button it works and change game change we leave like this we don't have quick release system we can't crotch the chair

W I can guess it is collapse chair if you have a car you have to break down something you can not fold

W if you could do cushion off then seat pull the seat down to I don't know do you need to remove the backrest can you fold it down a little bit more I think it would… I think it would pull down cushion is off there people back backrest down now see people no cushion up there pull more further

C/S yeah yeah

W so it thinks we remove you might fit in somebody trunk or something like that unusual situation

C are you in a folding chair Is that worry folding chair In case so there might be the reason of have all these hardware

W I assuming the rigid chair I saw what you mean you going to folding chair

S when you make put together easy to I to have

W I mean you could have this chair

C quick release system compromise the system

S I know why people like that become pop-up so easily

C right it has very straight forward mechanism

W yeah this is like here you are someone with rigid chair this is great just clamp might never have to move again the guy with the folding chair you can have different one of these that has just like push button or latch or something or you know just slight up off latch the clothes each time it would be…

C hardware pull lots of gears

W I would not want for my rigid chair but I could see if I have folding chair then you know that would be the way to go

C we wonder rigid is extern extra weight

W things are necessary

C we kinds know the answers already in terms of weights obviously light is better um… as you guys know the difference of weight is that too much as it says right now the difference is between the backrest is it we need to really focus on redesign to consider

W light weight pretty light weight

S but I mean that is the one and half pound and the another one and half pounds on and it three pounds but so it is three

C yeah but you can grab it but W already one and half pounds is really important to you if we got the mechanism it is down to the half pounds so we are moving up by that make more reasonable for you buy

W in terms of weight it's for sure yeah

W break for me the concept

C you would not use it

W yeah I am still depending on we spend enough time we can find one position backrest differ I don't just enough time we can figure it out pretty adequately

C for the clinical setting I know that is the first idea that is going to be very useful in clinic

W beautiful

C have any change
I know I can make 50 pounds in clinic it wouldn't matter but would you guys in clinician here would you guys clinician here use tomorrow if I put in angle find out the backrest…

S yep…

W as far as lightening up you can make holes here and here not probably affect not much strength probably take these gears put hole it makes look like bracket looking things something like that yeah we haven't open mind still yet

C but I know I think we know you know the better certainly

W first thing, I want to take home it today I mean put it myself

W I like it myself

C I would in clinician

W the only thing probably end up with changing this off better foam and better grab bar whatever put on that put a something out of poly something soft you know I am trying to remember the name of rubber is you know what I mean it's not quite foam

C it's not aesthetics

W no… stronger than that… hard rubber something Some little bit something between plastic and rubber than poly they have little bit of more rigid than the foam

C you know that would be the enough which one is priority we talk about few things the quick-release and the button instead of rope few things we talked about kinds of button and also some adjustment

S something side or in front of it not back

C what is the priority to do other those… other those… two you know whether we need to change the mechanism to releaser get rid of the rope is the our priority quick-release is priority some adjustment change angle limits

W for me it would be a button releaser I think I work wonder…

C so then I said angle adjustment being able to change you know -5 to 55 and then maybe obviously button alternative way to release it would be third one

W Quick-release actual removal

S I think I would like to divide this three things into two one more is like long term use one more is like clinical situation most point just somebody wants to ranking will be different regards these

C I understand that that is I think that is in terms of important, so in product…
I understand that because it's …
we can end up personally use….

W idea is I like kinds of the fact that you have hand and you have to guide yourself you know it is not countersink you know what your hand something like button on a side it will difficult to guide you

W for me I'm using my whole hands to push in and out I guide like this but if you don't have you are using and this way because you don't same dexterity

W were you looking for pulling a cord guiding with your hand

W yeah I could…
the only one issue I had with that was they want you go in put this instead of pushing handle here then you led through them and then it becomes dull that's…
I will be going out like this okay you're like that but I'm thinking pushing handle is here eliminate that

C that I mean lets say we have push with adjust different ways so it doesn't configure though pushing handle first of all have to be far enough to from the backrest still allow it rotate

W good point I didn't think that

C maybe the button is useful for any situation I got I obviously button is useful because you can benefit from it I am wondering is there more universal

W I did not think about the fact when you rotate the back the cushion with it
C we have to be aware of it the pivot
W unless you're there is no way you can have push hands put it in this mechanism because them you transfer a lot of stress
C we could but there is the first thing to do…
W I was really don't like the idea push in here because it is in the way coming around it hits my elbow
C something we can do is the priority here
W probably not
C and quick-release is necessary for people in folding chair that would be an optional
W yeah
C angle adjustment because even the type of users is the critical thing adjust the range
S I think one thing that we mention I think you are fill out outside that are which we have pre-set you know like because hare do find out giving the position you use before so you just have pre-set angle
W seeing the natural
W you find at one three spots that is it.. you can kinds of like that you want to recline that forward
S but range of angel is can be an issue
C so a pre-set is far making only 3 or 4 before positions not… thinking just feeling adjustment

S an option little bit has infinite
C so in the clinic, we need to be infinite or rotate
W you got three spots but then you can rotate down to the whatever degree you want to in it you know what I mean then you want you set those then you can be you know they can be primary set but it gives choice what does position would be or they would choose..
C okay in clinic there is 5 or 3 increment are enough or not for reading is not infinite Or is it infinite You have hard to measure angle we know 5 degree inclement can you guys
W I could one time I was up to kinds of bound up a little bit that were you know it is extremely example of it I have one matching group anymore
W if you have separate release that getting cock
W my body I would not think about shaft go through all over same time because you right there is no way you could independently you push both of them you know I don't know if the gaps are wider the chances get the bound up the slimp gludes so closer together it is possible to get a bound up I did it once I did something like back again it is kinds of backrest
C they can't do one side and the other sides
W it seems like when I got release smoothly but I bound up…
W instruction would you want would you cound completely count some people upload family adjusting or would you want to them their own
C I mean we haven't instruct people through I think it seems the way people do they upload right until they release and load up against you can adjust it
W yeah I noticed it I can pull it on here it wasn't doing anything but I just is that the a little bit with um relax I don't think it takes long to learn it that
C any problem
W no actually I like that that is we can use I mean upload but it would no because it will be available with one hand pretty easily
S is there problem with a push button
W I don't know I don't like there is no problem at all
that is really comfortable and using I wouldn't try to change it by myself

W did you find these are necessary as these are on there did just

C because we want to be able to pull on the cast/cap uniform well straight out that is one of degree freedom they can travel if you keep the line all they way pull the way down so bind it needs balance..

W floppy
that balance is important by hand

W have you done a how long it is going to start cord the

C we haven't done that testing yet something like we can work on that is it

W I think you got a good idea
I do

W good features
great I like angle you can control it…

C so we see the three pre-set do you think somebody might want buy five

W it is kinds of you almost runner a little bit
you probably right three might not be enough

C so three pre-set would be one sort of you're looking at you most of time it another one is really far recline and another one is forward what are you looking that's

W I guess what I will do

W I think you like the propulsion and where you are pushing sitting upright that's not support or not that's kinds of comfort whatever it's not critical issue but exactly I guess the matter

W what I understand what you meant was if we are talking about 5 holes in that's it you want five at least but if you are talking about just three spots and all teeth between that's fine too. You know one way to go find three spots again without thinking about it you just talking back and sleep in a way and ready to go

W you have one open up position for propelling and then one all way back for dressing and then would be

S but could you did you have one idea and then extreme end up further for the nap that might be comfort back individual preference when you release is that you might stop how far you want to go

W yeah I am thinking the system wasn't allowed angle extreme couldn't so far… it stop it really helpful okay…

W three spots right back to it rest of it adjustable wouldn't matter as long as we could find one spot again
I really like pushing handle right on it though still have full function because um.. I don't have push handle on this way right now because I have just keep just adjusting taking on and off changing things I just did not back it on again then my buddy's house trying help push handle back on… it bars really hard use okay I remember putting back on so it is over his house soon or later you end up being up step-up something okay you gotta have um…

C thank you very much

LWDAC focus group transcription
Thursday February 12, 2009

C = focus group coordinator speaking
S = clinician subject speaking
W = wheelchair user subject speaking

C Having a remote release definitely comes up. That's good idea.
One thing people would say remote release something below right on the frame something and what they say was after using a little bit. They realize maybe it is better to have a back there.
Remote release woks if you want to recline it, but getting it go back there you hands back there then you can actually…
W It will be awkward. That is too back there. When going uphill that motion would be helpful.
Leaning forward.
W It looks a little bit bulky. It needs to be cleaned. You want it to be as light as possible.
C Yeah.
W Put it in the car breaking wheelchair lighter is better. It looks bulky the clamps…
C Do you think you get it? Let's say reduce weights.
W Yes.
Feel myself.
S Remote? No remote
Kinds of pushing a button.
It might be helpful.
C What do you think?
W It needs to be more variable.
C What do you think about backrest mounting itself?
You're using a sling back. Why don't you use rigid back?
W I have it. First of all, you have to put it on and off when you need to put it in the car.
C You have folding.
W There had a piece of material to pull it loosened painful at sticking in the mechanism of locking and unlocking
You mentioned it looks heavier.
I noticed that… I lost 10 pounds weight is not initial problem(?).
Functions would be helpful?
W It was easy for me.

(Inaudible)

You rather to have constrains vertical and forward.

(Inaudible)

We make sure the spring last for a while

(Inaudible)

Quick-release

C Why don't you use rigid backrest?
W You know what? I consider my wonderful posture.
C Have you tried one?
W Yeah

(Inaudible)

C Rigid backrest takes more time to get and collapse the chair. Otherwise, you feel more comfortable when you have it on.
W Yeah
C Okay

(Inaudible)

C I guess a lot of backrests are longer that would be more private. Anyhow extra piece? You can't put weight on it, but you release it would be fine.

(Questionnaire time)

C You guys said that look forward some type of quick-release system, right?
That way a feedback from last time, also. It's pretty clear that's important to us. The company that makes the backrests has quick-release system set up. It would modify that system so we would combine that system.
What do you think?
W It works for me.

C Everyone knows that. The chair if you have rigid frame. The backrest can be folded forward.

(Inaudible)

W Adjustable pieces
S Adjustable accessories are the goal.

<mention about measuring/scoring different way such as 1 to 10>

C Let me get your attention.

C A lot of users and clinicians thought about some kinds of remote type of control mechanism are usable meaning that some cases you don't want to have hands back here because of high backrest those kinds of things.
The other functional thing came up?
I know we talked about quick-release already.
They mentioned it has so many position we can change to 5 increments some people said there are too fine of increments.
There are three spots, perfect spot, you want to be able to get to spot, and then otherwise, it can be as far back or far forward. They didn't care about where is infinitely adjustable, so they want to have three spot is that another thing we didn't bring up here?
W Power seat in my car…

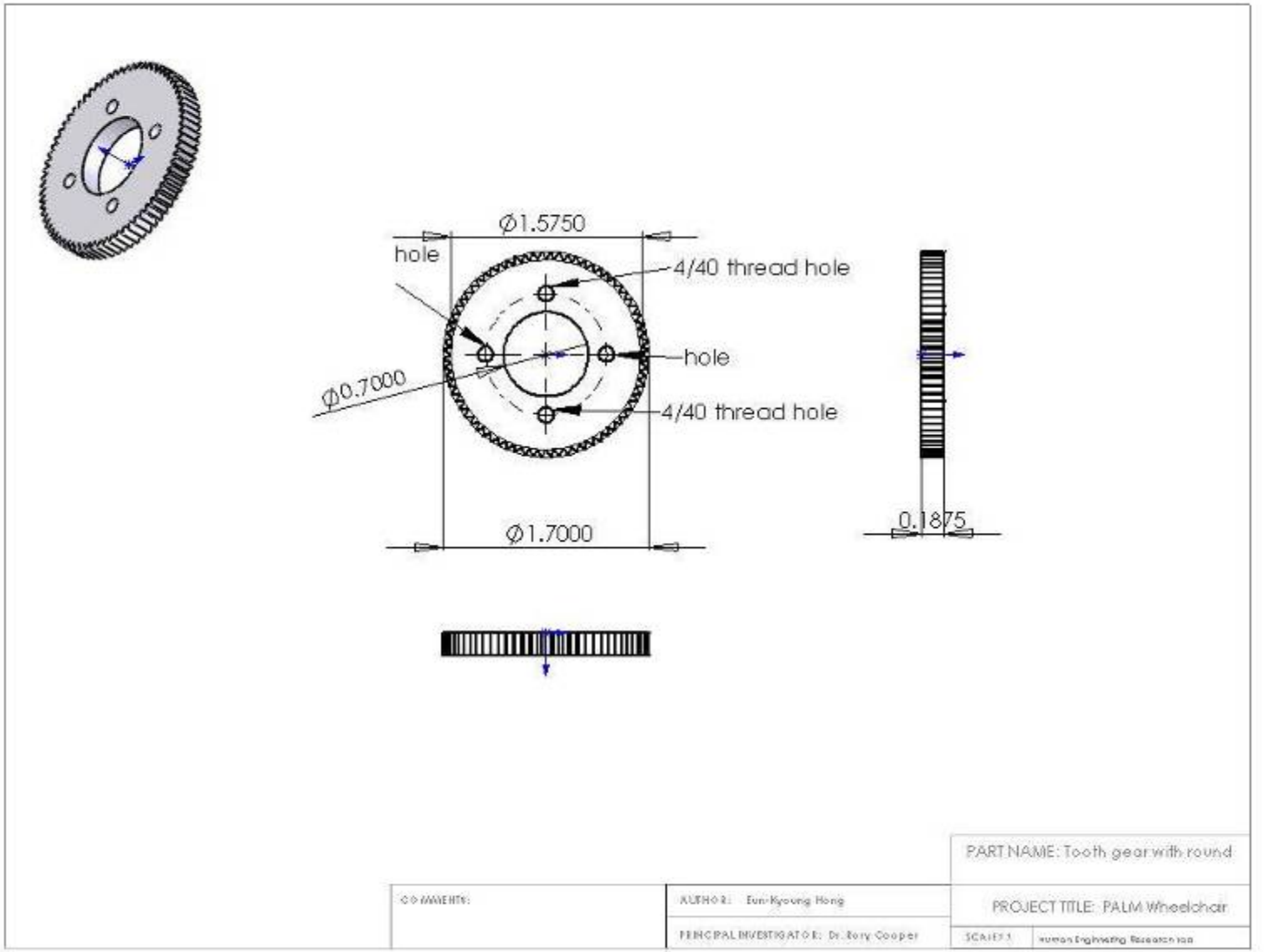
C should be ten degree? Or three spots?
S Going up the hill get dressing or something like that comfort the truth is we don't know how people are going to use it.
C Right.
Because we know problems with rigid backrest rigid now so people want to change their posture three times a day they can maybe it would be handy all the time we don't know for sure but that's the idea.
S Not same for everyone. It would be good that everyone have different three spots.
C For clinician, the design can be very useful in clinic to find posture of clients. Even though the person is not going to use the adjustable backrest people can use it to find the correct spot when they providing chairs.
S Like an evaluation tool?
S It can be helpful for pressure relief.
W I would like to add on to that. I am going to order right cushion because I have pressure sore on butt, this type of backrest can be helpful for repositioning it. The right cushion has most jobs.

Causes and pressure issue
Might be pinch while releasing

C Aesthetics?
S&W No No Yes Yes
C It is kinds of mixing.
W There are user's standpoints. As smaller as possible. Weightless. Provide more color
W Cheap…
W Cheap first! Lightweight! Looks! Color would be option for long term use.
Durability
C It will have a test for that.
W Wire type of functions… Durability for long term.

APPENDIX C

CAD DRAWINGS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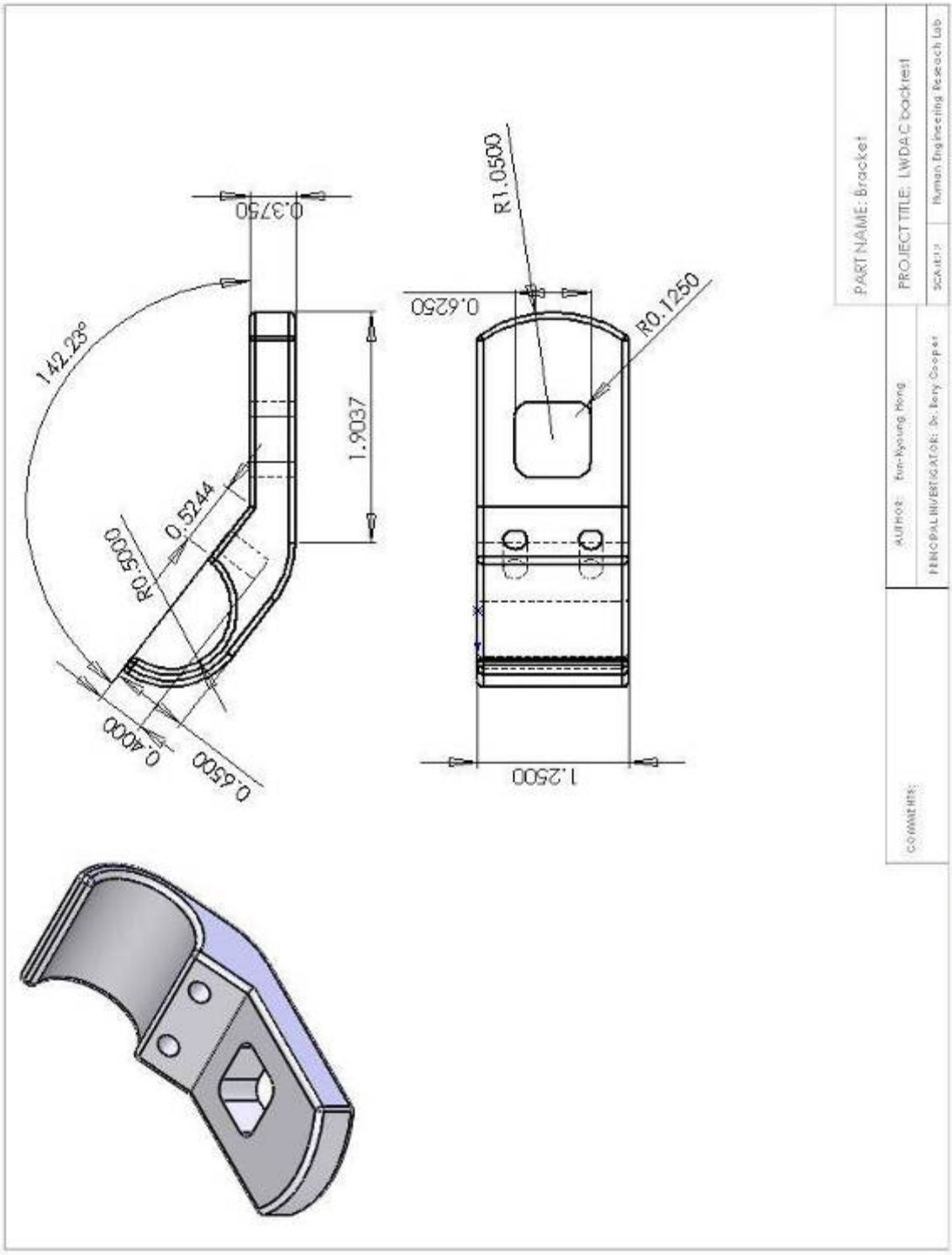
PART NAME: Tooth gear with round
COMMENTS:
AUTHOR: Eun-Kyoung Hong
PROJECT TITLE: PALM Wheelchair
PRINCIPAL INVESTIGATOR: Dr. Rory Cooper
SCALE: 1:1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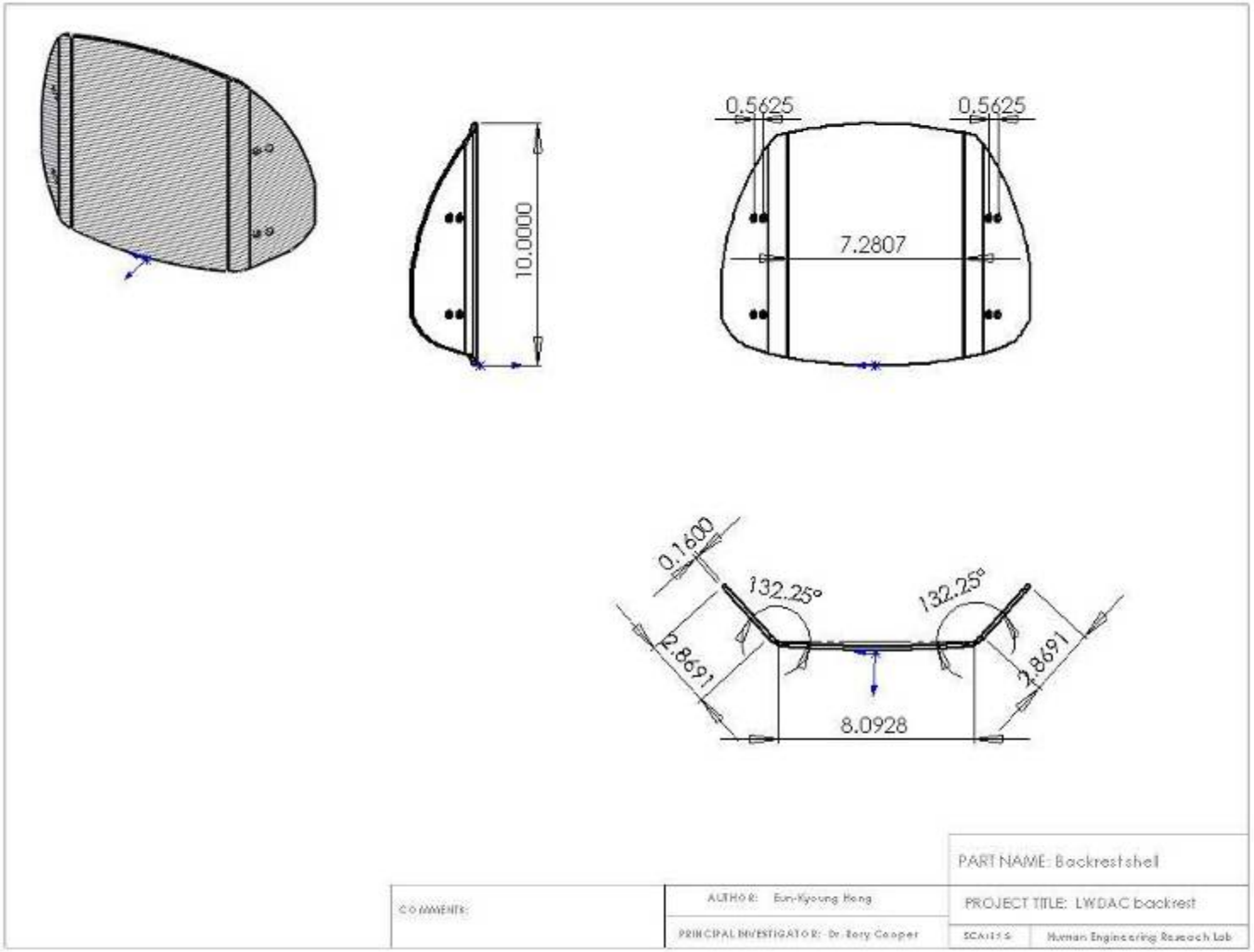
PART NAME: Bracket
PROJECT TITLE: LWDAC backrest
AUTHOR: Eun-Kyoung Hong
PRINCIPAL INVESTIGATOR: Dr. Rory Cooper
SCALE: 1:1
Human Engineering Research Lab
COMMENTS: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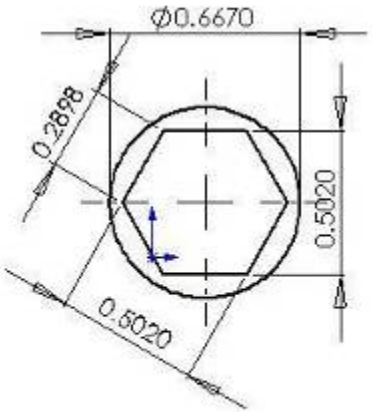
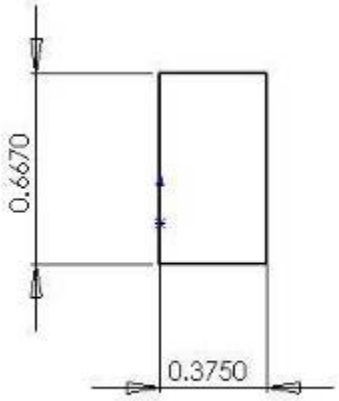
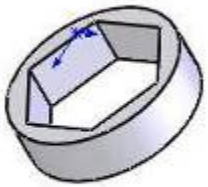
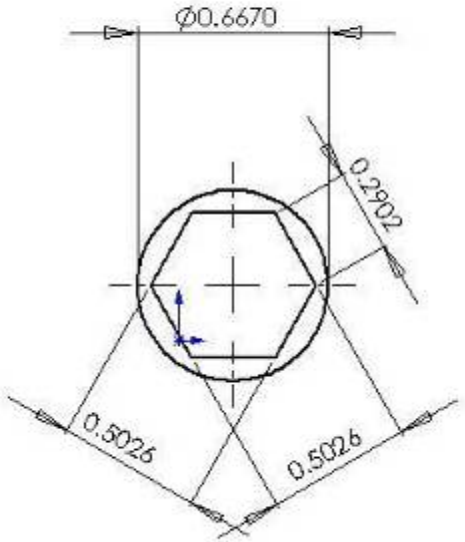
PART NAME: Backrestshell
COMMENTS:
AUTHOR: Eun-Kyoung Hong
PROJECT TITLE: LWDAC backrest
PRINCIPAL INVESTIGATOR: Dr. Rory Cooper
SCAI I T S
Human Engineering Research Lab

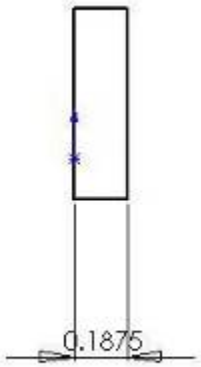




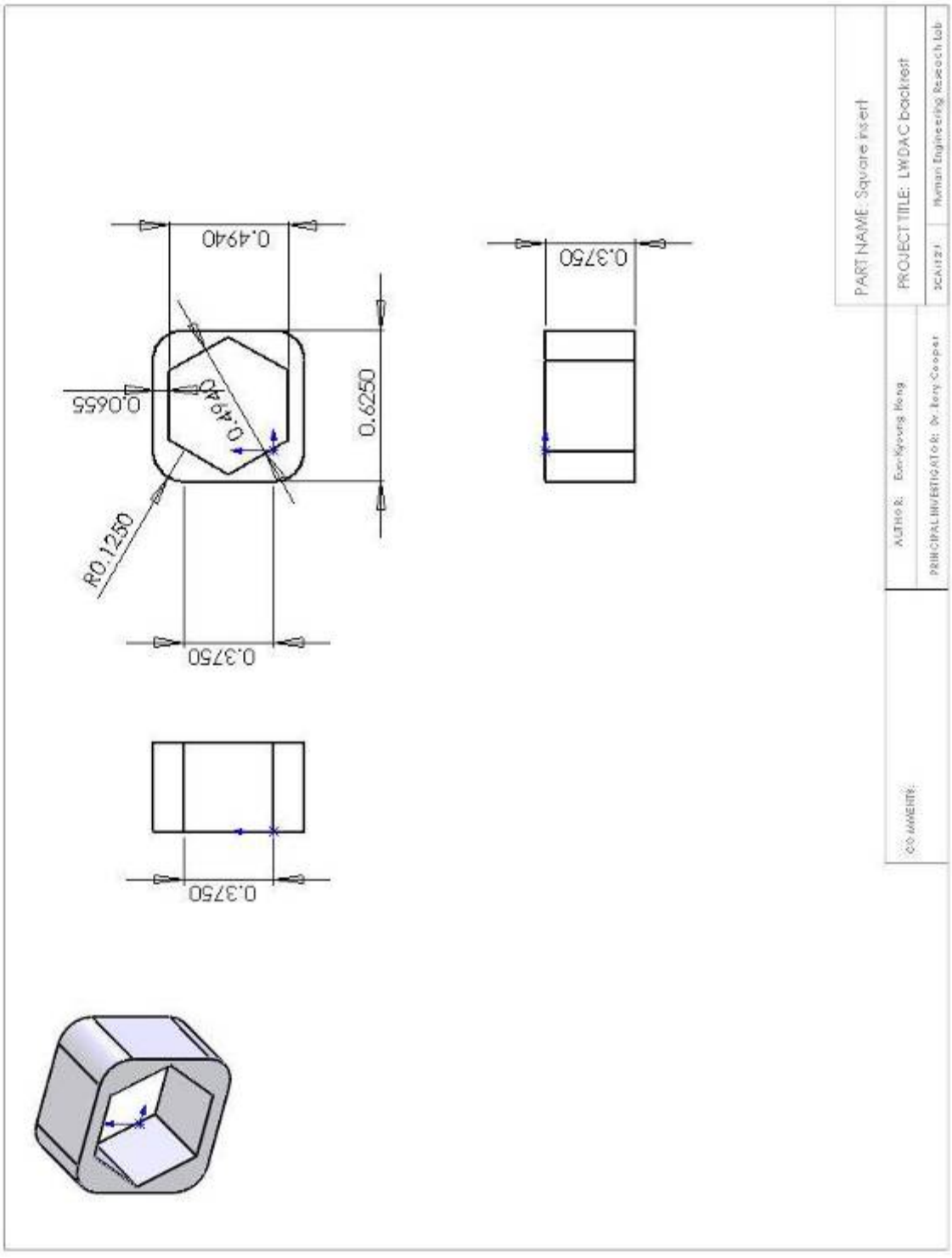
COMMENTS:	PART NAME: Round insert - long
AUTHOR: Eun-Kyoung Hong	PROJECT TITLE: LWDAC backrest
PRINCIPAL INVESTIGATOR: Dr. Rory Cooper	RERC on AT / Human Engineering Research Lab

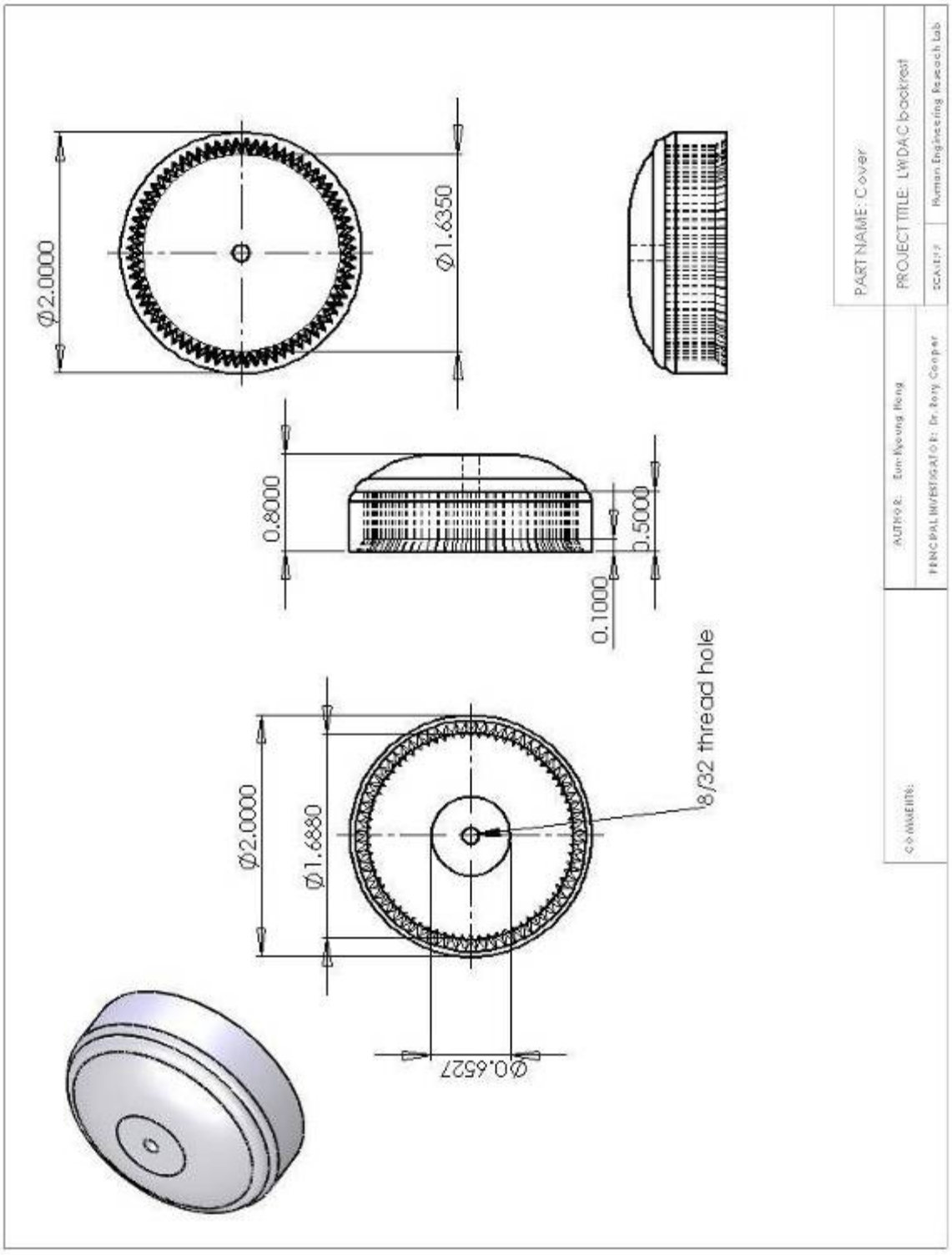


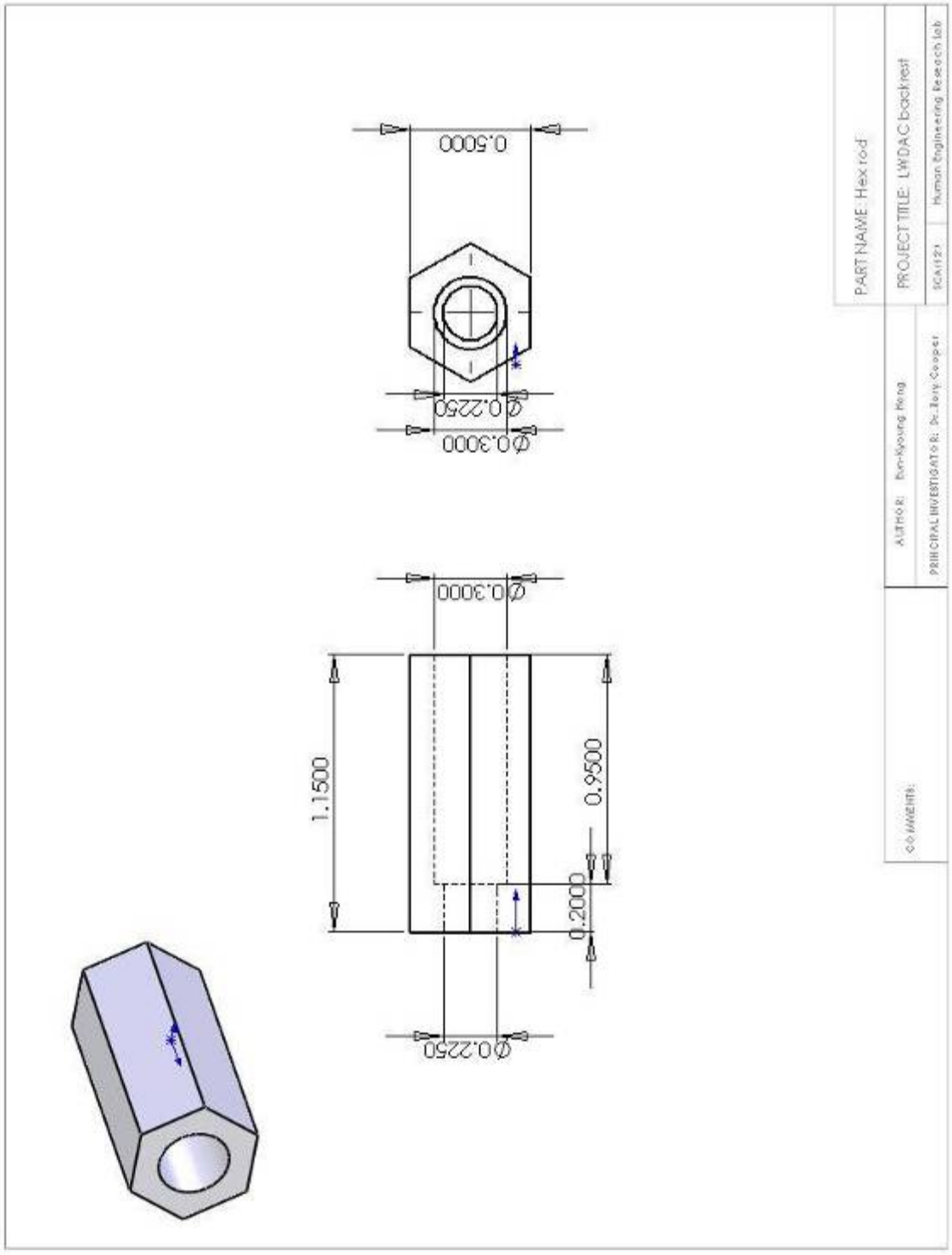


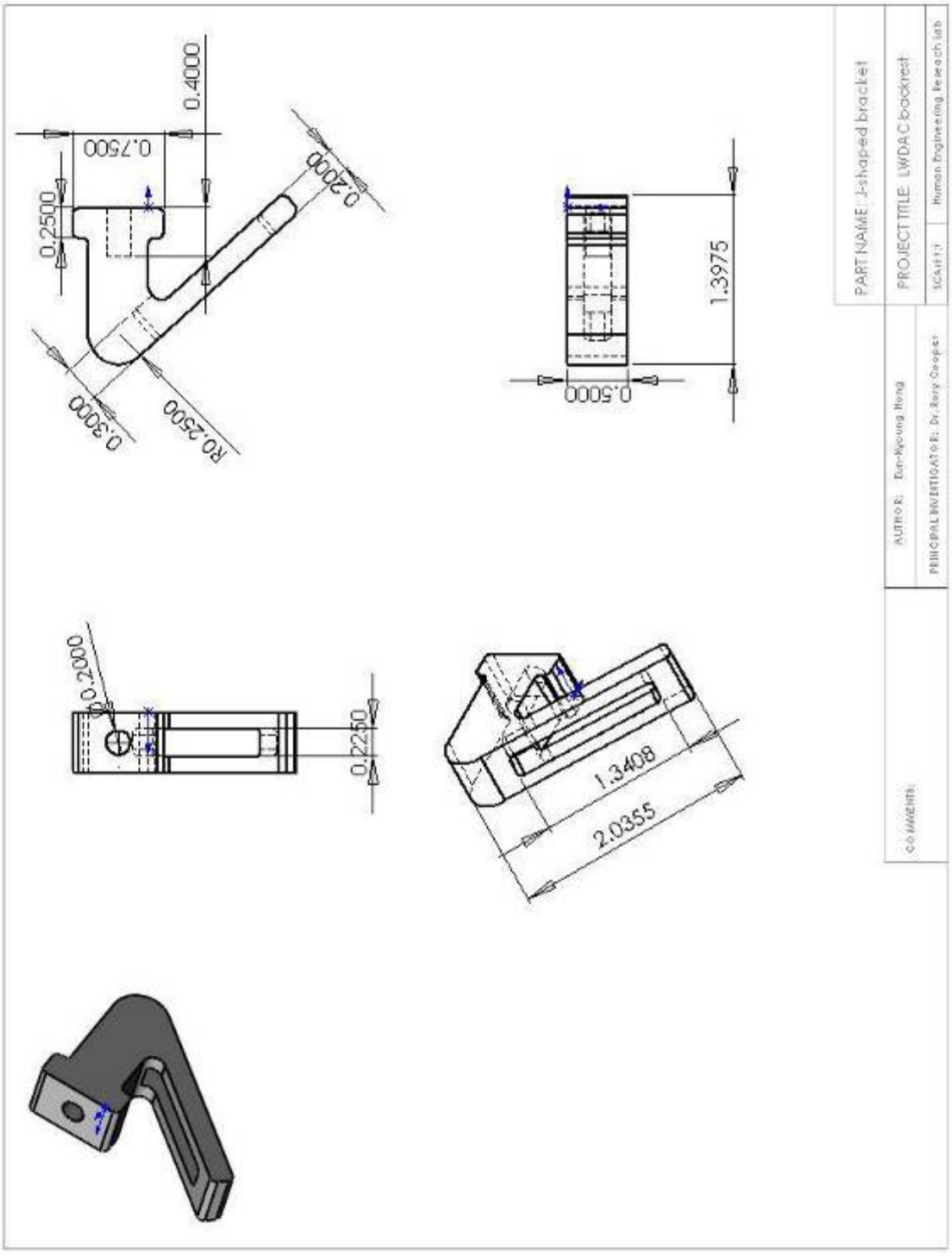


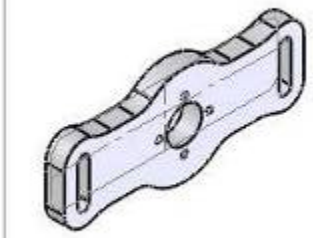
COMMENTS:	AUTHOR: Eun-Kyoung Hong	PART NAME: Round inser - short
	PRINCIPAL INVESTIGATOR: Dr. Rory Cooper	PROJECT TITLE: LWDAC backrest
		SCALE:1:1 Human Engineering Research Lab

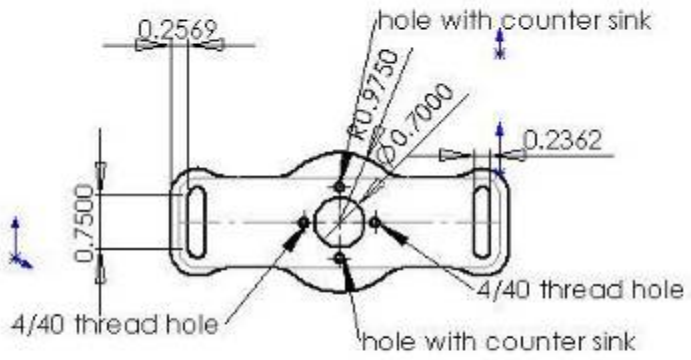

0.4940
0.6250
0.0655
0.4940
R0.1250
0.3750
0.3750
0.3750
PART NAME: Square insert
PROJECT TITLE: LWDAC backtest
SCALE:1
Human Engineering Research lab
AUTHOR: Eun-Kyoung Hong
PRINCIPAL INVESTIGATOR: Dr. Rory Cooper
© WARNING:

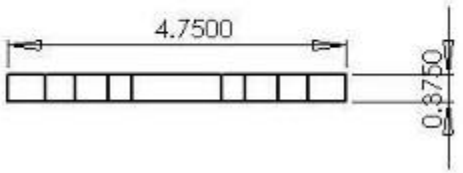

Ø2.0000
Ø1.6350
0.8000
0.5000
0.1000
Ø2.0000
Ø1.6880
8/32 thread hole
Ø0.6527
PART NAME: Cover
PROJECT TITLE: LWDA/C backrest
AUTHOR: Eun-Kyeung Hong
PRINCIPAL INVESTIGATOR: Dr. Rory Cooper
SCALE: ?
Human Engineering Research lab
COMMENTS:


PART NAME: Hex rod
PROJECT TITLE: LWDAC backrest
AUTHOR: Eun-Kyoung Kong
PRINCIPAL INVESTIGATOR: Dr. Rory Cooper
SCALE(2:1)
Human Engineering Research lab
0.5000
Ø0.2250
Ø0.3000
Ø0.3000
1.1500
0.9500
0.2000
Ø0.2250

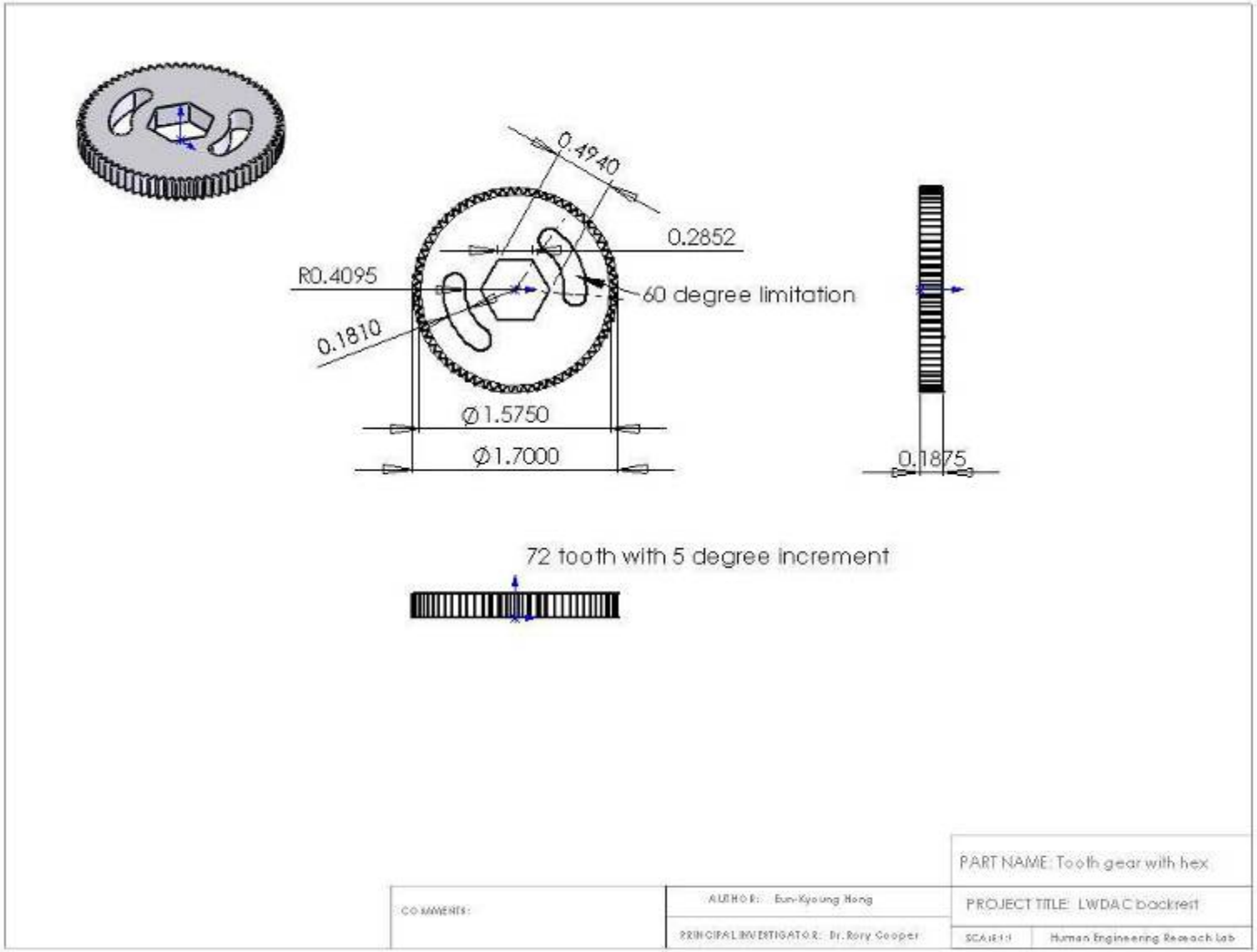

0.4000
0.7500
0.2500
0.2000
0.3000
R0.2500
1.3975
0.5000
0.2000
0.2250
1.3408
2.0355
PART NAME: J-shaped bracket
PROJECT TITLE: LWDAC backrest
AUTHOR: Eun-Kyoung Hong
PRINCIPAL INVESTIGATOR: Dr. Barry Cooper
SCALE: 1:1
Human Engineering Research Lab
<> MATERIALS:







COMMENTS:	PART NAME: Pivot bar
AUTHOR: Eun-Kyoung Hong	PROJECT TITLE: LWDAC backrest
PRINCIPAL INVESTIGATOR: Dr. Rory Cooper	SCALE: 0 Human Engineering Research Lab


0.4940
0.2852
R0.4095
60 degree limitation
0.1810
Ø1.5750
Ø1.7000
0.1875
72 tooth with 5 degree increment
PART NAME: Tooth gear with hex
COMMENTS:
AUTHOR: Eun-Kyoung Hong
PROJECT TITLE: LWDAC backrest
PRINCIPAL INVESTIGATOR: Dr. Rory Cooper
SCALE: 1:1
Human Engineering Research Lab

BIBLIOGRAPHY

1. *Disability Status : 2000* 2003 [cited 2008 October 10]; Available from: http://www.census.gov/prod/2003pubs/c2kbr-17.pdf.
2. *The limitation wheelchair use.* [cited 2008 October 10]; Available from: http://www.jan.wvu.edu/soar/wheelchair.html.
3. Scherer, M.J., et al., *Measuring subjective quality of life following spinal cord injury: a validation study of the assistive technology device predisposition assessment.* Disability & Rehabilitation, 2001. **23**(9): p. 387-93.
4. Smith, R.O. and R.O. Smith, *Measuring the outcomes of assistive technology: challenge and innovation.* Assistive Technology, 1996. **8**(2): p. 71-81.
5. Chaves, E.S., et al., *Assessing the influence of wheelchair technology on perception of participation in spinal cord injury.* Archives of Physical Medicine & Rehabilitation, 2004. **85**(11): p. 1854-8.
6. DiGiovine, M.M., et al., *User assessment of manual wheelchair ride comfort and ergonomics.* Archives of Physical Medicine and Rehabilitation, 2000. **81**(4): p. 490-4.
7. *New Freedom Initiative Act.* [cited 2008 October 10]; Available from: http://www.whitehouse.gov/news/freedominitiative/freedominitiative.html.
8. Janssen-Potten, Y.J., et al., *Chair configuration and balance control in persons with spinal cord injury.* Archives of Physical Medicine & Rehabilitation, 2000. **81**(4): p. 401-8.
9. Cooper, R.A., *Wheelchair Selection and Configuration*. 1998: Demos Medical Publishing, LLC. 410.
10. Desroches, G., et al., *Effect of system tilt and seat-to-backrest angles on load sustained by shoulder during wheelchair propulsion.* Journal of Rehabilitation Research & Development, 2006. **43**(7): p. 871-82.
11. Hastings, J.D., E.R. Fanucchi, and S.P. Burns, *Wheelchair configuration and postural alignment in persons with spinal cord injury*. Archives of Physical Medicine and Rehabilitation, 2003. **84**(4): p. 528-34.
12. Boninger, M.L., et al., *Postural changes with aging in tetraplegia: effects on life satisfaction and pain.* Archives of Physical Medicine and Rehabilitation, 1998. **79**(12): p. 1577-81.
13. Hobson, D.A. and D.A. Hobson, *Comparative effects of posture on pressure and shear at the body-seat interface.* Journal of Rehabilitation Research & Development, 1992. **29**(4): p. 21-31.
14. Kangas, K.M., *Seating for task performance: creating seating systems that allow weight-bearing, pelvic stability, and mobility.* Rehab Management: The Interdisciplinary Journal of Rehabilitation, 2002. **15**(5): p. 54-6, 74.

15. Allie, P. *Supporting Natural Human Motion While Seated*. Innovative Ergonomic Solutions [cited 2009 January 10]; Available from: http://www.steelcase.com/na/files/0c92024856674983a623b7e628e447dc/Natural%20Motion%20While%20Seated.pdf.
16. Alm, M., et al., *Clinical evaluation of seating in persons with complete thoracic spinal cord injury*. Spinal Cord, 2003. **41**(10): p. 563-71.
17. Brubaker, C.E., S. Ross, and C.A. McLaurin, *Effect of seat position on handrim force.* In Proceedings of the 5th Annual Conference on Rehabilitation Engineering, 1982.
18. Denise A. Chesney, L.H., Wayne Wright, and Peter W. Axelson. *Immediate improvements in wheelchair mobility and comfort with use of the adjustable back support shaping system*. in *Rehabilitation Engineering and Assistive Technology Society of North America (RESNA)*. 1995.
19. Hughes, C.J., et al., *Biomechanics of wheelchair propulsion as a function of seat position and user-to-chair interface.* Archives of Physical Medicine and Rehabilitation, 1992. **73**(3): p. 263-9.
20. Van der Woude, L.H., et al., *Seat height in handrim wheelchair propulsion.* Journal of Rehabilitation Research & Development, 1989. **26**(4): p. 31-50.
21. May, L.A., et al., *Wheelchair back-support options: functional outcomes for persons with recent spinal cord injury*. Archives of Physical Medicine & Rehabilitation, 2004. **85**(7): p. 1146-50.
22. Parent, F., et al., *The flexible contour backrest: a new design concept for wheelchairs.* Assistive Technology, 1998. **10**(2): p. 94-101.
23. *SCI Forum Reports. Back Pain, Wheelchair Seating and Posture* 2003 [cited 2009 April 30]; Available from: http://sci.washington.edu/info/forums/reports/posture.asp.
24. Boninger, M.L., et al., *Investigating neck pain in wheelchair users.* American Journal of Physical Medicine & Rehabilitation, 2003. **82**(3): p. 197-202.
25. DiGiovine, C.P., et al., *Analysis of vibration and comparison of four wheelchair cushions during manual wheelchair propulsion*. 2000. p. 242-244.
26. *Outcomes Following Tranumatic Spinal Cord Injury: clinical practice guidelines for health-care professionals*. 2000, Spinal cord Medicine
27. RESNA, *American national standard for wheelchairs.* 1998: Arlington (VA).
28. John C. Dinsmoor, I., Barry Van Everen, Michael W. Johnson, Grant C. Denton, *Wheelchair back system.* 1996, Jay Medical Ltd.: United States.
29. Pearce, T.M., *Adjustable wheelchair back seat back angle adjustment mechanism and related devices*. 1999, Teksource, LC: United States.
30. Peter A. Swisshelm, D.H.M., *Wheelchair with pivotal back rest* 1999, Sunrise Medical HHG Inc.: United States.
31. Thompson, L. *Prevention of shoulder pain*. November 14, 2006 [cited 2009 February 20]; Available from: http://www.agingwithdisability.org/factsheets/sci_shoulder_pain.htm.
32. Curtis, K.A., et al., *Shoulder pain in wheelchair users with tetraplegia and paraplegia.* Archives of Physical Medicine & Rehabilitation, 1999. **80**(4): p. 453-7.
33. McCasland, L.D., et al., *Shoulder pain in the traumatically injured spinal cord patient: evaluation of risk factors and function.* JCR: Journal of Clinical Rheumatology, 2006. **12**(4): p. 179-86.

34. Nawoczenski, D.A., et al., *Three-dimensional shoulder kinematics during a pressure relief technique and wheelchair transfer*. Archives of Physical Medicine & Rehabilitation, 2003. **84**(9): p. 1293-300.
35. ISO, *Wheelchair seating-Part3:Determination of static, impact and repetitive load strengths for postural support devices.* 2006.