UNIVERSITY OF WISCONSIN – MADISON
DEPARTMENT OF BIOMEDICAL ENGINEERING
BME 400 – DESIGN

Assistive Transfer Device

Final Report

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Abstract

The goal of this project is to develop an assistive transfer device for use in a clinical setting with elderly or post-operative patients. Since most patients have difficulty lifting themselves onto an exam table, it is necessary to employ alternative methods to facilitate the lifting process. Current methods and devices are inefficient, demand much physical exertion by the medical assistant, or are unsafe and uncomfortable for both the patient and assistant. The new device will be designed to safely transfer patients from the standing position to the top of an exam table. It will reduce the amount of necessary effort to lift the patient, and provide the patient with a sense of security during the lifting process. Additionally, the device will be easy to clean, user-friendly, cost-effective, and simple to store. After extensive brainstorming and analysis of previous designs, several design alternatives were generated for transfer methods and lifting mechanisms. The alternatives were then evaluated using design matrices to determine which design was best suited for the project purpose. The scissor link, standing position design was ultimately chosen due to its compactness and simple operation. The proposed design was fabricated and assembled according to the client's specifications. The prototype was then tested for simple functionality. It was not tested to failure, but was successfully able to repeatedly lift 150lbs pounds. Before testing the full 300 lbs, the team will make simple improvements to the integrity of the structure. Future development of the device, in addition to general mechanical enhancement, will include an improved ergonomic lifting system for both storage and patient security during the lifting process. Qualitative research will also be done to ensure that the device is a comfortable height and width for the average elderly patient.

Motivation and Problem Statement

In many medical situations, it is necessary to lift patients. This need for assistance could be due to reduced patient strength as a result of an extensively invasive operation, inherent weakness, or old age. As people age, their muscles degenerate, causing a reduction in their strength capabilities and increasing their force buildup time [1]. In addition to causing problems for the person in everyday activities (i.e. climbing stairs), it also makes difficult the routine examinations where a patient is required to climb up onto an exam table. This problem is compounded with more frail or obese patients. Generally, elderly or post-operative patients come to examinations in wheelchairs or with the assistance of a walker. In these situations, it is difficult for the medical assistant to help patients out of wheelchairs and lift them up to the top of exam tables.

To facilitate lifting of elderly or post-operative patients, it is necessary to design a device that is capable of safely transferring patients from a standing position on the ground to a level where they can easily get onto an exam table. To reduce patient anxiety, the device will include handles or another similar structure for patients to hold onto as they are being transferred. Finally, the device will be easy to operate and will minimize the required effort by the patient and medical personnel.

Background

One of the most common methods for lifting patients is manual labor. In this method, trained medical assistant wraps their arms around a patient underneath the shoulder joint (figure 1). The assistant then carefully lifts the patient vertically. Carefully walking backwards while holding the patient, the assistant must then rotate slowly and lower the patient down onto the desired destination which is, in many clinical settings, an exam table. If the patient's lower body is partially incapacitated, it is often necessary for a second assistant to hold the patient while the other assistant steadies the patient's legs. If the patient is totally incapable of using their legs, they are then placed onto a hammock type sling in the lying position. Two assistants are then required to hold the two ends of the sling and lift the patient. Although manual lifting is mechanically simple, it requires a lot of physical exertion by the assistant. The level to which patients can be lifted is solely dependent on the assistant's strength. Because of the large effort required for the lifting, there is a significant risk of injury for the assistant and a risk of injury for the patient if the assistant drops them.

Figure 1 - Medical assistant lifting patient out of wheelchair [4]

To alleviate the required effort in patient lifting, several devices have been developed. The first and most commonly used lifting device is the Hoyer Lift (figure 2). This device uses a non-automated hydraulic system to elevate patients. It also includes several adjusting mechanisms to widen or narrow the supporting base and wheels for easy transport. The cost of a Hoyer lift can range from $600-2000 [2]. To lift a patient, the device is first strategically positioned near the patient's desired destination. The patient is then inserted into a nylon or cotton sling that supports their back and upper legs. After the patient is secured in the sling, the assistant elevates the patient by operating a foot or hand pump. When the patient is fully suspended in air, the assistant then rotates the patient over the destination and then releases the hydraulic system so that the patient is lowered slowly into position. Although the Hoyer lift lessens the amount of effort required by the patient and by the assistant, it can cause emotional unease for the patient since they are in full air suspension during the lifting process. Additionally, several expensive modifications to the Hoyer lift are available. These devices include automated systems, a larger weight capacity, finer adjustment mechanisms, and different sling sizes.

Figure 2 - Elderly patient being lifted by Hoyer lift. [5]

Another commonly used device is the ambulation assistive device (figure 3). This device implements an automated hydraulic system to lift patients [3]. To facilitate storage and mobility, the device includes multiple wheels. This automated system is designed for helping patients from the sitting position to the standing position (e.g. from a chair or wheelchair). During operation, the patient is inserted into a harness and their arms are strapped to the top of the device. When the patient is properly secured, the top portion of the device will elevate, bringing the patient with it. When the patient is brought to the standing position, the top of the device is locked, the base wheels are unlocked, and the patient can then use the device to steady themselves as they ambulate. During the lifting process, the patient is often uncomfortable due to the number of straps and harnesses that are required to keep the patient secured to the device.

Figure 3 - Elderly patient using ambulation assistive device. [6]

Design Requirements

Before developing a unique device to assist in patient transfer, a list of constraints was established, taking into consideration functionality and user-friendliness. All the constraints considered can be seen in the attached PDS (Appendix A). The mechanical constraints are also summarized in table 1.

Figure 4 is an image of the exam table in the clinic, which is 32 inches tall. The bottom drawer is a 10 inch step that can be pulled out to assist the patients in getting onto the exam table. Unfortunately, many of the patients' legs are not strong enough to climb such a large step. Due to this, any step implemented in the design it must be 4 inches or less in height, which our client claims that the patients will be able to navigate. This height will be verified and refined through a research study in the future.

Figure 4 - Picture of typical exam table present in vascular surgery unit of UW West Health Clinic

We are designing the device to help individuals at least 4.5 feet tall and with a maximum weight of 300 lbs. With use of anthropometric tables, we were able to determine that, on average, the knee of a 4.5 feet tall patient is located 15.4 inches off the ground. Therefore, our device will have to raise the patients a minimum of 15 inches. Our client requests that we build the device for a subject of 300 lbs because it is well above the average weight of the standing from the wheel chair and the doctor would either examine them while in the wheel chair or would use the Hoyer lift to get them onto the table.

Qualitatively, the device also needs to be user-friendly during its operation. It needs to be simple, requiring very few steps to get the patient from the standing position to the table and back down. If an electric motor were to be implemented in the device, the required user input would be extremely minimal—just the touch of a button to raise and lower the platform. To reduce patient anxiety during use, additional safety features would be considered such as additional straps or railings so the patient feels secure.

In addition to making the design user-friendly during operation, we considered the ease of storage in the design—another constraint our client feels important. The design needs to be as compact as possible for two reasons: to allow for storage in a tight area and easily fit up next to the exam table during use. The device should be able to be stored behind a table or in the back of a closet somewhere when not in use. It would need to be easily moved from location to location, either by wheels or easily carried, which would require the device be less than 50 lbs in weight.

Table 1 - Summary of design specifications

Mechanical Design Constraints
Safely lift minimum of 300 lbs with a safety factor of 2.
Steps must be less than 4 inches off the ground.
Device must lift patient a minimum of 15 inches off the ground if from a standing position, 32 inches from seated or reclined position.
Total weight of device must be less than 50 lbs.
As compact as possible to allow for easy storage.

Generation 1 prototype

The first prototype of the assistive transfer device was constructed with a scissor link mechanism. The links were actuated with a hydraulic cylinder. The force was transferred from the hydraulic cylinder to the platform through a steel crossbar. A mechanical turntable was mounted onto the top platform and attached to a fitted sheet of corrugated metal to provide a rotating surface. A walker was securely attached to the rotating surface to provide assurance and balance to the patient. A small stop was attached to the rotating surface to prevent over-rotation. Patients were intended to mount from the side of the device with the aid of the walker, rotate 90°, and then sit on the exam table (after lifting).

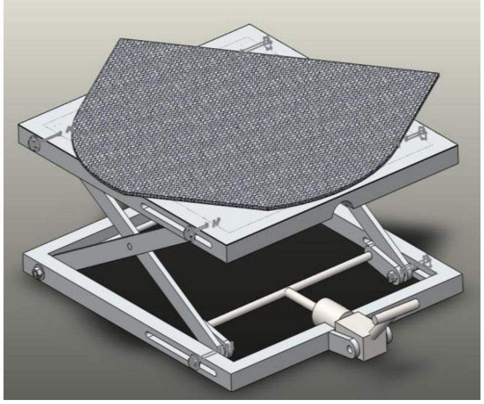

Figure 5 - SolidWorks Model of Generation 1 prototype

Although the device met the weight, size and mobility requirements, it was incapable of lifting the required load of 300lbs. Because the device was constructed with a very low mechanical advantage, it was only able to lift 150lbs before failing due to excessive bending of the bottom frame. There was also a great deal of instability during lifting and lowering due to friction in the scissor links. The patient would shift side to side as they are lowered, causing anxiety. There is also a need

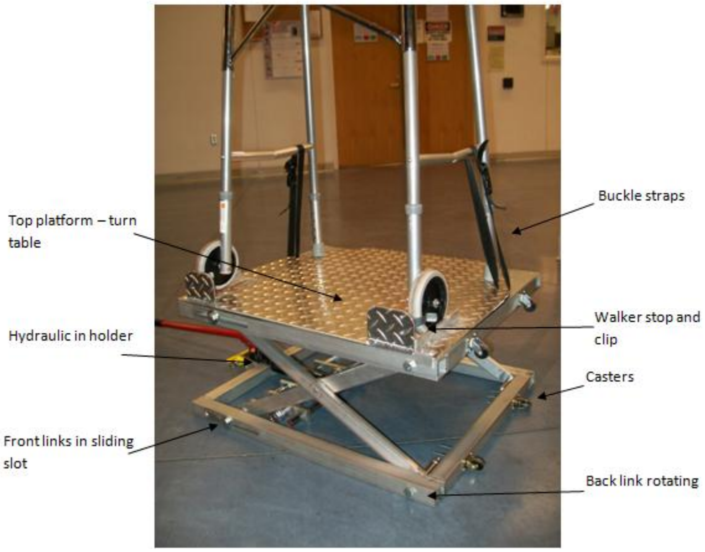

Figure 6 - Picture of final design, shown with walker strapped in place and slightly raised

to automate the lifting and lowering of the platform, as the device required manual pumping of the hydraulic cylinder. This proved to be awkward and uncomfortable for the medical assistant.

Design Alternatives

The main issues that needed to be corrected from the first prototype were to increase mechanical advantage of the actuator, increase general stability during ascent and descent, and reduce extrusions off of the main frame.

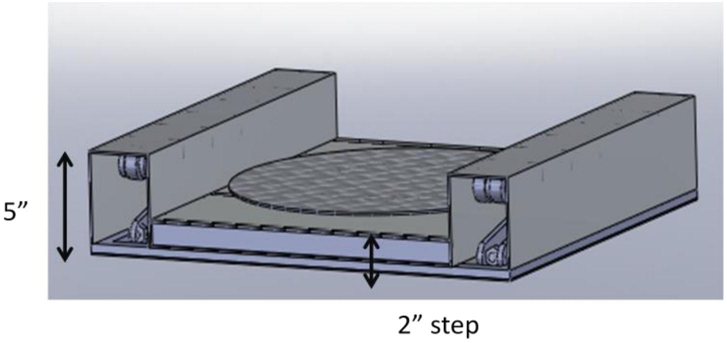

Figure 7 - SolidWorks Model of newly proposed valley design

One way to improve the mechanical advantage of the actuator is to increase the minimum rest height of the device. To maintain a low step height for patients while allowing for the raised rest height of the scissor links, the suggested geometry was the valley design. This design has a raised portion to house the cross links and a lower frame that the patient will be standing on. It allows the links to be raised higher than possible in the previous platform design while reducing the step height for patients from 3.5 in. to 2 in (figure 7).

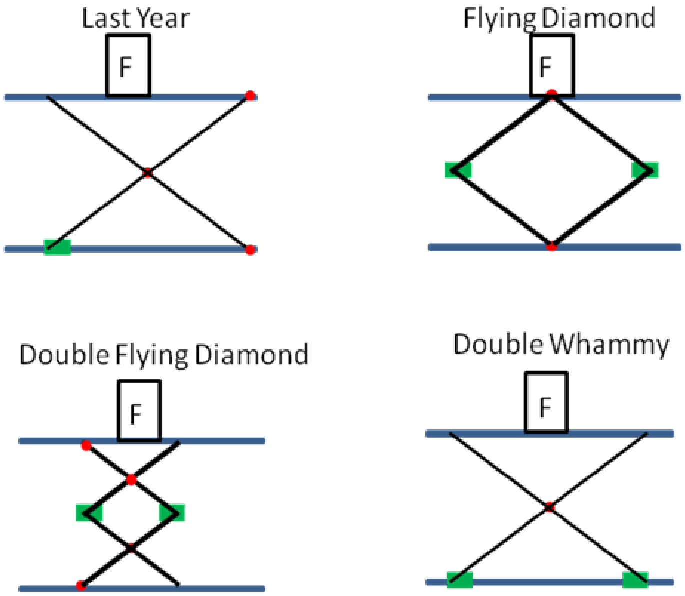

Figure 8 - Geometry alternatives for links. Blue lines indicated platforms and black lines represent the links. Red dots indicate fixed point, green boxes indicate point with 2 degrees of freedom (one direction transverse motion,

To further increase the mechanical advantage, several link geometries were considered (figure 8). In the figure, blue lines represent the frame and platforms, black lines represent the links, red dots indicate a fixed point, and the green boxes represent freely moving points. The actuator would be applying force at the green boxes. The previous design consisted of two sets of two links where one end was fixed and the other was free to move in tracks as pushed by the actuating hydraulic cylinder (labeled “Last Year” in figure 8). The various geometry alternatives were mathematically evaluated and it was determined that none of the alternative geometries produced a mechanical advantage over the generation 1 geometry. Therefore, the generation 1 link geometry will be used in the design as it is mechanically simplistic and produces the most mechanical advantage. The chosen link geometry would then be installed into each side of the ‘valley’ in the “valley design.” A relationship between the device dimensions and force required to lift the device was determined (equation 1). F_x denotes the force needed to lift the platform, F_y denotes the applied force, L denotes the distance between the ends of the links, and y denotes the initial starting height. Using this equation, we found that we will need a maximum horizontal force (F_x) of 2080 lbs per side. The maximum force will occur with the maximum load (F_y) of 600lbs and minimum height (y) of 4.75 in while the link length (L) is 17.2 in.

$$\boldsymbol{F_x = \frac{F_y}{2} \frac{\sqrt{L^2 - y^2}}{y}}$$

Equation 1 - Force-dimension relationship for "double whammy"

Lifting Mechanisms

After determining the link geometry, it was then necessary to determine the mechanism for actuating the links. The first design alternative was the use of a hydraulic cylinder. This design would require two cylinders, one installed inside either side of the valley. The two cylinders would be synchronized via a common reservoir to ensure steady elevation of the top platform. A compressor and motor would be necessary to automate the cylinders and reduce manual labor. While hydraulic cylinders are capable of producing large forces, the mechanism would be expensive and heavy due to the size and number of components needed.

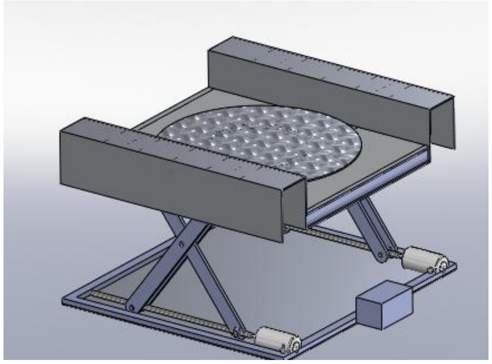

Figure 9- SolidWorks model of valley design with hydraulic actuator

The second design alternative involved the use of a drive shaft to actuate the links. A threaded shaft would run through each set of links. A motor would turn the shaft, moving the bottom of the links, raising the top platform. A gear and pulley system would be used to synchronize the two shafts and eliminating the need for multiple motors. A single motor would be installed so that it fits entirely underneath the platform. This design might require more fabrication due to the gear/pulley system.

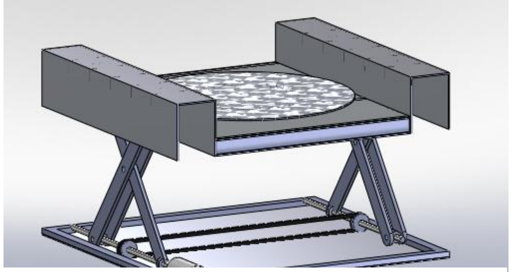

Figure 10 - SolidWorks model of valley design with drive shaft and pulley/gear system

The third design alternative consisted of using a complete, premade car jack to lift the device. The car jack would be installed into one side of the valley and would be connnected to another drive shaft on the other side of the valley with a gear system. This mechanism would reduce fabrication effort but raises concerns regarding stability, since all vertical force acts at one point.

Figure 11 - Premade electric car jack [7]

All three design alternatives were evaluated in a design matrix (table 1). The alternatives were evaluated in the categories of cost, feasibility, storage, design variability, and safety. Fabrication feasibility and design variability were weighted twice as much as the other categories. This was because it is of utmost importance that the actuation method can be adapted to any platform geometry and that the device can be fabricated easily. The alternatives were scored on a scale of 1-5, 1 being the lowest possible score and 5 being the highest possible score. As shown in table 1, the drive shaft was decidedly the best option for the valley design. While it may be slightly more complicated to construct, it is relatively cost efficient, safe, easily stored and, most importantly, can be adapted to work with any link configuration.

	Cost	**Feasibility (x2)**	**Storage**	**Design Variability (x2)**	**Safety**	**Total**
Hydraulics	1	4	4	5	4	18
Premade Electric Jack	4	8	1	4	4	21
Drive Shaft	2	5	4	8	4	23

Proposed Design

Based on the analysis and criteria outlined above, a design was proposed that combined the scissor cross links (in the generation 1 configuration) with the valley platform. It consists of a base for support, 2 sets of scissor links, a top platform, and a turntable. Figure 12 shows a SolidWorks model of the design. When the platform is completely lowered, the step height is 2 inches, with the links extending up on either side of the valley. Using the scissor links to raise the platform, the height can increase to 10 inches.

In order to lift the platform, a drive shaft will be placed at the bottom of the links, applying a horizontal force on the ends of one set of scissor links. A set of gears and a pulley system will be used to transfer the force to the other set of links, synchronizing the lifting and keeping the platform level. The amount of force the motor needs to produce is dependent on the amount of weight on the platform and the height the platform is raised to. The motor will have to produce the most amount of force when the platform is at its lowest position. The motor will be operated using a small handheld switch. A nurse will be able to operate the device at the push of a button.

Calculations were made to ensure that we have a motor that produces enough torque to turn the drive shaft and produce the correct force. According to equation 2, the torque is dependent on the threading width dm, force applied F, the angle of threading θ, the pitch l, and the coefficient of friction u. After using the equation, we found we need a maximum torque of 110 in-lbs when we need the maximum horizontal force of 2080 lbs. Since we are using one motor, the torque needs to be doubled for a total of 220 in-lbs. This is was easily attainable with the use of a gear box to amplify the motor torque.

$$\tau = \frac{F * dm}{2} * \frac{l + \pi * u * dm * \sec(\theta)}{\pi * dm - u * l * \sec(\theta)}$$

Equation 2 - calculation of torque

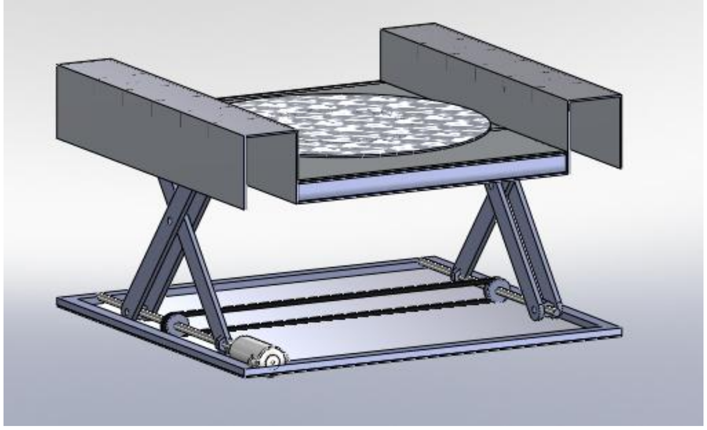

Figure 12 - SolidWorks model of final design

Final Design

Our final design has been adapted from our proposed design and is shown in figure 13. The base frame constructed of 1 inch aluminum square tubing and is 32 x 24 inches. The top platform is made from 1/8 inch aluminum sheets and 4 support bars made from ¾ inch aluminum square tubing. The scissor links are made from 0.5 inch thick aluminum and are 17.2 inches long by 1.5 inches high. The links are held in place with bolts in a 0.5 inch hole in the top and bottom frame. The other end of the links are connected to the drive shafts and supported by small milled aluminum abutments. On top of the top frame is a 24 x 24 inch thin aluminum sheet to cover any gaps below the platform. A 12 inch turntable is bolted onto the cross bar supports and a diamond plated 23 inch diameter circular sheet is bolted to the turntable. The platform is 0.1875 inch thick aluminum. The assembly is able to distribute the force to ensure that the system does not bend. When fully compressed the device has a step height of 2.25 inches and can rise to 12 inches.

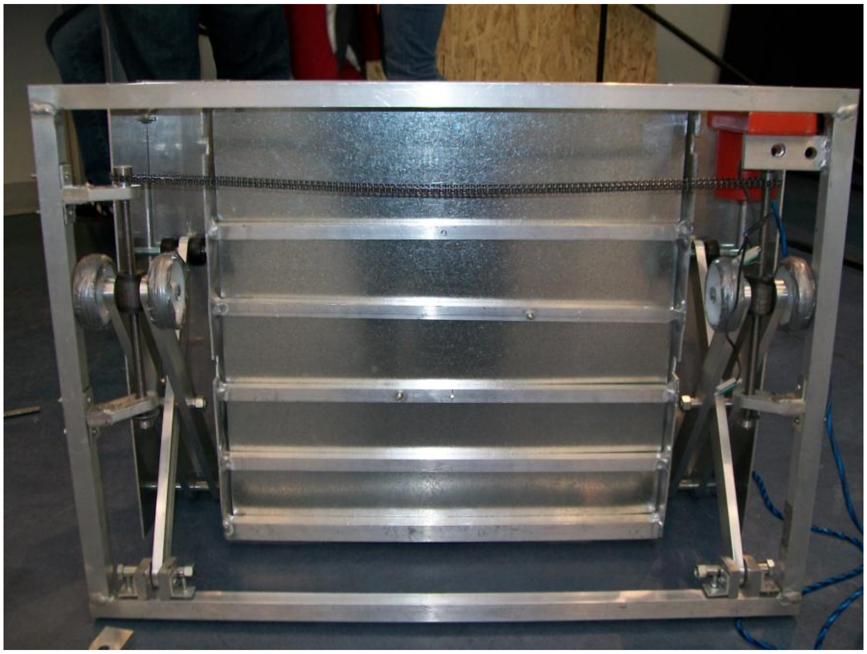

Figure 13 - Photo of lifting mechanism of final device

Pre-Prototype Design Testing

The electric motor used in our device was taken from an automatic electric jack. The electric jack could lift a maximum of 1760 lbs. Using the jack geometry, we found that the motor can produce a maximum torque of 470 in-lbs with amplification from the gear box (which increases the torque by a factor of 43). Therefore, the motor is powerful enough to be used in our device with a maximum torque of 110 in-lbs.

Since the device was designed to repeatedly lift patients, it was necessary to assess the framework integrity in the static state.

SolidWorks was used to perform finite element analysis of the support bars that the patient will be standing on and the plateau where the links meet the top platform. These areas were considered to ensure patient safety and that the platform will be able to hold 600 lbs. Figure 13 shows the testing of the support bars the patient will be standing on. The deformation is only 0.019 in. at the maximum load and the stress is only 6900 psi, below the yield strength of 7998 psi. This was with two bars supporting the weight in the middle of the platform. Because we were not comfortable with how strong our welds would be we chose to incorporate 4, slightly smaller square bars to decrease the stress at each weld. Figure 14 shows the deformation of the plateau where the wheels of the links support the top platform.. We conducted this FEA study to make sure that 1/8 in. thick aluminum would be rigid enough to raise the platform easily. Again the deformation is very small at the maximum load being 0.0002 in. meaning the design is sufficiently rigid.

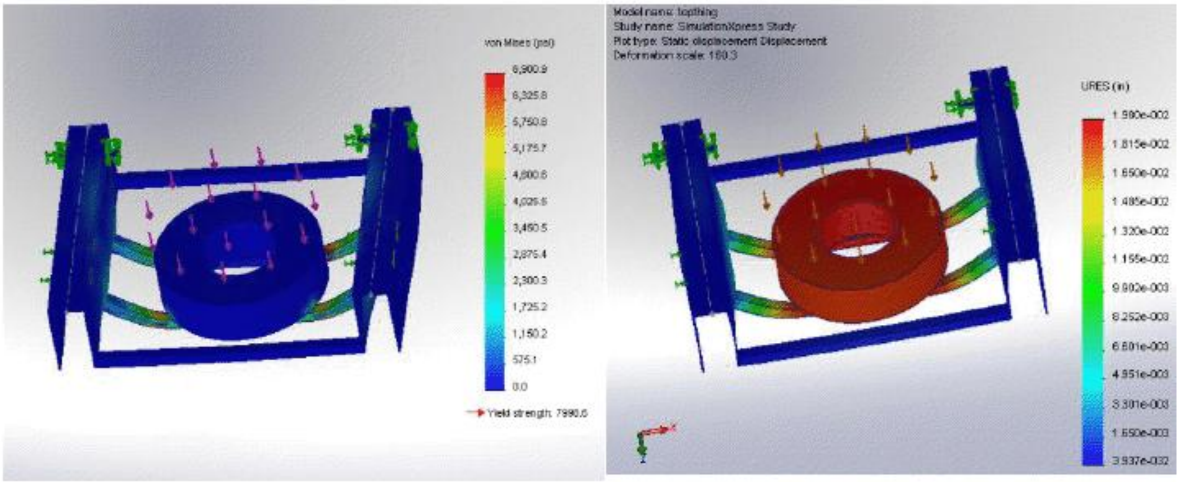

Figure 13 - SolidWorks model of deformation (right) and yield strength (left).

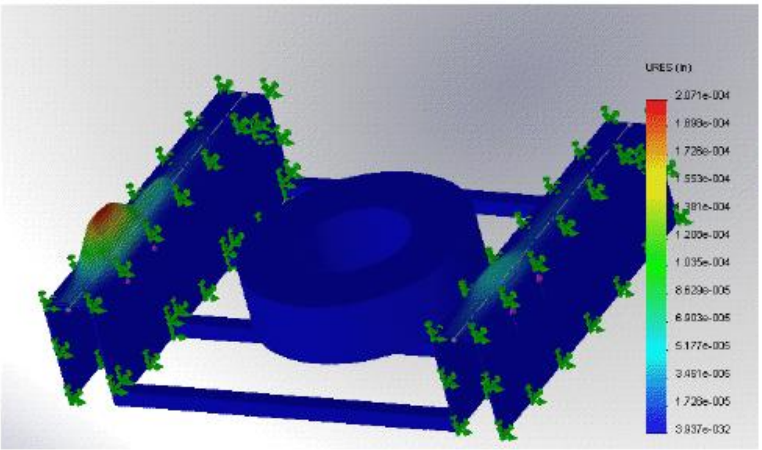

Figure 14 - SolidWorks model of plateau deformation.

Prototype Design Testing

After assembly, the device was loaded with various weights to observe how the aluminum frame withstood the weight. The device was loaded with 20, 40, 120, 150, 180, 270lbs. The frame remained intact during the loading, fulfilling the safety factor requirement.

To observe functionality, the device was dynamically loaded with various weights as it was simultaneously raised and lowered. The

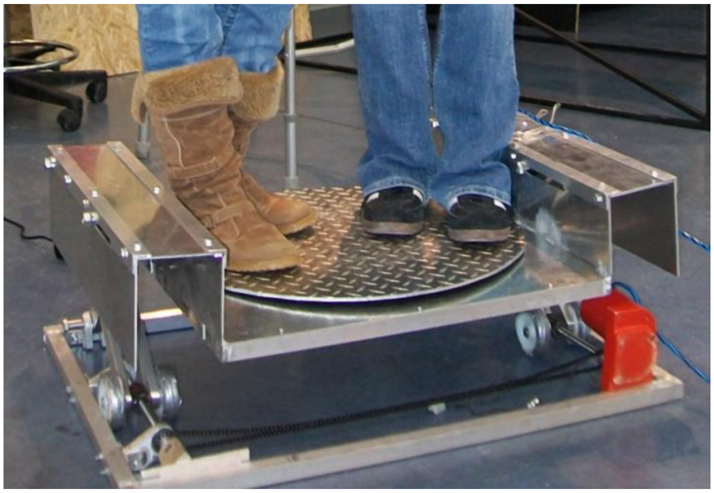

Figure 15 - Dynamic testing of device with ~270lb

device was first tested with no weight. It was then loaded with 20, 40, 120, and 150lbs. Since the device was not tested to failure, an exact maximum lifting capacity is not known. Weak connections in the drive shaft support prevented more weight testing. This problem can be fixed easily with welding.

IRB Research

Patient comfort was one of our highest concerns when building this device. Therefore, we would like to ensure that the step height and stance width parameters used to build our prototype are comfortable for the average patient. Current research indicates that 80% elderly females (ages 75-93) were able to step higher than an 8” step [1] and that stance widths range from 2” to 11.4” [3] from a point centered below the body to the center of the foot. This research indicates the maximum flexion and step height for elderly people, but does not give us any indication of what is comfortable for the patients. Ideally, our device would not force patients to strain themselves to get onto the device.

A qualitative research study will be done to determine the step height and stance width most comfortable to the average patient. Subjects will be recruited at a nursing home, to represent the elderly patients that will most likely be using this device, and asked to step onto stationary platforms of different heights. The subjects will also be asked to fill out a survey rating the step heights based on difficulty and filling out some demographic information. This information will further define our product specifications and determine whether a step height of 2” and a stance width of 23” are reasonable parameters for the average elderly patient.

Future Work

Safety is very important for our device, therefore the device needs to be put through more rigorous testing to ensure safety. In the design process, we based our calculations and dimensions on a maximum load of 600 lbs even though we only want to lift patients with a maximum weight of 300 lbs. In the future we would test the device with a load of 600 lbs to make sure it meets the safety factor. The prototype will need a few adjustments to make sure that it can handle 600 lbs. This will be easily done by welding some components instead of bolting them.

In the future we will also be conducting research on comfortable step height and step width. This semester we began by forming the research procedure and applying for IRB approval. Next semester we will be contacting nursing homes and retirement centers for volunteers to partake in our study. The results will help us determine if we need to change the size of the platform or the initial step height.

Improvements to our device that need to be completed are the addition of wheels, improvements to ergonomics, and a walker attachment mechanism. The device needs to be made more portable so that it can be moved around from exam room to exam room in a clinical setting. We plan to accomplish this by adding wheels so that the device can be lifted to its side and pushed around. The total weight is about 60 lbs, and would take about 35 lbs of force to lift it to its side. The open areas like the gaps between links and the chains to transfer power need to be covered so that there are no pinch points or dangerous areas. Lastly, a walker attachment mechanism needs to be added so that the patient can use a walker as a safety handrail during lifting.

Conclusion

Overall, the design team was very pleased with the outcome of the semester. Though the device will not yet be implemented in the clinical setting, the prototype is a sufficient proof of concept. In the end, the device maintained a low step profile, an acceptable NIOSH and OSHA lifting rating, a compact, mobile design, and a reasonable lifting capacity. Initial testing determined that the design was unable to handle the maximum weight capacity, but the team has analyzed the structural deficiencies within the frame and can modify them to achieve higher weight capacities. Additionally, the instability and friction within the design can be addressed in order to produce a medical lifting device that lives up to the client's safety requirements. Finally, the team will conduct the aforementioned IRB study to determine the optimal step height for the device and make additional design changes as needed. The team will continue this design in next semester to produce a usable clinical device to fully meet the client's specifications.

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Appendix A – Budget

The total costs for the project materials are summarized in the table below:

McMaster Carr	Structural material	$195.14
McMaster Carr	Structural material	$105.77
McMaster Carr	Structural material	$50.98
Home Depot	Nuts/Bolts	$26.11
Amazon	Adapter	$31.14
Amazon	Electric Jack	$60.00
McMaster Carr	Nuts/Threaded rods	$21.94
Total		**$491.08**

Appendix B – Product Design Specifications

Assistive Transfer Device Product Design Specification (PDS)

12/08/10

Gerhard van Baalen, Luisa Meyer, Sarah Springborn, Scott Sokn

Function: Develop an assistive device to safely transfer patients from the floor to a level at which they can easily sit on exam tables. Patients will be able to stand and hold onto the device while simultaneously being lifted and rotated into position on the exam table. The design will reduce physical exertion by the patient and medical personnel.

Client requirements:

- Small base , able to fit through door-way / easy storage
- Able to lift 300lbs
- Simple to operate; automated or manual
- Easy to sterilize
- Mobile in clinical setting
- Avoid in-air suspension of patient
- Cost-effective
- Reduce patient anxiety during transfer

Design requirements:

1. **Physical and Operational Characteristics**
    a. *Performance requirements:*
        i. 3-5 minutes per lift
        ii. 5-10 cycles per day
        iii. Handle loads up to 300 lbs
        iv. Lift to height of 15 in
        v. Rotate patient 90°
    b. *Safety:*
        i. Safety factor of 2 – hold 600 lbs
        ii. Few pinch points
        iii. Stable
        iv. Slow, constant raising and lowering rates
        v. Lockable turntable
        vi. Attachable walker for support
    c. *Accuracy and Reliability*
        i. Consistent performance
        ii. Does not let patient slip, tip, or fall

    - d. *Life in Service:*
        - i. 10 years
        - ii. Approximately 50,000 cycles
    - e. *Shelf Life:*
        - i. Oil joints
        - ii. Motor maintenance
        - iii. Non-corrosive
    - f. *Operating Environment:*
        - i. Room temperature
        - ii. Used by nurses
        - iii. Possible human fluids
        - iv. Impact resistance
    - g. *Ergonomics:*
        - i. Intuitive use/interface
        - ii. Patient comfort
        - iii. Non-abrasive materials
        - iv. Minimal operator effort (<50 lbs)
    - h. *Size:*
        - i. Less than 3 ft wide (approximately 25 x 28 in)
        - ii. Less than 4 in height when compressed (initial step height)
    - i. *Weight:*
        - i. Able to be moved on wheels
        - ii. Less than 50 lbs
    - j. *Materials:*
        - i. Prototype – Steel, Aluminum frame
        - ii. Wheels
        - iii. Electric jack
        - iv. Polymers – acrylic, Plexiglas
    - k. *Aesthetics, appearance, and finish:*
        - i. Paint – Blue
        - ii. Safe appearance

2. **Production Characteristics**
    - a. *Quantity:*
        - i. *One prototype this semester*
    - b. *Target Product Cost:*
        - i. Less than $500
3. **Miscellaneous**
    - a. *Standards and Specifications:* FDA approval, IRB review board
    - b. *Customer:* Hospitals, clinics, nursing homes
    - c. *Patient-related concerns:* Elderly, frail patients, amputees
    - d. *Competition:*
        - i. Hoyer Lifts
        - ii. EZ way

iii. Litegait
iv. Lift tables