

This is a student project that received either a grand prize or an honorable mention for the Kirmser Undergraduate Research Award.

Design of a cadaver rotation system

Kevin Garman, Chloe Boudreaux, Jack Ezell, and Phillip Mahoney

Date Submitted: May 6, 2015

Kirmser Award

Kirmser Undergraduate Research Award – Group category, grand prize

How to cite this manuscript

If you make reference to this paper, use the citation:

Garman, K., Boudreaux, C., Ezell, J., & Mahoney P. (2015). Design of a cadaver rotation system. Retrieved from <http://krex.ksu.edu>

Abstract & Keywords

The Kansas State University (KSU) Cadaver Dissection Team (CDT) is challenged to provide comprehensive human anatomy demonstrations to regular lab students. However, to see all structures adequately, the cadaver must be flipped over. Attempting to rotate a 300-pound cadaver without proper aid may result in labor injury, cadaver tissue damage, compromised lab spaces, and lost preservatives. The Rotational Anatomy Senior Design team is creating a system to help the CDT lift and rotate their cadavers. This design project was broken into two categories: harness and lift. The harness interfaces with the cadavers, while the lift is the supporting structure connecting to the harness and instigating rotational movement. After designing multiple frameworks for the lift, the team ran numerous Finite Element Analysis (FEA) models representing a concentrated static force slightly larger than that produced by the maximum cadaver weight via SolidWorks Simulation. This showed that the lift designed was able to withstand the weight of a 330-pound cadaver with minimal to no flexion. Rotational Anatomy also created a harness that distributes the cadaver's weight by wrapping around the legs and continuing up the shoulders, keeping the cadaver both stable and horizontal during lift and rotation. Upon installing the electric winch system, the lift and harness designs will be thoroughly tested with CDT's current cadavers and volunteer design team members. The criteria for successful testing are: 1) less than 1/16" flexion for framework means it is safe and stable and 2) no tears or ripped seams on harness means it is durable and appropriate. Time permitting, the framework will undergo polishing touches: rubber trimming to mitigate wall damage, and a powder coating to deter rust after years of use. Upon timely and successful test results, both the lift and the harness will be implemented in the Cadaver Dissection Lab by May 2015.

Keywords: Rotation of Cadavers, Biomedical Engineering Design Work

This item was retrieved from the K-State Research Exchange (K-REx), the institutional repository of Kansas State University. K-REx is available at <http://krex.ksu.edu>

This is a student project that received either a grand prize or an honorable mention for the Kirmser Undergraduate Research Award.

Course Information

School: Kansas State University
Course Title: Biological Systems Engineering
Design Project
Instructor: Edwin Brokesh

Semester: Spring 2015
Course Number: BAE 636

This item was retrieved from the K-State Research Exchange (K-REx), the institutional repository of Kansas State University. K-REx is available at <http://krex.ksu.edu>

DESIGN OF A CADAVER ROTATION SYSTEM

Authors:

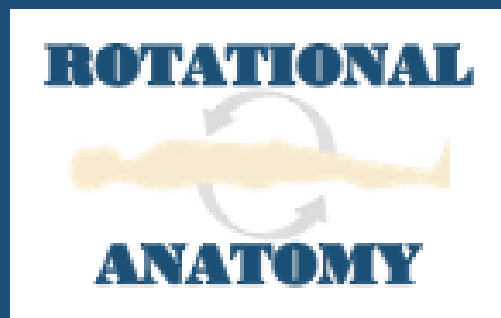
Kevin Garman

Chloe Boudreaux

Jack Ezell

Phillip Mahoney

KANSAS STATE
UNIVERSITY | Biological and Agricultural Engineering



BIOMEDICAL SENIOR DESIGN PROJECT REPORT

May 6, 2015

Project Title: Design of a Cadaver Rotation System

Abstract:

The Kansas State University (KSU) Cadaver Dissection Team (CDT) was challenged to design a new system that enabled one person to successfully lift and rotate a cadaver over in a timely manner and increase safety for instructors and students. Attempting to rotate a 300-pound cadaver without proper aid can result in injury to lab personnel, cadaver tissue damage, and lost preservatives. The Rotational Anatomy senior design team created a system to help the CDT lift and rotate cadavers safely and efficiently. This design project consisted of two distinct components: a harness and a lift. The harness distributes the cadaver's weight by wrapping around the legs and continuing up the shoulders, keeping the cadaver both stable and horizontal during lifting and rotation. The lift is the supporting structure connecting to the harness, lifting and rotating, while the harness interfaces with the cadavers. After developing designs for the lift, the team ran a Finite Element Analysis (FEA) model, which represented a concentrated static force of a 330-pound cadaver on the lift design via SolidWorks simulation. This verified that the lift design was able to withstand the cadaver weight with minimal deflection. Upon installing the electric winch system, the harness and lift designs were tested with cadavers and tractor counterweights. The criteria for successful testing are: 1) less than 1/16" deflection for the lift 2) no tears or frayed seams on the harness after testing. The framework will undergo polishing touches: rubber trimming to mitigate wall damage, and a paint coating to deter rust after years of use. After testing, both the lift and all 3 harnesses will be incorporated into the Cadaver Dissection Lab by June 2015.

Acknowledgements:

Faculty:

Edwin Brokesh - Advisor
Sam Wilcox - Client
Ashley Rhodes - Client

Financial Support:

KSU Biology Department
Dan Garman

Labor Support:

Aaron Spare
Kyler Macy

Supplies Contributors:

Sunflower Manufacturing
Ken Winslow

Jordan Reisinger
Tyler Siebels

Bohnert Welding

Table of Contents

1) INTRODUCTION

- 1.1 Problem Statement
- 1.2 Define Customer and Needs

2) RESEARCH

- 2.1 Previous Cadaver Lift
- 2.2 Floor Plan of the Cadaver Dissection Lab
- 2.3 Measurements of a Cadaver Tank
- 2.4 Human Cadaver Specifications
- 2.5 Rotation Methods
- 2.6 Quality of Craftsmanship
- 2.7 Ethical Considerations

3) SOLUTIONS CONSIDERED

- 3.1. Harness Designs
 - 3.1.1 Strap-Pulley System
 - 3.1.2 Body Bag
 - 3.1.3 Adjustable Nylon Webbing Harness
- 3.2 Winch Systems and Lift Designs
 - 3.2.1 Winch Systems
 - 3.2.2 Lift designs

4) FINAL DESIGN

- 4.1 Description of Chosen Options
 - 4.1.1 Harness
 - 4.1.2 Verifying FEA Tests
- 4.2 Budget Analysis

5) CONCLUSIONS

6) REFERENCES

1. INTRODUCTION

Rotational Anatomy team members Kevin Garman, Chloe Boudreaux, Jack Ezell, and Phillip Mahoney collaborated on the 2014-2015 Biomedical Senior Design Project in the Department of Biological and Agricultural Engineering at Kansas State University (KSU). The Department of Biology provided the Rotational Anatomy team \$1,000 for the completion of the project. This report explains the project objectives, research completed, solutions considered, final design, construction, and testing.

1.1 Problem Statement

Rotational Anatomy was contacted by Mr. Sam Wilcox, instructor of the Cadaver Dissection Team (CDT) from the KSU Biology Department, to design and produce a system that assists with rotating cadavers. This would benefit the 800 students enrolled in Human Body each year, EMS staff, and CDT instructors. The Biology Department had a cadaver lift, but it was cumbersome, unstable, unsafe, and loud to use. Currently, 4-5 people are required to rotate the cadavers from their initial position, from lying on their back to their stomachs or vice versa, to enable safe and easy access to every structure on the cadaver for studying, testing, and dissecting purposes.

1.2 Define Customer and Needs

The objective was to design a new system that would enable one person to successfully lift and rotate a cadaver quickly and safely. The clients, Mr. Wilcox and Dr. Ashley Rhodes, stated that the new design needed to meet these criteria: efficient to use, operable by one person, compact for storage, gentle on the cadaver, and a low implementation cost. Rotational Anatomy has corresponded on a regular basis regarding the progress of the project with Mr. Wilcox to ensure all standards were met.

2. RESEARCH

2.1. Previous Cadaver Lift

The previous cadaver lift that the Biology Department had was custom built by a past senior design team. Its functions were to aid in lifting cadavers out of vehicles from a loading dock when they were delivered to Ackert Hall, as well as to lift the cadavers in and out of the lab tanks where they were stored throughout the semester. This design had a swinging arm that was fitted with a winch system so that it could reach over the loading dock area and lift the cadaver. Though, when doing so, the cadaver lift became top heavy and would fall over, making it a danger to use. Rotational Anatomy made stability a focus while designing a new lift.

Also, the previous cadaver lift was incredibly difficult to maneuver around the cadaver lab and the frame was too large to store it in the cadaver lab. It had to be taken to the basement of Ackert Hall after every use. (Please see Figure 1 in appendix for additional measurements of the previous cadaver lift.) Instructors teaching the Cadaver Dissection Team disliked using this lift and eventually ceased using it altogether.

2.2. Floor Plan of the Cadaver Dissection Lab

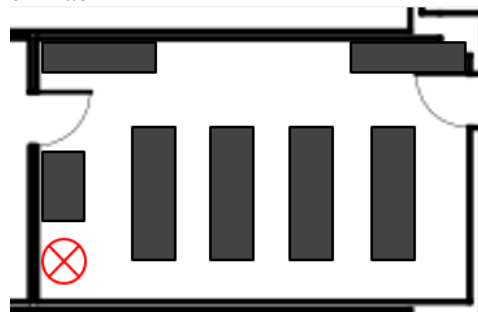


Figure 2. Cadaver Lab Floor Plan

(Adapted from Kansas State University Campus Planning and Facilities Management, 2012)

Figure 2 is the floor plan of room 229 of Ackert Hall, the Cadaver Dissection lab. The room has a total of 351 square ft. There are four cadaver tanks in the room indicated by the four vertical rectangles in Figure 2. The two rectangles at the top of the figure represent three bookcases. The rectangle on the left side of the figure was the sink in the room. The red circle marks the ideal area, an area 25in. x37in. in size, for the cadaver lift to be stored.

2.3. Measurements of Cadaver Tank

The cadaver holding tanks are made of stainless steel and contain a lifting tray inside as well as folding lids to protect each cadaver. The lifting tray is operated by a lever system to raise and lower the table to allow the person to dissect. Each tank is 34in. wide and 84.75in. long, while the tray is 27 in. wide and 81 in. long. This tray is what supports the cadaver, and limits the size of the cadaver than can be used. The bottom of the tank is 17 in. off the ground, as shown in Figure 3a/b in the appendix. These measurements had a significant effect on how the team designed the lift portion of this system.

2.4. Human Cadaver Specifications

According to Dana Townsend, Associate Professor in the Applied Health Science program at Wheaton College and previous KSU and University of Kansas Medical Center (KU Med) at Salina Cadaver Dissection Team Director, “Very few undergraduate courses in the United States teach human anatomy from human cadavers. Of these, an even smaller number have both the facilities and the opportunity for undergraduates to have actual dissection experience using human cadavers” (personal communication, November 19, 2014). It was also mentioned that feedback from students currently at professional schools who went to KSU and were on the Cadaver Dissection Team (CDT) give major credit to the CDT experience and the relative ease that they have had excelling in gross anatomy classes and the obstacles faced in any professional or graduate school setting. From Rotational Anatomy’s research, human cadavers play a pivotal role in preparing the next generation of medical experts, and that the donors who pledge their bodies to science are giving an incredible gift to any aspiring allied health care professional.

The KU Med Willed Body Program is the organization that the KSU CDT acquires their cadavers from. They have the following stipulations for human cadaver donations:

1. Must be less than 6 feet 4 inches in height
2. Must weigh less than 250 pounds upon delivery of the body to KU Med

These stipulations are put in place to keep the body from becoming too dangerous to physically lift upon completion of the embalming process. According to Sam Wilcox, “many cadavers [received at KSU] are heavier post mortem because of the preservatives” (personal communication, August 23, 2014). The fatty

tissue in the cadaver soaks up the fluids used during the embalming process at KU Med. The embalming fluid is flushed through the vascular system and penetrates into the tissues. The adipose tissue tends to have a higher affinity for the fluid and expands slightly as more fluid weight is added. The amount of body fat the individual has at the time of death will have a major impact on how much extra weight will be gained from preservatives. Mr. Wilcox also mentioned that everything coming from the cadavers in “fluid or saturated solid” form (e.g. tissues or preservatives) is considered a biohazard, and is regulated. Additionally, CDT at KSU does not worry “about preserving the cadavers . . . [we only] worry about keeping the tissues moist and workable” (personal communication, May 4, 2015). The solution used at KSU to keep the cadavers from drying out is 97% water, which significantly reduces the amount of hazardous material the students come in contact with.

Another aspect of the cadaver that had to be considered was the weight distribution. Because of a higher percentage of body fat being stored in and along the abdominal and thoracic cavities, most of the cadaver weight is seen in the upper body. Therefore, the centroid of the cadaver is also seen higher along the cadaver than on a living person. These facts also impact the dissection process. The CDT starts dissecting the pectoral and upper limb regions and then progresses down the rest of the body throughout the semester. Dissection removes many supporting structures for the body. For example, the removal of the skin and many underlying connective tissues will cause tissue displacement and exposes many unstable structures to the lab environment. When the cadavers are being rotated by hand, the force-needed to flip a 300-pound cadaver can be great enough to cause body parts and organs to be damaged.-As the dissection becomes more invasive, cleaved bones pose a potential threat for injury, which can make studying and rotating the cadaver very dangerous if done hastily.

2.5. Current Rotational Methods

Rotation of cadavers has been a consistent problem for the Biology Department and the CDT. The previous cadaver lift or direct manual labor are the current methods utilized to rotate the cadavers, but neither method is convenient.

Physical rotation of a cadaver via manually lifting, pushing, and pulling by 4-5 individuals is the most common method used, but it has many drawbacks. During cadaver demonstrations, a large amount of information is presented in a short amount of time. These demonstrations are given to several sections of students throughout a lab session, which requires that the cadavers are flipped 2-3 times per session. Constant rotation and handling of the cadavers causes accelerated deterioration of the cadaver tissue, which compromises both the structures being studied and the safety of the students and lab personnel. The implementation of a new rotation system could prolong the anatomical structures being studied and minimize the potential for injury to lab personnel due to physical strain. According to Finger, when caretakers must move patients manually they are at risk for developing back injuries (1999). With the cadaver’s weight and the added heaviness due to preservatives, it is easy to envision the risk of back injuries for those handling the cadavers. The design developed by Rotational Anatomy will reduce excessive upper limb, pectoral girdle, and back strain on the instructors and practicum students tasked with the rotation of the cadavers.

Rotational Anatomy decided to consider if an electric winch could be used in the design. An electrically powered winch would provide easier operation for students by enabling the cadaver to be lifted by the push of a button. Additionally, the client stressed that an electric winch system was a requirement for the design because of the large discrepancy seen in height and strength of students and instructors attempting to rotate the cadavers.

2.2. Quality of Craftsmanship

Rotational Anatomy took many precautionary measures throughout the design process. First, a faculty advisor with experience in industry design and clientele management was available to help guide the team and provide insight. Additionally, standards were researched to help ensure high-caliber, safe results were produced. However, much of the design work completed stemmed from constant contact with the client. Keeping the client fully informed was crucial to keep the whole operation streamlined. This was accomplished via face-to-face meetings, presentations, e-mails, and text messaging.

2.3. Ethical Considerations

Respect for cadavers was a major ethical concern that the team addressed. Human cadavers are an incredible gift and a phenomenal teaching tool that the Biology Department uses to help continue offering highly competitive academic classes and dissection teams. Rotational Anatomy sought to minimize damage is placed upon the cadaver in any way. Dropping the cadaver is not only unsafe, but would be extremely disrespectful, so Rotational Anatomy made sure to keep that in mind while designing prototypes and working with the cadavers throughout testing.

3. SOLUTIONS/OPTIONS CONSIDERED

Rotational Anatomy determined that both a harness and a lift design were necessary to enable the CDT, and all others using the cadaver lab, to lift and rotate the cadavers.

3.1. Harness Designs

The first part of the project focuses on the design of a harness. The harness must fully support the cadaver, provide the interface between the cadaver and the lift, and be practical enough to allow 1 person to adjust.

3.1.1. Strap-Pulley System



Figure 4. Strap Pulley System
(Reproduced from Morteck Manufacturing Inc, 2014)

The design shown above (Figure 4) is powered by manual rotation. The operator is required to pull on the straps to initiate the rolling process. It was a simple idea that was considered to fit the CDT's budget. However, this concept presented many drawbacks, such as: it cannot be used with a mobile lift, it would make closing the cadaver tanks difficult, and it would take 2-3 people to operate safely.

3.1.2. Body Bag

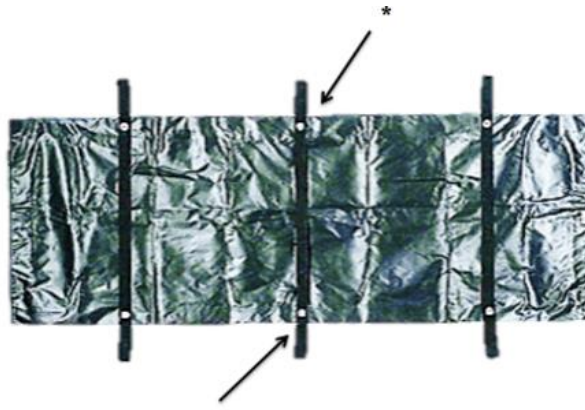


Figure 5. Body Bag Concept
(Adapted from Medical Products LTD, n.d.)

Inside the cadaver tanks, the cadavers are wrapped in plastic bags to preserve tissues and with every new cadaver, the Biology Department has to provide a new plastic bag to wrap them in. A roll of these bags costs approximately \$50. The idea behind this design was that a reusable plastic bag would encase the cadaver which would then be lifted by an overhead winch system. The bag would be attached to the winch via the middle rings on either side (* symbol on Figure 5). Another positive to the the body bag concept was that it promoted minimal damage to cadaver structures and tissues because it allowed the operator to evenly disperse the cadaver’s weight across a large surface area. As the cadaver is lifted, the operator would need to monitor the body bag for proper tilting of the body. However, a drawback was seen in this process. It became clear to Rotational Anatomy that the body would not rotate on the inside of the bag while the outside of the bag was being lifted. To counteract this unwanted rotation, manually providing a guiding motion to ensure that the cadaver is rotated properly, as it is lowered, may be necessary. The body bag would need to be specially made and would not be easy to replace if torn or broken. Its size and irregular shape also made it incompatible with a mobile lift. Therefore, Rotational Anatomy decided it was best to go with a simpler design.

3.1.3. Adjustable Nylon Webbing Harness

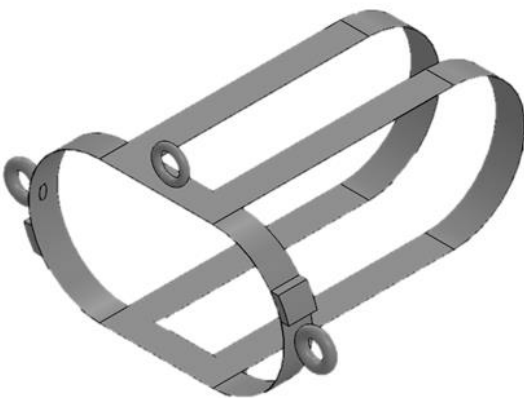


Figure 6. Preliminary Harness Design

(SolidWorks Models by Chloe Boudreaux, Adaptations by Kevin Garman)

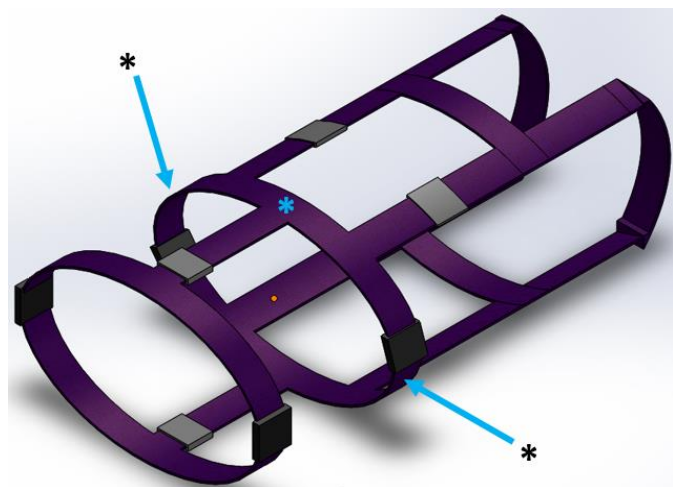
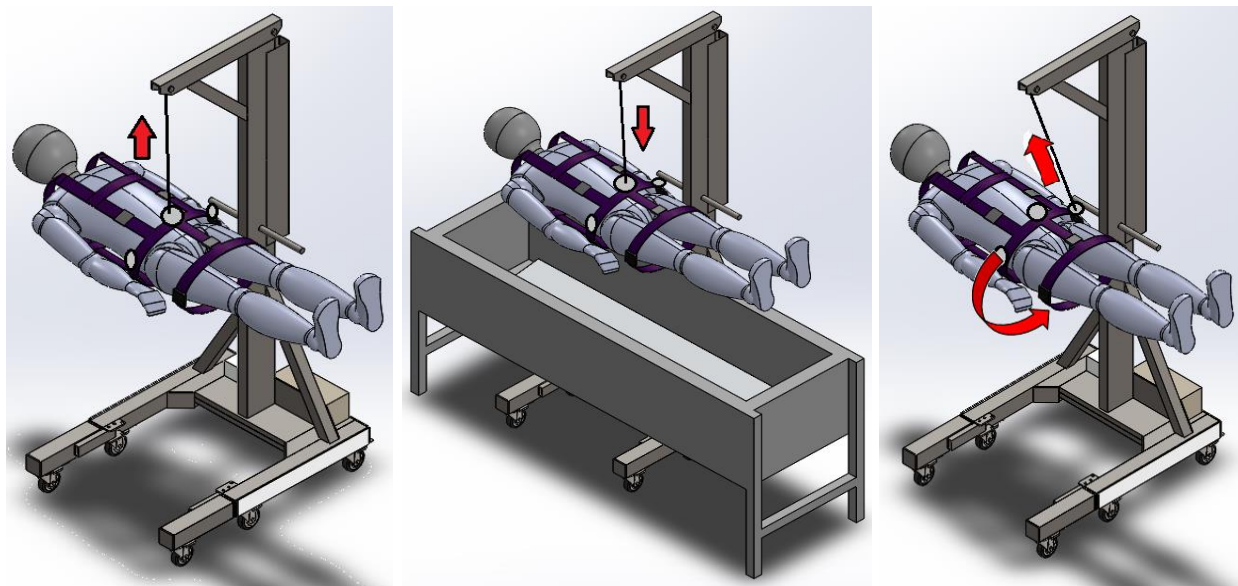


Figure 7. Final Harness Design Prototype

Rotational Anatomy tested a waist-only, rock-climbing harness to lift a cadaver. Though the lower half of the body was elevated off of the lifting tray easily, the head of the cadaver had difficulty elevating off of the tray. The upper body of the cadaver did not lift up as well as the lower half of the body. When a small head-supporting strap was attached to the waist harness, the upper half of the body was kept level so the head lifted completely off the table. Figure 6 represents Rotational Anatomy's original idea of a seat-belt harness for lifting the cadaver. The design was simple to use, cost effective, and easy to move out of the way when needed.

After more testing, the team found that support around the legs was still crucial to keep the cadaver horizontal. Figure 7 depicts the final harness prototype design that Rotational Anatomy constructed. (The *'s on the graphic indicate the three connection points, where D-rings are sewn.) These D-rings are the lifting points where the winch hook can easily connect to the harness so that one could lift, lower and easily rotate the cadaver by placing a winch hook to the desired ring, as shown in Figure 7. The gray squares in Figure 7 show the positioning of the clips that allow for adjustability and easy access to the cadavers when the harness needs to be removed. This is accomplished simply by releasing the four clips on either side of the harness and lifting it over the cadavers head. This harness design provides the exact amount of support where needed, while not sacrificing functionality.



Figures 8, 9, and 10: Demonstration of the Lifting, Lowering and Rotating of a Cadaver
(SolidWorks Models by Chloe Boudreaux, Phillip Mahoney, & Kevin Garman;
Adaptations by Phillip Mahoney)

3.2. Winch System and Lift Designs

The second part of the project focuses on a lift system that meets all of the criteria as previously stated. The lift is the support structure that will hold the cadavers during lift and rotation, and also is the support structure where the winch will be placed. The design process that the team underwent with the winch and lift is further discussed in this section.

3.2.1. Winch System

Through many conversations with the client, professors, and hardware experts, Rotational Anatomy chose an electric winch for lifting and rotating depicted in Figure 11. In terms of safety and labor requirements,

the electric winch was superior. A manual winch was considered and discarded because it had numerous pinch points and was dangerous when unwinding a heavy load. The electric winch system drives the movement of the cadaver in a manner that is more convenient, takes less effort, and has less safety hazards. It is powered by a 12 volt battery, and has a cable that would run up alongside the mast beam, then through the center of the hoist beam guided with 2 pulleys, and then have a hook come down to attach to a D-ring on the cadaver harness. Because the cable could become grimy and promote obstructions in the pulley system, cleanliness is a concern. Consequently, Rotational Anatomy will instruct the CDT to regularly clean and maintain sanitary conditions by wiping down the system after every use.



Figure 11. Champion Power Equipment Electric Winch with Remote - 3,000lb
(Picture taken by Kevin Garman)

3.2.2. *Lift Designs*

Rotational Anatomy decided, mostly for space considerations, that a C-Frame Lift Design would be the most convenient. The lift, equipped with casters, could be rolled up to the side of the cadaver tank so that a hook could be easily positioned over the center of gravity of the cadaver. Using a winch system, the cadaver then could be lifted so that the person utilizing the lift can grab the cadaver to have it rotate the desired way, and then lowered back down. The C-Frame base was designed to be compacted from a 32"x40" base down to a 32"x23" base, so that the entire frame could fit the required storage dimensions. This was achieved with a telescoping motion, which was chosen to increase stability, yet, easily maximize storage capacity. A peg would be inserted through both sides of the base and lock it into position, whether in storage or in use. However, after consideration the telescoping base would be difficult to create and the team found out to have a base made in such manner it would be expensive. Figure 12 is a SolidWorks model of the lift frame and its components. The frame is created from a steel alloy, and each bar is 11-gauge steel tubing to reduce weight, assuming it would make transportation easier.

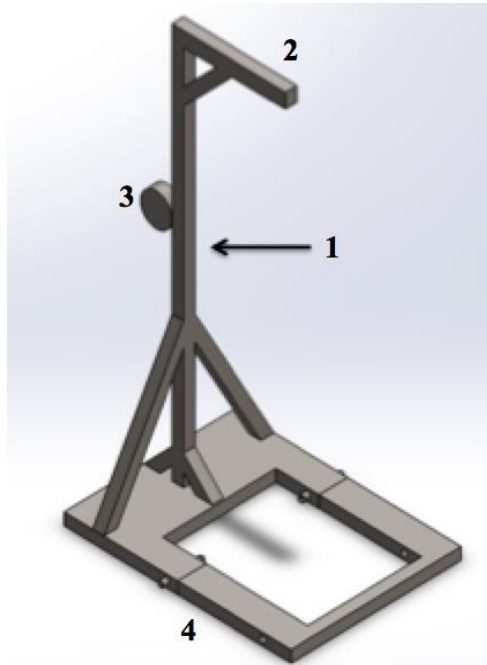


Figure 12.
Initial Design for Lift
 (SolidWorks Model by Chloe Boudreaux & Phil Mahoney, Adaptations by Kevin Garman)

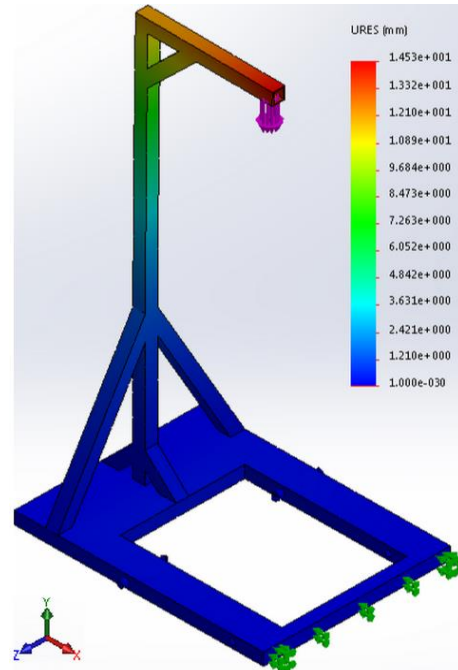


Figure 13.
Preliminary SolidWorks FEA –
1500 Newton Static Force
 (FEA Simulation Model by Kevin Garman)

Figure 12 shows the four major pieces involved in the proposed frame design for the lift. These pieces and their functions are as follows:

1. Mast: Main support line for cadaver lift and rotation. This beam also housed the winch.
2. Hoist Beam: Directional line that allowed the cable from the winch to be positioned above the cadaver.
3. Winch Unit: This depicted the anticipated winch placement. From here a guided wire cable ran up the Mast Beam, out along the Hoist Beam and then lowered its attachment hook to connect with the harness.
4. Telescoping Base: The base was divided into two pieces. The portion closest to the Mast Beam was stationary. The extending piece telescoped back into the stationary portion when the lift needed to be stowed away.

Not shown in Figure 12 are the 360° casters that were attached to the four corners of the base. For details about caster selection, please see Final Design section underneath Figure 13a/b.

Rotational Anatomy ran a Finite Element Analysis Model (FEA) in SolidWorks of the concept to understand frame loading and deflection. Figure 13 is a SolidWorks FEA model of the lift frame. Figure 13 depicts a true scale Static Displacement Deformation Analysis in millimeters (mm). As seen in the Figure 13, areas colored in red are points in the structure that deflected the most as the load was applied. This helped Rotational Anatomy determine failure points without wasting material. In this model, Rotational Anatomy found that the mast and hoist beams were the components with the largest deformation. Unfortunately, the deformation calculated was not within safety guidelines. Edwin Brokesh P.E., a Manufacturing Engineer and a Mechanical Product Engineer advised that this design should experience a total deformation of no more than 1/16-inch at maximum load (personal communication, December 2, 2014). Measuring around 14.53mm (approximately 0.572 inches) for maximum displacement, the

deformation shown in the hoist and mast beams was well over a 1/2-inch under an applied load of 1500N (approximately 337 lb_f). When deformation is greater than 1/16-inch, erratic “wobbling” becomes a safety and material endurance concern as the cadaver is lifted.

By running this FEA, Rotational Anatomy learned about the dangerous design flaws and material failure points in the concept. Consequently, the team made considerable change to the overall lift design. These changes are shown in Figure 14a/b.

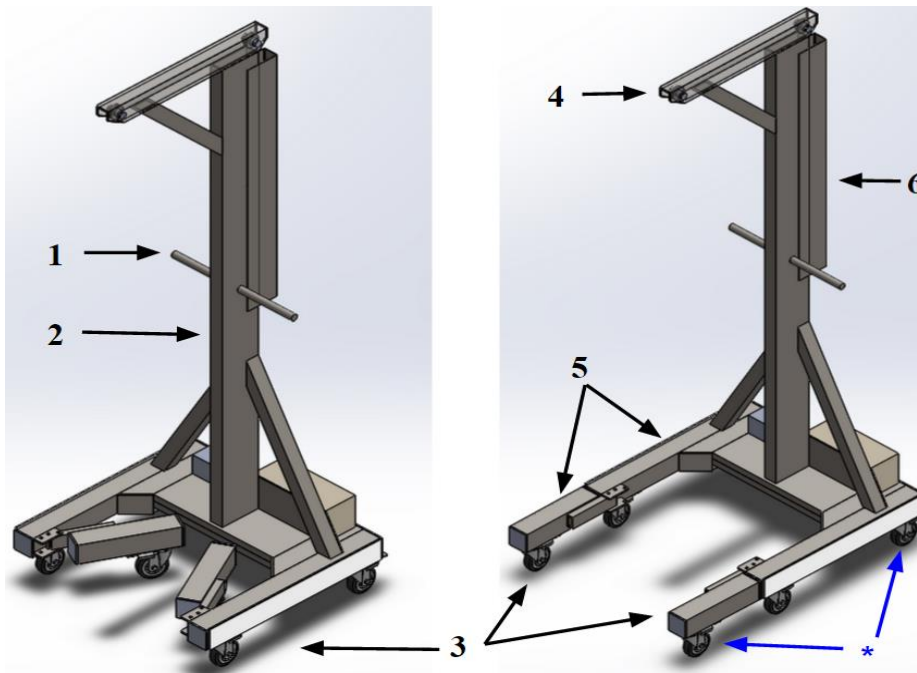


Figure 14a/b. Final Lift Design
(SolidWorks Models by Chloe Boudreaux, Phil Mahoney, & Kevin Garman;
Adaptations by Kevin Garman)

Figure 14a/b shows the lift in its storage position (left) and its functioning position (right). For dimensions, see Drawing 1 in the appendix. The light brown and dark gray boxes on the back side of the lift represent the placement of the winch and winch battery. The design features are as follows:

1. Handles were added along the Mast for increased maneuverability
2. Mast depth was extended from 2” to 6” for stability and safety
3. Pivoting legs replace the telescoping base for easier handling
4. Hoist beam height was extended from 2” to 3” to accommodate cable pulleys
5. Base sides were altered from 2”x6” to 3”x3” tubing
6. Cable guard placed along back of mast to protect operator from cable

These alterations were made to increase safety, efficiency, function, and maneuverability. Rotational Anatomy spent much of their time deliberating on how to go about fitting and choosing casters for this system. To keep a high level of stability, maneuverability, and durability, the casters became a significant portion of the design. The casters had to allow for the lift to be easily turned about the CDT lab in order to efficiently lift and rotate every cadaver in a timely manner. Additionally, the casters needed to be durable enough to withstand years of use and heavy loads. The team chose to incorporate two pairs of 360° swivel casters (indicated by blue “*”) for easy pin-point turns and one pair of uni-directional casters (middle pair, not indicated by blue “*”) to mitigate the lift from being too hard to control.

4. FINAL DESIGN

4.1. Description of Chosen Options

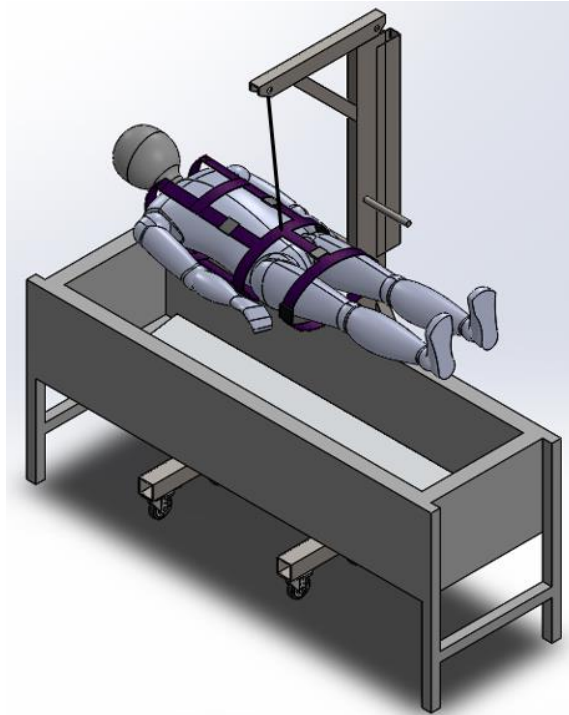


Figure 15. Final Assembly Visual
(SolidWorks Model by Chloe Boudreaux)

4.1.1. Harness



Figure 15. Prototype harness – w/out D-Rings
(Picture taken by Kevin Garman, Adaptations by Jack Ezell and Kevin Garman)

The harness design built by Rotational Anatomy incorporated nylon webbing, plastic buckles and adjusters. Metal D-rings will be added to the sides of the harness, as shown in Figure 7. The team used the ASTM Standard D6775-13 to determine the breaking strength of different types of webbing. Using this information, the team chose a seat-belt webbing that can withstand 5000 pounds of tensile stress, ensuring nothing will snap. A design comprising of this material is also easy to work with and allowed Rotational Anatomy to fit the design to all constraints and project requirements. For example, the team can customize the locations of where to put the D-rings and the connectors. This is a simple, durable, effective piece of equipment that will connect the cadaver to the lift. The harness was designed to dismantle at the sides of the cadaver to allow access to the body whether laying on its front or back.

4.1.2. Lift Frame

The team selected steel because not only did it provide the most strength it will last through years of use and many steel pieces were donated to the project. As seen in Figure 14a/b, the mast beam was increased from a 2x2 to a 6x2 rectangle tube to create enough support to lift and rotate at least a 300-pound cadaver. Complementing the support provided by the deeper mast beam is each pivoting leg, which provide increased stability and mitigate tipping forward during operation. It was determined through solidworks that the center of gravity with a 300 pound load on the lift came close to moving outside the lift's boundary. Adding pivoting legs ensures the center of gravity is always within the boundary of the lift, and will keep the entire system from tipping forward, even if the cadaver were to swing after lifting. This design was deemed safe by FEA testing in Solidworks. However, Rotational Anatomy conducted live testing to verify FEA results.

4.1.3. Winch Placement

The electric winch in the system was relocated to the base of the lift. This allowed for a sturdier support for the winch and lowered the lift's center of gravity to improve stability. The removable guard on the backside of the lift houses the winch cable. The team decided to house the winch cable to reduce operator's fingers, clothes, or hair exposure to the cable while operating the winch. Moreover, in case of mechanical failure, access to the entire cable is still possible.

4.2. Lift Design Testing

4.2.1. FEA Testing of Final Lift Design

Rotational Anatomy ran FEA tests on the final lift design to determine the total movement of the hoisting beam during a lift. A weight of about 337 pounds (1500 Newtons) was added to the end of the hoist beam. The results of the FEA are pictured below in Figure 16.

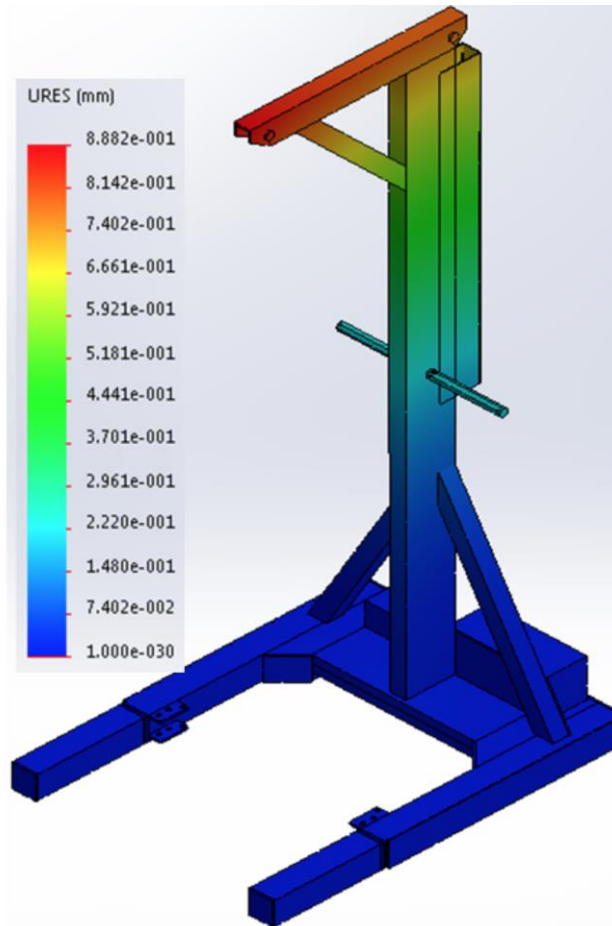


Figure 16. True FEA – Concentrated 1500 Newton Static Force
 (SolidWorks FEA Simulation Model by Kevin Garman)

The deformation of the system was concentrated on the end of the hoist beam, where the bending is expected to happen. The region at the end colored in red signifies a deformation of .8882 mm. That is roughly .0349 in, which falls well below the safety mark of 1/16in the project advisor recommended the team to be under. This verified that the lift is safe to lift and rotate a maximum weight cadaver.

4.2.2. Verifying FEA Tests

Once the lift was constructed, Rotational Anatomy verified the FEA simulation by applying a physical load to the lift. This testing was the final step in verifying safety, stability, and usability of the lift. The winch cable was looped through the handles of tractor counterweights and then retracted by the winch to lift the weights off the ground. In each test, the deflection of the hoist beam was measured before and after the weight was lifted. Without any load on the lift, the top of the beam measured 81 $\frac{3}{8}$ inches from the floor. The first load applied was 270 pounds as seen in Figure 17 (middle). As the load was lifted off the ground, the measured deflection was only 1/32 of an inch. This measurement was identical to the FEA result and verified our FEA analysis.



Figure 17. Testing Results Before and After Weight
(Pictures taken by Jack Ezell, Kevin Garman, and Chloe Boudreaux)

After consultation with Mr. Brokesh, Rotational Anatomy decided that the lift’s structural capacity beyond the expected load, or Factor of Safety (FoS), should be tested and verified. Therefore, an additional 90 pounds was added to perform a larger load stress test for a total of 360 pounds. Again, the deflection was only 1/32 of an inch as compared in Figure 17 above (left = no load, right = 360-pound load), verifying a FoS of 1.2. Beyond that, Rotational Anatomy tested a 450-pound load with results almost identical to those seen in Figure 17, verifying a new FoS of 1.5. This information showed the team that the lift was well designed for raising the maximum cadaver weight of 300 pounds. Along with the strength in the vertical direction, there was no movement from side to side, or “wobble,” as the load was raised, and the electric winch performed well lifting this weight quickly and efficiently.

4.3. Budget Analysis

Table 1 shows the overall cost. Tables 2-5 in the Appendix show a detailed expenditure breakdown for what it has taken Rotational Anatomy to build 3 harnesses and the lift.

Table 1. Summary of Costs

Category	Cost
Harness	\$79.28
Frame	\$137.06
Accessory Parts	\$304.77
Labor & Supplies	\$290.00
Shipping fees	\$28.08
TOTAL COST	\$839.19

Rotational Anatomy’s total expenditures to date is well under the \$1,000 budget. This has given the team a \$160.81 credit to use towards any unforeseen finishing costs.

5. CONCLUSION

The KSU Cadaver Dissection lab serves approximately 800 students per year and additional EMS staff beyond that, this rotational cadaver system is a necessity to aid in safely moving and manipulating the bodies for dissection work, studying, demonstrations, and lab exams. Rotational Anatomy recommends that their final lift and harness designs be what the Department of Biology use to enable the dissection team and human body course in flipping the cadavers. The team's constructs feature the sturdiest, lightest-weight frame coupled with the most effective, fastest-adjusting harness. The desired goals of the Rotational Anatomy team and client, Sam Wilcox, were fulfilled with the described designs by adhering to the following criteria:

- 1) One person is able to operate the system easily with the electric winch and connecting harness
- 2) The pivoting legs allow the lift to be stored in the small lab space and allow the center of gravity to stay inside the confinements of the lift
- 3) No cadaver tissue is damaged during lifting or rotating procedures
- 4) The system was designed, constructed, tested, and implemented for less than \$1,000
- 5) Must contain an electric winch

The progress made by raising the cadaver horizontally shows that the harness is on the right track. Mr. Wilcox believes that our material and design is sound for the cadaver and lift interface. Additionally, the max cadaver weight of 300 pounds is much lighter than the 450 pounds tested with the lift. The success seen with this higher load reassures the safety and durability of the constructed framework.

Overall, this project will create an environment that is supportive of student interaction with minimal hazards. By bolstering the safety of the cadaver lab and reducing the risk for destroying cadaver tissues, the Human Body course can begin to efficiently allow all students the time they need to see appropriate structures and allow for extended life of the cadaver anatomy. This will greatly enhance the learning experience of each student, and, therefore, build a solid reputation of quality anatomy and physiology at Kansas State University.

REFERENCES

- ASTM Standard D6775-13, 2013, “Standard Test Method for Breaking Strength and Elongation of Textile Webbing, Tape and Braided Material” ASTM International, West Conshohocken, PA, 2013, DOI: 10.1520/D6775-13, www.astm.org
- Finger, W. (1999). Design and control of an active mattress for moving bedridden patients. *Proceedings – IEEE International Conference on Robotics and Automation*, 3, 2044-2050.
- Genome Tuning Quality Performance Parts. (2014). *Cipher Racing Black 4 Point Quick Release Racing Harness Set (3” Inches)*. Retrieved from http://www.genometuning.com/index.php?main_page=product_info&cPath=291_333&products_id=11244&zenid=494mg49uocplngsna9pp50fhv1.
- Kansas State University Campus Planning and Facilities Management. (2012). *Ackert Hall (Chalmers Addition) Second Floor. FILE NAME: 136_3OF7ACKERT_JULY2012.DWG*. Retrieved from http://www.k-state.edu/planning/space_inventory/floor_plan/a-b/136_3of7Ackert_July2012-11x17.pdf.10
- Legion Safety. (n.d.). *DBI Sala Delta II Cross Over Harness*. Retrieved from <http://www.legionsafety.com/dbi-sala-delta-ii-cross-over-harness.html>.
- Loop11. (2012). *Affordances Can Point Your Users in the Right Direction*. Retrieved from <http://www.loop11.com/affordances-can-point-your-users-in-the-right-direction/>.
- McGill, S. M. (2005). Transfer of the horizontal patient: The effect of a friction reducing assistive device on low back mechanics. *Ergonomics*, 48(8), 915-929.
- Medical Products LTD. (n.d.). *Heavy Duty DOD Spec Human Remains Pouch*. Retrieved from <http://www.medicalproducts.com/product/six-handled-hd-dod-spec-human-remains-pouch/>.
- Mortech Manufacturing Inc. (2014). *Adjustable Strap Lift Assembly with Rigid Body Strap*. Retrieved from <http://mortechmfg.com/products/adjustable-strap-lift-assembly-rigid-strap-m607>.
- Northern Tool and Equipment (n.d.). *Dutton-Lainson StrongArm 120 V AC Electric Winch with Remote-1800-Lb. Capacity, Model# SA7015AC*. Retrieved from http://www.northerntool.com/shop/tools/product_200323049_200323049.
- Rosemont Textiles. (n.d.). *Seatbelt*. <http://rosemonttextiles.com/seatbelt/>.

APPENDIX

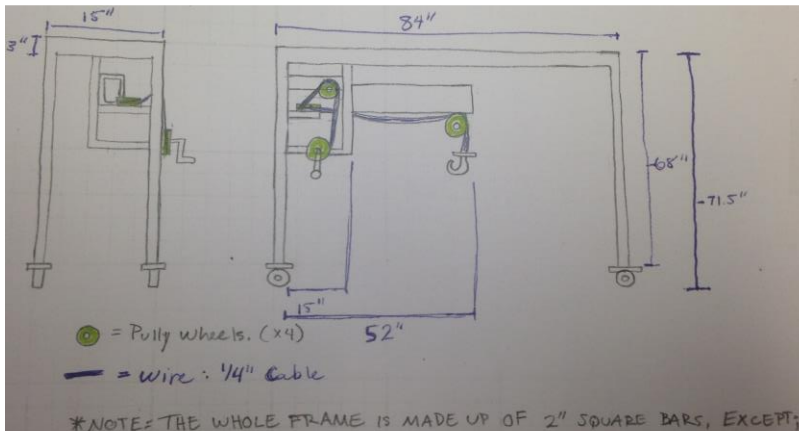


Figure 1. Old Cadaver Lift Measurements
(Drawing by Phil Mahoney)

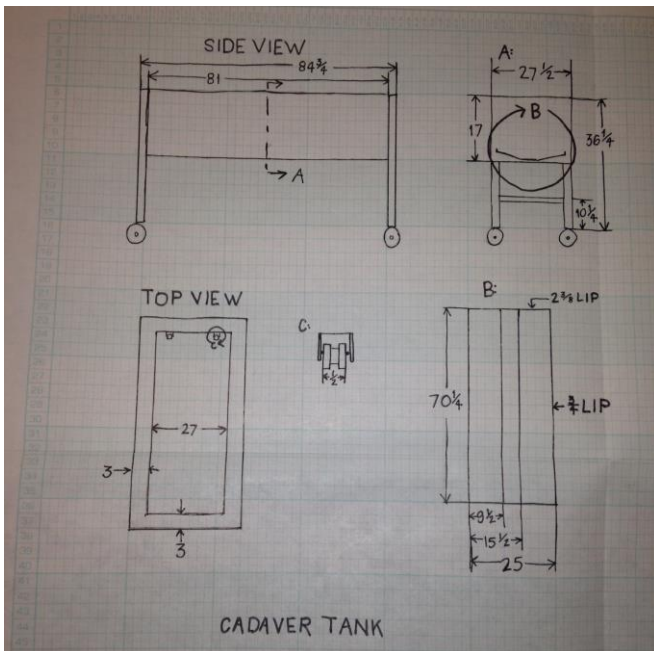


Figure 3a/b. Cadaver Tank Measurements & Picture
(Drawing by Chloe Boudreaux, Picture taken by Kevin Garman)

In compliance with privacy laws required to protect the dignity of the deceased, Rotational Anatomy is prohibited from taking pictures of the cadavers. To understand all of the cadaver tank dimensions, it is important for the reader to know that a lifting tray is housed in each cadaver tank. The lifting tray supports the cadaver and attaches to a pulley system that is activated by lowering a handle on each end of the tank (indicated by blue arrow in Figure 3b).

Drawing 1. Final Lift Dimensions

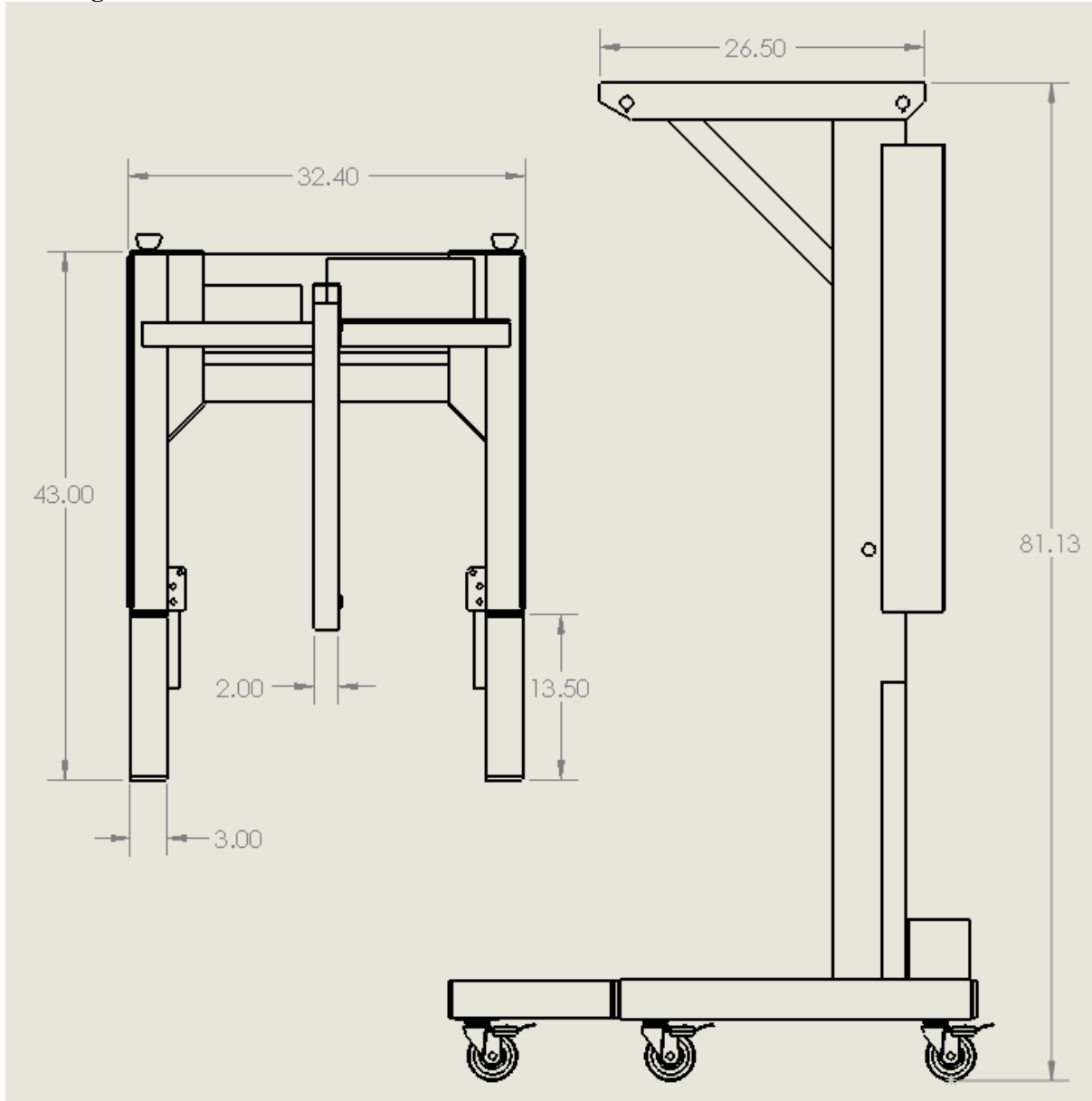


Table 2. Harness Cost List

Item	Price per Unit	Amount	Cost
2" Parachute Buckle	\$0.97	5	\$4.85
2" Flat Nylon Webbing	\$0.69	74	\$47.61
Steel-D-Rings	\$2.98	9	\$26.82
TOTAL COST FOR 3 HARNESES:			\$79.28

Table 3. Frame Cost List

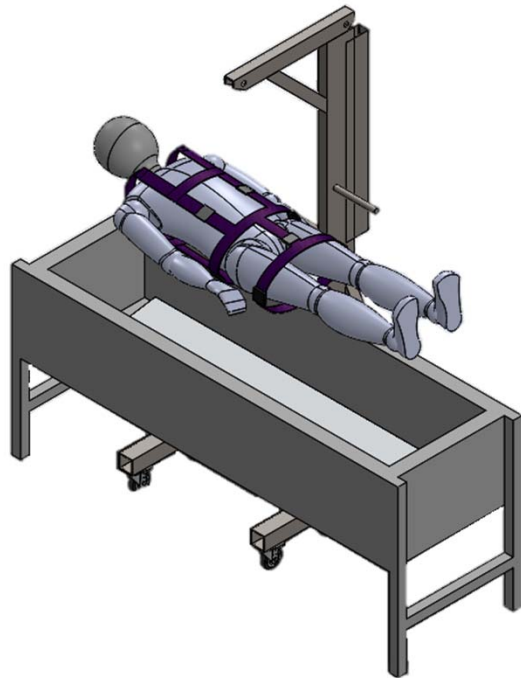
Item	Price per Unit	Amount	Cost
1" Round Bar (Handles)	\$2.42	1	\$2.42
2x6x3/16 Rectangle Tube (Mast Beam)	\$6.76	6	\$40.56
2x2x1/4 SQ Tube (Hoist Beam Support)	Donated	2.5	\$0.00
2x2x1/4 SQ Tube (Mast Beam Supports)	Donated	5	\$0.00
2x3x3/16 Rectangle Tube (Hoist Beam)	\$5.72	2.5	\$14.30
3x3x3/16 GA Steel Square Tube (Base Sides)	\$6.37	4	\$25.48
3x3x3/16 GA Steel Square Tube (Base Sides)	\$5.52	6	\$33.12
Solid Steel 1/4" Plate	Donated	1	\$0.00
Solid Steel 1" Plate	Donated	2	\$0.00
2x1 Rectangle Tube (Hinge Pieces)	Donated	1	\$0.00
14 GA Metal Sheet (Cable Guard)	\$2.47	2.5	\$6.18
Rubber	\$15.00	1	\$15.00
TOTAL FRAME COST:			\$137.06

Table 4. Accessory Parts Cost List

Accessory Parts	Price per Unit	Amount	Cost
ATV/UTV Winch kit	\$94.99	1	\$94.99
Swivel Caster (3BK4x1-1/4-S)	\$12.40	4	\$49.60
Stationary Caster (3BK4x1-1/4-R)	\$7.38	2	\$14.76
2 x 1732 x 7/8 Cable Pulley	\$11.95	2	\$23.90
Battery	\$84.99	1	\$84.99
Battery box	\$8.94	1	\$8.94
Washers (Hinge/Pulleys)	\$1.59	1	\$1.59
5/8 Hinge Bolts	\$3.99	1	\$3.99
Nuts for Cable Guard/Mounts	\$1.59	1	\$1.59
TOTAL ACCESSORY PARTS COST:			\$282.76

Table 5. Labor & Supplies Cost List

Labor & Supplies	Price per Unit	Amount	Cost
Welding	\$20.00	6	\$120.00
Paint Job/Coating	\$10.00	5	\$50.00
Paint Materials	\$40.00	1	\$40.00
TOTAL LABOR & SUPPLIES COST:			\$210.00



Rotational Anatomy

Chloe Boudreaux
Jack Ezell

Kevin Garman
Phillip Mahoney

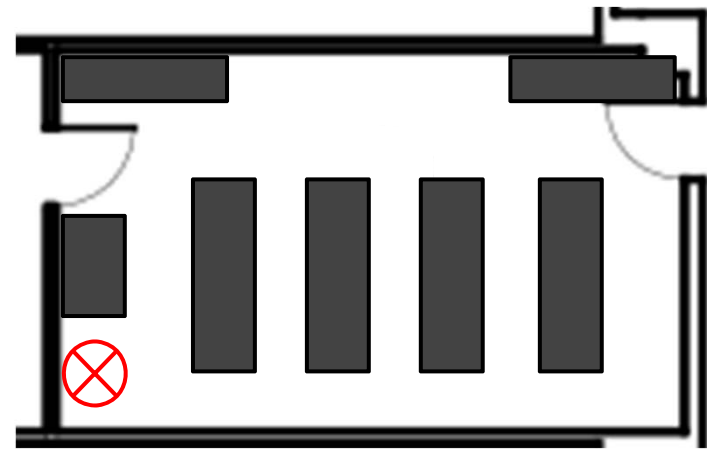


HUMAN CADAVER ROTATION SYSTEM

Design, construct, and test a portable device for the KSU Biology Department's Human Body Course that will effectively assist in the rotation of cadavers.

CRITERIA

- Durable
- Single Person Operated
- Fast and Efficient
- No Damage to Cadaver
- Small Storage Space
- Easy to Maneuver



Ackert 229; 351 ft²



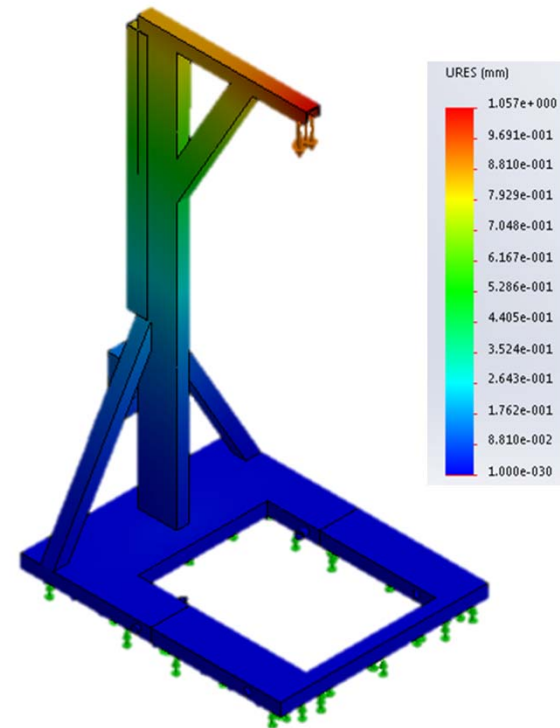
LAST SEMESTER



3/16 GA Steel

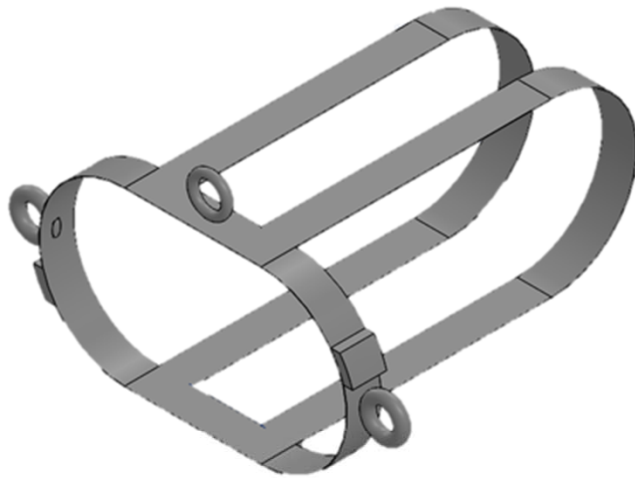
Telescoping Base

Weight ~245 lbs



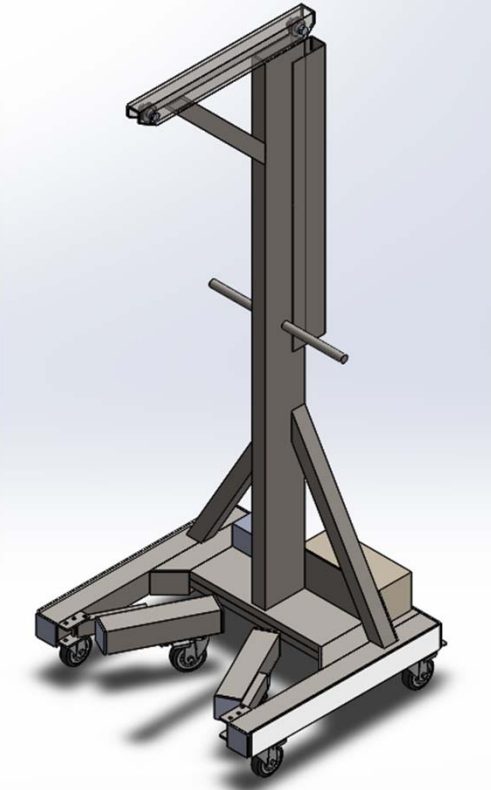


PREVIOUS HARNESS DESIGN

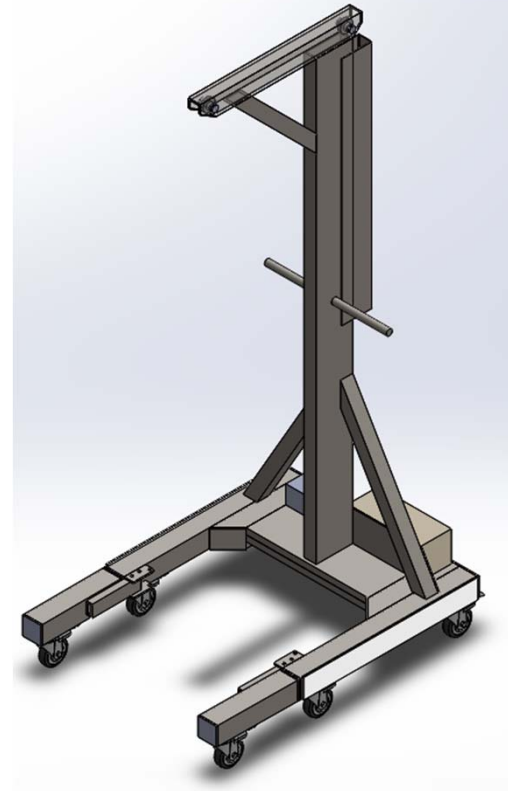


- 2 Buckles / 4 Adjusters
- Only Upper Body Support
- Simple
- Easy to Remove

CURRENT DESIGN



- Folding Base
- Casters
- Mast Position
- ¼" Steel Tubing
- Heavier





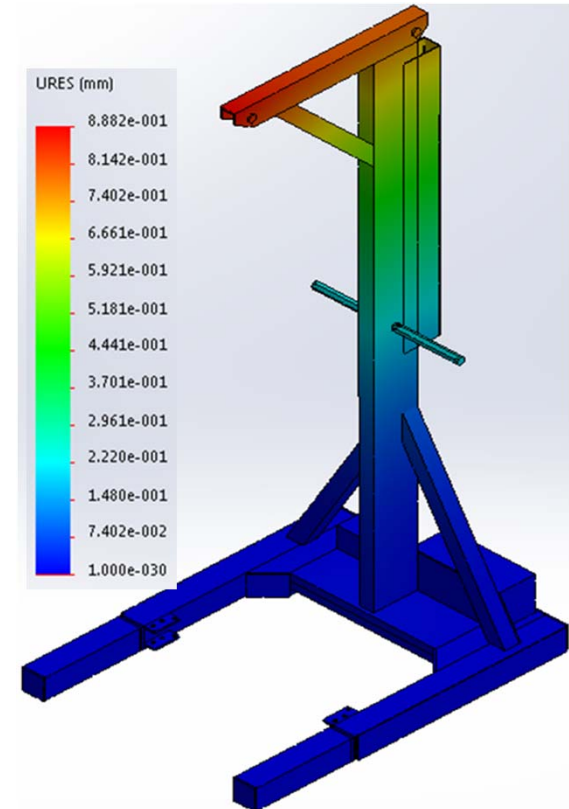
CURRENT FEA

SolidWorks Simulation RESULTS:

~1/32" Deflection

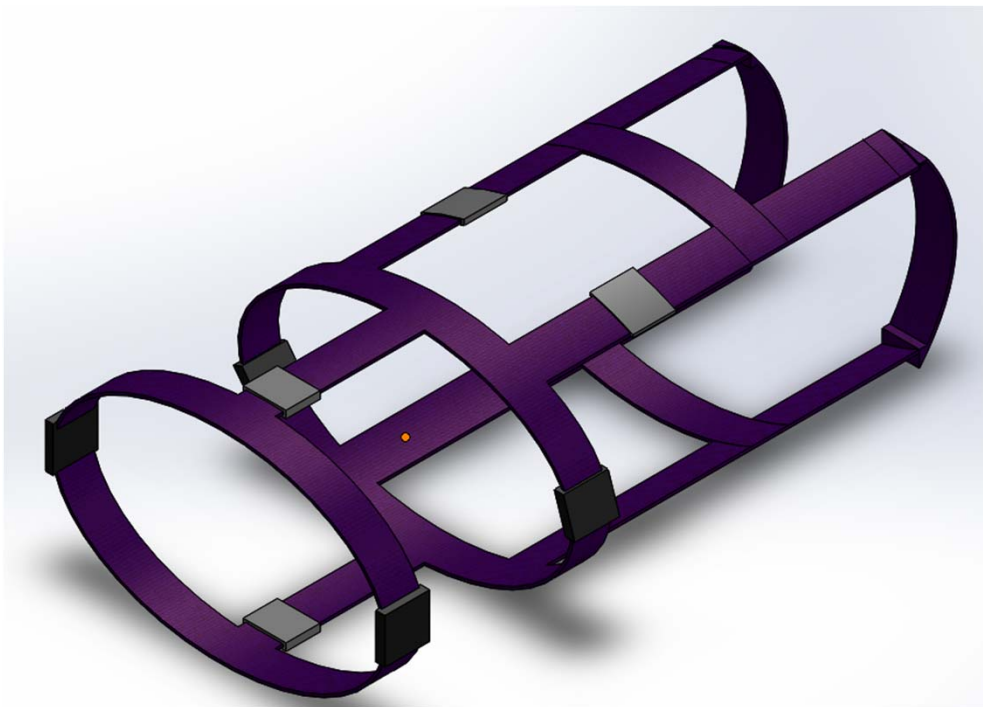
SAFETY MARGIN:

Less than 1/16" Displacement

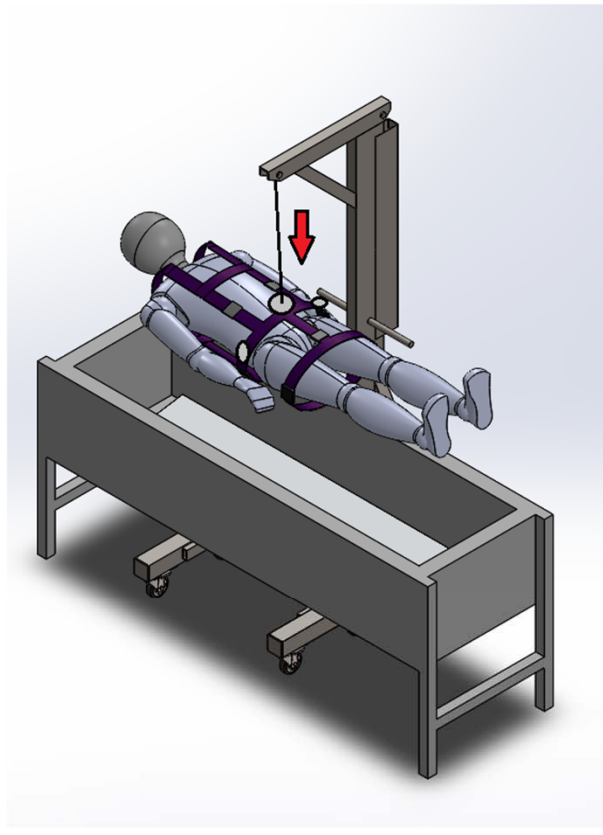
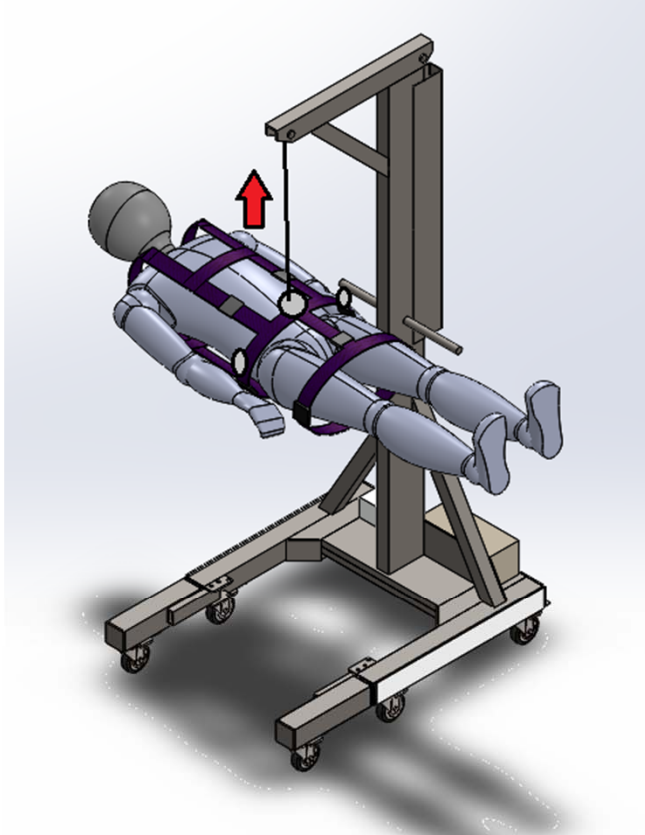


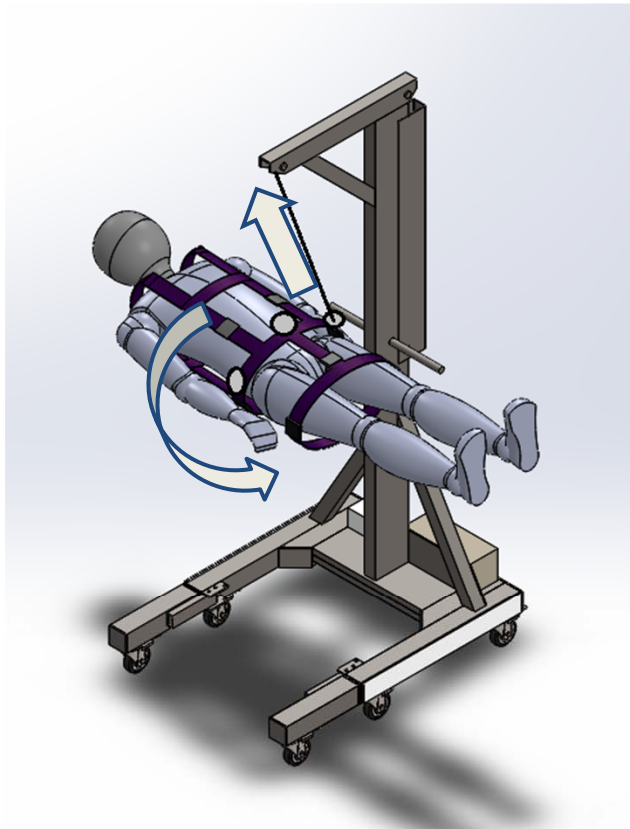


CURRENT HARNESS



- Leg strap support
- Increased Adjustability
- Neck Support
- 2" Nylon Straps
- Tensile Strength: 2,500lbs







COST ESTIMATE

OVERALL EXPENDITURES	
Harness Cost	\$69.00
Frame Cost	\$119.64
Accessory Parts Cost	\$297.08
Labor & Supplies Cost	\$190.00
TOTAL	\$675.72



QUESTIONS?

A special thanks to:
Mr. Brokesh
Sam Wilcox
1/4 Scale Tractor Team

Come see our Open House display in
Seaton 142!





The pictures above display the current building phase of the Final Cadaver Lift. The left picture shows the general placement of the pivoting legs during storage, and the right picture shows placement during use. The pivoting legs have not yet been welded in place because the hinge system is undergoing fabrication. The testing phases will be ongoing throughout the end of the Spring 2015 semester to make sure that the Biology Department will be able to utilize the end product in their labs. Rotational Anatomy truly wants to make sure this design is stable, safe, and that all parts (including moving pieces, electrical systems, etc.) abide by lab protocols to make sure that the CDT is capable of using the end product without any adverse stipulations.



The picture to the left, displays the idea for the hinging system that will allow the base legs to pivot in and out. Essentially, a bushing made from steel piping and a standard bolt (gold) will provide the pivoting action, while a locking mechanism will be achieved via a secondary bolt (silver). Unfortunately, Rotational Anatomy is unable to provide a better understanding of this than what is presented here and in the Final Report at this time.



This is an image of the Technical Display that was presented at the 93rd Annual Engineering Open House. Kevin Garman represented his design team and the Biological & Agricultural Engineering Department by competing in the Technical Display category. Essentially, this is the most current photo of the Harness Design. The current Harness Prototype is displayed on the white mannequin at the center of the picture. This was the best representation the Rotational Anatomy could supplement with their application so that the Kirmser Award judging panel might be able to see the extent to which the harness has been fabricated. Interestingly enough, the team has had to research and learn sewing skills (especially the men) because that was one major way for the team to cut costs. For a better reference, the mannequin stands at a height of 5'7". The lift (far right) stands a total height of 6'9" from floor to hoist beam top.

KIRMSER AWARD REFLECTIVE ESSAY

Submitted by:

Rotational Anatomy

Kevin Garman – Chloe Boudreaux – Phil Mahoney – Jack Ezell

The Kansas State University (KSU) Cadaver Dissection Team (CDT) is challenged to provide comprehensive human anatomy demonstrations. To see all structures adequately, the cadaver must be flipped over. Attempting to rotate a 300-pound cadaver without proper aid may result in labor injury, cadaver tissue damage, compromised lab spaces, and lost preservatives. The Rotational Anatomy Senior Design team took on the task of developing a system to help the CDT lift and rotate their cadavers. The process for this project was broken into four sections: defining client needs, conducting appropriate research, thoroughly evaluating all relevant research, and building a final design.

Rotational Anatomy was a biomedical engineering senior design team formed for BAE 536/636 - Biological Systems Engineering Senior Design I&II. Its members chose to address a rare engineering problem presented by the instructor of the CDT, Sam Wilcox. The team worked closely with Sam to define the criteria of the project. These criteria were as follows: simple and efficient to use, completely operable by one person, compact for storage, does not damage cadaver tissue, and has a low implementation cost.

As research began, the team found that this project consisted of two separate design sections: a harness and lift. The harness was considered the piece that would interface with the cadavers, while the lift was considered the supporting structure connecting to the harness and instigating rotational movement. Separating these two designs made the research considerably more focused and allowed for better evaluation of sources. Rotational Anatomy's research plan was accomplished by identifying relevant technical literature, obtaining that literature, searching the internet, and consulting with faculty and experts. Rotational Anatomy began with the highly collective Engineering and Medicine & Health database channels. Specifically, the Compendex, PubMed, and Ergonomic Abstracts databases. Compendex is the most comprehensive bibliographic database of engineering research that has technical reports from numerous journals that deal with mechanical systems, which applies to the strength and materials of the lift and harness designs. PubMed includes over 21 million citations from prestigious journals relating to biomedical articles, which was vital in finding information about health hazards of preservatives and loading strains on operator muscles. Lastly, functionality and handling of machine systems in lab and operating room environments is why Ergonomic Abstracts were pertinent. These databases gave the team a diverse array of resources including technical papers, journal articles, and conference proceedings, especially after realizing that multiple searches with varying keywords was a crucial step in acquiring varied sources. Since some team members weren't very efficient with the database system, they used Google Scholar and acquired many articles using the "Get It" feature. For any of the articles that were not immediately retrievable online, the team

learned that some could be found in hardcopy in the holdings of the Kansas State University Libraries. However, many articles were not retrievable in either of those ways, and, thus, were requested from the Interlibrary Loan Service. This was a service that no team member had ever used before, but, as they understood it more, it proved to be extremely useful. In the end, the team retrieved close to 20 articles with this service alone. However, Rotational Anatomy came across many problems when trying to find information directly related to the manipulation of cadavers, so the team went to Alice Trussell, the Fiedler Engineering Library Director, for guidance. Alice saw the team's troubles were ubiquitous with a significant number, if not all, databases that KSU had access to, thus, she encouraged Rotational Anatomy to contact companies that make cadaver lab equipment and schools that have cadaver programs to see if they might be able to answer questions and give the team specifications on their products. She also mentioned that Google Scholar patent searches could be applicable. Consequently, the team was able to find many design ideas that had uses for bedridden patients that could be modified to accommodate cadavers.

After a few weeks of researching, Rotational Anatomy quickly identified more relevant technical articles than needed. RefWorks was a tool that allowed the team to stay organized, but due to the sheer number of articles, the team quickly became overwhelmed. In the interest of time, the team developed a design matrix of criteria for all sources found to help eliminate those that would not advance the project goals. The criteria used in this matrix included: information is relevant to or deals with human cadavers, information is relevant to or deals with mechanical materials or strengths, references in article utilize up-to-date information, the digital article has been published in print or abides by quality standards seen in publication (e.g. peer-review, etc.), and all dates of publication are within the last 15 years. Rotational Anatomy also made contact via email with the following faculty members and experts regarding the use of cadavers: Dr. Ashely Rhodes the Human Body course director from Kansas State University, Dr. Dana Townsend the renowned anatomy and physiology professor at Wheaton College (who previously directed the KSU Human Body course), and Amy Deneke a Mortician of the Willed Body Program at the Kansas University Medical Center. The correspondence with these professionals was considered to be highly accurate and very credible based on their direct involvements with the KSU Cadaver Dissection Team and their experiences with cadavers in many other settings.

The next step in research came during the building and testing phases. As the team began constructing prototypes and attempting preliminary tests, additional research was needed to be conducted on proper testing methods. Most of this came from consultation with the client, and the team's advisor. However, material strength and durability research from library database searches had to be referenced in conjunction with machine shop professionals.

Altogether, Rotational Anatomy went through extensive lengths in learning and utilizing the highly innovative library services provided by KSU Libraries. Rotational Anatomy would like to acknowledge that KSU Library technology systems and personnel were vital in instigating the design of a quality product.

BIBLIOGRAPHY

Sources Used in Final Report:

- ASTM Standard D6775-13, 2013, "Standard Test Method for Breaking Strength and Elongation of Textile Webbing, Tape and Braided Material" ASTM International, West Conshohocken, PA, 2013, DOI: 10.1520/D6775-13, www.astm.org
- Finger, W. (1999). Design and control of an active mattress for moving bedridden patients. *Proceedings – IEEE International Conference on Robotics and Automation*, 3, 2044-2050.
- Genome Tuning Quality Performance Parts. (2014). *Cipher Racing Black 4 Point Quick Release Racing Harness Set (3" Inches)*. Retrieved from http://www.genometuning.com/index.php?main_page=product_info&cPath=291_333&products_id=11244&zenid=494mg49uocplngsna9pp50fhv1.
- Kansas State University Campus Planning and Facilities Management. (2012). *Ackert Hall (Chalmers Addition) Second Floor. FILE NAME: 136_3OF7ACKERT_JULY2012.DWG*. Retrieved from http://www.k-state.edu/planning/space_inventory/floor_plan/a-b/136_3of7Ackert_July2012-11x17.pdf.10
- Legion Safety. (n.d.). *DBI Sala Delta II Cross Over Harness*. Retrieved from <http://www.legionsafety.com/dbi-sala-delta-ii-cross-over-harness.html>.
- Loop11. (2012). *Affordances Can Point Your Users in the Right Direction*. Retrieved from <http://www.loop11.com/affordances-can-point-your-users-in-the-right-direction/>.
- McGill, S. M. (2005). Transfer of the horizontal patient: The effect of a friction reducing assistive device on low back mechanics. *Ergonomics*, 48(8), 915-929.
- Medical Products LTD. (n.d.). *Heavy Duty DOD Spec Human Remains Pouch*. Retrieved from <http://www.medicalproducts.com/product/six-handled-hd-dod-spec-human-remains-pouch/>.
- Mortech Manufacturing Inc. (2014). *Adjustable Strap Lift Assembly with Rigid Body Strap*. Retrieved from <http://mortechmfg.com/products/adjustable-strap-lift-assembly-rigid-strap-m607>.
- Northern Tool and Equipment (n.d.). *Dutton-Lainson StrongArm 120 V AC Electric Winch with Remote-1800-Lb. Capacity, Model# SA7015AC*. Retrieved from http://www.northerntool.com/shop/tools/product_200323049_200323049.
- Rosemont Textiles. (n.d.). *Seatbelt*. <http://rosemonttextiles.com/seatbelt/>.

Supporting Sources Not Used in Final Report:

- ASTM Standard A1023/A1023M-09, 2009, “Standard Specification for Standard Carbon Steel Wire Ropes for General Purposes” ASTM International, West Conshohocken, PA, 2009, DOI: 10.1520/A1023_A1023M-09, www.astm.org
- ASTM Standard D6775-13, 2013, “Standard Test Method for Breaking Strength and Elongation of Textile Webbing, Tape and Braided Material” ASTM International, West Conshohocken, PA, 2013, DOI: 10.1520/D6775-13, www.astm.org
- Basmajian, A. (2002). The marionette bed: Automated rolling and repositioning of bedridden patients. *Proceedings – IEEE Conference on Robotics and Automation*, 2, 1422-1427.
- Cargo Gear. (n.d.). *Light Gray Seat Belt Webbing - 2 inches wide. CargoGear Item#: TWWEBG2*. Retrieved from <http://www.cargogear.com/OneItemInfo.aspx?partnum=TWWEBG2>.
- Farwest Steel Corporation (1999) Standard Weights and Gauges of Steel. http://www.farweststeel.com/content/misc_uploads/FWS_Standard_Weights_and_Gauges1.pdf
- Harbor Freight Tools. (n.d.). *1/2 ton Capacity Hand Winch*. Retrieved from <http://www.harborfreight.com/1000-lb-capacity-hand-winch-65688.html>.
- McGill, S. M. (1997). The biomechanics of low back injury: Implications on current practice in industry and the clinic. *Journal of Biomechanics*. 30(5), 465-475.
- Soffritti, M., Belpoggi, F., Lambertin, L., Lauriola, M., Padovani, M. and Maltoni, C. (2002), Results of Long-Term Experimental Studies on the Carcinogenicity of Formaldehyde and Acetaldehyde in Rats. *Annals of the New York Academy of Sciences*, 982: 87–105.
- Strapworks. (n.d.). *Metal/Aluminum Airline Seat-Belt Buckle. Product Code: M-AASBA2-1*. Retrieved from http://www.strapworks.com/Metal_Aluminum_Airline_Seat_Belt_Buckle_p/m-aasba2-1.htm.