Brace to Facilitate Increased Mobility and Improved Posture for Patients Suffering from Spinal Abnormalities

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Abstract

Camptocormia is defined as a forward bend in the thoracic or lumbar region of the spine of at least 45 degrees when upright, which dissipates in the supine position. The cause of this condition is unknown and few treatments exist. Currently, the market for braces to treat this unique spinal condition is limited. The client and patient have reached out to the UW-Madison BME Department to design and fabricate a brace for the unique rehabilitation needs of camptocormia. The purpose of the brace is to facilitate increased mobility, while retaining a range of motion that will allow the patient to bend and perform daily tasks such as using the restroom, cooking, and gardening. With interest in biomechanics, the team embraced the opportunity. Relevant calculations to understand the dynamics of the condition and the forces possible with such a brace were performed, involving free body diagrams, work energy equations, and Newton's 2^{nd} law. The team developed three design alternatives. All featured a corset interior, to straighten the spine, and a metal hardware exterior with extensions spanning from the upper chest to the patient's thighs to hold the patient upright. The designs vary in their ability to generate the forces and corresponding moment about the hip that will provide resistance and return the patient to a vertical position. After contrasting helical torsion springs, flat coil torsion springs, and a cam system, the cam method yielded the highest score in the design matrix. In the upcoming weeks, the team will model the brace in SolidWorks, assess the stresses using ANSYS, and model the body wearing the brace in OpenSim. Then, the team will order appropriate materials, fabricate the product, and test the device on the patient.

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Introduction

Problem Statement

Design, develop, and build a brace or support to aid in holding a person in an upright position when standing or sitting, while also facilitating increased mobility.

Background

According to Doherty, et al., camptocormia is the name for a disorder in which the spine bends severely at the thoracic or lumbar regions. This leads to a stooped posture in milder cases, but in more severe cases could mean completely bent to a point where the thoracic cavity appears to be near parallel with the ground (Figure 1). Unfortunately, no specific definition or terms for diagnosis exist for camptocormia. Therefore, doctors make subjective diagnoses by looking for at least 45° of thoracolumbar flexion that arises when upright but is corrected in the supine position.[1] This ambiguity is a direct result from the absence of a known cause for camptocormia.

Figure 1: Depiction of a man with severe camptocormia. As evident from the figure, the man's thoracic cavity nears parallel to the ground and is still severely curved while seated. The curve is not present while lying down

Two different theories have developed for propagation of the disorder. One idea pertains to degenerative spinal issues. Studies of those with camptocormia have shown spinal muscles with low density on CT and MRI scans.[2] Additionally, lobulated fibrosis and atrophy of fibers have been observed from muscle biopsies.[2] These results suggest myopathic complications in spinal muscles. The second theory relies on the principle of neurological issues including striatal damage in the brain, which affects the basal ganglia and thus motor control.[2] Of course some simply combine these two theories saying muscular and neuromuscular disorders both contribute to the cause of camptocormia.[3] Furthermore, there is a positive correlation between the severity of Parkinson's disease (PD) and the development of camptocormia. On average, camptocormia sets in seven to eight years after the onset of Parkinson's.[1] This is logical as Parkinson's is a neurological disease that hinders a person's ability to control their muscles.

Pain is something often experienced by those with camptocormia and it is unclear whether or not camptocormia has something to do with previous back problems. In some cases patients may feel as though they are being 'pulled' forward or as though their abs are flexing.[1] Rarely able to pull themselves upright, patients' spinal erector muscles are either not engaging or are rigid. Conversely, the patient has not experienced pain associated with camptocormia.

A number of patients have been able to utilize ‘sensory tricks’ to correct their bent posture—for example, one man used a low set, weighted backpack to be able to walk upright.[4] Some can push off of their thighs using their hands, which allows them to walk more upright.[5] Others are able to put themselves upright against a wall or hold themselves upright via their arms on a walker.[5]

Due to the absence of an exact cause for camptocormia, few treatments exist for the disorder. Drugs have not worked thus far as camptocormia does not respond to levodopa, a drug used for PD. In fact those who have this complication also do not respond well to the levodopa for treatment of their Parkinson’s symptoms.[1]

Some orthoses have been developed but have either been very rudimentary or have not worked well. A study done by de Sèze, et al., out of Bordeaux, France used a thoraco-pelvic anterior distraction (TPAD) device (Figure 2) for patients with camptocormia as well as a physiotherapy regiment to treat the disorder.[3] The device used a rigid bar between a hip belt and a chest belt to force the chest away from the hips causing the person to be upright. The study did exhibit positive results in increased lumbar lordosis, thoracic kyphosis, and sagittal balance.[3] However, the orthosis does not allow for the patient to bend and would prove troublesome for toileting. A newer, more mobile brace is highly sought after.

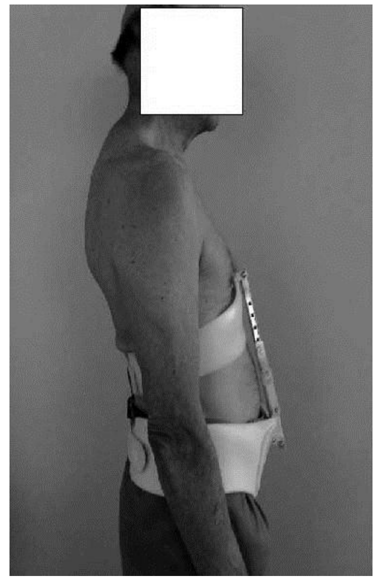


Figure 2: Thoraco-Pelvic Anterior Distraction (TPAD) device. The figure shows the orthosis used in the study done by De Séze et. al., consisting of a rigid bar to separate the chest and pelvis.

The patient we are dealing with has a more severe case of camptocormia in which she is completely bent and cannot pull herself upright without the use of a walker and a wall simultaneously. The 65-year-old would like a mobility brace that would allow her to use her kitchen and garden again. This requires the brace to allow the user to bend over and return to an upright position. Currently, a patent exists for a torso assist device and our client has been in contact with the inventor for nearly a year.[6] He claims to be fabricating a prototype for her. However, she has not received a functional brace thus far. The team will produce a prototype for the patient.

Project Motivation

Team motivation for this project focuses mainly on interest in the biomechanics specialization. The team members have taken or are currently taking courses such as Statics, Dynamics, Mechanics of Materials, Biomechanics, BME 201, and Introduction to Engineering 160. These courses have prepared the team to do a biomechanics, rehabilitation, and human subjects based design project. Carie and Isabel were on the same BME 201 design team and worked well together on the simple bioreactor; therefore, they can work well as a team and successfully complete a project together. This project is interesting to the team because directly impacting the life of a client will be personally gratifying. Furthermore, this project will provide the team with the opportunity to develop technical skills.

Project Design Specifications (PDS)

See Appendix A.

Design

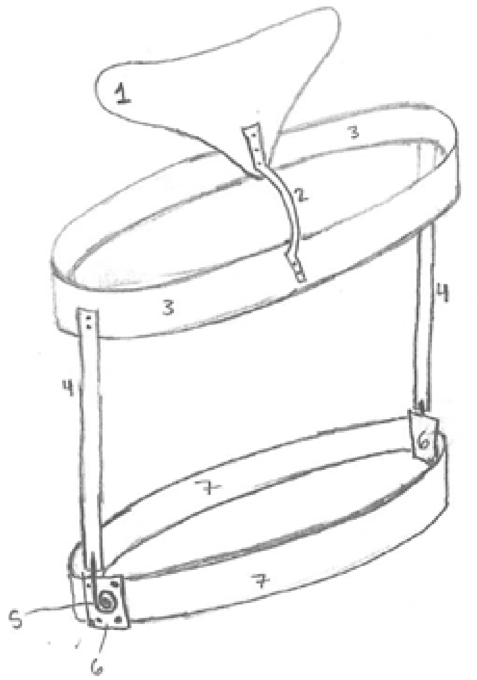
Design Alternatives

In the beginning, the team began brainstorming and designing individually to generate a maximal amount of ideas and perspectives. This proved valuable because when the ideas were presented to one another, each person had taken a different direction. From there, the stronger ideas from each design were brought together and led to three different hybrids that were considered for the final design. Each design consisted of two components—a corset to hold the patient's body rigid and a frame to facilitate mobility. The corset (Figure 3) is a corset body with a shoelace tightening mechanism and is used in conjunction with each of the three designs.

Corset Design Reference Number	Design Component
1	Corset Body
2	Shoelace Tightening Mechanism

Figure 3: Corset Component. This is the corset component that will be used in conjunction with each of the three frame component designs.

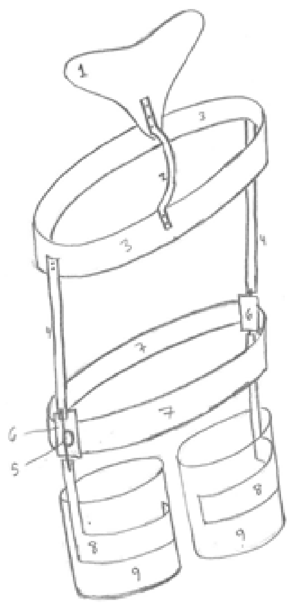
The first design, which will be referred to as “Flat Coil Torsion Spring” (Figure 4) consists of a rigid frame (parts 3 and 4) that is hinged by a flat coil torsion spring (part 5) to the metal anchoring plate (part 6). This metal plate will be housed on the sides of the lower anchoring ring (part 7) that will fit the patient’s hips like a glove. Furthermore, there will be a padded chest plate (part 1) that will be attached to the frame via a connection piece (part 2).



Design One Reference Number	Design Component
1	Chest Plate
2	Chest Plate Connection Rod
3	Upper Anchoring Ring
4	Vertical Connection Arm
5	Flat Coil Torsion Spring
6	Metal Connection Plate
7	Lower Anchoring Ring

Figure 4: Flat Coil Torsion Spring Frame Component. This is the frame component design that utilizes a flat coil torsion spring so that no leg cuffs would be needed.

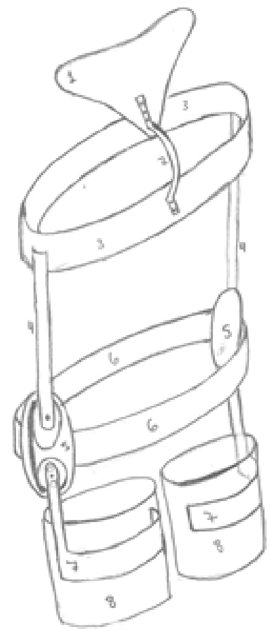
The second frame design, “Helical Torsion Spring”, can be seen in Figure 5. Again, a metal frame (parts 3 and 4) is used in conjunction with a chest plate (part 1); however, this design utilizes a helical torsion spring (part 5) to hinge the metal frame to the metal anchoring plate (part 6) that is housed in the lower anchoring ring (part 7). Moreover, the other end of each of these springs is connected to metal leg inserts that extend down and wrap around the front of each thigh (part 8). These metal inserts are secured to her leg with leg bands that will wrap around the whole circumference of her thigh, functioning to keep the device in place (part 9).



Design Two Reference Number	Design Component
1	Chest Plate
2	Chest Plate Connection Rod
3	Upper Anchoring Ring
4	Vertical Connection Arm
5	Helical Torsion Spring
6	Metal Connection Plate
7	Lower Anchoring Ring
8	Metal Leg Inserts
9	Leg Anchoring Band

Figure 5: Helical Torsion Spring Frame Component. This is the frame component design that utilizes a helical torsion spring to connect the upper metal frame to the leg cuffs.

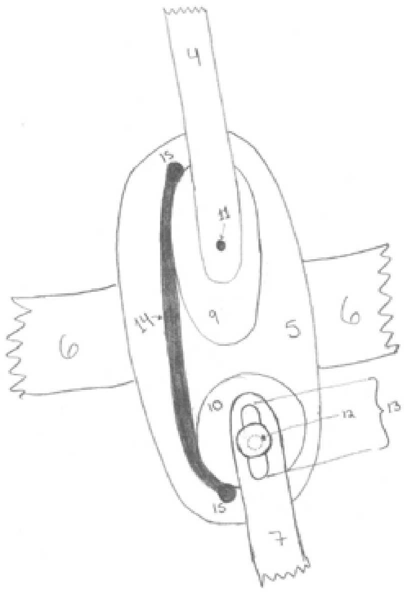
The third design, “Cam Mechanism” (Figure 6) incorporates the same metal frame and chest plate apparatus for the upper section and utilizes the same leg bands with metal inserts for the lower section as design two (Figure 5). However, instead of a torsion spring, this design uses a cam device housed in the metal connection plate (part 5).



Design Three Reference Number	Design Component
1	Chest Plate
2	Chest Plate Connection Rod
3	Upper Anchoring Ring
4	Vertical Connection Arm
5	Metal Connection Plate
6	Lower Anchoring Ring
7	Metal Leg Inserts
8	Leg Anchoring Band
9	Ellipsoid Wheel
10	Circular Wheel
11	Upper Axis of Rotation
12	Lower Axis of Rotation
13	Pin Activation System Knob
14	Cam Band
15	Cam Band Anchor Points

Figure 6: Cam Mechanism Frame Component. This is the frame component design that utilizes a cam mechanism to connect the upper metal frame to the lower leg cuffs.

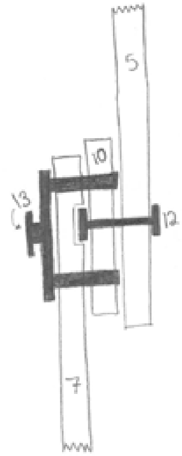
Figure 7 displays a close up of this mechanism. The ellipsoid wheel (part 9) moves with the vertical connection arm (part 4) from the metal plate about the upper axis of rotation (part 11). In the same manner, the circular wheel (part 10) moves with the metal leg insert (part 7) from the metal plate about the lower axis of rotation (part 12). On the side of the cam device towards her dorsal side, there is a cam band (part 14) that is connected to each of the wheels (part 15). When the angle between her torso and lower body starts to decrease below 180°, there will be tension in the cam band, creating resistance. The cam band will be made of an elastic material so that the patient is able to bend her upper body forward or bend her legs at the hip, but there will be some degree of kickback to bring her back to an upright position.



Reference Number	Design Component
4	Vertical Connection Arm
5	Metal Connection Plate
6	Lower Anchoring Ring
7	Metal Leg Inserts
9	Ellipsoid Wheel
10	Circular Wheel
11	Upper Axis of Rotation
12	Lower Axis of Rotation
13	Pin Activation System Knob
14	Cam Band
15	Cam Band Anchor Points

Figure 7: Cam Mechanism Front View. This is a close up of the cam mechanism used in the design seen in Figure 4. The cam band connects two wheels that will move with the body producing a resistant force in the band.

Figure 8 shows a side view of this mechanism. Here, there is a pin activation system knob (part 13) that can be pulled outwards to release the metal insert of the leg apparatus (part 7) from the circular wheel (part 10). This will provide a quick release if she would like to sit down without having a constant tension in the cam working against her.



Reference Number	Design Component
4	Vertical Connection Arm
5	Metal Connection Plate
6	Lower Anchoring Ring
7	Metal Leg Inserts
9	Ellipsoid Wheel
10	Circular Wheel
11	Upper Axis of Rotation
12	Lower Axis of Rotation
13	Pin Activation System Knob
14	Cam Band
15	Cam Band Anchor Points

Figure 8: Cam Mechanism Side View. This is a side view of the lower wheel of the cam mechanism seen in Figure 5. It emphasizes how the pin system is used to function as a quick release for when the patient would like to bend his/her body unhindered.

Decision Matrix

With these three designs, a design matrix was created (Figure 9). It consists of the seven following categories: functionality, self-operability, feasibility, durability, comfort, cost, and aesthetics. Functionality was ranked based on how well the device would work. It took into consideration the range and ease of motion that would be provided by each design. Self-operability was our second highest priority category and was gauged based on how easily the device could be put on and used without assistance. Points for the feasibility category were assigned with regards to how difficult the fabrication process would be. Ultimately, the winner was the cam design due to its high scores among the design matrix criteria, especially functionality and durability. It may be concerning that it only won in two of the seven categories, but taking a closer look reveals that it was only one point value behind the winning design of each of the other criteria. Also, functionality was the most pressing concern and the cam design won in that category by a large measure.

Category	Point Allocation	Flat Coil Torsion Spring	Helical Torsion Spring	**Cam**
1. Functionality (range of and ease of motion)	30	25	18	29
2. Self-Operable	20	18	19	18
3. Feasibility	20	16	16	15
4. Durability	10	6	4	9
5. Comfort	10	7	8	7
6. Cost	5	4	4	3
7. Aesthetics	5	3	4	3
Total Points: 100	100	79	73	**84**

Figure 9: Design Matrix. This is the design matrix for the three different frame components. The highlighted portions represent the winners for each respective design matrix criterion and also the winner in overall points, the cam mechanism.

Calculations

Calculations were performed to obtain the necessary strength of the cam component of the brace and prove the ability of the designs to hold the patient upright. This involved obtaining the forces and moments generated from the weight of the upper body, and also considering additional weight that may be picked up by the patient. Referring to Appendix B Figure 1, the forces and their resultant moment arms were calculated with use of an anthropometric table and measurements of the patient's height and weight. The body was modeled at the most extreme possibility, with the upper body parallel to the ground (Appendix B Figure 3). Additionally, an upright figure was produced (Appendix B Figure 4) modeling the condition in two equivalent ways—with an applied moment at the location of the cam (the hip), and with a coupled force pair. A function was generated to determine the required moment magnitude the cam must produce to counteract the moments generated by the camptocormia condition as a function of the angle from the vertical (Appendix B Figure 5).

Angular acceleration assumptions were made in order to solve for the force and moment equations. A five second duration was decided for the patient to go from the horizontal to vertical position. Utilizing kinematic equations, tangential acceleration was obtained, which could be translated into angular acceleration with the radius of curvature, the distance from the hip to the center of mass (Appendix B Figure 7).

Using work energy equations, the torsional spring constant was obtained. Considering two distinct orientations of the patient—one upright and the other horizontal—the potential energies were compared. As shown in Appendix B Figure 7, the torsional spring constant was obtained.

Final Design

The cam mechanism was ultimately chosen as the final design. Looking strictly at the design matrix this design won in total point value and won by a large measure in functionality, the most important category. Additionally, in the categories where the cam design did not win, it scored just one point short of the winner.

Future Work

For future work, the brace needs to be modeled using software such as SolidWorks, in order to determine precise measurements of the brace. Additionally, ANSYS will be a valuable tool for stress analysis to ensure adequate material strengths are used for future fabrication. Utilizing human modeling software such as OpenSim, and integrating camptocormia side effects into the figure, the brace may be pretested to determine its ability to straighten the spine.

Once testing has been completed, and the brace is proven to be adequate, the team will begin finalizing materials. More specifically, extensive research into available cam components will be done to eliminate the need to fabricate this intricate product. It is hoped that a cam with appropriate strength and size is available for purchase through a manufacturer. If not, the team will look into companies that would be willing to design one with unique specifications tailored to the project. The chosen materials will then be presented and discussed in a proposal to the

Biomedical Engineering Department, who will hopefully allocate funds for the rehabilitation project. The team will also attempt to contact manufacturers to obtain free samples and trial products, to further help reduce costs.

After the materials are obtained, fabrication will begin. Once the brace is built, the patient will then test the brace. This will involve human subject testing, which two of the four team members have certification to do. Before this step, the design team will be sure to research whether this is an adequate percentage of the team, and if not, the team will take necessary measures to certify all team members. If, for some unanticipated reason, the brace does not operate as intended on the patient, the team will reflect on past steps, in attempt to improve the brace's function.

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Appendix A: PDS

Function

Design, develop, and build a brace or support that can be worn to aid in holding a person in an upright position when standing or sitting, while also facilitating increased mobility. The client, Linda Oberstar, is a 65 year old petite female who has suffered from Parkinson's disease for over 15 years and has developed a common complication called camptocormia. Camptocormia has caused Mrs. Oberstar to have abnormal flexion in her trunk that occurs when standing or sitting but disappears when lying down. Due to this abnormal trunk flexion, Mrs. Oberstar has lost the ability to perform every day movements due to a significant reduction in her mobility. The brace or support device must hold Mrs. Oberstar in an upright position so that she is able to comfortably perform everyday tasks, especially cooking in her kitchen.

Client Requirements

- Brace must fit a petite sized woman weighing 556.03 N (125 lbs.) with average strength.
- Device must be less than 44.48 N (10 lbs.), as per patient request.
- A weight of 13.34-22.24 N (3-5 lbs.) on her mid-section is enough to hold her upright.
- Manageable from the front of the body, to ensure independent use.
- Device should be able to fit over and underclothing; adjustable for differing daily conditions.
- Brace must be able to withstand and work with body functions including walking, minor twisting or arm movement, and using the restroom.
- Device must be quickly and easily put on/removed—to enable simple and independent dressing and undressing.
- Device must have a quick release, in case of emergency or bathroom usage.
- Provide adjustable mechanical settings, to facilitate an upright position while both standing and sitting.
- Must replace lack of lower lumbar strength, in order to straighten spine.
- Must be comfortable enough for client to wear for most of the day.
- Facilitate activities such as kitchen and garden usage.

Design Requirements

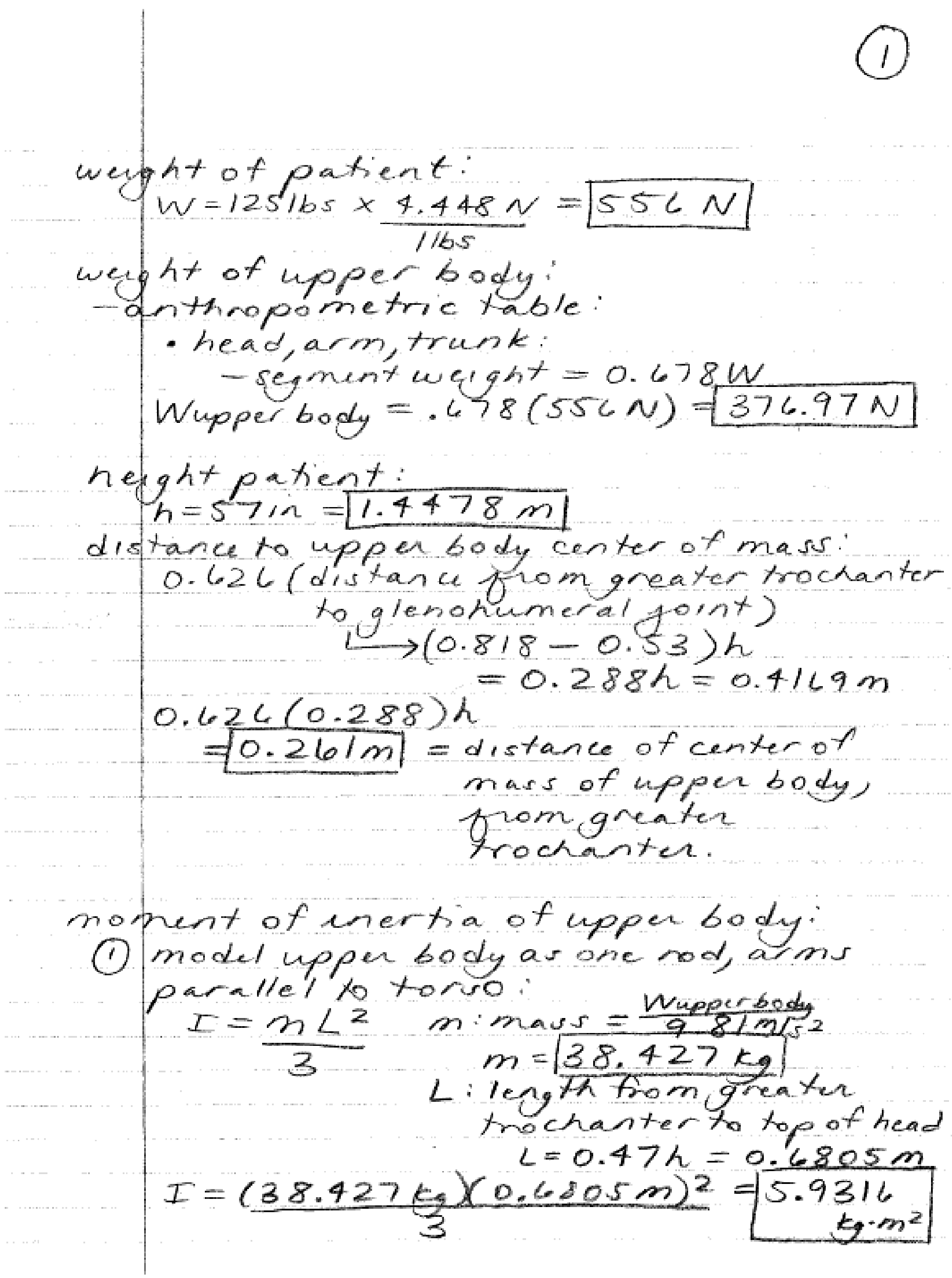
1. Physical and Operational Characteristics
   a. *Performance requirements*: The device will be used as needed throughout the day when the client is not lying down or sleeping, and allow for comfortable sitting, standing and minor twisting. The device must apply a load of at least 13.34-22.24 N (3-5 lbs.) to patient's midsection to effectively pull spine upright, and be comfortably worn all day.
   b. *Safety*: Material must be breathable in order to prevent skin irritations such as bedsores. Device must be able to be removed quickly and easily, in case of

emergency. For the sake of retaining muscle strength, the patient should not be able to become completely reliant on it upon use.

c. *Accuracy and Reliability*: Device must apply necessary forces in correct locations and amounts—which are unique to patients—in both standing and sitting position. An adjustable system will provide this benefit for patient wearing different clothing. Device should be usable over a lifetime.
d. *Life in Service*: The device will be used seven days a week, 10 hours a day, for approximately 20 years.
e. *Shelf Life*: Device is not assumed to be "on shelf" unless patient is sleeping. In that case, conditions will be the same as those endured when brace is being used.
f. *Operating Environment*: Operating environment constraints will be determined when the brace material has been chosen.
g. *Ergonomics*: The brace should ideally have no restrictions of motion for the patient. It should allow for both extension upward (to reach high cabinets) and to sit/bend (to garden). Patient expressed interest in being able to twist to approximately 60° left and right. Device should be comfortable enough to wear throughout life in service.
h. *Size*: Device should be less than 44.48 N (10 lbs.) and fit to the patient's unique body type. Should be portable.
i. *Weight*: Less than 44.48 N.
j. *Materials*: Device materials should not be flammable, as device will be used often in a kitchen environment. Material should be stiff, assuming that it will provide support. Device should be washable, and not rust/tarnish over time. Material should be durable for the life in service, 20 years.
k. *Aesthetics*, *Appearance, and Finish*: Disguisable, if possible. Potentially hidden beneath some clothing. However, patient expressed interest in function over fashion.

2. Production Characteristics
    a. *Quantity*: One device is needed, two if financial means are available.
    b. *Target Product Cost*: Yet to be discussed, assumed to be as low-cost as possible, yet still effective. With BME Funding for Rehabilitation Project, a cost of less than $500 was predicted to be realistic.
3. Miscellaneous
    a. *Standards and Specifications*: Thus far, aware of none. (EC Medical Device Directive)
    b. *Customer*: Utmost, stressed completion. Disappointed multiple times from others pursuing project—including WI orthoist currently in process of designing such braces as a new business venture. Desire function over fashion, but disguisable would be an added bonus.
    c. *Patient-related concerns*: Does not want to be "a robot"—wants to garden and use kitchen, twist and bend.
    d. *Competition*: Mechanical engineering student and outside private orthoist are both working on a device for patient as well. There are surprisingly few articles, patents, and devices aimed towards camptocormia patients, or other patients experiencing trouble straightening and maintaining normal gait.

Appendix B: Calculations



(1)

weight of patient:

$W = 125 \text{ lbs} \times \frac{4.448 \text{ N}}{1 \text{ lbs}} = \boxed{556 \text{ N}}$

weight of upper body:

– anthropometric table:

- head, arm, trunk:
  - segment weight = 0.678W

$W_{upper\ body} = .678(556\text{ N}) = \boxed{376.97\text{ N}}$

height patient:

$h = 57 \text{ in} = \boxed{1.4478 \text{ m}}$

distance to upper body center of mass:

0.626 (distance from greater trochanter to glenohumeral joint)

$\hookrightarrow (0.818 - 0.53)h$

$= 0.288h = 0.4169 \text{ m}$

$0.626(0.288)h$

$= \boxed{0.261 \text{ m}}$ = distance of center of mass of upper body, from greater trochanter.

moment of inertia of upper body:

(1) model upper body as one rod, arms parallel to torso:

$I = \frac{mL^2}{3}$ m: mass $= \frac{W_{upper\ body}}{9.81 \text{ m/s}^2}$

$m = \boxed{38.427 \text{ kg}}$

L: length from greater trochanter to top of head

$L = 0.47h = 0.6805 \text{ m}$

$I = \frac{(38.427 \text{ kg})(0.6805 \text{ m})^2}{3} = \boxed{5.9316 \text{ kg}\cdot\text{m}^2}$

Figure 1: Determining locations and magnitudes of forces, with use of anthropometric table, and determining moment of inertia.

(2)

(2) model upper body as one rod, with two rods (arms) perpindicular to body.

$$I = \frac{m_{torso,head} L^2}{3} + 2\left(\frac{m_{arm} l_{arm}^2}{12} + m_{arm} r^2\right)$$

r: distance from hip to arm (⊥)

r = distance from hip to shoulder

$= (0.818 - 0.53)h = 0.4169\ m$

↳ (see page 1)

$m_{arm} = 0.050W = \frac{27.8\ N}{9.81\ m/s^2} = 2.834\ kg$

$l_{arm} = (.818 - .377)h = 0.441h$

$= 0.6385\ m$

$m_{torso,head} = m_{torso,head,arm} - (m_{arm})2$

$= 38.427\ kg - 2(2.834\ kg)$

$= 32.759\ kg$

$$I = \frac{(32.759\ kg)(0.6805\ m)^2}{3} + 2\left(\frac{2.834\ kg(0.6385\ m)^2}{12} + 2.834\ kg(0.4169\ m)^2\right)$$

$= 5.0567 + 2(0.09628 + 0.49256)$

$= \boxed{6.23438\ kg \cdot m^2}$

→ scenario: if an object is picked up, more mass is added to the arm axis, causing an increased moment of inertia

Figure 2: Determining the moment of inertia of the upper body.

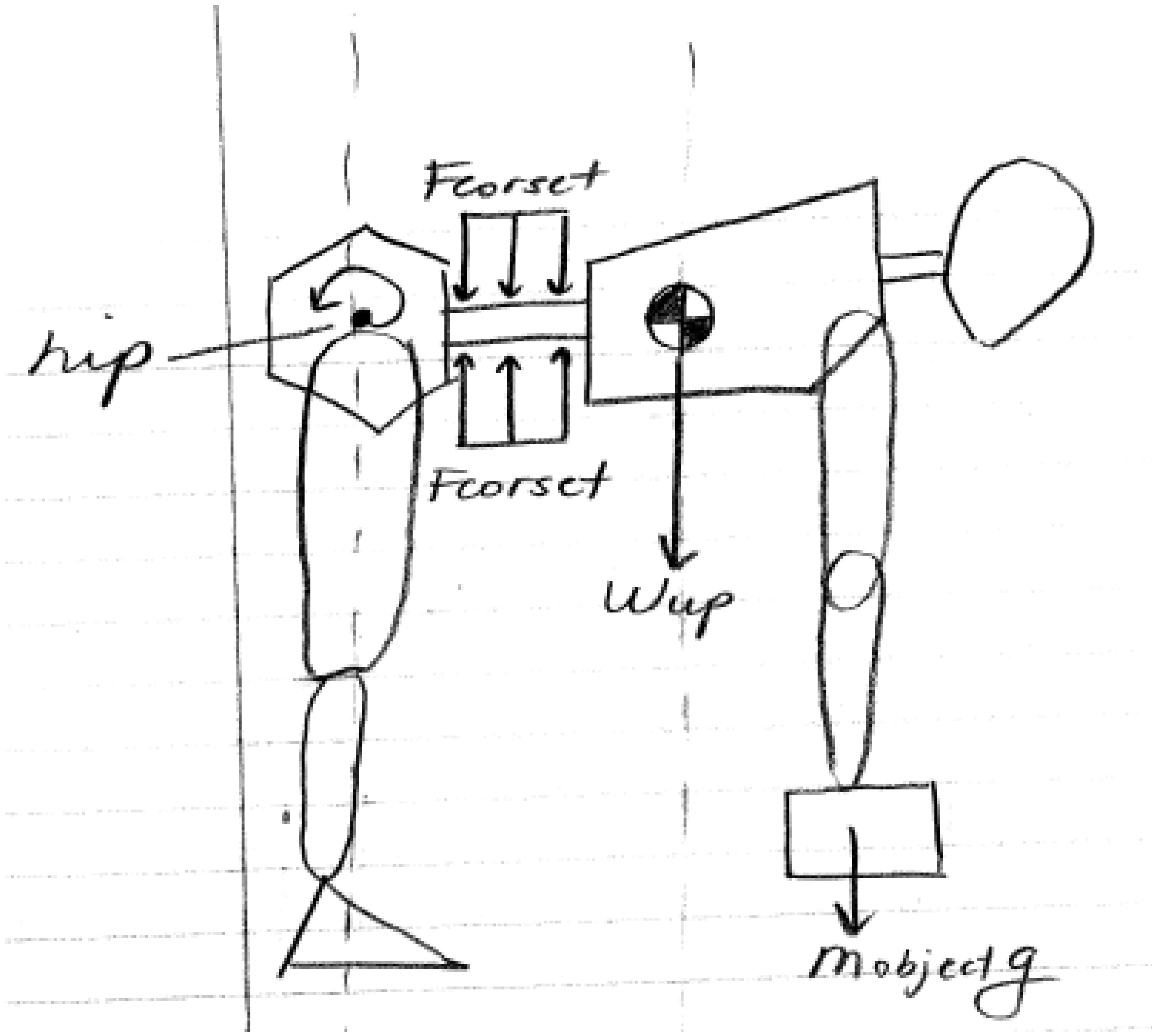


Figure 3: Free body diagram of subject, including weight of allowable object to pick up. Corset component is modeled as a distributed force, and cam moment modeled as point moment.

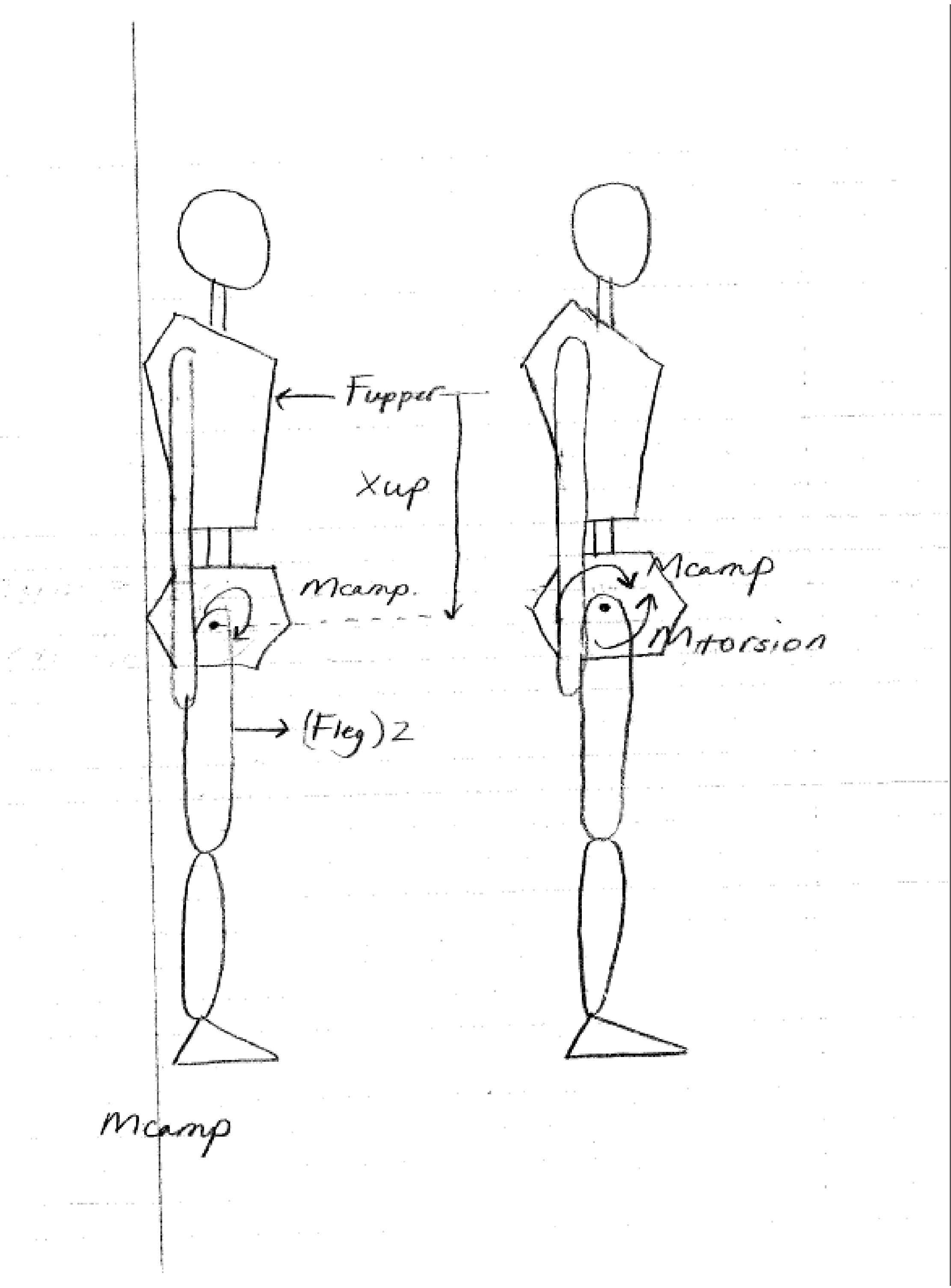
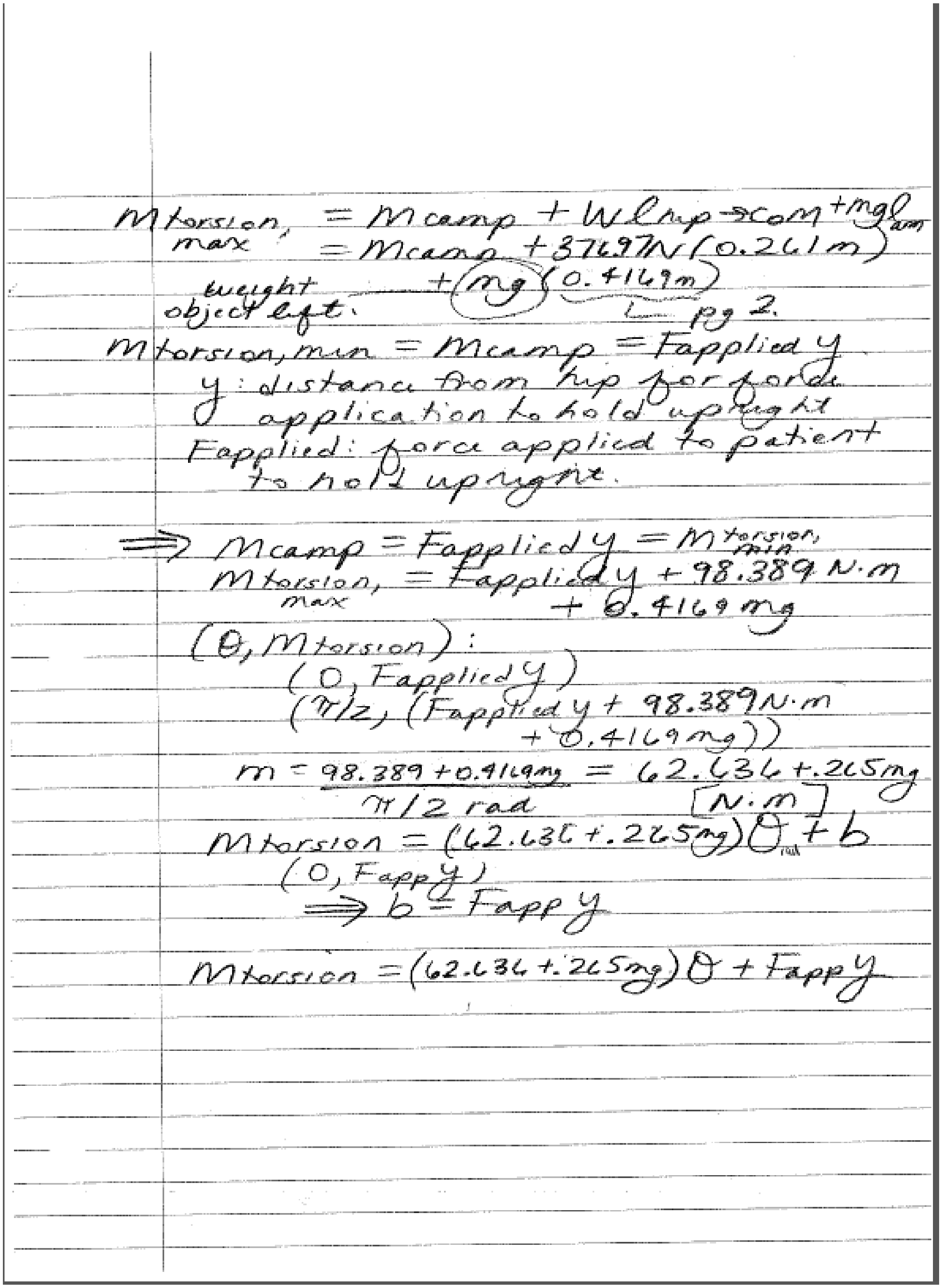


Figure 4: Free body diagram of upright patient. Camptocormia condition is modeled as a point moment at hip, and brace is modeled both as a point force opposing the conditions moment, and as a force couple.



$M_{torsion,max} = M_{camp} + W l_{hip \to com} + mg l_{arm}$

$= M_{camp} + 376.97N(0.261m)$

$+ (mg)(0.4169m)$

weight object lift. — pg 2.

$M_{torsion,min} = M_{camp} = F_{applied}\, y$

y: distance from hip for force application to hold upright

$F_{applied}$: force applied to patient to hold upright.

$\Rightarrow M_{camp} = F_{applied}\, y = M_{torsion,min}$

$M_{torsion,max} = F_{applied}\, y + 98.389\, N \cdot m + 0.4169\, mg$

$(\theta, M_{torsion})$:

$(0, F_{applied}\, y)$

$(\pi/2, (F_{applied}\, y + 98.389\, N \cdot m + 0.4169\, mg))$

$m = \frac{98.389 + 0.4169 mg}{\pi/2\ rad} = 62.634 + .265mg\ [N \cdot m]$

$M_{torsion} = (62.636 + .265mg)\theta_{rad} + b$

$(0, F_{app}\, y)$

$\Rightarrow b = F_{app}\, y$

$M_{torsion} = (62.634 + .265mg)\theta + F_{app}\, y$

Figure 5: Calculations to determine the necessary moment of the cam component, modeled as a function of the angle of the patient relative to the vertical.

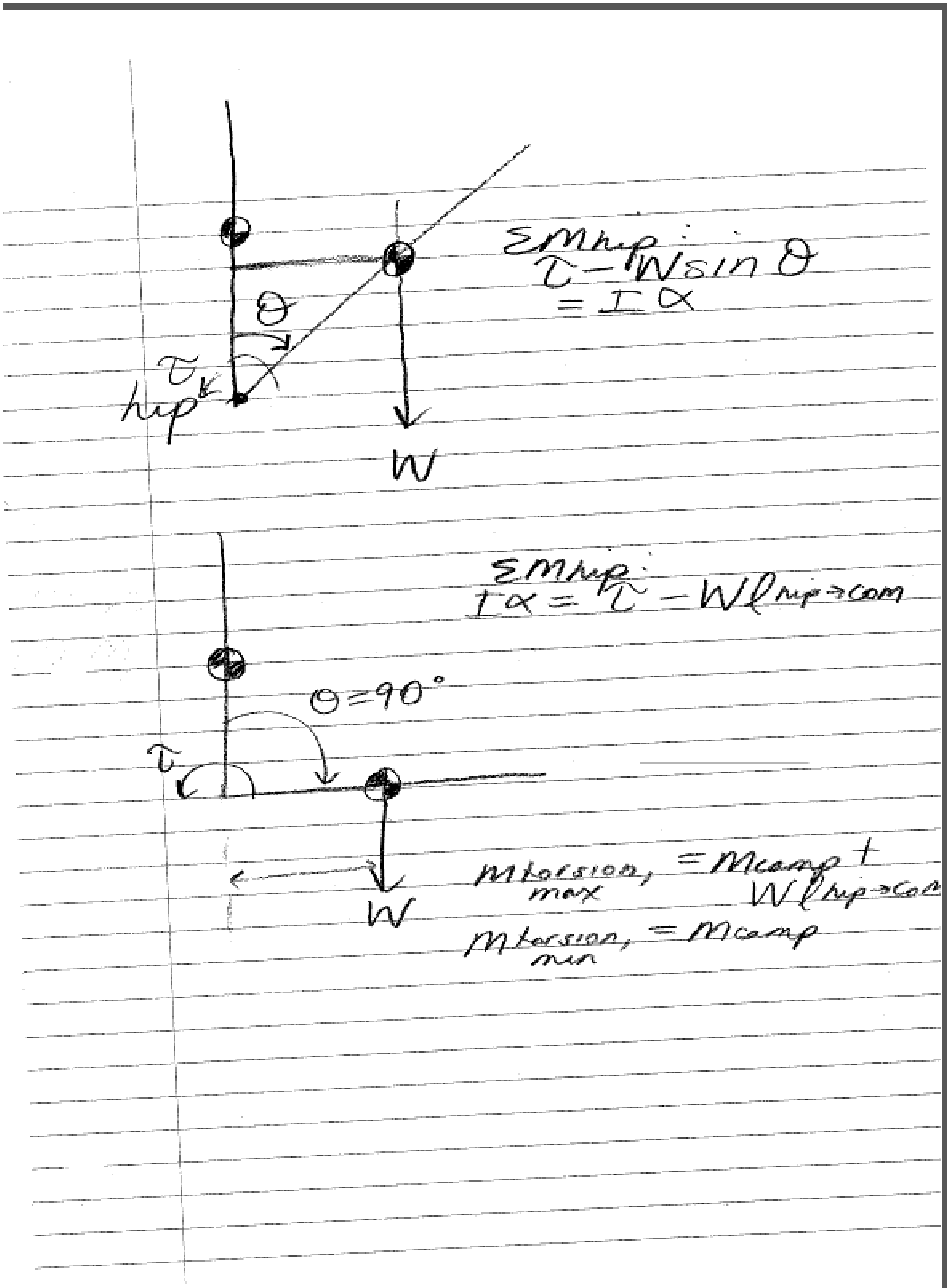


Figure 6: Modeling the body and moment diagrams as a function of the angle from vertical.

torsional spring constant →

use work-energy equation

$T_1 + V_1 + V_{spring} = T_2 + V_2$

$T_1 = T_2 = 0$, no kinetic energy at points considered

(1) upright (2) horizontal

$mgH_1 + \left(-\frac{1}{2}k\theta^2\right) = mgH_2$

datum: set at hip

H = vertical distance to CoM.

mg = weight upper body = 376.97N

$H_1 = 0.26102\ m$

$H_2 = 0$

$$(376.97N)(0.2610m) = \frac{1}{2}k\left(\pi/2\ rad\right)^2$$

$$\boxed{k = 79.7574\ N \cdot m/rad}$$

angular acceleration:

5 seconds to get from horizontal to upright

$\Delta x = V_0 t + \frac{1}{2}at^2$

$R\theta = \frac{1}{2}at^2 \qquad a = \frac{2R\theta}{t^2} \qquad \alpha = \frac{a}{R}$

R = distance from hip to center of mas

$\theta = \pi/2$ radians

$t = 5$ seconds

$$a = \frac{2(0.26102m)(\pi/2\ rad)}{(5sec)^2} = 0.0328\ \frac{m}{s^2}$$

$$\alpha = \frac{0.0328\ m/s^2}{0.26102\ m} = \boxed{0.12564\ rad/s^2}$$

Figure 7: Obtaining the torsional spring constant for the cam component with work energy equations. Allowable angular acceleration was determined, from the decision that it should take 5 seconds to move upright from bent position.