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Knee Crutch

BME 200/300

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Abstract

The market for assistive mobility devices lacks an emphasis on stability and therefore accessibility, especially for users needing support ascending or descending stairs. The team plans to create a design that will ensure patients with lower leg extremities have the assistance and stabilization necessary to climb stairs without needing to possess significant body strength. The design will incorporate materials easily accessible for the client through the Makerspace's 3D printers and suggested manufacturers. The design will be easily fabricated and withstand repetitive use throughout a year. The ease of use and stabilizing factors will be evaluated through a survey and force plate generated stabilogram, respectively. After using the prototype, students will complete a survey to assess whether the model is more effective than the previous competing design.

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Introduction

Motivation

The ability to maneuver around different terrain can be the difference between a patient moving home or staying in the hospital. A U.S. study found that half of adults over 65 had some form of disability, with nearly one-third reporting difficulty climbing a flight of stairs [a]. Since internal or external stairs are a common aspect of homes, patients with lower-limb injuries must use an assistive device to eliminate pressure on an injury when climbing stairs.

Competing Designs

Current solutions, such as motorized stair glides, are stationary, expensive, and do not promote independence [b], and other assistive devices, such as crutches or a walker, reduce stability and increase the risk of falls on stairs [c]. A well-known product on the market is the iWalk. Though this strapped-on product provides sufficient support for walking, it is cumbersome to put on and does not account for the offset height required between knees to climb a flight of stairs [d]. Overall, these solutions are unstable, expensive, and do not promote independence for an older demographic. Therefore, to ensure patients can get home safely, the improved knee crutch will provide ample stability and assistance for stair climbing without the additional use of crutches. The goal is to create an improved version of an existing prototype that will provide users with sufficient mobility and stability when climbing stairs.

Figure 1: Competing Design for Frankenstein Model (iWalk) [d]

Problem Statement

Knee crutches are an assistive device used to help non-weight-bearing patients recovering from a lower limb injury move efficiently and comfortably. Current devices available target assistance with walking, but are not suitable for ascending or descending stairs. To ensure patients can get home safely, the improved knee crutch will provide ample stability and assistance for stair climbing without the additional use of crutches. The goal is to create an improved version of an existing prototype that will provide users with sufficient mobility and stability when climbing stairs.

Background

Client information

Our client, Daniel Kutschera, is a physical therapist who works primarily with rehabilitation patients experiencing lower limb injuries. Many of his patients are older adults with limited mobility and struggle to safely use traditional crutches or canes. A major goal in their recovery process is regaining the ability to climb stairs independently, as this is a key requirement before they can be discharged home. Mr. Kutschera is currently utilizing a "Garden Box" prototype, but has requested the design of a new knee crutch that enables patients to comfortably and safely ascend and descend stairs. The proposed design must prioritize safety, stability, and ease of use while addressing the mobility challenges faced by this demographic.

Figure 2: Daniel Kutschera's "Garden Box"

Physiological and Biological Considerations

The knee crutch should enable patients to climb stairs naturally, without relying on hip hitching or other awkward movements that cause strain or imbalance. The device will primarily serve users with non-weight-bearing injuries below the knee and should be suitable for adults aged 50 to 70, though it must remain adaptable for patients of any age. It will be used both indoors and outdoors in environments ranging from 0°C to 40°C. A well-designed ergonomic structure is essential to maintain balance and prevent falls, supporting a safer and faster recovery. Crutch users often move more slowly and less efficiently, with altered gait patterns that reduce stability and greatly increase the risk of falls, particularly when navigating stairs [i].

Design Specifications

The knee crutch will be used continuously anytime the patient ascends or descends stairs. The device is used and moved for every step the patient takes up the stairs, around 10 steps at a time. The crutch should be able to bear the full weight of a patient, over 200 pounds, for 5-15 seconds as they lift themselves to the next step. In order to avoid exceeding a weight limit of 300 pounds, a warning label will be needed to ensure proper stability and function of the device. When testing and designing the knee crutch, regulations and quality standards from ISO 13485 must be followed to ensure the device is safe for its intended use [e].

The knee crutch device should have a service life of approximately five years under regular clinical use. Since the device will experience limited daily wear, durability testing should focus on repeated stair use. Periodic visual inspections should be recommended to ensure the stabilizing components of the device remain intact.

The device should be slightly shorter than the shin of the patient's uninvolved leg, allowing the patient to easily maneuver it up each step. It must accommodate users between the heights of 5’ 2” to 5’ 9”, through adjustable height settings. The handle of the device should correspond with anthropometric ratios so that the patient can grasp and position it without discomfort. The target device weight is approximately five pounds, providing a balance between portability and stability. The main structural components of the device will be constructed from lightweight aluminum, chosen for its high strength-to-weight ratio and corrosion resistance. The base of the crutch will be a soft or rubber-like material, designed to increase traction and conform to uneven stair surfaces. The knee platform will be slightly concave to cradle the leg securely, reducing lateral movement and providing consistent support during use.

The final device must meet ISO 7176-24:2004 [f], ISO 13485 - QMS [h], and ASTM F3580-24 [g], which outline strength and fatigue testing requirements for mobility aids. The foot platform should fit comfortably on a standard stair tread, approximately ten inches deep, to provide sufficient stability without restricting movement.

Preliminary Designs

Wrap-Around Handle

This design features a wide 9x10-inch base, supported by four small, curved legs with rubber caps on the bottom for added stability. Attached to this base is a long, adjustable square rod that supports a flat plate parallel with the ground. This flat plate is where the patient rests their knee and where a knee cushion can be placed for added comfort. Around that knee support is an extended handle. The patient can utilize this for support while pushing themselves up the step and also to help lift the device from one step to the next. It wraps around 3 of the 4 sides of the knee support plate, allowing the patient to find a grip location that works best for them. Lastly, all components of this design are made of aluminum.

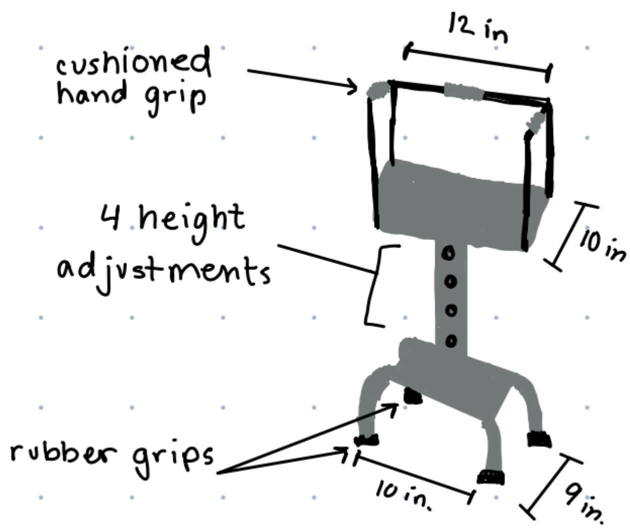


Figure 3: Wrap-Around Handle Design

Adjustable Three Leg

This design features a three-legged base that stabilizes the cushion on the top. The base is a square shape that is hollow in the middle to avoid excess weight in the crutch. There is a silicon cap that wraps around the base to stabilize the knee crutch on slick surfaces. Each of the three legs are adjustable using a pin and hole mechanism. The top has a curved and cushioned pad that uses the curvature as lateral support for the patient's knee. The handle is placed on the front of the device, and is cushioned with a handle. The main materials for this design would include metal (aluminum or steel) and foam.

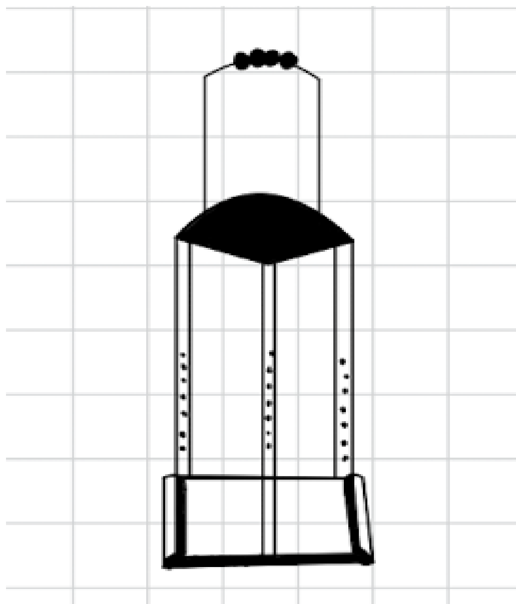


Figure 4*:* The Adjustable Three Leg Design

The Frankenstein Design

This design is an amalgamation of components from the team's individual designs. The handle component wraps around three sides of the knee support, allowing users to place their hand wherever is most comfortable when ascending and moving the device up stairs. There are three legs for support, allowing the design to be both stable and lightweight. Additionally, these supports are not adjustable, eradicating the possibility of instability that accompanies adjustability. The leg support is curved, creating lateral support of the knee when placed in the crutch. This leg support is also cushioned to allow the user to be comfortable when using the knee crutch. To accommodate for the lack of adjustability in the legs, the base of this knee support has stackable blocks that can be added beneath the knee cushion, allowing the height to be adjusted to best fit the user. Finally, the base, or 'foot' is wide and flat, allowing the structure to have more security in use. It also has a rubber tread component to increase friction between the base and the stair, minimizing the risk of slipping. This design's frame will be made of aluminum, the cushion out of foam, and the tread rubber.

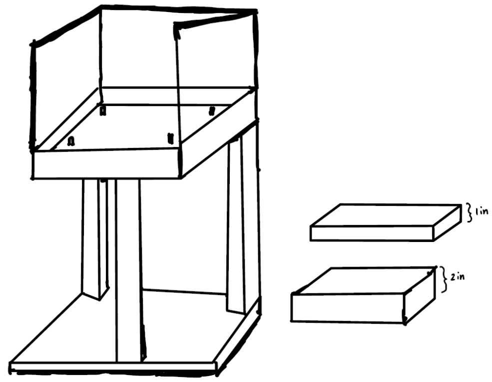


Figure 5: The Frankenstein Design

Preliminary Design Evaluation

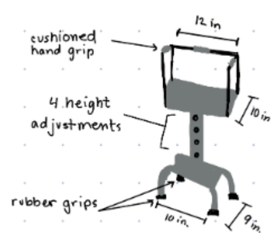
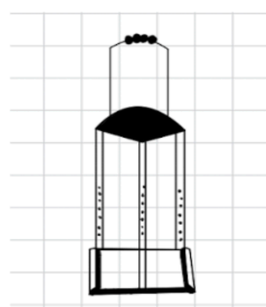
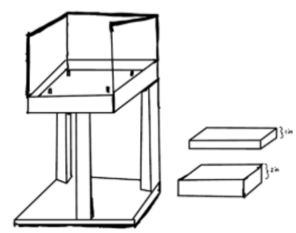
Knee Crutch Design Matrix	Wrap Around Handle		Adjustable Three Leg		The Frankenstein	
						
	Score out of 5	Weighted Score	Score out of 5	Weighted Score	Score out of 5	Weighted Score
Ease of Use (25)	4	20	4	20	5	25
Safety/Stability (25)	3	15	3	15	5	25
Weight (15)	5	15	4	12	4	12
Comfort (10)	5	10	4	8	5	10
Ease of Fabrication (15)	2	6	3	9	4	12
Cost (10)	3	6	3	6	4	8
Total (100)	72		70		92	

Table 1: Design Matrix of Competing Preliminary Designs

Criteria for Design Matrix

Ease of Use:

The "ease of use" criterion gauges the degree to which each design satisfies the needs of the patients, specifically their ability to utilize the device. This includes analyzing the different components of each design and its contribution to completing the intended task: climbing stairs with an injured lower extremity. It will consider how easily the device can be lifted from one step to another, looking at handle design and placement. It will also consider the functionality of the device, aspects like the height of handles and knee supports. This criterion was weighted higher than the rest, 25/100, because the patients are the main demographic for these devices, so having strong functionality and being easy to use needs to be a key component in all design considerations. The wrap-around handle and 3-leg designs both scored a 4 in this criterion, as they are both lightweight and easy to maneuver. However, the Frankenstein includes a much simpler adjustable component, giving it a score of 5.

Safety:

The safety of users is one of the most important considerations to be made when evaluating possible designs. Stability of the device being a key factor in safety; the base support and foot are crucial components in determining if users will be able to maintain their balance. Additionally, the handle design impacts the usability and safety of the device. These three factors were taken into account when assigning safety rankings for each respective design. Due to the high importance of the device's stability, this criteria was ranked 25/100. The wrap-around handle and 3 leg designs both scored a 3 in this category. Both of these designs include pin adjustments in the leg, which the client specified was a key source of instability in the previous prototype. The frankenstein removes this leg instability by replacing it with the stackable blocks in the knee rest. This combined with the factors from the other two designs gives it a score of 5.

Weight:

The weight component of the design involves both the total weight of the product itself, as well as the distribution of weight that factors into stability. It is important that the design is lightweight and easy to maneuver to accommodate the needs of the client's patients, most of whom are elderly. While having a lightweight design is ideal, this factor isn't as crucial as safety or ease of use, leading to the rank of 15/100. Since the wrap-around handle design only includes one leg, it scored a 5 on weight, while both 3-leg designs scored a 4.

Comfort:

The criteria for comfort assess the support and give of the device. This includes assessing if the patient's knee fits comfortably into the curved cushion on the knee support. It will also consider how large the platform is and how much cushion the support provides to the patient's knee. Additionally, it will take into account the curvature of the cushion and the placement of the handle on the device. Finally, the cushion on the handle will be analyzed to make sure the downward force on the handle will be cushioned. Comfort was weighted 10/100 because although it is a favorable feature to include, it is not as functionally relevant as ease of use, or stability. Both designs that included the wrap-around handle feature scored a 5 on comfort, as this component allows more flexibility in how the patient can use the device. The adjustable 3-leg design only included one handle in front, and as such scored a 4 for comfort.

Ease of Fabrication:

The ease of fabrication is an important factor when deciding on the final design. The design should be able to be fabricated using the resources and materials available to the team. The client has been generous with the budget for this project, so fabrication complexity can range and does among the three possible designs. However, all of the possible designs are capable of being fabricated, and therefore this criteria was given a lower weight of 15/100, compared to Ease of Use and Safety, in the design matrix. The wrap-around handle design scored a 2 in this category, as the pin system and foot component would both be quite difficult to accurately manufacture. The wrap-around handle design scored a 3, as it still includes the adjustable pin system but replaces the complex 4-leg foot with a simple base plate. The Frankenstein replaces the pin system with the stackable blocks which are significantly easier to manufacture, giving it a score of 4.

Cost:

Cost is an important factor when choosing a final design, however, it is less important than some of the other criteria given the flexibility of the teams budget. The current budget for the device is around $500, based on client feedback. Cost can be minimized by careful selection of materials, and prioritizing ease of fabrication. As a result, the cost criteria was weighted 10/100. Both of the designs including adjustable legs scored a 3 on cost, as these adjustable components require extra material to manufacture. The Frankenstein once again scored higher here, as the adjustable blocks are much more cost effective, giving it a score of 4.

Proposed Final Design:

Based on the criteria laid out in the design matrix, the clear choice for the final design is the Frankenstein. This design outperformed the other two in almost every category, and scored best in the most heavily weighted categories. The most important design choice that sets the Frankenstein apart from the others is the decision to place the adjustability component on the knee rest rather than in the legs, improving stability while still allowing the device to be used with a variety of patients.

Fabrication

Materials

In selecting materials, the team had to pay close attention to two criteria: weight and durability. The entire device must weigh less than five pounds, but its components must be able to withstand the weight of users weighing up to 250 pounds. For the base and legs of the prototype, the team intends to use extruded aluminum components. Extruded aluminum parts can be specially ordered with the necessary dimensions, and the team will also be able to purchase connector units to easily assemble the legs and base [n]. For the knee rest, the team will use PLA as the base support and for the stackable height adjustment pieces. This plastic is lightweight and durable, fitting both constraints for material selection. Additionally, the knee rest will utilize a foam padding layer to increase the comfort of the user. For the handle component, the team intends to use PVC components. PVC is lightweight, and the frame can be assembled with joint connectors. PVC can withstand high loads, making it optimal for assembly and use.

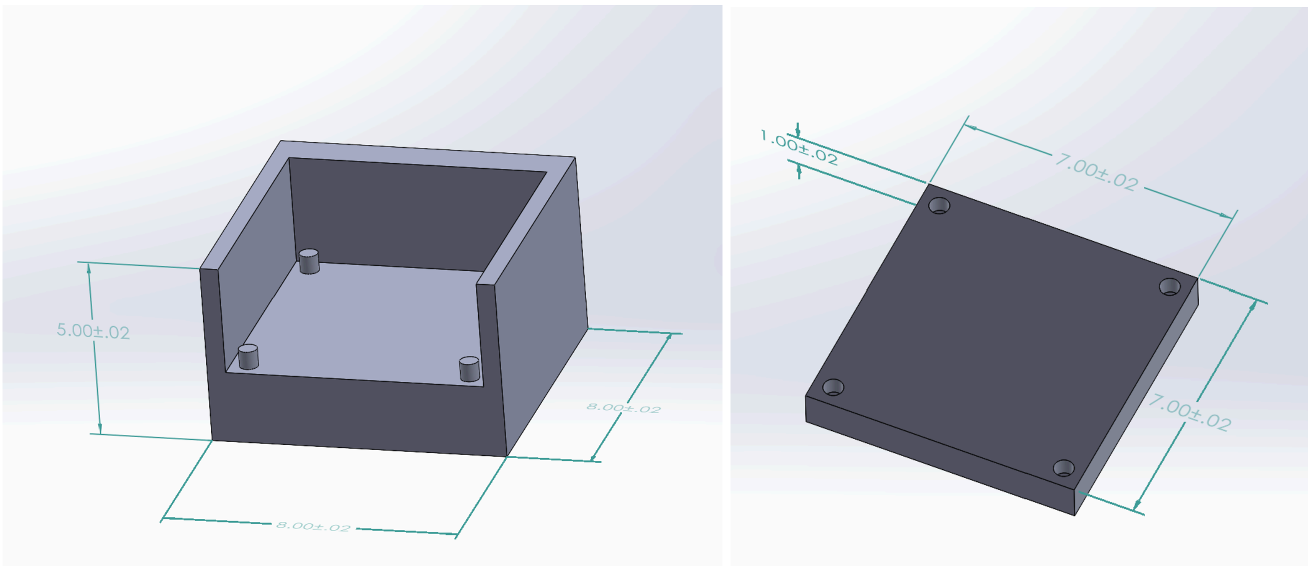


Figure 6: SolidWorks Design of Knee Rest

Methods

The team intends to approach fabrication in three sections: base support, knee rest, and handle. The fabrication of the base support will be very straightforward. After the team purchases components for the bottom and upper (below the knee rest) frames, as well as the three 'legs', the parts will be assembled using their respective connector pieces from the vendor. For the knee rest, the team will assemble a design in SolidWorks. Figure 5 above shows the design for the knee rest component, and the stackable components for height adjustment will be designed in SolidWorks as well. These designs will then be used to 3D print the prototype. For the handle component, the team will cut and assemble PVC using PVC joints. This will then be secured to the exterior walls of the knee rest.

Testing and Results

Testing

Testing for the Knee Crutch will begin after the initial fabrication of the device is completed. The testing will serve as a way to gauge the stability of the device, as well as a way to evaluate comfort and usability. It will gather stability data using force plates that can be compared to stability data from the existing prototype. With this data, the average path length can be calculated for each device, which gives a quantified value to compare the stability between the two devices. Stabilogram graphs can also serve as a clear visual representation of any differences in stability. For comfort and usability, a comprehensive survey will compile diverse and unbiased ratings for both respective categories. The team will conduct this survey with both peers and patients to best address different user needs and inputs.

<u>Testing Protocol</u>

I. *Force Plate Stability Testing*

i. Power on the force plate of intended use, open Bertec Acquire 4 Software, and zero the force plate. See Figure 6 for a visual of the power switch.

ii. Place the previous prototype in the center of the force plate and kneel on the device. Once in position, quickly start recording and collect data for 20 seconds before stopping the recording and stepping off. During the 20-second test, the test subject should try to remain balanced and in an upright position. Perform three different data collections under these conditions, exporting each data collection between trials. Export in a .csv file and select output data to be in newtons and meters. Record the test subject's weight in kilograms for later data calculations.

iii. Using the same test subject, repeat step ii with the new, improved prototype. Make sure to differentiate trial names when exporting this data.

iv. After all data is recorded and exported, log out of the software and turn off the force plates.

v. Import data trials to MATLAB to create stabiligram graphs and calculate the path length for each trial. Average the three path lengths for each device.

Figure 7: Amplifier boxes for in-ground force plates with indication of the power switch [o]

II. Comfort and Satisfaction Testing

i. Using a random and compliant test subject, have the subject use each prototype (previous and new) to go up and down at least 7 stairs.

ii. Once the test subject has had a chance to use each device, offer a comprehensive survey regarding comfort and stability ratings between the two devices.

iii. Repeat steps i and ii with different test subjects until you have 10-15 data entries to document. Make note of any general demographics of each test subject (age, gender, height, etc).

iv. Average the stability and comfort ratings for each device. Record in the corresponding data collection chart.

Results

Once testing is conducted, the results will be recorded and organized in the charts below. Additionally, from the first testing method, a stabilogram will be provided for the trial with the smallest path length for each prototype. See Appendix 3 for example MATLAB code for calculating path length and generating stabilograms.

Previous Prototype Stability Values:

Path Length (cm) Trial 1	Path Length (cm) Trial 2	Path Length (cm) Trial 3	Path Length (cm) Average

New Prototype Stability Values:

Path Length (cm) Trial 1	Path Length (cm) Trial 2	Path Length (cm) Trial 3	Path Length (cm) Average

Survey Data Collection:

Previous Prototype		New Prototype	
Average Comfort Rating (on a scale of 10)	Average Usability Rating (on a scale of 10)	Average Comfort Rating (on a scale of 10)	Average Usability Rating (on a scale of 10)

Discussion

One of the greatest issues with current assistive walking devices is the emphasis on mobility instead of stability. Devices like the iWalk and Stair Chair, while effective in assisting young, healthy individuals walk freely, don't possess the necessary stabilizing factors to aid users who lack strength and stability naturally. Additionally, because the selling point of these devices is mobility, the dimensions replicate that of an average human shin length, and operate like a stilt replacing the injured lower leg. However, the patients utilizing the team's device do not require significant mobility, and rather need stabilizing assistance in ascending and descending stairs. The dimensions necessary to provide stability must be shorter than that of an average shin length, to allow for users to lean on to the knee support as they lift their operating leg to the same step, and then maneuver the device up to the next step. Therefore, determining an appropriate depth for the device's legs was a very important consideration in designing the prototype for fabrication. The Frankenstein design has a depth of 10" from the knee support to the base. This dimension comes in well below the average knee to foot length of adult humans (15.24in for women and 16.93in for men), which will ensure ample space for users to lean down on and lift up the device [m]. This specific dimension was supported by the client, as it was confirmed a successful minimum height through patient trials. After determining the dimensions, the team identified a source for error - adjusting the weight without losing stability. This was resolved by incorporating a stacking block component that will allow taller users to utilize the device by adjusting the knee to foot length at the knee support, while maintaining sturdy, stable leg and base components.

Conclusion

Current assistive devices lack the stability and ease of use required to support patients in an older demographic navigating stairs in their home. Last semester's prototype has enough support to handle high loading forces, and supportive aspects such as the knee cushion and the handle. However, it lacks stability due to the adjustable height component in the base, and the prototype is heavy due to the incorporation of heavier materials for the handle and base, such as wood. By creating a lighter and more stable knee crutch, patients with lower limb injuries will be able to navigate stairs safely and comfortably. The improved knee crutch made with extruded aluminum provides stability due to its three-legged design. This design creates comfort for the patient through the height adjustable foam knee cushion. Additionally, the lighter materials, extruded aluminum and PVC, will make the prototype easy for patients to use and carry. These improvements in the knee crutch address the client's concerns as this design will be lighter, more stable, and have a larger range of height compatibility. Extruded aluminum is the best choice of material for this design, as it has a high weight capacity and it is lightweight due to its hollowed components. This choice of material will support the patient, but will not make the design cumbersome to carry up stairs. In order to ensure success of this model, future work for this design include developing and fabricating the base of the knee crutch using extruded aluminum, developing an AutoCAD file for 3D printing the top of the base, performing stability and loading tests and adjusting our design based on the results, and taking a survey to understand the comfort and ease of use of the product.

References

[a] Kondo, Kyoko, et al. “Factors Associated with Functional Limitation in Stair Climbing in Female Japanese Patients with Knee Osteoarthritis.” Journal of Epidemiology, vol. 16, no. 1, Dec. 2005, pp. 21–29. PubMed Central, https://doi.org/10.2188/jea.16.21.

[b] Clinical Evaluation Of A Novel Assistive Device For Safe Stair Negotiation. https://www.resna.org/sites/default/files/conference/2019/emerging_technology/Triolo.html. Accessed 2 Oct. 2025.

[c] Research Gate, https://www.researchgate.net/publication/337252945_Walking_Assistance_Using_

Crutches_A_State_of_the_Art_Review. (accessed Oct 2., 2025)

[d]“Hands Free Crutch: The Future of Mobility for Below-the-Knee Injuries,” iWALKFree. Accessed: Oct. 02, 2025. [Online]. Available: https://iwalk-free.com/

[e] ISO 13485:2016. (n.d.). ISO. Retrieved September 15, 2025, from https://www.iso.org/standard/59752.html

[f]“Wheelchairs - Part 28: Requirements and Test Methods for Stair-Climbing Devices.” Compass. https://compass.astm.org/content-access?contentCode=ISO%7CISO%207176-28%3A2012%7Cen-US. Accessed 18 Sep. 2025.

[g]ASTM Standards “Standard Test Method for Exoskeleton Use: Stairs.” Book of Standards Volume: 15.13. Developed by Subcommittee: F48.03. Accessed Sep. 18, 2025 [Online]. https://compass.astm.org/content-access?contentCode=ASTM%7CF3580-24%7Cen-US.

[h]ISO 13485:2016. (n.d.). ISO. Retrieved September 15, 2025, from https://www.iso.org/standard/59752.html

[i] Research Gate, https://www.researchgate.net/publication/337252945_Walking_Assistance_Using_

[j] iWALKFree, “Clinical Research,” *iWALKFree*. Accessed Sep. 14, 2025. [Online]. https://iwalk-free.com/clinical-research/

[k] W. B. Johnson *et al.*, “Exoskeletal solutions to enable mobility with a lower leg fracture in austere environments,” *Wearable Technologies*, vol. 4, p. e5, Feb. 28, 2023, doi: 10.1017/wtc.2022.26.

[l] “Hands Free Crutch - Crutch Alternative - Freedom Leg.” Freedom Leg Brace, 3 Sep. 2025, https://www.freedomleg.com/.

[m] Ergonomics Resources and Tools - The Ergonomics Center. 11 Mar. 2021, https://ergocenter.ncsu.edu/resources-and-tools-hub/.

[n] “Frame Connectors - Parts Library.” Vention. Accessed: Oct. 03, 2025. [Online]. Available: https://vention.io/parts-library?category=SF&sub_category=FC

[o] Wille, C. Lab 1—Force Acceleration (BME 315). Accessed: 2025, October 8, 2025. [Online]

Appendix

Appendix I: Product Design Specifications

Function:

Patients with an injury below the knee are often asked to utilize crutches or a cane when ascending and descending stairs, but when patients are unable to use these devices, there isn't an effective medium. A stair chair works for many wheelchair users, but when they are only temporarily wheelchair bound, it is not plausible to install one in their homes for a brief period of time. There are similar devices to such physical constraints on the market; however, these aids are intended for walking, not stair usage, and lack the offset height necessary to accommodate for the lack of a knee joint in use. Additionally, many are difficult to put on and remove, making stair ascension a more time consuming task than necessary [j]. The Knee Crutch is a necessary solution to this problem; it will allow users to climb stairs efficiently with a mechanically tested, stable, light, and height-adjustable frame. Additionally, it will utilize a handle component to allow ease in transferring the device to the next stair, and the knee support will be comfortable, with a length that does not encumber an area of injury.

Client requirements:

- The product's frame should be height adjustable and made of steel, with a material stability component at the foot.
- The knee rest should be concave and fitted with padding to allow comfortable, lateral support of the knee
    A. It should be a length that does not encumber the area of injury
- The product should be mechanically stress tested
- The product should be about 5 lb with a handle to allow users to move it up stairs

Design requirements:

- **Physical and Operational Characteristics**
    - *Performance requirements*

The knee crutch will be used anytime the patient ascends or descends stairs. The device is used and moved for every step the patient takes up the stairs, around 10 steps at a time. The crutch should be able to bear the full weight of a patient, over 200 pounds, for 5-15 seconds as they lift themselves to the next step.

- - *Safety*

In order to avoid exceeding a weight limit of 300 pounds, a warning label will be needed to ensure proper stability and function of the device. When testing and designing the knee crutch, regulations and quality standards from ISO 13485 must be followed to ensure the device is safe for its intended use [h].

- *Accuracy and Reliability*

This device must have a yield strength of 17 MPa +/- 2.5 MPa, as a result of a 1,334.4 newton (300 pound) axial stress test.

Additionally, as a result of the stress test, the device will maintain a factor of safety of at least 2.

The device should withstand daily use for 6-8 weeks

- *Life in Service*

The knee crutch device should be durable and ideally last for many years with numerous patients. The device is expected to be used to assist in ascending and descending fewer than ten steps at a time, and therefore should not experience significant wear and tear. However, the device should still be inspected before use to ensure the stabilizing factors of the device are operating correctly. The target life in service is 5 years.

- *Shelf Life*

The final design must be able to withstand room temperature conditions and must be able to stay in storage for the entirety of its life in service.

- *Operating Environment*

The device will be used by patients with non-weight bearing injury below the knee. Users' ages will range from 50 to 70 years old, but the device should be suitable for use by patients of all ages. The device will be used in outdoor and indoor environments and should be suitable for temperatures 0°C-40°C.

- *Ergonomics*

The height adjustability of the leg should be located in an easily accessible area for the user of heights ranging from 5'2" to 5'9". Additionally, the base of the device should incorporate a shock absorbing mechanism and significant friction to avoid slipping and ensure comfort during use. Lastly, the leg rest component should possess concavity to provide lateral support to the knee for users with varying degrees of instability.

- *Size*

The device should be slightly shorter than the shin of the patient's uninvolved leg, allowing the patient to easily maneuver it up each step. Most patients fall between the heights of 5' 2" to 5' 9", so the device should be adjustable enough to cover this range. The handle of the device should correspond with anthropometric ratios so that the patient can grasp and position it without discomfort.

- *Weight*

The product's weight should be slightly lighter than the current prototype, similar to the weight of the competitors. The device should weigh approximately five pounds.

- *Materials*

The device needs to be sturdy enough to support patients over 200 pounds. Aluminum will be used for the leg and foot of the device. The foot should include a soft or rubber-like base in order to provide some give to keep the device stable on uneven surfaces.

- *Aesthetics, Appearance, and Finish*

The device will have a relatively simple design, similar to a small chair. The main components will be the single leg and large foot, the brace for the knee to be placed, and the handle for the patient to move the crutch up and down. The area for the knee to be placed should be slightly concave to provide lateral support to the knee. The foot should be small enough to comfortably fit on a standard stair tread- about 10”.

- **Production Characteristics**
  - *Quantity*

The developed knee crutch should be adjustable, so only one prototype will be required. This product should also have the ability to be quickly produced as the client will require one per patient.

- *Target Product Cost*

A competing design called the iWalk [j] retails for around $179 dollars. Our product will be similarly priced. Our target product cost range will be $100-$150.

- **Miscellaneous**
  - *Standards and Specifications*
    - Must meet ISO 7176-24:2004 [f]
    - Must meet ASTM F3580-24 [g]
  - *Customer*
    - Knee Crutch is intended for individuals with lower limb injuries who need to briefly be able to go up and down a small set of stairs.
  - *Patient-related concerns*
    - Device must be stable and not heavy
    - Device must be able to be moved with arms
    - Patient must be able to kneel on the device
  - *Competition*
    - iWalk Hands Free Crutch [j]
    - Stair Chair
    - Freedom Leg [l]

<u>Appendix II: Materials Expense Sheet</u>

Item	Description	Manufac-turer	Date	#	Cost Each	Total	Link
HDP	3D printing material for knee support	Makerspace	Have not purchased	N/A	N/A	$0.00	N/A
Extruded Aluminum	Material for legs and knee support frame		Have not purchased		N/A	$0.00	
Memory foam cushion	Material for knee to rest directly on		Have not purchased		N/A	$0.00	
Rubber base	Material for non-slip bottom base		Have not purchased				
					TOTAL:	**$0.00**	

<u>Appendix III: Example MatLab Code For Force Plate Analysis</u>

```
Generate stabilogram:

figure;

plot(cop1_xso2,cop1_yso2);

title('Stabilogram Two Feet, Eyes Open');

xlabel('Medio-Lateral (m)');

ylabel('Anterior-Posterior (m)');

axis equal;

Calculate path length:

dcpxso1=diff(cop1_xso1(~isnan(cop1_xso1)));

dcpyso1=diff(cop1_yso1(~isnan(cop1_yso1)));

distanceso1 = sqrt(dcpxso1.^2 + dcpyso1.^2)

plso1 = sum(distanceso1)
```