Walker 2.0

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In collaboration with Dennis Chan and Professor Grace O'Connell

I. Introduction

For many senior citizens as well as patients with lower extremity injuries or amputations, walkers are recommended to provide additional stability and balance. This improves mobility by increasing their base of support and supporting their weight for use in various environments.

Standard walkers possess a drab gray frame, about waist high and semi-adjustable, with or without wheels on the front two legs, depending on the strength of the user. Seeing as many users are lower-strength individuals and are older in age, there is a stigma around using a walker for those that may not fit this demographic. The issue with this is that those discouraged from using a walker turn to less stable alternatives such as canes and crutches, which leads to falling, further injury, and slipping in unideal terrains.

In order to encourage those that require a high level of stability to use walkers for assistance with daily activities, the standard walker should be redesigned with a more of a human-centered focus, for which we propose various aesthetic and functional improvements. Four main changes that make it more appealing to potential users include (1) an easily adjustable handle that minimizes wrist joint loading, (2) a futuristic Z-shaped frame that furthers stability, (3) aesthetic, customizable, and colorful magnetic supports on the inner top and bottom of the frame, and (4) larger wheels, allowing for use of the walker in a greater variety of environments. The proposed walker design revolutionizes the stigma surrounding current walkers while enhancing ergonomics, driving mobility with a sense of exploration, and promoting customizability with confidence.

II. Background

Biomechanics

In using a walker, users put a majority of the load on their upper extremities, most specifically the shoulder, elbow, wrist, and hand joints, with some degree of loading on the hip joint of the lower extremities. Each respective joint has articular cartilage that prevents the bones from rubbing together upon movement using the walker. Cartilage tissue in the elbow joint is especially thin, and the highest torque is at the elbow, so degradation of this cartilage is common in those using assistive walking devices such as walkers and crutches, leading to eventual elbow pain.

Bones of interest include the carpals, metacarpals, and phalanges in the hand and wrist, which experience most of the loading contact with the walker. Additional bones of interest include the radius and ulna bones in the forearm and the humerus in the shoulder, making up the elbow [2]. In transforming from stance to swing, joint loading varies based on angle deviations in the aforementioned parts of the body. Studies have found compressive forces to be greatest at the wrist joint and then decreasing proximally. When holding the walker, the hand is in direct contact with the handles and therefore experiences normal force from the walker. Experimenting with a softer handle material can lessen hand strain by allowing for increased points of contact between the hand and walker handles and distributing the normal force more evenly throughout the hand.

Because upper extremity joints are designed for mobility rather than bearing heavy loads, using assisted walking device frequently and for long periods of time, especially those on the upwards of 10 or more pounds, causes many users to experience wrist, shoulder, and especially elbow pain. This occurs because over time and especially for older walker users, cartilage in the joints degrades and causes the bones to in fact rub against each other, promoting irritation and most commonly carpal tunnel syndrome due to constant hand strain. Finally, patients that move with assistive walking devices often experience larger angular displacement in the hip joint which can lead to the development of osteoarthritis in the hip as other upper extremity joints [3].

Estimated Joint/Tissue Loading

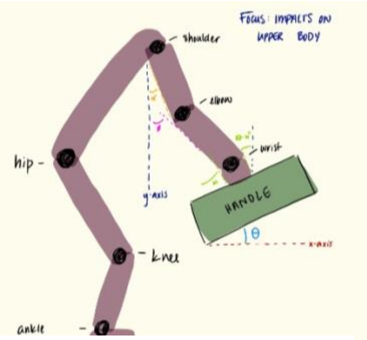

Figure 1. *Diagram of the major joints involved in using a walker.*

Using a walker essentially distributes forces that would originally be placed on the legs (and therefore the ankle, knee and hip joints), and places them onto the upper body (adding loads to the shoulder, elbow and wrist joints). Because one's full body weight changes from being loaded on two appendages to four, the force on the legs is reduced by 50% while the arms take on the rest. More accurately, post-surgical walker users place about 26% BW on their non-surgical side and 20% BW on their surgical side, a total of 46% BW placed on the upper extremities [1].

To simplify, we analyze a single arm supporting approximately 25% body weight. We assumes that the force experienced are continuous from the shoulder to the elbow, and that no external force increases or decreases that load. We consider the weight difference from the shoulder to the wrist as negligible. Following this, if an average male (expected to experience the highest joint forces) weighs 89kg [4], then each joint should be withstand approximately 872 newtons of force.

To continue, we largely simplify the upper human body to a set of beams and pin joints, treating the connection of the hand to the walker handle as a wall, as seen in Figures 1 and 2. In Figure 2, we further simplify this image to show that when the walker user bends their arm to support themselves, such as when they slightly flex their arms and bend the wrist to achieve a proper stance, the reaction force that supports the body weight migrates from being entirely internal (where the bone acts as supportive column) to requiring a sum of external forces to maintain the position of the join. In addition, Figure 2 highlights that the application of weight coming from the shoulders creates a moment on the bent elbow and wrist joints, and that the larger the bend, the larger the moment becomes.

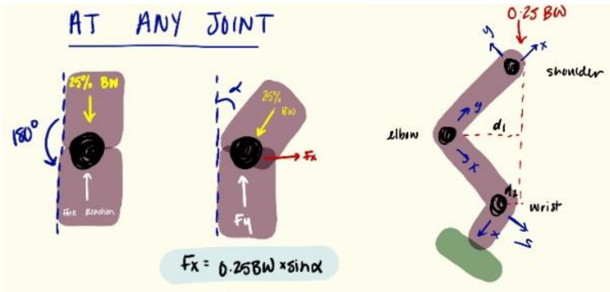

Figure 2. *(Left) The balance between internalized forces and external forces and (Right) the effects of angles in the creation of moment.*

For proper usage, a walker is recommended to be used with a 15-30˚ angle of flexion in the elbow, which would roughly translate to about 50% of the stabilizing force coming from muscles, tendons, and ligaments that support the joint. Because the wrist is radially bent when gripping the walker, it is more prone to damage if the angle of bend is higher. Too much force is required of the wrist ligaments if it must support the 25% BW at an angle. Therefore, it is vital to design the walker handles at a downward angle of 15-30 degrees to compensate the 15-30˚ bend of the elbow and ensure that the wrist acts as a rigid column.

III. Brainstorming

Our client, Dennis, has limited lower leg mobility and uses redesigned crutches that are more aesthetically pleasing than the standard crutches. Inspired by his Crutches 2.0, Dennis wanted our group to redesign the standard walker and create a Walker 2.0 that is more aesthetically pleasing and would encourage more users to opt for a walker instead of less stable forms of walking aids, such as canes or crutches. In addition to talking with Dennis, we also interviewed a walker user, Art Poskanzer, from the Osher Lifelong Learning Institute at UC Berkeley to better understand how we could improve the standard walker. Art wanted to see a redesigned walker that was foldable, lighter, adjustable in height, and contained a better wheel design to be able to navigate different environments. He did not emphasize the need to improve the aesthetics of the standard walker but focused more on improving its functionality.

After talking with our client and a walker user, each team member worked individually to brainstorm as many different Walker 2.0 ideas that would balance both aesthetics and function. Our group also used design heuristics cards to help generate more unique designs and think about how the design of other products, such as modern furniture and existing walkers, could be incorporated into a novel Walker 2.0 design. Each team member then shared their design ideas with the group. Using sticky notes, our group then grouped similar design ideas into categories. The top brainstorm ideas were then identified by ranking the brainstorm ideas using a PUGH chart.

Our group selected the following criteria for the PUGH chart: aesthetics, function, stability, ease of use, and ease of manufacturing. The first and most important criterion was aesthetics. Our client wanted us to focus on the aesthetics for our Walker 2.0 and design an aesthetically pleasing walker that would appeal to wider range of users. As it was the main requirement that the client requested, aesthetics was weighted the heaviest with 40 percent. The second criterion was function, which was weighted at 30 percent. After talking with a walker user, it was evident that we needed to improve the functionality of the walker. The next weighted category was stability, with a weight of 15 percent. Since walkers are considered the most stable form of walking aid available, our Walker 2.0's design also needed to be just as stable as the standard walker. The next criterion we considered was ease of use, which was weighted at 10 percent. To better adapt to a wide range of users, our group wanted a design that would be simple for a user to be able to use. Our last criterion was ease of manufacturing, which was weighted at 5 percent. Given our limited budget, resources, and time, we needed to choose a Walker 2.0 design that we were capable of creating a prototype within the given timeline.

One of the top ideas was a Walker 2.0 with a "Z-shape" and truss design. The "Z-shape" silhouette design looked much more aesthetically pleasing and provided a minimalistic modern look that would appeal to a wider range of users. The truss designs at the corners of the "Z-shape" further added an aesthetically pleasing and modern look to the Walker 2.0.

Another one of the top ideas was incorporating larger wheels into our Walker 2.0. Some noteworthy feedback we obtained from the walker user was that the wheels on his walker were too small to be able to easily navigate different environments. To better improve the function and allow users to navigate more environments, larger wheels provided a simple and economical method to be able to accomplish this. The larger wheels also complimented the sleek and minimalistic "Z-shape" design, further improving the aesthetics.

Our third top idea was an adjustable oval handle angled at 15 degrees. A major issue with the standard walker is that it encourages the user to maintain a hunched posture. An adjustable handle would help to ensure that the height of the walker could be customizable to the user's height and better position the handle to a comfortable position for the user. We also determined that if the handle was angled at 15 degrees, it would help the user to better maintain an upright position. In addition, the oval shape of the handle complimented the modern "Z-shape" design and improved the overall aesthetic.

These top three design ideas were incorporated into the Walker 2.0 design. The three design ideas help to improve the aesthetics of the walker and the walker's functionality, providing a balance between aesthetics and function.

IV. Prototyping

Low Fidelity

For simplicity purposes and cost effectiveness, we scaled down our low-fidelity prototype and 3D printed our Walker 2.0 design. This, however, did constrain us by limiting our ability to test the design between our user and the environment. For testing purposes, we performed finite element analysis, which allowed us to predict the behavior of our design by physical effects. Although this was just a simulation, we

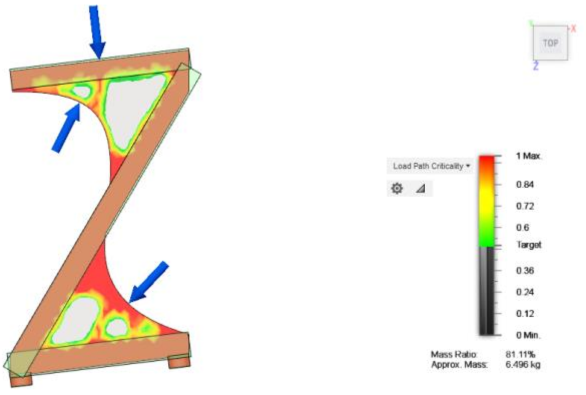

Figure 3. *The topology optimization result of low fidelity model. The blue arrows represent forces applied and the red, yellow and green color represent necessary segments for the model to bear the same load. The study had a target mass of 60% the original mass.*

Figure 4. *(Left) Low fidelity 3D printed model showing front loaded behavior. (Right) CAD model from two different views.*

proved that the "Z" Shape design was not strong enough to support itself and that trusses were necessary to be able to support the structure of the walker. This allowed us to optimize our design around mechanical stress and strain limiting-parameters.

Additionally, we noticed that our Walker 2.0's center of mass was shifted towards the upper-front of our design. Ideally, our center of mass, for stability and mobility purposes, should be located closer to the ground and centered between the front and back of the walker. This shift in center of mass induced a problem that forced our design to be top heavy, allowing it to easily tip forward. With this understanding we needed to put steps in place to implement a design that would shift the center of mass to a more optimal location. Figure 4 depicts the direction in which the walker design tips.

High Fidelity Prototype

The purpose of the high-fidelity prototype was to construct a full-scale Walker 2.0 that incorporated similar elements to what could ultimately be mass produced and commercialized. This includes interchangeable parts, such as supportive trusses of various designs, wheels, and handles. Without access to manufacturing equipment, it was challenging to replicate something completely sturdy. The overall assembly was intended to mimic what could potentially be manufactured.

In order to build this prototype, it was necessary to configure methods beyond 3D printing, as was done with the low fidelity prototype. While 3D printing was practical to visualize the weight distribution and aesthetics of the designed Walker 2.0, it would be inefficient and not mass-producible to print a full-scale walker. Instead, this new prototype switched from printed plastic to aluminum pipes, assembled with PVC pipe connectors.

The largest advantage to creating a structure from metal was its strength. Considering the angled Z shape of the walker, and the large expected forces on it, plastic PVC pipes bent severely when tested. Surprisingly enough, the purchased metal pipes were also lighter than PVC pipes of smaller size, solely because of the metal's ability to remain rigid despite a thin circumference.

If pipe-bending equipment had been available, each half of the walker would have been made from one continuous metal pipe. However, for ease of manual assembly the metal pipes were joined by plastic PVC connectors. To create the desired Z shape, an elbow connector (90 degrees) was coupled with the commercially available 22.5 degree joint, using PVC glue and interlocking PVC pipes. About 6 inches of PVC pipes, covered with duct tape for a snug fit, extended from the joints into the metal structure to offer additional support. While these were ultimately still the weakest points of the walker due to the forced choice in material, this could easily be rectified with the ability to manufacture a completely metal prototype.

For the carriage, which connected the two metal halves of the walker, we designed it using Fusion 360 and exported the file using Slicer for Fusion 360 to be laser cut and assembled. Following the results seen in the low fidelity prototype, the front overhang was made much smaller and lighter,

Figure 5. *(top) Fusion CAD of the high-fidelity, looks like prototype. (bottom) Physical model of the high-fidelity prototype.*

as to avoid the front-loaded effects witnessed in the low-fidelity 3D print. With the tolerance of the cut parts, the carriage was fitted into the pipes snugly enough to remain stable. The carriage was also spray-painted black for aesthetics, and to illustrate the potential variability in colors.

The wheels were selected to be 8 inches, black, and also connected to the frame by a bolt in a PVC connector. The large wheel diameter promoted easier handling of uneven surfaces, while maintaining the client's desire for aesthetics.

The handles were designed on Fusion 360 and 3D printed. They easily fit into the frame using elbow shaped PVC connectors, illustrating the interchangeable design for variable user heights and needs. The ones in the existing high-fidelity prototype are sloped downward at 15 degrees to accommodate for the clinically recommended use of a walker with arms bent 15-30˚ for support.

Finally, the aesthetic trusses were laser cut from wood, spray painted for aesthetics, and

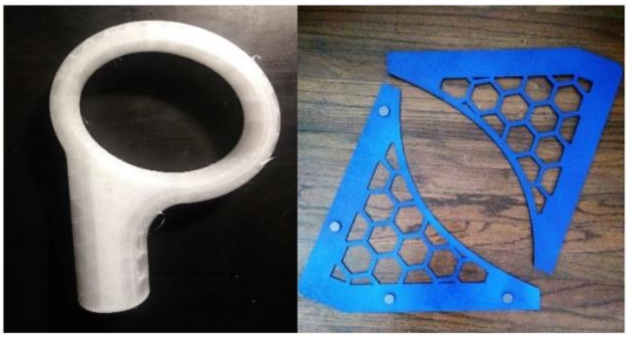

Figure 6. *(left) 3D print of the handle (right) sample laser cut trusses, spray painted blue and attached with magnets*

temporarily attached to the frame using magnets. While we opted for a hexagonal pattern for the built prototype, this could easily be customized for each individual user based on their style preferences.

Ultimately, this high-fidelity prototype allowed users to put mild amounts of weight on the Walker 2.0 and visualize how a user would walk around with it. In addition, this combination of a "looks like" and "works like" prototype allows for the easy interchanging of parts to demonstrate how a customer can customize parts for their walker, and encourage its use. On a production scale, customers could choose the colors of each part of their walker, the heights and angles of the handles, the types of wheels, and even the design on their trusses.

V. Results

Assessment

Looking deeper into the design after assembly and user testing, there are some potential weakness with this design. As you roll forward and backward, the front wheels will tend to bow inwards and outwards. Overall, this issue causes stresses on the lower frame and needs to be further stabilized before commercialization. This is evident in figure 7. Furthermore, the material used in this walker design, the combination of metal rods and PVC connectors with wooden truss supports, does not allow for distribution of the full 50% of the user's body weight. Future work will be dedicated to constructing the walker out of a more stable yet lightweight material that can be better molded to the user's frame, such as heat-bent metal. In addition, the overall walker weight is slightly heavier than existing models. Finally, in order to design for an

Figure 7. *(left) Testing the high-fidelity prototype on rocks. (right) Attachment to prevent wheels from moving out of place.*

even greater variety of terrains, the wheel diameter can be increased further than 8 inches.

Most of these problems are easily resolvable with manufacturing, however. First, using a completely metal walker reduces the weakness of the plastic joints. Creating these joints required extensive additional material which added large amounts of weight. While the trusses will add heftiness, since existing walkers do not have these inner supports, they are beneficial in that their aesthetic and customizable aspects are likely to catch the eye of the target consumers and greater expand our walker market. Also, the addition of wheels, along with their potential improvement, lessens the effects of walker weight on the user while increasing the device's usability. Finally, a manufactured walker would likely have a front carriage that is welded or screwed in place, rather than press fit. This would help prevent rotation of the wheels inward while using the walker.

Similar existing products (Figure 8) are currently on the market. While some address function and others focus on aesthetics with alternative futuristic designs, they all still address the same goal of increasing mobility and stability while walking. A commonly used surgical walker is shown in Figure 8, in the first image on the far left. This walker serves the purpose of functionality, but does not address aesthetics. In the images to the right, you can clearly see that some designs have the potential to address both aesthetics and functionality, similar to ours.

Compared to the designs above, we used front wheels similar in diameter to the middle design to permit the ability to traverse multiple

Figure 8. *Existing walker and walker prototypes.*

terrains, maintaining our aesthetic Z-shaped frame. Some designs, like the middle and right ones, have bigger front wheels compared to the back; some also utilize stoppers in the back, just as ours does. This was a conscious choice to prevent the need for brakes in the walker system, as well as to prevent users with different strength levels from slipping while using their walkers.

In more futuristic designs, we observed that users tend to walk by stepping in front of the walker rather than behind it, making the walker less of a burden to use to complete daily activities. In focusing on ergonomics, we also incorporated this principle by optimizing the angle of the walker handles and making the walker height easily adjustable and customizable, improving posture and lessening strain on the joints. Both aesthetically and ergonomically, our design is more practical, stable, and easy to manufacture.

Client review

In our fourth and final meeting with Dennis Chan, he was happy with the improvements we had made. He previously asked for more of a futuristic frame design, in addition to more appealing colors and more means of customizability. We took this advice and created a more defined Z shape for the frame, spray painted and laser cut magnetic supports, and made the handles both adjustable and customizable in color and wrist angle, which he agreed satisfied his expectations for the high-fidelity prototype. He agreed with us in that once we obtain access to a metal bender and make the frame more stable, it is up to the end users—lower extremity amputees, paraplegics, and the elderly—to decide whether it appeals to them and convinces them to use a walker instead of a cane or crutches, just as his "Crutches 2.0" did for him.

VI. Acknowledgements

We would like to thank Dennis Chan for his valuable resources and contributions to the class, along with Professor O'Connell for her help. We would also like to thank Susan Hoffmann and Christina Carr from the Osher Lifelong Learning Institute for putting us in contact with walker users and Art Poskanzer for allowing us to interview him.

VII. References

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VIII. Appendix

Camille assisted the group design process, including brainstorming, and built the high-fidelity prototype. This includes cutting the pipes, assembling the carriage, and spray painting and gluing various parts. She wrote the high-fidelity prototype section of the paper, in addition to the joint analysis portion of the biomechanics. In addition, Camille led the third and fourth meetings with project partner Dennis Chan.

Greg participated in group design process, brainstorming, and laser cut the designs with Jonathan and 3D printed the handles. Additionally, Greg wrote the assess section and made the poster with Kyelo.

Kyelo participated in the group design process, brainstorming and was mainly responsible for the CADs of the project. This includes the stress analysis and topology optimization involved in the low fidelity prototype. In addition, this includes the CAD renderings for the high fidelity prototype and the lasercut files for the connector piece.

Jonathan helped the group in the design process, including brainstorming and laser cutting parts and assembly, helped with contacting the Osher Lifelong Learning Institute, managed the group's finances and purchases, and wrote the brainstorming section of the paper.

Yasmine assisted the group in the design process, including brainstorming and prototype design and assembly, was the point of contact for user interviews with the Osher Lifelong Learning Institute, and wrote the introduction and biomechanics sections in addition to assisting with the design assessment section of the paper.