BACKGROUND

Current prosthetics pose several problems for children including weight, comfort, durability, and fit. Most importantly, they do not grow with the child as the healthy leg grows. This causes families to have to replace the prosthetics approximately every two years [1]. With below knee prosthetics costing ranging from approximately $6,400 to well over $46,000, continually replacing prosthetics becomes a financially stressful task for the average family [2]. Creating an adjustable prosthetic will address the need of having to replace prosthetics as well as provide the opportunity to analyze other problems. A lightweight prosthetic with a socket that properly fits the child’s stump will be critical to improving the comfort and minimizing the amount of the socket wounds the child will experience. Not compromising functionality and durability for cost will be crucial in creating a realistic prosthetic that will not only withstand, but also assist a child in their daily activities of playing, running, walking, and standing. The goal of this project is to redesign a child’s physical independence while satisfying the ultimate prosthetic function of replacing an unhealthy tibia to the highest accuracy possible. In order to classify a child’s leg size, the ASTM D6488–12 size standards were used. Child weights were chosen to be ASTM size 8 through 20 (Table 1). All testing was done in comparison to these sizes [3]. Functional comparison was made in accordance with the US Health Care Financing Administration MFCL system [4].

OBJECTIVES

The prototype goals were:
1. To create a prosthetic which will fit ASTM sizes 8 through 20
2. To design a K4-Level 7 functioning prosthetic [4]
3. To be cost effective
4. To reduce all socket shear stress to under 0.58 psi

The prototype was designed and tested using Solidworks CAD software. The prototype socket was 3D printed from a Stratasys Solidworks CAD software. The prototype was designed and tested using a Connex 500 printer while the prototype was manufactured using aluminum.

PROTOTYPE SOCKET

The socket attaches to the stump through four methods:
1. Two supports run up the medial and lateral sides of the tibia, knee, and femur connecting the socket to a strap that goes around the femur
2. Two bladders are then wrapped around the stump prior to putting it inside the socket (Figure 1, 4).
3. The stump is connected to a piece of Velcro inside the socket (Figure 2)
4. A strap is then wrapped around the socket just below the knee (Figure 3)

In having several contact points throughout the stump, knee, and femur, it theorized the socket will move more directly with the femur and tibia bone. This will then minimize the shear stress induced on the stump further reducing the skin damage caused by a prosthetic.

The lateral and medial supports of the socket are locked at a 90 degree, to the socket, simulating a true extension of an anaptee’s tibia allowing the bottom of the stump to be loaded directly on the bottom of the socket, which has 1 inch of high density memory foam as well as a 0.25 inch gel loading pad to minimize load impact from jumping or running. The rest of the socket is lined with 0.25 inches of slow recovery polyurethane foam and 0.125 inches of polyester-PVC foam mesh covered with a fabric lining helping reduce possible shear stress.

The socket is adjustable at four locations (Figure 3, 4):
1. The bladder has two easily accessible pumps and release values allowing for fine adjustment inside the socket
2. Two straps, each on the tibia and femur, can adjust to custom girth
3. Interchangeable backboard supports can adjust to custom height
4. The two lateral and medial supports can adjust laterally 2 inches

The prototype is able to successfully adjust between ASTM sizes 4 through 18 through 9 slot options (A, B, C, D, E, F, G, H, I). It easily supports the predicted max jumping forces, which were modeled as:

\[
F = 3.0 \times (\text{maximum body weight of ASTM size})
\]

During FEA, the highest Von Mises stress the prototype experienced was just under 4,300 psi, which is much smaller than aluminum’s yield strength of approximately 35,000 psi. During FEA, the highest Von Mises stress the prototype experienced was just under 4,300 psi, which is much smaller than aluminum’s yield strength of approximately 35,000 psi (Table 2).

The next step for the project is to work towards quantitatively satisfying Objective 4. This will be done by approximating the shear stress in various areas of the socket through experimental trials and finite element analysis in order to eliminate possible high pressure points leading to skin tissue damage. Additionally, conducting user surveys in regards to comfort including breathability, weight, and aesthetics. Lastly, the entire prosthesis’s induced gait will be analyzed.

CONCLUSION

Overall, the prototype itself can comfortably fit ASTM sizes 6 through 18. The pylon can adjust to fit ASTM sizes 4 through 18. Together, the prosthesis can fit ASTM sizes 6 through 18, almost satisfying Objective 1. The prosthesis can easily withstand the appropriate size and adjust to fit the child making it satisfying Objective 2. The entire prototype cost under $500 for materials and manufacturing, satisfying Objective 3. Lastly, the entire prototype weighs under 2 kg, without the foot.

FURTHER WORK

REFERENCES


ACKNOWLEDGMENTS

Rhonda Beck, Paul Tompkins, James Howard, Student Research Grants, Professor R. Bucinell, Professor J. Currey, Professor A. Rapoff, Professor J. Rieffel, Professor G. Sanders, Orthotics & Prosthetics Lab, Kristen and Shelly Shinebarger, Joshua Fields '15, Carson Miller '15, Kadeam Vendryes '15, Kate Sgroi, Lindsey Sullivan.