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Title
Modular ankle- 3D printed custom feet prosthesis system to improve footwear options for persons with lower-limb amputations.

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Summary
A modular ankle-3D printed feet system was designed to improve footwear options for persons with lower limb amputations. Shoe-specific 3D printed feet can easily be attached/removed from the compact ankle unit. Improving footwear options may lead to improved body image and participation for users.

Introduction/ basics
Recent surveys of over 300 persons with lower-limb amputations have shown that ability to participate and satisfaction with participation are associated with amputee-specific body image. Those with poor body image tend to participate less and be less satisfied with their participation in important life activities.
Access to a variety of footwear options contributes to body image but prosthesis users are limited by current prosthetic feet. Changes in shoe heel height alter the alignment of the prosthesis, causing instability and possible injury to the user. Although some heel-height adjustable systems exist, they accommodate only a limited range of heel heights and their physical geometries do not adapt to the shapes of various footwear.
The goal of this work was to develop a system that would broaden access to footwear of different heel heights with customized 3D printed feet to match shoe geometries, while not requiring user adjustment of the prosthesis for different shoes.

Material method; implementation/ process
Our primary design concept includes use of a single prosthetic ankle that remains connected to the prosthesis, and that can interface with different 3D printed prosthetic feet customized to fit a

variety of footwear (Figure 1). This concept allows the user to switch between shoes of different heel heights and shapes without requiring any changes in prosthesis alignment.

The requirements of this system included:

• Provide realistic shapes of prosthetic feet over a wide range of sizes, heel heights, and widths using parametric design and 3D printing technologies.

• The ankle must be designed to fit within the smallest desired foot length in heel heights ranging from 0 to 10 cm.

• The ankle must operate in a biomimetic fashion during walking, providing natural plantarflexion and dorsiflexion during roll-over.

• The system must allow simple and quick connection to different feet without requiring the use of tools.

• Ankle designed to withstand walking loads without feet.

Results

To address the requirements of the design, we created a parametric digital foot model (Figure 2) that scales foot geometry based on desired foot length and shoe heel height. The digital foot model was created using parametric design software allowing the automatic creation of foot models over a continuous range of foot lengths, widths, and shoe heel heights. Scans of human foot models were also used to refine the digital foot model, improving the aesthetics of the resulting feet.

Thanks to the development of an APP, the user will be able to take the information required in the simplest way possible. With a few measurements the the user will select the preferred options and the information needed to create the 3D printed custom feet.

Additive manufacturing (3D printing) was used to fabricate shoe-specific prosthetic feet using data from the digital foot model. Feet can be further customized with different designs and colors to uniquely express personal body image preferences (Figure 3).

To allow use with a wide variety of feet, a compact ankle was designed and fabricated. The ankle utilizes a wiper mechanism coupled with an outer shell (Figure 4). Bumpers allow biomimetic plantarflexion and dorsiflexion under normal walking loads. The ankle outer shell

was designed to support body loads without a prosthetic foot as a safety feature. The outer shell is also designed to intimately fit within the 3D printed custom feet (Figure 5).

Discussion/ conclusion; conclusion for the practice

The ankle- 3D printed custom feet system developed allows the geometry of feet to closely match specific footwear, which should improve coupling of the foot-shoe system. Designing each 3D-printed foot to match the shoe simplifies the process of changing shoes for prosthesis users by removing the need to realign for each shoe. Lastly, incorporating the biomechanics of the system into the compact ankle design supports biomimetic walking function for a wide variety of foot-shoe systems.

The ankle- 3D printed custom feet system presented may dramatically improve footwear options for persons with lower-limb amputations. This improved access to different footwear of choice may improve each individual's body image, supporting self-expression. Improving body image may lead to increased ability to participate and satisfaction with participation in important life activities, leading to improved health and quality of life.

References

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Image: Figure.1_138.jpg

Figure 1. Example of the system

Image: Figure.2_139.jpg

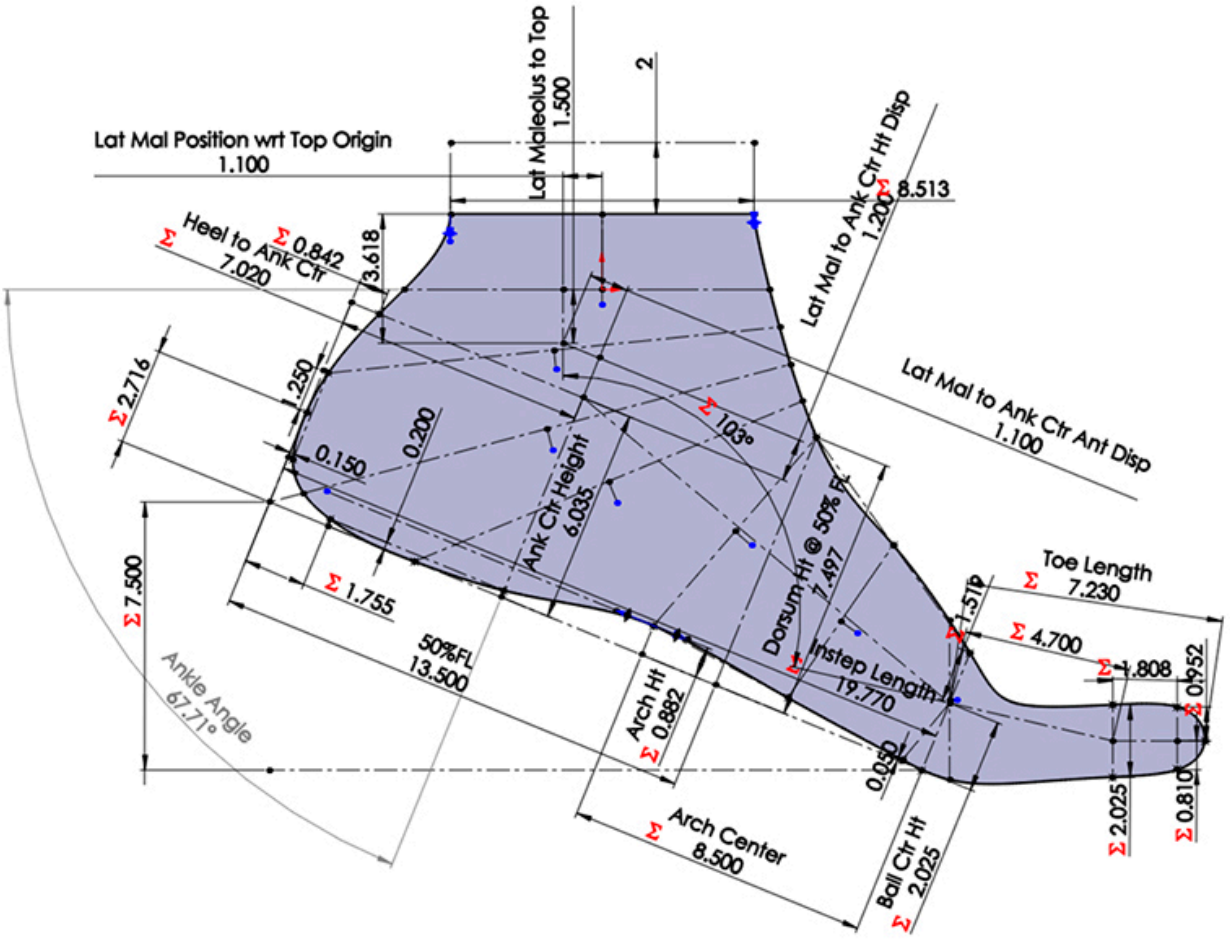

Figure 2. Parametrized digital foot model

Image: Figure.3_140.png

Figure 3. Prototype of the 3D custom parametric foot

Image: Figure.4_141.jpg

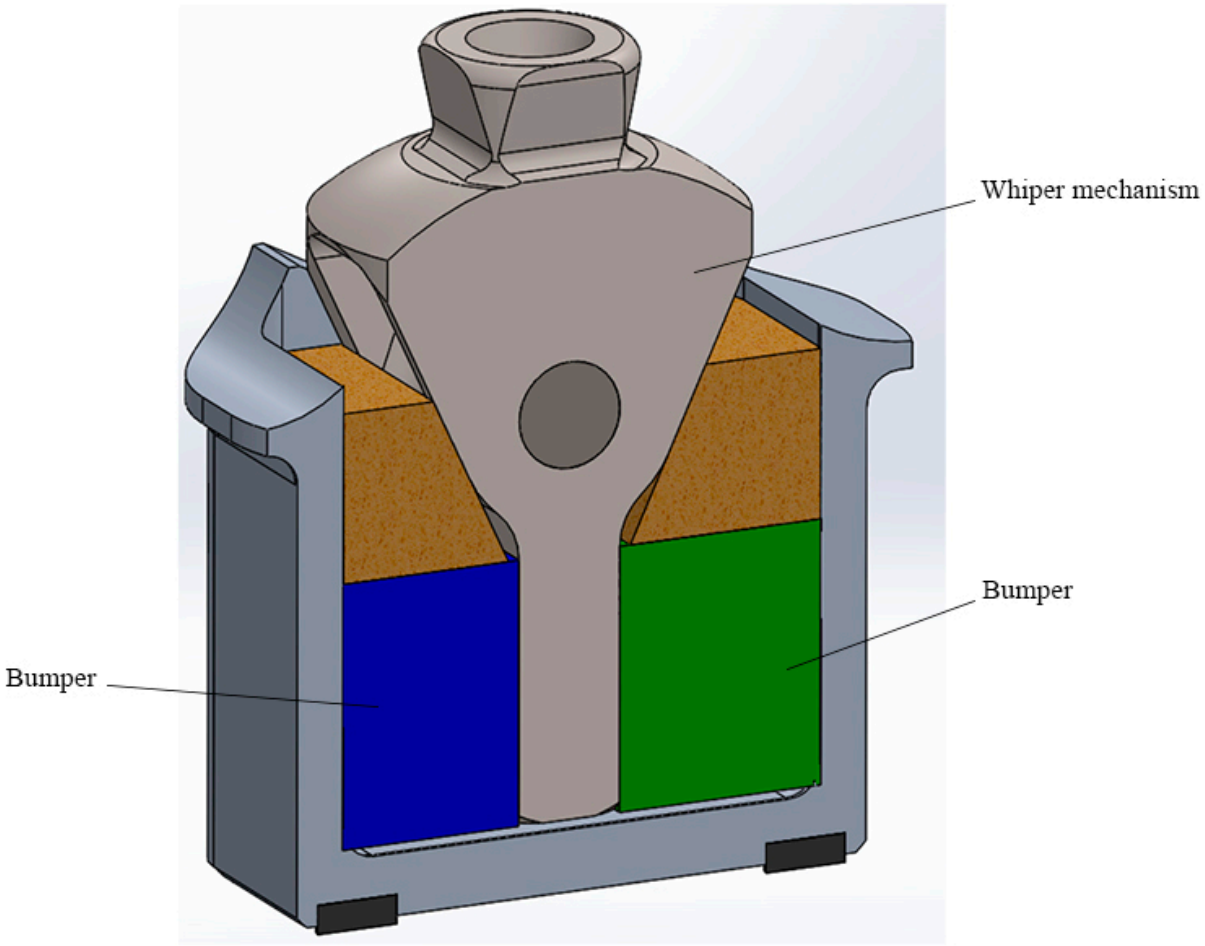

Figure 4. Compact dynamic ankle

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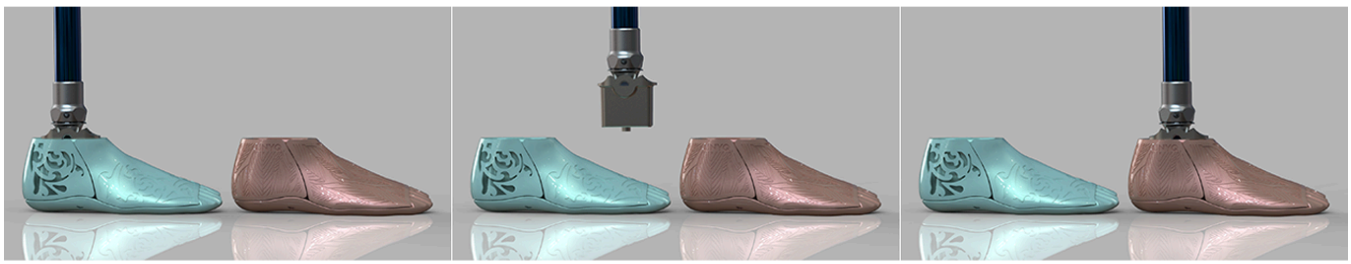

Figure 5. Render of ankle-3D printed custom foot