MIT Media Lab | BioMechatronics Group

VIPr Socket: 3-D Printing of Prosthetic Sockets for Below-Knee Amputees

David Sengeh and Hugh Herr

Could we use digital anatomical data to make comfortable, wearable, mechanical interfaces for amputees?

INTRODUCTION

Today, 100 percent of amputees experience some form of prosthetic socket discomfort. Comfort relies on the residual limb's fit in the prosthetic socket. Friction and high contact pressures between the socket and skin result in sores, infection and broader health concerns. Unfortunately, conventional socket design and production relies on limited data from the residual limb. Furthermore, sockets designed are often comprised of a single, stiff material, unlike the residual limb. This project evaluates the design of a Variable Impedance Prosthetic (VIPr) Socket for a below-knee amputee using computer aided design and manufacturing (CAD/CAM).

METHODOLOGY

1) Acquire anatomical data of residual limb:

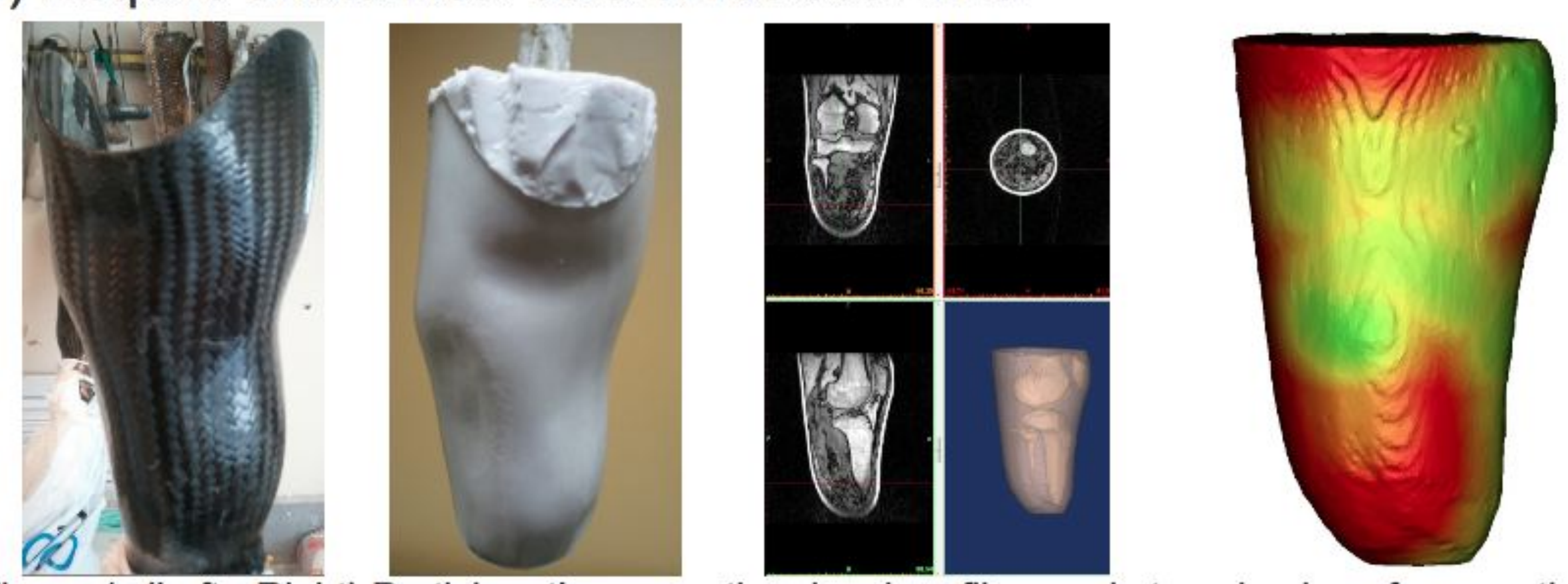

Figure 1: (Left - Right) Participant's conventional carbon fiber socket, male plug of conventional socket, MRI capture of residual limb, soft tissue density of residual limb.

2) Map residual limb stiffness to socket material stiffness and CAD:

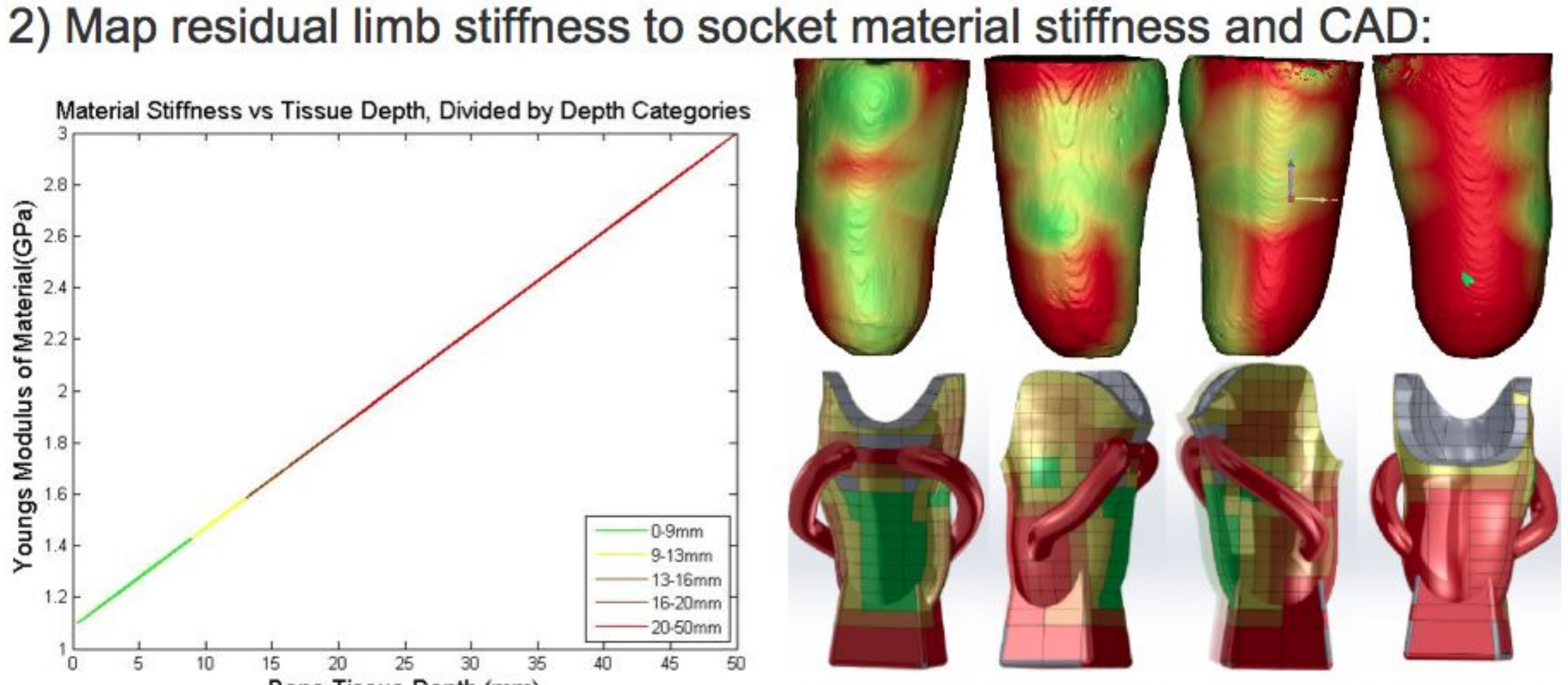

Figure 2: (Left) A mapping of the Young's Modulus of socket interface materials to the soft tissue depth at each location. (Right) Row 1 and 2 represent soft tissue depth of the right residual limb of a transtibial amputee, and the 3D design of a variable viscoelastic socket, respectively.

3) Conduct Finite Element Analysis (FEA) and CAM:

Factor of Safety = 2.62 for applied uniform pressure of 280,000 Pa within the socket and a force of 1,455 N at patella tendon bar.

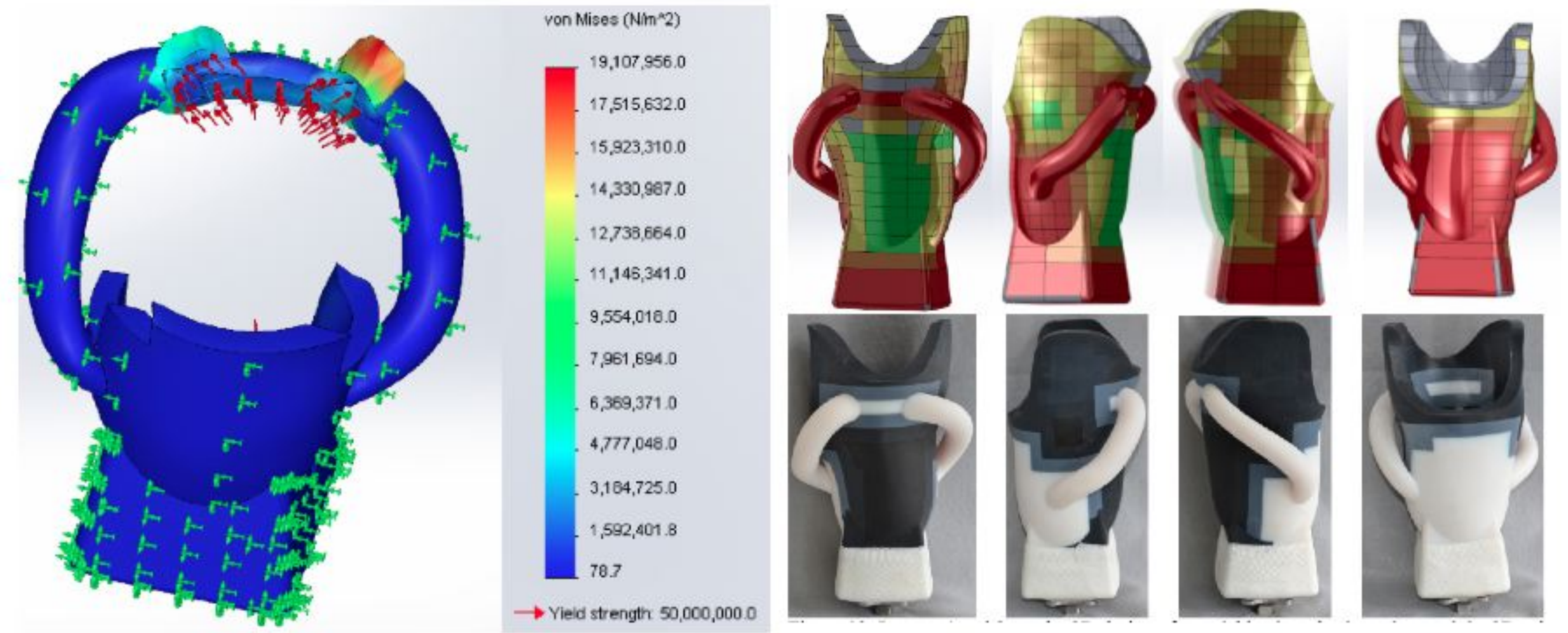

Figure 3: (Left) FEA illustrating fixture location, distributed pressure at stance and applied force at toe-off. (Right) Row 2 shows physical images for CAD images in row 1.

4) Evaluate VIPr and Conventional Socket:

Conduct level-ground walking trials at self selected speeds and measure ground reaction forces, socket pressure distribution, and joint trajectories.

Figure 4: (Left - Right) Tekscan pressure sensors taped to residual limb, Residual limb with sensor inserted into a socket, and reflective markers taped on amputee for gait analysis.

RESULTS

Data during stance of a complete gait cycle show a 15% and 17% reduction in contact pressure at toe-off and heel-strike respectively at the fibula head while the subject uses a VIPr Socket in comparison to a conventional socket of similar internal shape. A corresponding 7% and 8% reduction in contact pressure is observed along the tibia at similar walking speeds.

The CAD/CAM socket's compliant features allows the bony protuberances of the fibula head and the tibia to be displaced a minimal amount allowing for the 44% and 36% reduction of contact pressure over the fibula head and tibia respectively during stair ascent.

The average walking speeds of the participant are 0.84 and 0.72 m/s while using the VIPr and conventional socket respectively.

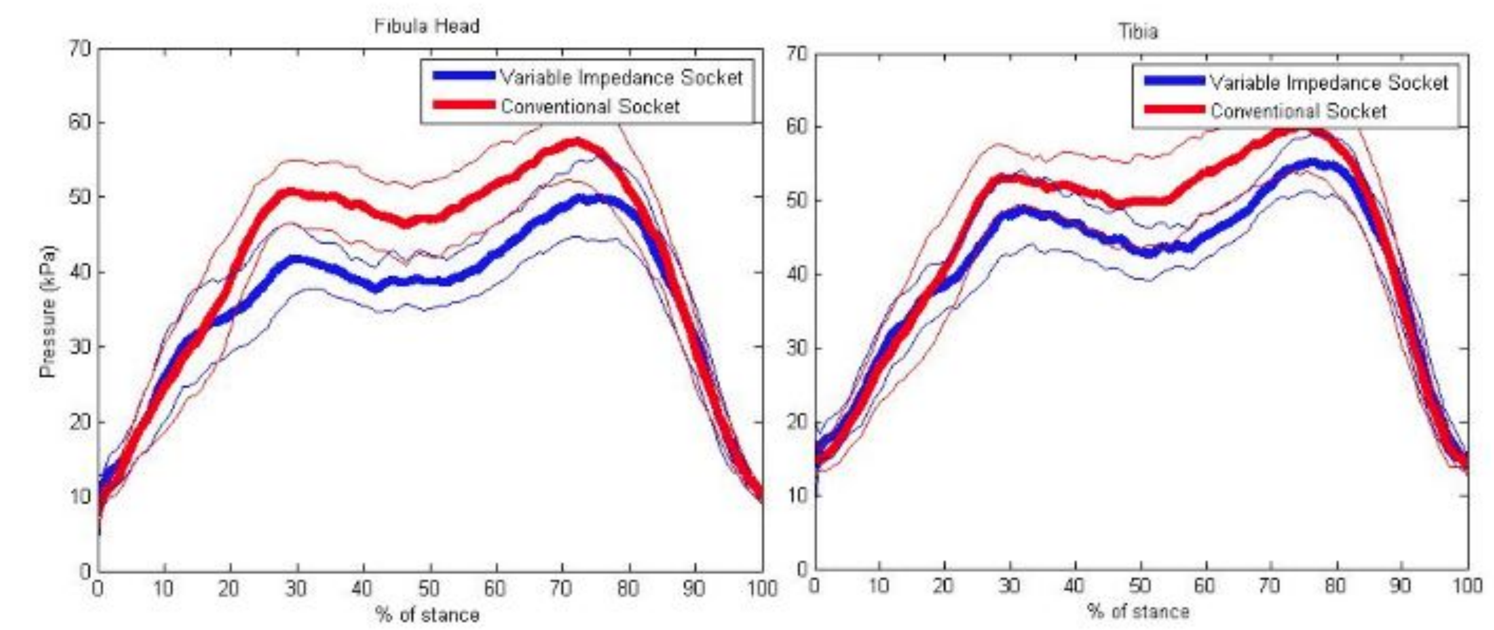

Figure 2: (Left) Contact pressure at fibula head during stance. (Right) Contact pressure at tibia during stance.

Activity	% Reduction of Contact Pressure	
	Fibula Head	Tibia
Standing on Leg 1 and Leg 2	26%	16%
Standing on Leg 1	8%	16%
Stair Ascent: Leg 1 lead	33%	6%
Stair Ascent: Leg 2 lead	44%	36%

Leg 1: Leg with sockets fitted with pressure sensors for evaluation.
Leg 2: Leg with a conventional socket that is not evaluated. No pressure sensors attached.

Table 1: Percentage reduction of contact pressure at fibula head and tibia achieved by use of the VIPr over a conventional socket for various dynamic activities.

CONCLUSION

A Variable Impedance Prosthetic Socket designed using MRI data of the residual limb of a below-knee amputee produces reduced interface pressures between the socket and the residual limb, thereby improving amputee comfort. The self-selected speed for the VIPr socket is higher than experienced while amputee uses conventional socket though the former is 1.5 times heavier than the latter.

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