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Digital Sockets: Towards Manufacturing Tailorable Prosthetic Sockets Utilizing Voxel-Based Composites

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Abstract

In 2017, the World Health Organization (WHO) estimated there were about 40-47 million people worldwide who lacked access to prosthetics and/or orthotic services. The demand is expected to grow as the global population ages, and as the prevalence of diabetes increases. The current techniques used to manufacture necessary prosthetic sockets are expensive, slow, and require highly trained prosthetists, leading to these devices being inaccessible for many. However, advances in additive manufacturing (AM) have provided an opportunity to address this crisis. AM can print custom sockets that perfectly fit the patient, while remaining cost-effective and structurally sound. Additionally, a consensus has formed that tailoring the stiffness of the socket to the stiffness of the corresponding tissue is critical to improving comfort and preventing injury. By utilizing multi-material 3D-printing, the material composition of the socket can be controlled so that the stiffness is tailored to the residual limb. If discrete sections of two different materials are used, then the socket's stiffness could only alternate between the Young's modulus of both material's, with potential for stress concentrations along the material boundaries. However, if a material gradient was used, then material properties can be finely controlled across the socket, potentially with any Young's modulus value in between those of the two constituent materials being achievable. To achieve a material gradient, the socket could be discretized into voxels, or 3D pixels, with each individual voxel corresponding to a material. Voxel-based 3D printing has been done using Polyjet 3D printers, but fused deposition modelling (FDM) 3D printing is a more promising candidate. Polyjet printers are very expensive, and the resin photopolymers they use tend to be weaker and less ductile in comparison to the thermoplastics FDM printing offers. Therefore, this study investigated whether two thermoplastic polyurethane (TPU) filaments of varying stiffness could be used to manufacture voxel-based composites with an intended use in prosthetic sockets. Static compression testing determined that the Young's modulus of these composites could be controlled by varying the proportion of voxels of both materials in test samples. The relationship between the proportion of materials and the Young's modulus was compared to existing composite models such as the Halpin-Tsai model. Cyclic testing up to 1000 cycles then showed that the voxelated samples were as mechanically stable under repeated loading as single material samples. Finally, micro computed tomography (micro-CT) was used to investigate porosity and print quality within test samples.