Extremity Trauma Rehabilitation and Treatment

Optimization of Dynamic Ankle-foot Orthosis Design for High Level Activity Performance Following Limb Salvage for Severe Lower Extremity Trauma

The Intrepid Dynamic Exoskeletal Orthosis (IDEO®) is a custom carbon fiber ankle-foot orthosis (AFO) that has helped wounded Service Members return to a highly active life following limb salvage after blast injuries. Its growing use within the Military prompted researchers to investigate how to better improve the customization process for patients. Researchers from the Extremity Trauma and Amputation Center of Excellence (EACE) and Brook Army Medical Center (BAMC) utilizing funding from the Center for Rehabilitation Sciences Research (CRSR), in collaboration with the University of Texas, used 3D printing techniques and systematic modifications to IDEO® properties to better understand and optimize the design, manufacturing, and prescription process (Figure 1). Specifically, stiffness, bending axis, and alignment of the IDEO® were modified to determine their respective impacts on movement mechanics. Individuals who had undergone lower limb reconstruction and experienced plantar flexion weakness were recruited from the Center for the Intrepid (CFI) and underwent gait analysis during walking, running, and stair and ramp ascent/descent. Results demonstrated that participants adapted to a wide range in IDEO® stiffnesses with few deviations to joint mechanics and muscle activity, possibly reducing the burden on the orthotist to test numerous designs for an individual. When the bending axis of the IDEO® flexed low, near a biological ankle, there were few large changes in walking gait, but greater range of motion and power during running: potentially a beneficial design feature for patients who can tolerate greater motion. The alignment of the IDEO® in a toe-down position was important for minimizing knee extensor muscle activity during a variety of activities, but it compromised push-off power during running. Patient preference across all three studies was generally mixed with no single design preferred by all

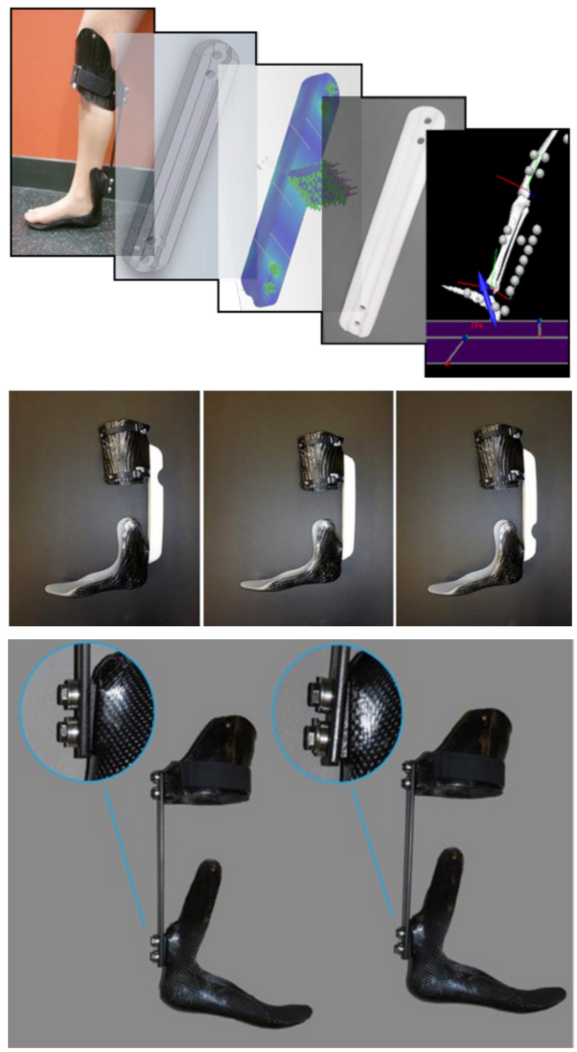

FIGURE 1: Top Image: 3D printing methods (selective laser sintering) modified the stiffness of the IDEO®'s posterior strut.

Middle Image: High, mid, and low IDEO® bending axis locations were created using 3D printing techniques (selective laser sintering).

Bottom Image: IDEO® alignment was modified by placing a 3-degree wedge between the posterior strut and footplate

users. The combined results indicate that a single design may not be optimal for all individuals or for all activities and stress the importance of considering the preference and functional goals of the patient. The work of this group has resulted in seven manuscripts accepted in peer reviewed publications[1-7] and two additional manuscripts currently under review. By evaluating the IDEO®'s design properties and investigating new manufacturing techniques, researchers can provide clinicians with important information regarding improvements in the device to aid the Service Member return to a highly active life after injury.

---

1 Aldridge Whitehead, J. M., Russell Esposito, E., & Wilken, J. M. (2016). Stair ascent and descent biomechanical adaptations while using a custom ankle- foot orthosis. Journal of Biomechanics, 49(13), 2899– 2908. https://doi.org/10.1016/j.jbiomech.2016.06.035

2 Ranz, E. C., Russell Esposito, E., Wilken, J. M., & Neptune, R. R. (2016). The influence of passive-dynamic ankle-foot orthosis bending axis location on gait performance in individuals with lower-limb impairments. Clinical Biomechanics (Bristol, Avon), 37, 13–21. https://doi.org/10.1016/j.clinbiomech.2016.05.001

3 Russell Esposito, E., Choi, H. S., Owens, J. G., Blanck, R. V., & Wilken, J. M. (2015). Biomechanical response to ankle-foot orthosis stiffness during running. Clinical Biomechanics (Bristol, Avon), 30(10), 1125–1132. https:// doi.org/10.1016/j.clinbiomech.2015.08.014

4 Haight, D. J., Russell Esposito, E., & Wilken, J. M. (2015). Biomechanics of uphill walking using custom ankle-foot orthoses of three different stiffnesses. Gait & Posture, 41(3), 750–756. https://doi.org/10.1016/j.gaitpost.2015.01.001

5 Harper, N. G., Esposito, E. R., Wilken, J. M., & Neptune, R. R. (2014). The influence of ankle-foot orthosis stiffness on walking performance in individuals with lower-limb impairments. Clinical Biomechanics (Bristol, Avon), 29(8), 877–884. https://doi.org/10.1016/j. clinbiomech.2014.07.005

6 Russell Esposito, E., Blanck, R. V., Harper, N. G., Hsu, J. R., & Wilken, J. M. (2014). How does ankle-foot orthosis stiffness affect gait in patients with lower limb salvage? Clinical Orthopaedics and Related Research, 472(10), 3026–3035. https://doi.org/10.1007/s11999-014-3661-3

7 Harper, N. G., Russell, E. M., Wilken, J. M., & Neptune, R. R. (2014). Selective laser sintered versus carbon fiber passive-dynamic ankle-foot orthoses: a comparison of patient walking performance. Journal of Biomechanical Engineering, 136(9), 91001. https://doi. org/10.1115/1.4027755