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Examining the Integration of Digital Technology for Ankle-Foot Orthosis Registration and Quantitative Shape Comparison

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I. Abstract

Ankle-foot deformities can affect an individual's gait and cause increased pain and discomfort during the activities of daily living. Custom-made ankle-foot orthotics (AFOs) are widely used in patient care and rehabilitation to improve and restore ankle-foot positioning, support, mobility, and stability. The traditional approach in designing custom-made AFOs relies heavily on the experience and craftsmanship of the orthotist during shape capture, design, and fabrication [1]. Recent breakthroughs in digital technology have the potential of transforming the design processes of orthoses by replacing traditional methods. Digital workflows involve using an optical scanner to capture the ankle and foot shape. Computer-aided design and computer-aided manufacturing (CAD/CAM) systems are used to optimize the shape and fabricate the AFO. The use of digital technology requires less physical labor and increases design flexibility. Further, it allows for models to be easily stored, modified, and replaced. However, translating the subjective skills of orthotist into the digital realm remains a challenge [2].

The traditional design process can be considered an art-form as clinicians must apply manual modifications to a plaster cast to achieve the desired shape and volume of the AFO. Creating a visual representation of the areas of shape change during manual fabrication helps quantify the design process. This is often referred to as digital mapping. Registration is the process of digitally overlaying or superimposing two shapes with respect to each other. This is needed to compare (digitally map) direct (3D) scans of the lower leg to unmodified and modified lower-limb plaster cast models. Current registration methods require the use of anatomical landmarks or reflective markers as reference points for aligning two shapes [4]. This process is inefficient and tedious. Therefore, this study serves to investigate and validate a suitable registration method that will streamline the process of aligning digital AFO models for shape comparison. This proposed digital algorithm will be used to align and compare AFO models acquired using both traditional and digital shape capture methods.

The constraints and limitations of current registration methods were identified by systematically testing the alignment digital models. An optimized registration algorithm using both iterative closest points (ICP) and principal component analysis (PCA) was developed and evaluated to align digital AFO models. Evaluations were conducted by aligning digital AFO models with known deformations to their original shapes. Mean registration errors for the each of the three principal component axes and mean cloud-to-cloud distance were calculated for each pair of registered models. While ICP and PCA were ineffective on their own, results showed that these methods could be used together to obtain accurate registration for shapes misaligned in both translation and rotation.

In collaboration with the Department of Orthotics and Prosthetics (O&P) at the Holland Bloorview Kids Rehabilitation Hospital (HBKRH), participants prescribed a unilateral or bilateral AFO will be recruited. The participant will undergo traditional and digital shape capture in the same session. Scanning the ankle and foot directly will allow for alignment corrections to be applied digitally before quantitatively comparing the shapes. This work is essential in adopting full digital workflows for AFOs. Important for both research and educational purposes, quantifiable data can be used for orthotist training to further adopt digital technologies for O&P design and fabrication.

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