CMBES/SCGB

2025 CMBEC47/ACCES26
Fredericton, NB
May 27-29, 2025

PACT: A predictive algorithm for automated upper-limb prosthetic socket design

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ABSTRACT

Prosthetic socket design significantly affects prosthesis comfort and abandonment [1]. However, current processes are subjective and time-intensive, relying on extensive clinician–patient interactions that can result in long lead times and reduced access to care. Advances in digital scanning, additive manufacturing, and machine learning present an opportunity to streamline the initial stages of this design process, freeing up clinicians' time to focus on where their expertise is most impactful [2]. Despite these advances, there remains limited understanding of digital design applications for upper-limb prostheses [3]. To address this gap, we developed and validated the Predictive Algorithm for Customized Transradial socket design (PACT), which accurately approximates prosthetist-fabricated sockets (PFSs) for individualized prosthetic care.

Nineteen (n=19) participants with transradial limb absence were recruited during regular fitting appointments. Their limbs and corresponding PFSs were scanned using the Spectra scanner (Vorum, Canada) to create a limb–socket library. Our algorithm takes a new client's limb as the input, scaling and comparing it to all limbs in the library using the average Euclidean distance to determine the best match, whose corresponding socket is used as a basis for design. Critical areas affecting socket functionality—such as the distal end and supracondylar suspension—are then adjusted for optimal fit.

Using leave-one-out validation, sockets were predicted for all 19 limbs and compared to their respective PFSs. Strong Spearman's rank correlation ($\rho = 0.81$, $P < 0.05$) between scaled limb shapes and socket fits validated the accuracy of our scaling method. The algorithm consistently predicted reasonable approximations of PFSs, with a mean deviation of only 2.1 ± 0.6 mm across the dataset—within the acceptable range of typical inter-prosthetist variability observed during rectification for lower-limb [4] and transradial sockets [5]. Data clustering using machine learning (DBSCAN) identified localized regions on the socket needing improvement, specifically in anterior–posterior compression and the trimlines. Preliminary client fitting sessions on a subsample of participants showed that the 3D-printed predicted sockets provided satisfactory fit and suspension.

The results demonstrate that PACT predicts reasonable approximations of PFSs, marking the first integration of clinician-created designs into predictive modeling for prosthetic sockets. Unlike prior research using genetic algorithms [6] and the eigenvector algorithm [7], PACT offers a more tailored fit by incorporating clinician-informed adjustments. The widespread deployment of this algorithm could significantly reduce the burden of prosthesis provision on clinicians and patients. Limitations include a relatively small sample size; future iterations of this algorithm will incorporate machine-learning techniques for limb classification and additional fitting parameters to advance toward end-to-end modeling.

Keywords: Transradial prosthetics, prosthetic socket design, predictive modeling, digital scanning, machine learning, additive manufacturing, personalized care.

Conflict of Interest: The authors declare no conflicts of interest related to this study.

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