Title: Dynamic socket interface mechanics for a transfemoral amputee during walking

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Introduction

Dynamic coupling at the residuum/socket interface of lower-limb amputees is an important research topic. Coupling is the complex biomechanical interaction involving multi-directional kinetic forces including pressure and shear exerted at socket interface, and relative residuum kinematics within the socket, simultaneously. To date, there are limited studies assessing combined kinematics and kinetics at this critical interface.

Research Question

We aim to study transfemoral socket interface loading and residuum relative motion using interface sensors and a verified Finite Element Analysis (FEA) platform.

Methods

A left-sided female transfemoral amputee participated (weight 56kg, ischial containment socket). Flexible tri-axial pressure and shear (TRIPS) sensors [1] were placed within the socket at known load-bearing regions (Figure 1a), i.e., posterior-distal-end (PD), posterior-proximal (PP) and anterior-proximal (AP) sites, from which pressure (P), circumferential (S_C) and longitudinal shear (S_L) were obtained while walking along a 35-metre level surface. Interface stresses and ground reaction forces (GRFs) were obtained during gait cycles (GCs).

The participant's residuum and socket were 3D-scanned to develop models for FEA. Young's Moduli of 200kPa and 278kPa and Poisson's ratios of 0.45 and 0.49 were used to represent skin and liner, respectively. Friction coefficient of 0.5 was applied to liner/socket interface; other interfaces were assumed bonded [2]. The hip joint was fixed while corresponding GRFs were applied to socket's distal-end to evaluate relative residuum displacement during a typical GC.

Results

Figure 1b-j shows pressure and shear of up to 40±2kPa and 5±3kPa, respectively. Figure 1k shows axial and anterior-posterior movement of distal-end region. The residuum moved 9mm down the socket and experienced anterior-posterior displacement of up to 8mm relative to its position at 0% GC.

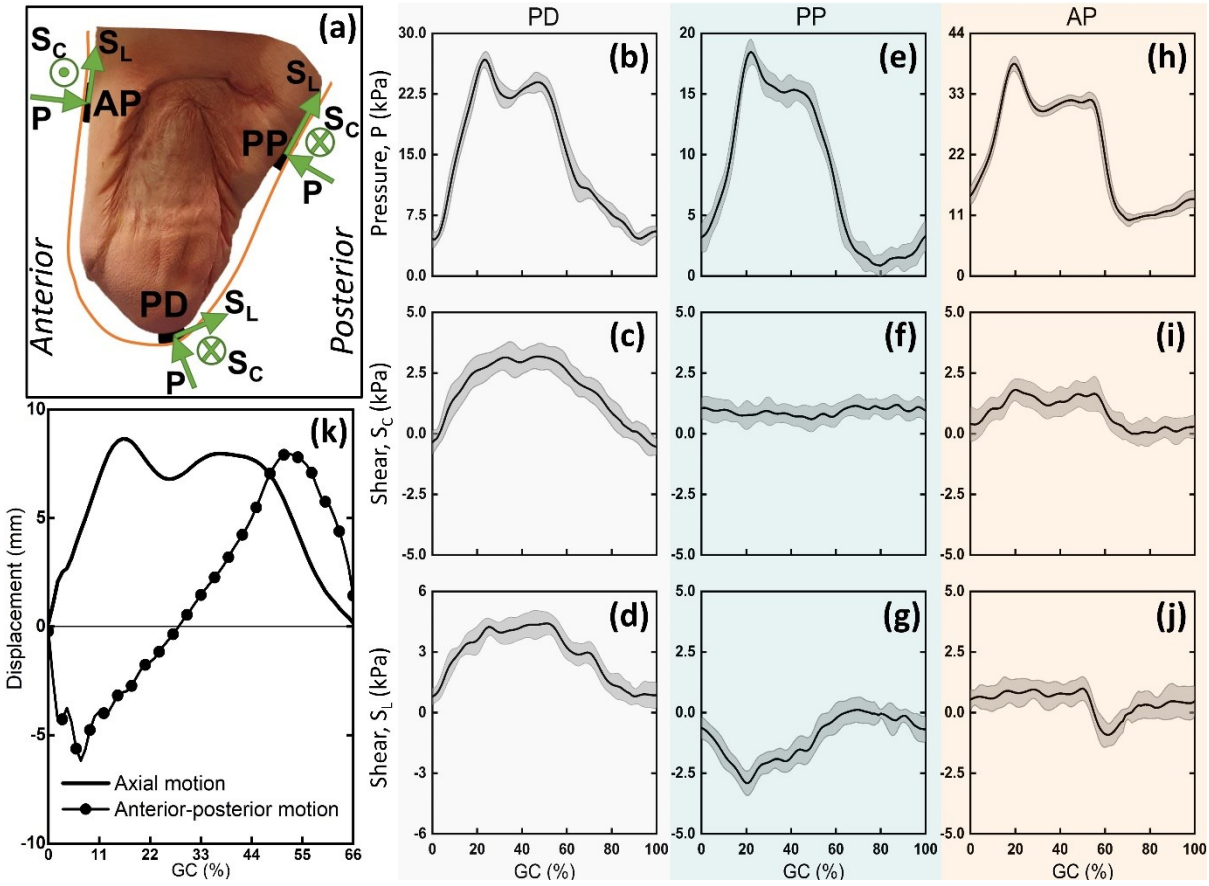

Figure 1. (a) Image of participant's residuum with directions of shear annotated. Mean and one standard deviation of stresses at (b-d) PD, (e-g) PP and (h-j) AP sites during full GC. (k) Axial and anterior-posterior displacement at PD during stance phase obtained using FEA.

Discussion

Double-hump pressure profiles aligned with known gait profiles at all sites indicating effective transfer of GRFs to socket interface confirming sensors were indeed located at load-bearing anatomical landmarks [3]. Pressure and shear obtained via FEA roughly align with those in Figure1b-j.

Axial displacement at PD site was lower than previous measurements through means of 3D-motion capture [4], possibly due to amount of tissue present and different socket type. More importantly, peak axial displacement at 15% GC aligns with $+S_L$ peak (Figure 1d) indicating "pistoning" as the residuum moved down in the socket during early-stance. Furthermore, negative anterior-posterior displacement during early-stance (7% GC) suggests the residuum moved in posterior direction as bodyweight transferred to prosthetic side. In contrast, positive anterior-posterior displacement during late-stance (50% GC) coincides with peak pressure of 32±1kPa at AP (Figure 1h), suggesting the residuum moved anteriorly in the socket.

References

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