Evaluating dynamic biomechanics at a transtibial socket interface during gait phases using finite element analysis

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Abstract

Introduction

The interface between a lower extremity amputee residuum and prosthetic socket is subjected to extensive loading during ambulation. Prolonged use of a prosthesis can result in discomfort and possible tissue injury, which is more likely with ill-fitted sockets. Study of the interface mechanical coupling is important to improve understanding at this important interface. Finite element analysis (FEA) has been extensively used to evaluate interface stresses and help assess load distribution and potential risk of tissue injuries [1]. However, few FEA studies report both pressure and shear at load-bearing locations, e.g., patella tendon (PT), fibula head (FH), popliteal depression (PD), especially at different phases of the gait cycle; nor utilise experiment outputs to assist validation. This work reports FEA pressure and shear of a transtibial (TT) interface during key gait phases such as weight acceptance (WA), midstance (MS) and toe-off (TO). Outputs were analysed alongside experimental sensor outputs obtained using a lab-based TT stump/socket simulator [2].

Methods

Pressure and shear at the PT, FH and PD were experimentally measured using a stump/socket interface simulator. A corresponding FE model was created to align with the simulator's set-up mimicking key gait phases, e.g., WA. Stump tissue was assigned a compressive modulus of 146kPa, aligning with the silicone material used in the simulator [2]. FEA pressure (P), circumferential shear (S_C) and longitudinal shear (S_L) at these load-bearing areas were obtained and validated by experimental sensor outputs.

Results & Discussion

FEA results show peak pressures of 152kPa, 120kPa and 31kPa at PT, FH, and PD, respectively, during WA. Relatively higher P at PT is attributable to the bony prominence in the area as compared with

FH and PD. Magnitude of S_C at the three sites exhibited small differences (approximately 3kPa at PT, 1kPa at PD, and 4kPa at FH) which may suggest the stump's negligible circumferential movement in the socket. S_L towards the distal direction at FH (14kPa) and PT (36kPa) were observed, with no notable S_L at PD. This aligns with the fact that the stump moves downwards in the socket during WA, as load is transferred from the contralateral to prosthetic side.

The FEA outputs largely align well with interface pressure and shear sensor measurements under WA conditions when using the simulator. The validated model was further used to study pressure and shear during other gait phases including MS and TO. Detailed results and discussion on experimental data and FEA will be presented.

Conclusion

A computational FE model was developed to estimate pressure and shear distribution during typical phases in gait cycles. The model was evaluated using a corresponding simulator and interface sensor measurements.

References

[1] A. S. Dickinson, J. W. Steer, and P. R. Worsley, "Finite element analysis of the amputated lower limb: A systematic review and recommendations," *Medical Engineering & Physics,* vol. 43, pp. 1-18, 2017/05/01/ 2017, doi: https://doi.org/10.1016/j.medengphy.2017.02.008.

[2] M. P. McGrath *et al.*, "Development of a residuum/socket interface simulator for lower limb prosthetics," *Proc Inst Mech Eng H,* vol. 231, no. 3, pp. 235-242, Mar 2017, doi: 10.1177/0954411917690764.