Author
Ko, Siu-Teing (Reykjavik IS) | MEng
Össur - Research and Innovation

Title
Pressure measurements in prosthetic sockets of transfemoral amputees during ambulation and the relationship with socket fit: A systematic review

Coauthors
Ko ST, Asplund F, Brinkfeldt K

Summary
The review presents pressure data at the stump-socket interface of transfemoral amputees (TFAs) during normal gait. Eight scientific papers were analysed to suggest a quantitative relationship between pressure and socket fitting conditions, and to propose experimental protocols for future studies.

Introduction
Discomfort at the human-prosthesis interface is a critical reason for prosthesis abandonment [1, 2]. Poorly fitting prosthetic sockets can lead to tissue breakdown, pressure ulcers, and in severe cases, surgical intervention [3-5]. There exist numerous transfemoral socket types aimed to influence intra-socket pressures, stability and comfort. Designs are selected and modified based on individual characteristics, such as residual limb features and activity level [6]. Current state-of-the-art in socket design and manufacture is highly subjective and does not typically employ the use of any quantitative measures. It is hypothesised that the quantification and mapping of pressures at the stump-socket interface can aid in improving socket design; for pressure relief and stability [4, 6]. Expected pressure values and their distribution within sockets during normal gait have not been established for TFAs, nor has a relationship between pressure magnitudes and comfort been ratified.

Methods
Three scientific databases were utilised in the search for journal articles that investigate pressures in transfemoral prosthetic sockets. Articles were filtered to exclude those that did not present quantitative experimental data on TFAs. Three reviewers assessed the selected publications following an adaptation of the quality assessment criteria outlined in a Cochrane

Review on lower limb prosthesis prescriptions. Due to the large number of variables that exist in such investigations and to enable a strict comparison of the pressure data, analysis on the experimental methods presented in the articles was required. Only the papers deemed eligible following the quality assessment were evaluated further. This involved identification of variables such as subject mobility, socket type, sensor position, and whether the results were presented with reference to the gait cycle. Only pressure measurements collected under similar conditions were compared against each other.

Results

Over 1500 articles were initially found containing one or more keywords. The screening process resulted in 17 articles for quality assessment, which led to eight papers considered eligible for detailed evaluation. In all eight studies, subjects were tested while walking on level-ground at normal walking speed. Six articles compared dynamic pressure values with the gait cycle but did not necessarily map pressure at the socket brim. Three studies obtained pressure data at the socket brim and correlated the measurements with the gait cycle.

Within these three studies, three active TFAs underwent testing without expressing any discomfort with their sockets. Peak pressures were identified in the ischial region, measured in the 90-160 kPa range and occurred approximately during midstance; independent of socket type. One less active subject was highly sensitive to pressures on the ischium and displayed maximum pressures at the mid-lateral edge of his stump. In two out of the three studies, a net loading on the stump posterior was suggested. The opposite was found in the third study; possibly explained by the fenestration in the walls of the socket tested.

All articles that presented pressure as a function of the gait cycle suggest peak pressures arise during stance phase; irrespective of socket type. The maximum measured pressure across all eight papers approximately ranged from 24 to 380 kPa. The subject who exhibited nearly 400 kPa pressure did not express discomfort.

Conclusion

The studies suggest maximum pressures at the stump-socket interface occur in the ischial region during midstance, for both ischial containment and quadrilateral socket types. When

fitting prosthetic sockets, care should be taken at the ischial interface to ensure pressures here do not lead to tissue breakdown or pressure ulcers.

Although the maximum pressure presented (380 kPa) across all studies occurred at the medial anterior compartment of the stump, no other papers in this review cited high pressures in this region. This may be due individual patient characteristics, and/or the sensor positioning, which may have resulted in an unrealistic local stress zone.

Common variables across the studies were extracted and outlined in Table 1. A stringent experimental protocol can be designed based on a requirement for a minimum number of variables that must be recorded in future intra-socket pressure studies. This may enable a stricter and unbiased evaluation of intra-socket pressure.

References

[1] C. W. RADCLIFFE, "Functional considerations in the fitting of above-knee prostheses," (in eng), Artif Limbs, vol. 2, no. 1, pp. 35-60, Jan 1955.

[2] T. O. P. Edge, "Amputee Patient Comfort and Compliance," vol. 21, A. Coalition, Ed., ed: inMotion, 2011, pp. 34-39.

[3] F. A. Appoldt and L. Bennett, "A preliminary report on dynamic socket pressures," Bull Prosthet Res, vol. 10, no. 8, pp. 20-55, 1967.

[4] A. F. T. Mak, M. Zhang, and D. A. Boone, "State-of-the-art research in lower-limb prosthetic biomechanics-socket interface: A review," Journal of Rehabilitation Research and Development, vol. 38, no. 2, pp. 161-173, Mar-Apr 2001.

[5] P. Laszczak et al., "A pressure and shear sensor system for stress measurement at lower limb residuum/socket interface," (in eng), Med Eng Phys, vol. 38, no. 7, pp. 695-700, 07 2016, doi: 10.1016/j.medengphy.2016.04.007.

[6] L. Paterno, M. Ibrahimi, E. Gruppioni, A. Menciassi, and L. Ricotti, "Sockets for Limb Prostheses: A Review of Existing Technologies and Open Challenges," Ieee Transactions on Biomedical Engineering, vol. 65, no. 9, pp. 1996-2010, Sep 2018, doi: 10.1109/tbme.2017.2775100.

Image: Table1_ListOfVariables_2561.PNG

Table 1 List Of Experimental Variables

Group	Variable
Subject Information	Number of subjects
	Cause of amputation
	Sex
	Age
	Weight
	Activity Level
Prosthesis Information	Number of sockets tested per subject
	Socket type
	Prosthesis type
Sensor Information	Sensor type
	Number of sensors per socket
	Sensor position(s)
	Inclusion of sensors at socket brim? [Y/N]
	Sensor placement method e.g. embedded in socket, adhered to socket, held by friction
Pressure Information	Maximum measured pressure (kPa)
	Anatomical location of maximum pressure
	Position in gait cycle of maximum pressure (%)
	Pressure range
Gait Information	Cadence (m/s)
	Reference to gait cycle? [Y/N]