

Development of a customised protocol for diagnosis and treatment of obesity specific foot biomechanics

Bhavathy Kathirgamanathan

(168005N)

Thesis submitted in partial fulfilment of the requirements
for the degree Master of Philosophy

Department of Electronic and Telecommunication Engineering

University of Moratuwa
Sri Lanka

May 2019

Declaration of Authorship

I declare that this is my own work, and this thesis does not incorporate without acknowledgement any material previously submitted for a degree or diploma in any other university or institute of higher learning, and to the best of my knowledge and belief it does not contain any material previously published or written by another person except where the acknowledgement is made in the text.

Also, I hereby grant to University of Moratuwa the non-exclusive right to reproduce and distribute my thesis, in whole or in part, in print, electronic, or any other medium. I retain the right to use this content in whole or part in future works (such as articles or books).

Signed:

Date:

The candidate, whose signature appears above, carried out research for the MPhil dissertation under my supervision.

Signed:

Date:

Abstract

The foot plays a crucial role in locomotion, impact bearing, and vertical stability and hence disruptions to the foot biomechanics can be detrimental to a person's ability to carry out daily activities. Foot disorders and pathologies can cause alterations in the overall foot and lower limb biomechanics. This thesis develops and applies a methodology using computational and experimental methods to analyse the lower limb biomechanics. The biomechanical analysis allowed foot pressure, stress and other changes that occur during gait due to pathology to be identified. The developed methods were implemented on obese subjects to characterise changes in the lower limb biomechanics caused due to increased loading following which some computational studies were carried out to further characterise the link between obesity and osteoarthritis. Finally, a subject specific modelling method is explored in order to take the initial methodology which is purely a research solution into one that may be used in a clinical setting. The findings of this study highlight the importance of studying the foot biomechanics as a whole whilst undertaking biomechanical studies, as the lower limb is a chain where problems occurring at the foot can be observed higher up in the lower limb and vice versa. The results of this study suggest that alterations in the foot posture are a key indicator of increased internal stress and pressure. The data collected for this thesis was from a South Asian (Sri Lankan) population, and hence a useful data-set for future comparison with the large body of European data currently available has been obtained.

Keywords: Foot Mechanics, Obesity, Finite Element Modelling, Biomechanics, Gait Analysis

Acknowledgements

First and foremost, I would like to take this opportunity to thank all the people who have helped to make this project a success.

I would like to express my sincere gratitude to my supervisor, Dr Pujitha Silva for the constant encouragement, motivation, and knowledge provided to me throughout the course of my research. Thank you for keeping me focused on the project and for always making yourself available for discussion when a problem in the project came about. All the time and effort you have put into making sure that I complete this project successfully is greatly appreciated.

Many thanks must also go to my co-supervisor Dr Justin Fernandez from the Auckland Bioengineering Institute, New Zealand for all the knowledge he brought into this project. I am very grateful for the expert guidance you provided to me for this project.

Additionally I would like to thank Dr Inoshi Atukorala and Professor Saroj Jayasinghe from the Colombo Medical Faculty for the expert medical knowledge you provided and for helping us towards getting MRI scans. My thanks goes to Dr Angelo Karunaratne and all the panel members on my MPhil progress review panel for the very insightful advice, feedback, and suggestions I received which ensured that I stayed on the right track in my research.

I also wish to thank the University of Moratuwa Senate Research Council (SRC) for the SRC/CAP/15/01 grant which provided the funding for this project. I thank the Kairos sensing team for help with the gait analysis, Asiri Surgical in Colombo for the MRI scans, all the volunteers who took part in the experiments, and to my fellow students and staff from the University of Moratuwa for your valuable input, advice, and encouragement throughout the project.

Finally a huge thank you to my parents, my brother, and to all my family and friends, both near and far, for your full support and encouragement not only for this project but in every endeavour I take in life.

Contents

Declaration of Authorship	i
Abstract	ii
Acknowledgements	iii
List of Figures	viii
List of Tables	x
Abbreviations	xi
Publications	xiii
1 Introduction	1
1.1 Aims of the Research	3
1.2 Thesis Overview	4
2 Literature Review	6
2.1 Basic Structure and Mechanics of the Foot	6
2.2 Foot Posture	9
2.3 Experimental Methods for the Analysis of Foot Biomechanics	10
2.4 Geometry Reconstruction and Finite Element Modelling of the Foot Anatomy	12
2.5 Clinical Applications of Foot Modelling	15
2.6 Obesity and its Effects on Lower Limb Biomechanics	16

2.6.1	Prevalence of obesity in Sri Lanka	18
2.7	Osteoarthritis and its effects on the lower limb biomechanics	19
2.8	Subject Specific Modelling	20
2.9	Summary	21
3	Development of Methodology for Analysis of Foot Problems	23
3.1	Introduction	23
3.2	Experimental procedure	24
3.2.1	Subject Identification	24
3.2.2	Collection of basic patient data	25
3.2.3	Gait Study	25
3.2.4	Plantar Pressure	26
3.3	Computational Modelling Procedure	28
3.3.1	Data Acquisition	28
3.3.2	Image processing and 3D geometry creation	29
3.3.3	Finite Element Model development	32
3.3.4	Material Models	35
3.4	Summary	37
4	Effect of obesity on the biomechanics of the foot and lower limb	38
4.1	Experimental Study	39
4.2	Computational Study	41
4.3	Discussion	47
4.4	Summary	53
5	Modelling of alterations in foot posture to simulate osteoarthritic conditions	55
5.1	Introduction	55
5.2	Methods	56
5.2.1	Simulation Methodology	58
5.2.2	Results and discussion	60
5.3	Summary	65
6	Subject Specific Modelling of the Foot	67
6.1	Problem Statement	68
6.2	Computational Implementation	69
6.2.1	Registration to ISB coordinate system	69
6.2.2	Soft Tissue Customisation	71
6.2.2.1	Transformations	73

6.2.2.2	Least Squares regression	75
6.2.3	Bone Customisation	76
6.3	Results and Discussion	77
6.4	Summary	82
7	Conclusions and Further Work	84
7.1	Conclusions	84
7.2	Further Work	86
A	Information Sheets and consent forms for experimental study	88
B	Matlab Code for Subject Specific Modelling	91
	References	106