UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

EVALUATION OF RESISTANCE TRAINING EQUIPMENT USING THREE DIMENSIONAL MUSCULOSKELETAL MODELLING FOCUSING ON THE BIOMECHANICAL AND ANTHROPOMETRIC CONSIDERATIONS OF THE END-USER

by

Kim Nolte

Submitted in partial fulfilment of the requirement for the degree

DOCTOR PHILOSOPHIAE

In the

FACULTY OF HUMANITIES
(Department of Biokinetics, Sport and Leisure Sciences)

University of Pretoria

Promoter: Prof. PE Krüger

Pretoria

September 2011

ACKNOWLEDGEMENTS

I would like to express my sincere thanks and gratitude to the following persons and institutions for their guidance, without who's assistance, this study would not have been possible.

Prof. PE Krüger (Department Biokinetics, Sport and Leisure Sciences, University of Pretoria): Who acted as my promoter, for his invaluable guidance and support.

Prof. S Els (Department of Mechanical and Aeronautical Engineering, University of Pretoria): Who acted as my co-promoter, for his guidance and wise input throughout my studies.

ERGONOMICS TECHNOLOGIES (ERGOTECH): For their willingness to allow me to use their facilities and equipment for the modelling process as well as their assistance with my training.

Dr. M Thoresson (ESTEQ Engineering): For his time, guidance and support regarding the MSC software system Adams and its plug-in Lifemodeler™.

Heinrich Nolte: To my very special husband, for his never failing encouragement, support and invaluable assistance throughout my studies. It has been an incredible journey completing our Doctoral studies together.

Yvonne De 'Ath: My mother's unconditional love and support in all my endeavours.

ABSTRACT

TITLE	Evaluation of resistance training equipment using three dimensional musculoskeletal modelling focusing on the biomechanical and anthropometric considerations of the end-user
CANDIDATE	Kim Nolte
PROMOTER	Prof PE Krüger
CO-PROMOTER	Prof PS Els
DEPARTMENT	Biokinetics, Sports and Leisure Sciences University of Pretoria
DEGREE	Doctor Philosophiae

The main goal of this study was to evaluate whether three dimensional musculoskeletal modelling (3D) is effective in assessing the safety and efficacy of resistance training equipment. The focus of the evaluation was on the biomechanical and anthropometric considerations of the end-user. 3D musculoskeletal modelling was used to evaluate four pieces of resistance training equipment, namely the seated biceps curl, abdominal crunch, seated row and chest press. Three anthropometric cases were created; these represented a traditional 5th percentile female as well as a 50th and 95th percentile male based on body mass index (BMI). Resistance on the training machines was set at fifty percent of the functional strength one repetition maximum (1RM), for each anthropometric case and piece of exercise equipment two repetitions were performed except for the abdominal crunch model during which four repetitions were simulated. Each piece of equipment presented unique challenges. In three of the four studies (seated biceps curl, seated row and chest press) the default model created by the modelling software was not adequate to solve the forward dynamics simulations and thus adjustments had to be made to the default model

in order to complete the modelling process. 3D musculoskeletal modelling by means of LifeModeler™ software was able to identify some potential risk for musculoskeletal injury as well as highlight the discrepancies between the anthropometric cases, specifically the accommodation of the 5th percentile female and the machines' engineered adjustability. 3D musculoskeletal modelling has the potential to indicate shortcomings in resistance training equipment design. Therefore it appears as if 3D musculoskeletal modelling can be used to evaluate resistance training equipment design however the limitations as indicated by this study must be taken into consideration especially when using default models.

KEY WORDS: Resistance training equipment, modelling, LifeModeler™, inverse dynamics, forward dynamics, biomechanics, anthropometric, musculoskeletal injury, safety, efficacy

OPSOMMING

TITEL	Evaluasie van weerstands oefenapparaat deur middel van driedimensionele muskuloskeletale modellering deur te fokus op die biomeganiese en antropometriese oorwegings van die end-gebruiker.
KANDIDAAT	Kim Nolte
PROMOTOR **MEDEPROMOTOR**	Prof PE Krüger Prof PS Els
DEPARTEMENT	Biokinetika, Sport- en Vryetydswetenskappe Universiteit van Pretoria
GRAAD	Doctor Philosophiae

Die doel van die studie was om die effektiwiteit van driedimensionele (3D) muskuloskeletale modellering te evalueer in terme van die tegniek se vermoë om die veiligheid en doeltreffendheid van weerstands oefenapparaat te evalueer. Die fokus van die evaluasie was op die biomeganiese en antropometriese oorwegings van die end-gebruiker. 3D muskuloskeletale modellering was gebruik in die evaluasie van vier weerstands oefenapparate genaamd die sittende biceps krul, abdominale krul, sittende roei en sittende borsstoot. Drie antropometriese gevalle is geskep, die het ‘n tradisionele 5^{e} persentiel vrou, sowel as ‘n 50ste en 95ste persentiel man voorgestel en was gebasseer op liggaamsmassa indeks waardes. Die eksterne weerstand van die apparaat was bepaal teen vyftig persent van die funsionele krag een-repetisie- maksimum vir elk van die antropometriese gevalle en twee repetisies is uitgevoer behalwe vir die abdominale krul waartydens vier repetisies gesimuleer is. Elke apparaat het unieke uitdagings gestel. In drie van die vier studies (sittende biceps krul, sittende roei en sittende borsstoot) was die standaard model van die sagteware

onvoldoende om die voorwaards dinamiese simulasie op te los en moes aanpassings aan die modelle gemaak word vir suksesvolle simulasies. Die modellerings proses met die Lifemodeler™ sagteware kon potensiële risiko vir muskuloskeletale besering sowel as verskille tussen die verskeie antropometriese gevalle uitwys. Dit was veral opvallend vir die akkomodasie van die 5^{e} persentiel vrou asook betreffende die apparaat se vervaardigde verstelbaarheid. 3D muskuloskeletale modellering beskik oor die vermoë om voorstelle vir verbetering in die ontwerp van weerstands oefenapparaat uit te wys. Dit blyk dus dat 3D muskuloskeletale modellering beslis gebruik kan word vir die evaluasie van weerstands oefenapparaat ontwerp, die beperkings van die studie moet egter in gedagte gehou word, veral wanneer standaard modelle gebruik word.

SLEUTELTERME: Weerstandsoefening apparaat, modellering, Lifemodeler^{TM}, omgekeerde dinamika, voorwaardse dinamika, biomeganiese, antropometriese, muskuloskeletale besering, veiligheid, doeltreffendheid

TABLE OF CONTENTS

LIST OF FIGURES (Chapters 1 and 2)

LIST OF TABLES (Chapters 1 and 2)

LIST OF ABBREVIATIONS (Chapters 1 and 2)

3D	Three dimensional
F	Force
T	Torque
FA	Force Arm / Moment Arm
COTS	Commercially off the shelf
pCSA	Physiological Cross-sectional area
aCSA	Anatomical Cross-sectional area
F_{max}	Maximum force
M_{stress}	Maximum tissue stress
PID	Proportional-integral-differential
P_{error}	(Target value – current value) / range of motion
D_{error}	First derivative of P_{error}
I_{error}	Time integral of P_{error}