

Analysis and Correlation Study of Human Masseter Muscle with EMG, Ultrasonography & 3D Imaging



Shazia Naser-ud-Din

BDS, MSc (Orthodontics), DPHDent, FICCCDE, DCPSP-HPE

Thesis submitted for the degree of

Doctor of Philosophy

The University of Adelaide

September 2009

For

Harris Haseeb

TABLE OF CONTENTS

ABSTRACT	XI
DECLARATION	XIV
THESIS FORMAT	XVII
ACKNOWLEDGEMENTS	XIX
1 LITERATURE REVIEW	1
1.1 Introduction	1
1.2 The Masseter Muscle	2
1.2.1 Gross Anatomy of the Masseter Muscle	2
1.2.2 Superficial Masseter	3
1.2.3 Intermediate Masseter	3
1.2.4 Deep Masseter	4
1.2.5 Function	4
1.2.6 Nerve Supply	4
1.2.7 Control of Mastication	4
1.2.1 The motor units and muscle fibre types	5
1.2.2 Muscle Spindles	7
1.2.3 Reflexes	9
1.2.4 Stretch reflexes	9
1.2.5 Unloading Reflex	9
1.2.6 Periodontal Mechanoreceptors (PMR's)	10
1.2.7 Modulation of reflexes of PMR origin	11
1.2.8 Images for determining masseter muscle dimensions	11

1.3	EMG Studies	12
1.3.1	Development of Devices	12
1.3.2	EMG studies and significance in Orthodontics	14
1.3.3	Limitations & methodological Issues	15
2	IMAGING	17
2.1	Introduction	17
2.2	ULTRASONOGRAPHY	19
2.3	3D IMAGING	22
2.3.1	Anthropometry	24
2.3.2	Other Imaging techniques	25
2.4	PREDICTIVE EQUATIONS	26
3	AIMS & OBJECTIVES	27
3.1	Statement of the Problem	27
3.2	Hypothesis	27
3.3	Possible Clinical Applications	27
4	MATERIALS AND METHODS	28
4.1	EMG STUDY	28
4.1.1	Subject selection	28
4.1.2	Skin preparation and electrode placement	28
4.1.3	Impressions	29
4.1.4	Orthogonal Probe	29
4.1.5	External movement minimization to reduce level of noise	29
4.1.6	Local Anesthesia	30
4.2	EQUIPMENT DETAILS	30

4.2.1	Equipment Safety	32
4.2.2	Visual Feedback	32
4.2.3	Stimulus Profile	33
4.2.4	EMG Recordings	35
4.2.5	Off Line Data Analyses	36
4.2.6	CUSUMS	36
4.3	REFLEX ANALYSES	38
4.4	LATERAL CEPHALOMETRICS	38
4.4.1	Analyses on Dolphin	39
4.4.2	Manual tracing	44
4.5	ULTRASONOGRAPHY	47
4.6	3 D IMAGING	48
4.6.1	3D Imaging Analyses	49
4.6.2	3D Indices	49
4.6.3	Transverse dimensions	49
4.6.4	Perpendicular measurements	50
4.6.5	Tangential / Curvilinear measurements	50
4.7	STATISTICAL ANALYSES	51
4.7.1	Reliability	51
4.7.2	Dahlberg's statistic	52
4.7.3	Bland and Altman	52
4.7.4	Predictive Equations	52
5	MODULATION OF MASSETERIC REFLEXES BY SIMULATED MASTICATION	54
5.1	ABSTRACT	55
5.2	INTRODUCTION	56
5.3	METHODS	56

5.3.1	Participants	56
5.3.2	Protocol	57
5.3.3	Data Analysis	59
5.4	RESULTS	59
5.4.1	Modulation of reflexes pre-local anaesthetic	60
5.4.2	Modulation of reflexes during local anaesthetic	61
5.5	DISCUSSION	61
5.5.1	Acknowledgements	65
6	MASSETER LENGTH DETERMINES MUSCLE SPINDLE REFLEX EXCITABILITY DURING JAW CLOSING MOVEMENTS	66
6.1	ABSTRACT	67
6.2	INTRODUCTION	68
6.3	SUBJECTS AND METHODS	69
6.3.1	Experimental set-up	69
6.3.2	Reflex recording	70
6.3.3	Reflex calculation	72
6.3.4	Cephalometrics	73
6.3.5	Masseter length	74
6.3.6	Statistical analysis	74
6.4	RESULTS	74
6.4.1	Muscle spindle response during mastication	74
6.4.2	Cephalometric Factor Analysis	75
6.4.3	Correlation between Muscle Spindle reflex and Masseter Muscle Length / vertical facial height.	77
6.5	DISCUSSION	78
6.5.1	Acknowledgements	81

7	STUDY OF FUNCTION AND FORM FOR HUMAN MASSETER MUSCLE WITH ULTRASONOGRAPHY AND LATERAL CEPHALOMETRICS	82
7.1	ABSTRACT	83
7.2	INTRODUCTION	84
7.2.1	US and muscles of mastication	84
7.2.2	US and facial dimensions	85
7.3	SUBJECTS & METHODS	85
7.3.1	Pilot Study	85
7.3.2	Subjects	88
7.3.3	Linear cephalometric Indices	92
7.3.4	Angular cephalometric Indices	92
7.3.5	Proportional Indices	92
7.4	RESULTS	93
7.4.1	Bland and Altman for Pilot Study	93
7.4.2	Predictive Equations	96
7.4.1	Reproducibility	96
7.5	DISCUSSION	100
7.5.1	Acknowledgements	102
8	ANALYSIS AND CORRELATIONS OF HUMAN MASSETER MUSCLE WITH 3D IMAGING, ULTRASONOGRAPHY AND LATERAL CEPHALOMETRICS	103
8.1	ABSTRACT	104
8.2	INTRODUCTION	105
8.2.1	3D Imaging	106
8.2.2	Ultrasonography	106
8.2.3	Lateral Cephalometrics	107

8.3	SUBJECTS AND METHODS	108
8.3.1	Experimental set-up	108
8.3.2	3D Imaging	108
8.3.3	3D Image Analyses	110
8.3.4	3D Linear measurements	113
8.3.5	3D Transverse Dimensions	114
8.3.6	3D Perpendicular Measurements	115
8.3.7	3D Tangential/ Curvilinear Measurements	115
8.3.8	3D Indices	115
8.3.9	Ultrasonography (US)	116
8.3.10	Lateral cephalograms	119
8.3.11	Linear cephalometric measurements	119
8.3.12	Angular cephalometric measurements	121
8.3.13	Cephalometric Indices	121
8.3.14	Statistics	121
8.3.15	Error Method	121
8.3.16	Predictive Equations	122
8.4	RESULTS	122
8.5	DISCUSSION	132
8.5.1	Muscles of mastication	135
8.5.2	Scope and Application of Imaging	135
8.6	CONCLUSIONS	137
8.6.1	Acknowledgements	137
9	SUMMARY AND CONCLUSIONS	138
9.1	MASSETER MUSCLE SPINDLES	138
9.2	MASSETER MUSCLE DIMENSIONS	139
9.3	3D IMAGES	141

9.4	METHOD ERROR	143
9.5	PREDICTIVE EQUATIONS	144
9.6	CLINICAL APPLICATIONS	145
9.7	FUTURE APPLICATIONS IN ORTHODONTICS	145
9.8	FINAL REMARKS	146
10	REFERENCES	148
11	APPENDIX	168

Abstract

Form and function are inextricably intertwined in orthodontics. Our understanding of the hard tissue relationship has been comprehensive, with extensive clinical trials both cross sectional and longitudinal over the past several decades. The majority of studies have used standardized cephalograms that reflect our current concepts. However, the same cannot be stated for soft tissues and, more specifically, the muscles that envelope the skeletal bases.

The aim of the current study was to objectively evaluate the masseter muscle – one of the key elevator muscles in the human masticatory system with innovative diagnostic tools like electromyography (EMG), ultrasonography (US) and 3-D imaging (Mona Lisa[®]). Standard lateral cephalometrics were used as the gold standard for measuring the vertical facial dimensions and correlating the findings to the above mentioned modalities. This extensive study comprised three major components and involved subjects from the same cohort.

Firstly, the masseter muscle spindle reflexes were studied in dynamic chewing and the responses recorded with EMG in 28 human subjects. These were then analysed and correlated to the vertical facial proportion from standardized lateral cephalograms. Although substantial work has been done to evaluate the various trigeminal reflexes¹⁻³, limited research has investigated the reflexes from the muscle spindles in different facial proportions⁴. This is primarily due to the inherent complexity of the neurophysiology compounded by noise within the experimental models. Most often the method used to elicit a muscle spindle reflex in the human jaw involves a brief mechanical depression of the mandible, either by use of a tendon

hammer or, if a more controlled stimulus is required, a computer-controlled stretching device⁵⁻⁷. In the current study, a sophisticated apparatus was utilized to deliver precise profile stimulus at predetermined intervals. Significant correlations were observed between the muscle spindle response and selected vertical proportions.

The second phase of study was to utilize US for measuring masseter muscle dimensions in the same cohort and once again correlate the various dimensions of the masseter muscle to the facial proportions generated by the lateral cephalometrics. US has been studied in dentistry for over four decades and it has been established as a safe, non-invasive, comfortable and cost-effective diagnostic implement. Also, US produces high resolution images of soft tissues more readily than MRI and CT scans⁸. Among the limitations for US there is the concern about reproducibility and standardization particularly between operators. Hence, it is advisable to have a single operator for data collection in order to preclude inter-examiner variability. Future use of US in dentistry will be favoured especially where periodic evaluation is needed and there are concerns about radiation.

Finally, for a more holistic assessment, 3D optical scanning was used in the same sample cohort to analyse and correlate masseter muscle dimensions to vertical and transverse facial proportions. Regression equations were generated, albeit from the convenience sample, to explore a mathematical model for deriving variables of interest rather than physically conducting the individual measurements, particularly if that required radiation. Current work shows strong correlations between lateral cephalometric and 3D imaging variables, but relatively weak associations with the ultrasonography. The findings from this study support the use of predictive equations from 3D imaging for lateral cephalometric variables but larger scale studies are required to confirm reproducibility. Moreover, curvilinear measurements from 3D

images were significantly different ($p < 0.0001$) to the linear and should be adopted for more meaningful representation of the soft tissues.

These findings are relevant to facial form and function assessment which is used in orthodontic diagnosis and treatment planning; in particular, orthodontic functional appliance therapy. Analyses of the face can be carried out with a myriad of cephalometric packages; however, the role of the elevator muscles is often overlooked and their contribution to changes and/or characteristics that could benefit the orthodontic treatment is not fully appreciated. Thus, the assessment not only of anatomical but also physiological variations in the masseter muscles is important in the management of different facial patterns. The above tools provide a means to evaluate muscle functions which would be of particular interest in growing children and where functional orthopaedic appliances utilize forces from the muscles of mastication. Furthermore, periodic evaluation of such cases is generally desirable and needs to be safe, radiation free and cost-effective.

DECLARATION

This work contains no material which has been accepted for the award of any other degree or diploma in any university or other tertiary institution to *Shazia Naser-ud-Din* and, to the best of my knowledge and belief, contains no material previously published or written by another person, except where due reference has been made in the text.

I give consent to this copy of my thesis when deposited in the University Library, being made available for loan and photocopying, subject to the provisions of the Copyright Act 1968.

The author acknowledges that copyright of published works contained within this thesis (as listed below*) resides with the copyright holder(s) of those works.

I also give permission for the digital version of my thesis to be made available on the web, via the University's digital research repository, the Library catalogue, the Australasian Digital Theses Program (ADTP) and also through web search engines, unless permission has been granted by the University to restrict access for a period of time.

*The following papers have been generated from this research and are submitted/ or to be submitted to the journals in parenthesis:

- ◆ Modulation of Masseteric Reflexes by Simulated Mastication (**accepted Journal of Dental Research**).
- ◆ Masseter length determines Muscle Spindle Reflex excitability during jaw closing movements (submitted American Journal of Orthodontics and Dentofacial Orthopedics).
- ◆ Study of function and form for human masseter muscle with ultrasonography and lateral cephalometrics (to be submitted Investigative Radiology).
- ◆ Analysis and correlations of human masseter muscle with 3D imaging, ultrasonography and lateral cephalometrics (to be submitted American Journal of Orthodontics and Dentofacial Orthopedics).

Shazia Naser-ud-Din

June 2009

Co-Author Contributions

Prof WJ Sampson

Professor Wayne Sampson is the principal supervisor and has assisted in conceptualization and realization of the project, supporting development of the research and managing funding. He has provided pivotal support with interdisciplinary liaison, vital feedback, essential corrections and comments throughout the research project.

Dr CW Dreyer

Dr Craig Dreyer has been the co-supervisor and provided assistance with proof reading and constructive criticism of the thesis, along with reading the drafts for the publications.

Prof KS Türker

Prof Kemal Türker is co-supervisor and instrumental in the EMG study with his custom-made device. Soon after the experiments concluded he left for Turkey but has continued his supervisory role and provided valuable feedback from across the globe and on his annual visits to Adelaide.

Dr P F Sowman

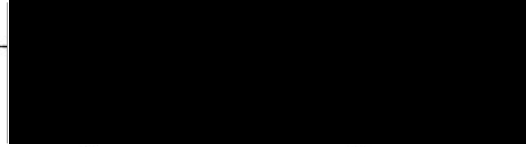
Dr Paul Sowman was a research associate with Prof Türker and has provided in depth analyses of the raw data for the study of muscle spindles. With his strong physiology background his contribution to papers on EMG have been indispensable.

Dr K Thoires

Dr Kerry Thoires provided expertise for the ultrasound investigations and has been immensely helpful with the information related to its application in orthodontics research. She helped with the ultrasound sections in the papers and her contributions are duly acknowledged.

Permission for papers to be included in Thesis

Permission for papers to be included in Thesis



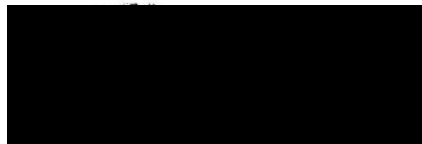
Prof WJ Sampson

Begg Chair, Orthodontic Unit, School of Dentistry, The University of Adelaide,
Adelaide, AUSTRALIA



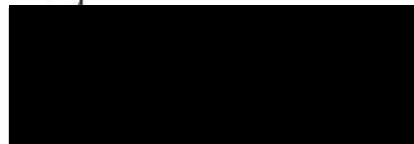
Dr CW Dryer

Orthodontic Unit, School of Dentistry, The University of Adelaide, Adelaide,
AUSTRALIA



Prof KS Türker

E.U. Center for Brain Research, Department of Physiology, Faculty of Medicine, Ege
University, Bornova, Izmir, TURKEY



Dr P Sowman

Macquarie Centre for Cognitive Science (MACCS), Macquarie University, Sydney,
AUSTRALIA



Dr K Thoires

Director Undergraduate Medical Radiation Program & Lecturer in Medical
Sonography, City East Campus, University of South Australia. AUSTRALIA

Thesis Format

This work is in accordance with the guidelines for University of Adelaide 2009 thesis by publication. This thesis is a combination of the conventional narrative and submission by publication only. Hence, there are four chapters reflecting the publications along with comprehensive literature review, aims and objectives, materials and methods followed by general discussion. Two articles have already been submitted to peer reviewed journals of which one has been accepted for publication by the Journal of Dental Research.

Dedication

This work is dedicated to my Abbi Prof Dr Naser-ud-Din whose quest for academic excellence, brilliant mind, youngest PhD at University of Peshawar, Presidential Award for Scientific endeavours in Pakistan, art of teaching with humour and simplicity inspired myself to walk his path.

The 3D chemistry model, frequent visits to the Chemistry Dept. as a toddler and young child, visiting different continents of the world with him on his post-doctoral projects, intriguing story of the benzene ring discovery ignited my passion for academia.

I am very blessed to have got this rare opportunity to be able to complete my long felt desire of doctorate and am grateful for this extraordinary journey in life.

Acknowledgements

The journey of doctorate is often challenging and cannot be achieved without the help and cooperation of supervisors, colleagues, friends and family. I am truly indebted to Prof W Sampson and Dr C Dreyer for supervision of the project, your assistance all along made the process very rewarding. Co-Supervisor Prof K Türker who gave me the opportunity to work with his testing apparatus prior to leaving for Turkey. To Dr P Sowman who was nearing the finish of PhD when I entered the program and has been a guide, mentor and inspiration. Sincere thanks to Dr M Draper for always helping out in the moment of need with e-technology and researching the library database.

Thanks are due to Dr K Thoires for assisting with Ultrasonography study and has been very accommodative of timelines. Thanks are also due to Dr A Cresswell at UQ, for providing the tangent for US and exploring the avenues. To Dr J Fricker and Scott Vallance for 3D imaging and Mona Lisa software thus adding a new dimension to the study. Thanks are due to dear Mrs S Donaldson for patience and diligence during the formatting of the thesis. Finally for all the wonderful staff at the University of Adelaide who have supported and helped out with the thesis at many different levels, Mr I Linke, Engineering Dept, Dr Nancy Briggs (statistician), Mrs L Hatch, , Mrs B Boehm, and Ms G Drexel.

Special thanks are due to dearest friend Dr J Benson (AMA doctor of the year 2009) for taking us under her wings and opening her heart and house to us after being traumatized by a break-in. A chance meeting turned into a very delightful friendship. We would like to thank all the lovely friends here in Adelaide who have made us feel at home and be our family. Their love, generosity and kindness is appreciated from the depth of our hearts.