THE PARTICLE SIZE DISTRIBUTION OF SOLID FOODS AFTER HUMAN MASTICATION

A thesis presented in partial fulfilment of the requirements for the degree of

Doctor of Philosophy

in

Food Technology

at Massey University, Auckland, New Zealand

Christine Sandra Flynn

2012

ABSTRACT

Bolus formation is a complex process for which two theories are generally accepted, both theories describe how food changes through the mastication process which results in specific properties of the bolus being detected in the mouth to initiate swallowing. This research aimed to identify how food type, portion size (2 g and 4 g) and subjects affects the fate of ingested food solids and their particle size distributions, and bolus moisture content at the swallow point. Then the dynamics of bolus formation up to and past the point of natural swallowing were investigated by the use of a single subject to identify key trends.

Trials involved up to five processed foods; subjects were asked to chew portions of food and expectorate the bolus at the point they felt ready to swallow, or to expectorate the bolus at a specific number of chewing cycles. The solids loss from the bolus and moisture content of the bolus was determined. Particle size distribution (PSD) was measured for the expectorated bolus, and the debris (solids rinsed from the mouth after the bolus).

The food type had the greatest influence on the bolus moisture content, loss of solids from the bolus and PSD of the bolus and debris fractions. Solids are lost from the bolus progressively from the first chew cycle. PSD differed significantly between the bolus and debris fractions, and the PSDs were characteristic for each food type. The rate of change in PSD appears to plateau near the swallow point for some foods, whilst moisture addition continues to increase up to and past the point of swallowing. The bolus moisture content at the swallow point was approximately 50%, despite the differences in chewing strategy between subjects. Saliva does not appear to be added at a constant rate due to no significant effect of portion size.

The results from these studies indicate that bolus does not have to meet specific particle size criteria to achieve a safe swallow, and that particles circulate in multiple compartments during mastication. Results suggest a defined moisture content is required for a safe swallow.

ACKNOWLEDGEMENTS

Thanks to my volunteers who made this research possible.

I would like to acknowledge the support and advice provided to me by Dr. Kylie Foster, Prof. John Bronlund, Prof. Roger Lentle, Prof. Jim Jones, and Mr Marco Morgenstern each of whom provided me with support in different ways throughout the course of this research. Also, Prof. Lisa Duizer for support with my initial planning, ethics and literature review.

Thanks to Plant and Food Research Ltd., who provided the funding for this research from New Zealand Foundation for Research, Science and Technology under contract C02X0401, Lifestyle Foods for Energy Balance. Thanks to Plant and Food Research staff with which I enjoyed discussions on topics from sensory to glycaemic load, statistics to lab methods: Dr. John Monroe, Virginia Corrigan, Sandra Hedderley, Duncan Hedderley, Dr. Esther Kim, Lidia Motoi and Arran Wilson. I really enjoyed being part of the wider picture in the research programme.

Massey University, Institute of Food, Nutrition and Human Health is gratefully acknowledged for assistance throughout this project. Special thanks to Garry Radford for assistance with equipment; Chris Booth for sharing her office space and a listening ear; Peter Jeffrey and Matt Levin for always sorting out any computer issues and recommending analysis packages for my various ideas; Nigel Grigg for discussions on design of experiments; Sue Pearce and Jenny Kaufmann for friendly chats and their assistance with admin and accounting. Thanks also to the library staff, DRC support, and Albany Ethics Committee.

The Biomouth Research Group and students who have passed on through the group as they have completed their studies deserve thanks for their support, encouragement and discussions. In particular, Professor Jules Kieser, for being a wonderful friendly dentist and not scaring any of my subjects during the recruitment phase. Also, thanks to Jules' former student Dr. Rob Pollard and staff at Dental Solutions Ellerslie who carried out subject's dental examinations and prepared the moulds of their teeth.

Thanks to my family and friends in the United Kingdom and New Zealand who constantly asked me whether I was finished yet. Lorna for washing up and helping me set up the lab, and both Lorna and Wendy for proofreading the thesis.

I wish to thank Dr. Amy Overington, Ms. Candice Rudelle, Ms. Shiji Nair, Palmy and Albany office mates. Special thanks to Dr. Catootjie Nalle and William who looked after me during my Palmy stay; and Suzy and Jamie who didn't mind me staying over, feeding me, or missing John when deadlines were looming.

To my dear husband Steve, many thanks for the support and encouragement you have given me throughout; the weekends spent accompanying me in the lab, and the many days (and months) alone while I worked on my thesis. We can celebrate together as this part of our journey is complete, without your support I could not have made this happen. And finally, much love to our beautiful daughter Nicola, who joined us when I was in the final writing stage of this thesis, your smiles are inspiring.

LIST OF PUBLICATIONS AND PRESENTATIONS

Peer-reviewed publications

Flynn, C. S., Foster, K. D., Bronlund, J. E., Lentle, R. G., Jones, J. R. & Morgenstern, M. P. (2011). Identification of multiple compartments present during the mastication of solid food. *Archives of Oral Biology,* 56 (4): 345-352.

Flynn, C. S., Foster, K. D., Bronlund, J. E., Lentle, R. G., Jones, J. R. & Morgenstern, M. P. (2012). Changes to bolus moisture during mastication of selected processed foods. *Food Quality & Preference – Manuscript under review*.

Conference presentations

Lawrence, C. S.*, Bronlund, J. E., Jones, J. R., Lentle, R. G., Morgenstern, M. P. & Foster, K. D. *The effect of food type on the particle size distributions of the bolus and remaining particles after human mastication.* Biomouth Symposium, Auckland, NZ, 13-14 December 2006 (*Oral presentation).

Lawrence, C. S.*, Lentle, R. G., Foster, K. D., Bronlund, J. E., Jones, J. R. & Morgenstern, M. P. *Are sensory panel descriptions related to food breakdown in the mouth?* NZIFST Conference 2007: Food – The Challenges, Wellington, NZ, 19-21 June 2007. (*Oral presentation).

Lawrence, C. S.*, Lentle, R. G., Foster, K. D., Bronlund, J. E., Jones, J. R. & Morgenstern, M. P. *An analysis of correlations between the physical outcomes of chewing and the dynamic sensory quantification of solid foods.* 7th Pangborn Sensory Science Symposium, Minneapolis, MN, USA, 12 – 16 August 2007. (*Poster presentation).

Lawrence, C. S., Foster, K. D.*, Lentle, R. G., Jones, J. R., Bronlund, J. E. & Morgenstern, M. P. *Biting off more than we can chew: the effect of portion size on food bolus properties after human mastication.* 10th European Nutrition Conference, Paris, France, 10 – 13 July 2007. (*Oral presentation).

Flynn, C. S.*, Bronlund, J. E., Foster, K. D., Jones, J. R., Lentle, R. G. & Morgenstern, M. P. *Dynamics of mastication: changes in bolus composition during mastication*. 1st Food Oral Processing Conference – Physics, Physiology and Psychology of Eating, Leeds, UK, 5 – 7 July 2010. (*Oral presentation).

Flynn, C. S.*, Bronlund, J. E., Foster, K. D., Jones, J. R., Lentle, R. G. & Morgenstern, M. P. *Mastication in a multi-compartment system: food bolus properties just before swallowing*. 1st Food Oral Processing Conference – Physics, Physiology and Psychology of Eating, Leeds, UK, 5 – 7 July 2010. (*Poster presentation).

LIST OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF NOMENCLATURE

ANOVA	Analysis of variance
BMI	Body Mass Index
CPG	Central Pattern Generators
d.p.	Decimal place
DMB	Dry Mass Basis
EMG	Electromyography
IDM_{food}	Ingested dry food solids (g)
K-S test	Kolmogov-Smirnov test
LSD	Least Significant Difference
$M_{(d)bolus}$	Mass dry bolus (g)
$M_{(d)food}$	Mass dry food (g)
$M_{(d)pellet}$	Mass dry food centrifuge pellet (g)
m.s.	mean square
M_{bolus}	Mass wet bolus (g)
MC_{bolus}	Moisture content bolus (g/100 g dry solids)
MC_{food}	Moisture content food (g/100 g dry solids)
M_{food}	Mass wet food (g)
M_{pellet}	Mass wet food centrifuge pellet (g)
M_{sample}	Mass of ingested sample (g)
MSDS	Material Safety Data Sheet
N_{chew}	Chew cycle number
P	Probability
PC	Principal Components
PCA	Principal Component Analysis
PSD	Particle Size Distribution
SEM	Standard Error of the Mean
S_{insol}	Insoluble solids (%)
S_{loss}	Bolus solids loss (g/100 g dry solids)
S_{sat}	Saturated solids (g/100 g dry solids)
S_{sol}	Soluble solids (%)

t_{chew}	Chewing time (s)
TMJ	Temporomandibular Joint
TPA	Texture Profile Analysis
VFG	Videofluorography
WHC	Water holding capacity
WMB	Wet Mass Basis
ΔMC_{bolus}	Change in moisture content of the bolus (g)
υ_{chew}	Chewing frequency (1/s)