MASSEY UNIVERSITY
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MODELLING FOOD BREAKDOWN AND BOLUS FORMATION DURING MASTICATION

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ABSTRACT

Mastication is a complex process that transforms food into a bolus which can be swallowed safely. However, it can be simplified within an engineering context, where the mouth is the equipment carrying out a unit operation to convert ingested food (raw material) into a safe-to-swallow bolus as the process output. Two questions emerge from this observation (i), 'What processes transform the food from its initial state into a bolus?' and (ii), 'How do humans assess when the food is ready to initiate swallowing?' This research examines these questions and a mathematical model is developed which can track the bolus properties during mastication.

A range of common foods with contrasting textures were examined in an observational study to investigate the rate processes of mastication. A wide range of breakdown pathways and textures were observed, from the brittle fracture of carrots to the work softening of a fibrous beef steak. However, despite differences in their structure and properties, breakdown is dominated by a small number of rate processes. Size reduction and work softening occur at occlusion and account for majority of the structural breakdown. Absorption, dissolution and melting are generally more subtle. These are facilitated by mixing, which is the circulation, gathering, folding and placement of food on the occlusal plane.

Mechanical sensory testing (MST) occurs simultaneously to breakdown as the food is manipulated around the mouth during occlusion and between chews. During occlusion this provides gross information about the toughness and hardness, whereas between chews the tongue-palate interactions provide more detailed information about yield and flow. These MST's assess the properties of volume, adhesion, bolus deformation, particle deformation and particle size. Adhesion refers to the binding forces between the food particles and the oral surfaces. Bolus deformation is important for boluses that do not contain individual particles. If they do then swallowability is constrained by their size and individual deformability.

In order for safe swallowing, thresholds for each of the MST properties must be met. These were justified using a *hazard and operability* study of swallowing, on the premise that attempting to swallow a bolus which does not meet the threshold property could result in aspiration or choking. As mastication proceeds, the properties assessed by the MST's are evaluated against the required threshold properties and contribute to the decision making process of whether to swallow or continue chewing.

From this analysis, this work proposes a universal conceptual model of mastication that combines the rate processes, the MSTs and a decision making model. The conceptual model was then described mathematically. It is universal, that is, it is not specific to any food type, because solid foods follow similar physical breakdown paths where occlusion is of primary importance followed by the incorporation of saliva and the other rate processes. Model parameters require *in-vivo* experiments about the breakdown dynamics of specific foods. Subject variability was avoided by using single subject studies for three separate foods; brown rice, a sweetened gelatine gel and peanuts embedded in a food matrix. Each case study explored a limited number of rate processes and food properties. Bolus properties predicted by the model were compared to the experimental data. The output of the model, including particle size distribution and moisture content, closely matched the data during mastication and at swallow point using input parameters fitted from the single subject experiments.

This work provides a platform for further research into mastication modelling. It is recommended the mathematical model be expanded to mechanistically describe the mixing and work softening of non-particulate food boluses. Additional experimental work would achieve a better understanding of the heat transfer in the mouth which would improve the models ability to handle heat sensitive foods.

The model developed here has the potential to aid future food design where a particular breakdown pathway is desired and will reduce the number of time intensive *in-vivo* experiments needed.

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Lastly, it would be remiss of me not to end this section with some noble insight or pearl of wisdom. Therefore, I leave you with this. There are two types of people in the world, those who can extrapolate from incomplete data sets.

Warning: This thesis may contain traces of nuts!

LIST OF PUBLICATIONS AND PRESENTATIONS

Refereed conference papers:

Gray-Stuart E., Jones, J. R., Bronlund, J. E., & Morgenstern, M. P. (2012) Rate processes during mastication important for modelling mastication. In: *Chemeca 2012*. Wellington, New Zealand 23-26 September 2012.

Gray-Stuart E., Jones, J. R., Bronlund, J. E., & Morgenstern, M. P. (2012) Control loops in mastication: whether to keep chewing or prepare for swallowing. In: *Chemeca 2012*. Wellington, New Zealand 23-26 September 2012.

Gray-Stuart E., Jones, J. R., Bronlund, J. E., Moongngarm, A., & Morgenstern, M. P. (2011) A discrete population balance to simulate the particle size distribution in a bolus of chewed rice. ICEF 2011, Athens, Greece.

Conference presentations and posters:

Gray-Stuart. E., J R Jones., Bronlund, J.E. and Morgenstern. M. Modelling the Food During Mastication. Oral presentation, Food Oral Processing, Wageningen, 29th Jun - 2nd July 2014.

Gray-Stuart E., Jones, J. R., Bronlund, J. E. A mathematical model to simulate the breakdown of a gelatine based gel during chewing (2010). Oral presentation, International Conference on Food Oral Processing, 5-7 July 2010, Leeds, UK

Gray-Stuart E., Mongngarm, A., Jones, J. R., Bronlund, J. E. (2010). A conceptual model of particle size reduction during chewing of brown rice. Poster presentation, International Conference on Food Oral Processing, 5-7 July 2010, Leeds, UK

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES