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Symposium 3: Dietary factors in energy metabolism

Oral processing in elderly: Understanding eating capability to drive future food texture modifications

Anwesha Sarkar*

Food Colloids and Bioprocessing Group, School of Food Science and Nutrition,
University of Leeds, Leeds LS2 9JT, UK

*Corresponding author:
Dr. Anwesha Sarkar
Food Colloids and Processing Group,
School of Food Science and Nutrition, University of Leeds, Leeds LS2 9JT, UK.
E-mail address: A.Sarkar@leeds.ac.uk (A. Sarkar).
Tel.: +44 (0) 113 3432748.

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Abstract

Ageing population suffer from increased risk of malnutrition which is a major determinant of accelerated loss of autonomy, adverse health outcomes and substantial health-care costs. Malnutrition is largely attributed to reduced nutrient intake, latter may be associated with several endogenous factors, such as, decline of muscle mass, oral functions and coordination that can make the eating process, difficult. From an exogenous viewpoint, nutritionally-dense foods with limited innovations in food texture have been traditionally offered to elderly population that negatively affected pleasure of eating and ultimately, nutrient intake. Recent research has recognised that older adults within the same age group are not homogenous in terms of their preferences, nutritional needs, capabilities and impediments in skill-sets. Hence, a new term 'eating capability' has been coined to describe various quantifiable endogenous factors in the well-coordinated eating process that may permit characterisation of the capabilities of elderly individuals in food handling and oral processing. This review covers current knowledge on eating capability focusing on parameters, such as hand and oro-facial muscle forces. Although limited in literature, eating capability score measured using a comprehensive toolkit has shown promise to predict eating difficulty perception and oral processing behaviour. Further systematic studies are required to explore relationships between individual/multiple constituents of eating capability and oral comfort. Such knowledgebase is needed to underpin the creation of next generation of personalised texture-modified foods for elderly population using sophisticated technologies, such as 3D printing to enhance eating pleasure, increase nutrient intake that will ultimately contribute to tackling malnutrition.

Globally, the age demographic structure is changing with a rapid rise in the ageing population. Presently, 0.9 billion people in the world are 60 years or older and this population is projected to rise to 2.1 billion by 2050 (1). In the UK, there is an increase in the older population with 18% aged 65 and over and 2.4% aged 85 and over. Malnutrition (in this review, we only refer to "undernutrition") is a common clinical and public health challenge, particularly in older adults that results in accelerated loss of independence, compromised quality of life, adverse health conditions leading to increase in hospital admissions, length of stay, as well as hospital readmission following discharge. Nearly, 1.3 million people aged 65 years and over suffer from malnutrition in UK, whilst 93% of those affected are reported to live in the community (2; 3). Malnutrition poses a major economic threat to UK healthcare, with an estimated cost of over £10 billion in England in 2011–12 (3). Elderly malnutrition is multifactorial and is generally associated with 'anorexia of ageing' i.e. lack of appetite and reduced nutrient intake (4; 5).

Besides ageing related physiological changes in gut and onset of early satiety (6), such reduced nutrient intake in elderly individuals is directly or indirectly associated with progressive loss of muscle mass, decline of oral functions and coordination capabilities, all of which partly or as a whole affect the intricate process of eating (7; 8; 9). These complex physiological age-related changes are not yet fully understood but are thought to be related to lifelong accumulation of impairments at molecular, tissue and organ level. Although the process of eating is often underestimated, it involves a systematic series of well-coordinated unit operations, such as opening a package, lifting objects, cutlery manipulation, transporting the food to the mouth, closing the mouth, chewing, saliva incorporation, bolus formation and swallowing. An older adult may find difficulties in executing one or more of these important unit operations in the overall eating process that can result in reduced food intake. Indeed, there has been vast amount of literature on dysphagia (swallowing disorder) (10; 11; 12), however, focussing only on swallowing can underestimate the challenges that one might face during the entire eating process, such as transporting food to mouth.

For this reason, a new term 'eating capability" has been coined by Laguna et al. (2015)(8) and Laguna and Chen (2016) (9) to collectively represent a healthy individual's endogenous capability that is directly or indirectly associated with food handling and oral management. The individual parameters needed for the eating process can probably be grouped into the following four categories: i) hand manipulation, ii) oral manipulation, iii) oral sensation and iv) cognition and coordination capabilities (Fig. 1). Under-representation of such quantitative capabilities might not be always linked to age-dependent physiological decline that has somehow been over-emphasised in literature (13) but may be also associated with particular conditions, such as chronic diseases, multiple morbidity conditions or polypharmacy (Fig. 1). This review paper will explore the present data on eating capability, its individual constituents, eating capability score and how these capabilities are linked.

We will specifically focus on hand capabilities (hand gripping force, finger force, finger touch sensitivity) and oral capabilities (bite force, tongue pressure, lip sealing pressure) with reference to the diagnostic devices (Fig. 2) that are used for their quantitative measurements. Detailed reviews on other endogenous factors, such as salivary quantity and quality (14) and taste modification (15) are reported elsewhere.

From an exogenous viewpoint, nutritionally-dense foods have been traditionally offered to older adults with little emphasis on the texture and associated pleasure of eating these food items that can affect food consumption. In particular, such foods are mostly ‘pureed’ and have been designed without taking into account the individual needs and abilities of older adult consumers. Hence, this review will discuss how one’s eating capability measure can be used as objective ‘data inputs’ to design personalised food with tailored textural properties that can act as an ‘enabler’ to ensure safe food consumption and optimise food intake by an individual elderly consumer (Fig. 1). In this review, we will especially emphasise two key research works (8; 16) carried out in our laboratory with elderly individuals aged 65 years and older within the frame of EU FP7 Project OPTIFEL (2014-17). This is because these were the first two experimental works that have formalised eating capability for older adults, calculated eating capability scores to cluster older adults into capability-based ‘archetypes’ and have shown promising results for the prediction of eating difficulty perception and real oral processing behaviour.

Age-related change in measures of eating capability

Hand gripping force, finger force and finger tactile threshold

For hand capability measurements, the hand gripping force is an important parameter that is a reliable indicator of upper limb function, general muscle strength and health status. Hand gripping force has been frequently used a diagnostic parameter in clinical studies (17; 18). This objective measure can give useful information about an individual’s ability to do a range of unit operations effectively in the eating process, such as holding a coffee mug, opening a jam jar, grasping an apple to lift it and transport it from the plate to mouth. Hand gripping force is measured using an adjustable handheld dynamometer (Fig. 2a) (9) that is squeezed by the older adults with maximum effort for a few seconds with elbow flexed at 90 degrees and forearm, wrist in relaxed position. Bohannon et al. (2006) (19) presented a multinational meta-analysis of the normative values for hand grip strength obtained with this dynamometer from 12 studies (3317 subjects) and concluded that age group, gender, tested side (left or right hand), affected the hand gripping force. The mean right hand values for people aged 65 years and older were 28-41.7 kg and 18-24.2 kg for males and females, respectively, as compared to younger adults aged 20-40 years (53.3-54.1 kg and 30.6-33.2 kg for males and females, respectively). In a recent study conducted on eating capability (8), we measured right hand gripping force in healthy

British and Spanish older adults (203 subjects) and demonstrated that although age had an influence on reduction of hand gripping strength, the decline was prominent only in participants above 80 years (Fig. 3a). Interestingly, these values were in line with normative data for the functional grip strength of elderly population in a Singapore population (233 subjects) measured using a custom-made hand strength measurement device.

Finger force is an equally important parameter as decline in finger dexterity might impact one's ability to perform the eating process effectively, such as, cutlery manipulation, pulling the lid of a packaged yogurt or ready meal's foil lid, holding a cracker or a biscuit to transport it to mouth. We measured finger gripping force in older adults (8) using a thin flexible force transducer connected to a multimeter with neoprene disc (Fig. 2a), the latter was squeezed by the elderly subjects with their thumb and index finger to record resistance. This resistance is converted into finger grip force using appropriate calibration. Based on results from 203 elderly subjects (8), it can be observed that finger force decreased with age (Fig. 3a), however, the relationship was not definitive. In fact, this result contradicts previous literature (20), where it has been proposed that elderly subjects generally produce more finger grip force in excess of the slip force (the "margin of safety" needed to prevent slipping of an object) to compensate for the reduced friction and tactile sensitivity. Besides evaluating finger grip force, researchers have emphasised the importance of tangential lift i.e. load force to the grip surface (21) as well as tangential torques (22). The finger grip-to-load force balance has been proposed to be automatically adjusted to a given finger-surface frictional condition. In other words, finger grip-to-load force balance is known to be largely associated with age-related changes in the surface properties of skin (23). As ageing progresses, the skin becomes drier with reduction in skin hydration of the outermost layer that may in turn reduce the friction at the contact surfaces between the object and the finger. Thus, an elderly person might exert more finger grip force to hold the object to compensate for the decline in the friction force. Noteworthy that the friction coefficient is not an intrinsic property of the skin but is highly dependent on the material chemistry and microgeometry of the surfaces, such as plastic, metals, glass, fabric with which the skin is in contact (24). For instance, the average friction coefficients can be low and range from 0.27 to 0.7 when skin comes in contact with textile materials (24). On the other hand, considerably high friction coefficients of skin can be encountered against dry, smooth glass (2.18±1.09; range: 0.39–5) whereas lower coefficients on wet smooth glass (0.61±0.37; range: 0.07–2.12). Hence, it is important not only to understand the finger grip force but also to examine the friction force against a variety of surfaces which an older adult may encounter.

Finger tactile sensitivity is crucial for identifying food texture and can lead to food rejection. Older adults often suffer from marked degradation in tactile sensitivity as a function of normal ageing process that can result in slipping objects. In other words, the mechanoreceptor tactile thresholds may increase with ageing. Finger tactile sensitivity measurements is generally measured using Semmes-Weinstein Monofilament test (Fig. 2c). The monofilament of different forces is pressed in perpendicular direction against the surface by elderly participants and the first monofilament that is detected by the participant is recorded as the tactile threshold. Thornbury et al. (1981) (25) suggested that touch sensitivity decreases i.e. the threshold increases with age significantly. However, in touch sensitivity trial conducted in our laboratory (8), most of the elderly individuals had a relatively low threshold and most participants were able to detect < 0.16 g of force (Fig. 3c). And, tactile sensitivity did not correlate with age or gender, but was largely associated with some health conditions, such as arthritis, Parkinson.

Bite force, tongue pressure and lip sealing pressure

Optimum oro-facial muscle force involving lips, tongue and teeth are of central importance to a normal eating process. Once the food is consumed, it is accommodated inside the mouth with lip closure, chewed by exerting appropriate bite force to experience the texture of the product and subsequently reduce the structural size of the ingested food, dilution and lubrication by saliva, compression between the tongue and oral palate by a range of tongue forces and other orofacial muscular forces followed by swallowing of the bolus (26; 27; 28). Consequently, any decline in oro-facial muscular capability can directly affect one's eating process and in turn reduce food intake.

Maximum bite force is used as a capability measure, which can directly influence fragmentation of food, chewing and mastication. To ensure safe food mastication, one's bite force should be higher than the yield force require to fragment a food material. For instance, a food with a yield force of 100 N, may be sensed as soft by a person who can exert 300 N force, but will be perceived as hard and almost not friable to the one who could only apply a maximum of 110 N (29). In general, bite force is measured using a flexible transducer (Fig. 2d) that is placed between a pair of teeth (30), similar to the sensor used for finger force measurement. We demonstrated that bite force decreased with age (Fig. 3d), however, influence of preserving natural teeth was the deterministic factor for higher bite force as compared to that of the age (8). This is in line with previous studies, where bite force was significantly smaller among the denture wearers than among the dentate persons (31). In other words, the greater number of natural teeth, greater is the bite force and ease of food mastication. Another study conducted with 850 independently-living people over the age of 60 years, also postulated that tooth loss is not a consequence of physiological ageing but pathological ageing, and thus, reduction of bite force cannot be considered as a natural effect of ageing (32).

During the process of swallowing, the tongue positions the food bolus and plays a critical role in the propulsion of the bolus with the help of tongue pressure arising from its contact against the hard palate (33; 34). Obviously, optimal swallowing performance requires the complex movements of the tongue to transport the bolus safely and efficiently. Maximum isometric tongue pressure can be measured using a simple clinical device with a disposable tongue bulb (Fig. 2e) that can be placed in the mouth between the tongue and the palate, which is linked to a pressure transducer recording the maximum tongue-palate isometric pressure. Unlike other oro-facial muscle forces, tongue pressure parameter has emerged as a measure of considerable clinical and research interest in the field of dysphagia over the past two decades (35). Lip closure is another crucial oral function that helps to retain the food or beverages inside the mouth. This is even more critical during swallowing when the pressure is elevated within the oral cavity (9). The lip sealing capability can be measured by quantifying the magnitude of maximal closing force that is held between the upper and lower lips using the same sensor that is used to measure tongue pressure (Fig. 2e). Both tongue and lip sealing pressure showed no correlation with age increment in the study conducted with 203 elderly participants (Figs. 3 e and f) (8). A recent study with 201 older adults aged ≥ 65 years demonstrated that magnitude of tongue and lip pressure were inversely correlated with food intake (36). The same group of authors conducted a cross-sectional study (37) with 174 older adults aged 65 years and older in rehabilitation and demonstrated that isometric tongue strength was associated with nutritional status assessed (β-coefficient = 0.74, 95 % CI 0.12–1.35, p = 0.019), latter was assessed using mini nutritional assessment. It is worth pointing out that tongue plays a crucial role in controlling the flow of food-saliva mixture (bolus) and fragments of, within the oral cavity as well as swallowing. Tongue plays a series of well-coordinated roles in mastication and swallowing by controlling the pressure against the hard palate (38). Decreased tongue strength and consequently tongue pressure exerted against the oral palate can result in limited or abnormal transportation of the food bolus to the oesophagus, which can lead to aspiration, oral residues, longer meal times, and finally low food consumption (37). Overall, this suggests that objective eating capability measures can be used not only to understand health status but also to get indications about nutrient intake. Also, focussing on objective eating capability measure rather than age might help to design personalised food for elderly, however, the research evidences in this area is at its infancy and expected to grow considering the rapid rise in ageing population and associated malnutrition challenges.

Relationship between hand and oro-facial muscle forces

Although oro-facial muscle force measures can be directly useful to understand effectiveness to perform oral functions and eating process, a major issue is that many of these devices are not easy to use in care homes. Hence, studies have been attempted to understand whether hand grip strength can be used as an indirect measure for oral functions. For example, Sakai et al. (2017) (37) conducted a multivariate linear regression analysis and revealed that isometric tongue strength was correlated with grip strength (β-coefficient = 0.33, 95 % confidence interval (CI) 0.12–0.54, p = 0.002) in older adults.

Similarly research work in our laboratory (8) also demonstrated strong linear relationships between hand-gripping strength and most of the oro-facial muscle forces (bite force, tongue pressure, lip sealing pressure) in UK (Fig. 4a) and Spanish (Fig. 4b) subjects (except for lip sealing pressure, where it was a polynomial relationship in the latter). A related study was conducted in 381 persons older adults aged 67–74 years to understand the relationship between hand grip strength and self-reported chewing ability (39). The masticatory ability was classified into three groups: 1) ability to chew all kinds of food, 2) slightly hard food and 3) only soft or pureed foods. As can be expected, handgrip strength was significantly lower in those individuals who could chew only soft or pureed food than in those individuals who could chew all kinds of food inferring that chewing ability was significantly related to handgrip strength after adjusting for the skeletal muscle mass, dentition status and background factors. In another study in Japan (40) with independent 159 community-dweller elderlies of 65 years old and above showed that maximum occlusal force was significantly correlated with the handgrip strength ($r = 0.382$, $p < 0.01$), All these observed relationships between hand grip and oro-facial muscle strengths indicate possibilities of using hand gripping force by the carers as a non-invasive parameter to predict oral functions.

Eating capability (EC) score

The literature on elderly population have mostly examined a defined older group and compare their behaviour with younger groups. However, it must be recognised that elderly population of 65 years and older are not homogenous in their needs, expectations, capabilities and frailty within the same age group. For example, a recent European survey (Finland, France, Poland, Spain and United Kingdom) was conducted with over 400 elderly people aged 65 years and older and they were categorised into three groups based on their different levels of dependency (category 1: participants living at home needing help for food purchasing; category 2: participants living at home needing help for meal preparation or meal delivery; category 3: participants living in nursing homes/ sheltered accommodation) (41; 42). Laguna et al. (2016) (42) suggested that category 1 participants did not perceive difficulties during meal preparation and reported some level of difficulties in hand manipulation and oral processing (<30%), whereas the ~ 60% of older adults in categories 2 and 3 suffered from such eating difficulties. Besides these self-reported studies, structured protocols of observation of meals have been used to detect eating difficulty (43; 44). For instance, Jacobsson et al. (2000) (44) used observational experiments together with video-recording and interviews during meal consumption in a small group of older adults aged 70 years and older to understand eating difficulties. Authors reported not only swallowing-related difficulties but also other issues in terms of preparing and transporting the food to the mouth. As one might recognise, assessment of capability of an individual has been largely based on subjective measurements traditionally.

Hence, a composite score termed as ‘eating capability score’ was developed (7; 8; 16) that can serve as a reliable multifactorial objective score to categorise elderly populations into different groups based on their individual abilities rather than age. To do the same, five measurable parameters i.e. right hand gripping force, right hand finger gripping force, finger tactile threshold, bite force, tongue pressure) were selected to calculate a composite eating capability (EC) score (equation 1) (8), where each of these parameters was normalised versus the strength of the strongest participant within that measured parameter:

$$EC\ score = \left(\frac{RH_{Par}}{RH_{Str\ Par}}\right) + \left(\frac{RF_{Par}}{RF_{Str\ Par}}\right) + \left(\frac{TS_{Par}}{TS_{Str\ Par}}\right) + \left(\frac{BF_{Par}}{BF_{Str\ Par}}\right) + \left(\frac{TP_{Par}}{TP_{Str\ Par}}\right) \qquad (1)$$

where, RH is the right hand gripping force (kg), RF is the right hand finger gripping force (kg), TS is the tactile sensitivity threshold (g), BF is the bite force (kg), TP is the tongue pressure (kPa), subscripts $_{Par}$ and $_{Str\ Par}$ represent the individual and strongest individual scoring the highest in that particular test, respectively. The EC score was used to characterise participants from weakest to strongest in groups i.e. participants with EC ≤ 2 were placed in group one (the weakest group); participants with EC > 2 and ≤ 4 were placed in group two, and so on (8).

The EC score was further updated using equation (2) considering the importance of coordination capability (7; 16), importance of both right and left hand forces rather than just right hand force as used in equation (1) and removing the less reproducible parameters from equation (1), such as finger force and tactile sensation:

$$EC\ score = \frac{\left(\frac{RH_{Par}}{RH_{Str\ Par}}\right)+\left(\frac{LH_{Par}}{LH_{Str\ Par}}\right)}{2} + \left(\frac{BF_{Par}}{BF_{Str\ Par}}\right) + \left(\frac{TP_{Par}}{TP_{Str\ Par}}\right) + \frac{\left(\frac{RD}{RD_{Str\ Par}}\right)+\left(\frac{LD_{Par}}{LD_{Str\ Par}}\right)}{2} \qquad (2)$$

where, LH is the left hand gripping force (kg), RD is the right hand dexterity count and LD is the left hand dexterity count (using manual dexterity kit). The role of EC score on difficulty perception and oral processing of real food and gels is discussed in the next section.

EC score as predictor of eating difficulty perception/ real-life oral processing behaviour

To understand the application of eating capability, tests (45) were conducted with 11 young subjects with a range of food with different textural complexity to understand if individual physical forces (hand or oral forces) were important to understand food difficulty perception. Interestingly, no relationship could be established between individual’s dominant hand grip force, isometric tongue pressure, bite force and food perception difficulty for the young participants. This was attributed to the selected young population having significantly higher hand force/tongue force ratio, which might not interfere with their eating process. It appeared obvious that eating capability measurement might be more useful for the elderly population, where one or more capability parameters can be limiting. To understand the relevance of EC score for elderly participants, Laguna et al. (2015) (8; 46) grouped British and Spanish participants into four independent groups based on EC score using equation (1) and older adults rated food images on how difficult they perceived them to be manipulated by hand (e.g. cutlery manipulation, cutting or lifting the food) or in mouth (e.g. chewing, biting, swallowing). It was demonstrated that participants from the weakest EC groups having composite EC score less than 6.64 perceived fibrous and hard food products significantly more difficult to eat than participants with higher EC score (9.95). This strongly suggested that EC score can be an input feature for personalised food product design for the elderly population.

To validate whether eating capability concept holds promise for predicting eating difficulty in real-life food oral processing scenarios i.e. chewing cycles, bolus-swallowing time (16) rather than subjective perception as studied previously (8), 31 elderly subjects were asked to eat model and real foods. These model foods were hydrogels (47) that were designed in our laboratory with different degrees of inhomogeneity (i.e. the inclusion of different sizes of calcium alginate microgel particles to a κ-carrageenan continuous network). As can be observed in Fig. 5a (16), the number of chews needed to fracture the gels did not correlate significantly with the instrumental hardness of the gels. The gels chosen were harder than the food products (Fig. 5b). However, when the maximum force at break was similar, the time in mouth was dependent on the food structural heterogeneity, and the time in mouth increased with the heterogeneity increment (e.g. number of beads). In this study, it was demonstrated that although EC score allowed grouping of the elderly participants it was not suitably stratified and all the groups had relatively low EC score with the most capable group having EC score of 3.23. The EC score was not sufficiently correlated to real eating difficulty perception. Interestingly, the bite force was the key discriminating parameter in distinguishing bite, oral processing time, number of chews, and preference. This suggests a non-composite scoring system beyond EC score, such as an individual measure (e.g. bite force or tongue pressure) may be more important in predicting eating difficulty, however this cannot be generalised at this early stage. Also, it is worth pointing out that EC score might require further refinement to categorise elderly individuals of similar capability into independent groups that can be beneficial to develop the creation of food of just-right texture and desired oral processing properties (chew cycles, swallowing time). Besides eating capability, another concept termed as “oral comfort” has also been coined (48) recently that covers multidimensional oral sensations perceived by older adults including ease of chewing, humidifying and swallowing as well as oral pain sensations that might occur due to decline in oral comfort, for e.g., oral comfort may be lower for dry textures. Oral comfort has been defined using a set of factors determined from a discriminable questionnaire. Future work is needed to explore the relationship between oral health, oral comfort and eating capability to generate a clear brief for food design for older adults from texture viewpoints.

Future perspectives on food texture modification

In general, texture modified foods designed for the elderlies are the foods that are softened by processing, such as pureed as well as liquids that have been modified in viscosity to various extents by physical or chemical means (49). Since, the rationale behind such softer food development is to address dysphagia patients, the main textural parameters used for such texture modified food design includes hardness (hard to soft) and cohesiveness (ability of food particles to stick to each other to form a swallowable bolus) (50). However, it has been elucidated that not only endogenous factors such as bite force, and exogenous factors such as consistency (hardness) of food but also the heterogeneity of the matrix affect food oral processing behaviour (number of chews and time in mouth) (8). This suggests that optimised food design for the elderly should not only focus on just-right texture but also attempt just-right structural heterogeneity that can act as an enabler to increase food intake in people with low EC score or reduced individual eating capability measures (Fig. 1).

Besides modifying viscosity by using thickeners, one of the strategies that can be used to create pleasurable texture can be to use microgel particles as discussed previously with calcium alginate particles. Such soft microgel particles made up of alginate, whey protein or starch with or without oil can be used not only to have an impact on increasing viscosity but also to modify the lubrication aspects of the food (47; 51; 52; 53; 54; 55) for older adults, who generally suffer from dry mouth conditions due to lack of secretion of bio-lubricant saliva (14; 28). Besides textural properties, such microgel particles can be used to modify food structural complexity and also to encapsulate and deliver essential fat soluble vitamins, such as vitamin D, which is much needed for older adults suffering from vitamin D deficiency or insufficiency (56).

It is well known that pureed foods are often associated with a decreased food intake due to the unpleasant changes in appearance, texture and mouthfeel and thus may result in increased incidences of malnutrition (57). Hence, there has been increased research efforts to convert pureed foods into a three-dimensional (3D) forms via appropriate viscosity enhancement and moulding so that the food resembles its natural shape. Studies (58; 59) have demonstrated that using a moulded smooth puree diet can increase nutrient intake as compared to the non-moulded pureed version in a nursing home setting. Recently, texture modification has achieved attention due to recent advancements in sophisticated technologies, such as 3D printing and food-grade printable materials for innovative food textural design (60; 61). In particular, scientists in EU Project PERFORMANCE have developed customised nutrition of the elderly using 3D printed food, where the pureed food is endowed with ‘the best clone possible’ i.e. transformed into its original shape via jet printing technology, providing the same texture and appearance, with added health benefits. Although this is still in the early stages of development, 3D printing can be immensely useful to design precision foods with just-right texture and just-right structure created with optimised nutrient levels for elderly population with known eating capability.

In summary, eating capability is a relatively recent undertaking in elderly food management. There are still large gaps in knowledge related to ageing and eating capability and the role these may play in predicting oral functions and ultimately oral comfort and eating difficulty. As our ageing population increases, more research studies may help us to better understand those capabilities, irrespective of age groups within the elderly population. Ultimately, such data inputs from eating capability measures should be used to drive objective food texture modifications using sophisticated technologies, such as 3D printing in order to design personalised food and optimise food intake rather than designing ‘blanket’ unplesurable pureed food for the entire elderly population.

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Conflict of Interest

None.

Authorship

The author had sole responsibility for all aspects of literature search and preparation of the paper.

References

1. UN (2017) World Population Ageing - Highlights (ST/ESA/SER.A/397). NewYork, US: United Nations, Department of Economic and Social Affairs.

2. Russell CA, Elia M (2011) Nutrition screening survey in the UK and Republic of Ireland in 2011. UK: A Report by the British Association for Parenteral and Enteral Nutrition (BAPEN).

3. Elia M (2015) The cost of malnutrition in England and potential cost savings from nutritional interventions (short version). UK: A report on the cost of disease-related malnutrition in England and a budget impact analysis of implementing the NICE clinical guidelines/quality standard on nutritional support in adults. A Report by the British Association for Parenteral and Enteral Nutrition (BAPEN) and the National Institute for Health Research (NIHR) Southampton Biomedical Research Centre.

4. Soenen S, Chapman IM (2013) Body weight, anorexia, and undernutrition in older people. *Journal of the American Medical Directors Association* **14**, 642-648.

5. Malafarina V, Uriz-Otano F, Gil-Guerrero L *et al.* (2013) The anorexia of ageing: Physiopathology, prevalence, associated comorbidity and mortality. A systematic review. *Maturitas* **74**, 293-302.

6. Britton E, McLaughlin JT (2012) Ageing and the gut. *Proceedings of the Nutrition Society* **72**, 173-177.

7. Laguna L, Sarkar A, Chen J (2017) Chapter 10 - Eating capability assessments in elderly populations. In *Nutrition and Functional Foods for Healthy Aging*, pp. 83-98 [RR Watson, editor]: Academic Press.

8. Laguna L, Sarkar A, Artigas G *et al.* (2015) A quantitative assessment of the eating capability in the elderly individuals. *Physiology & Behavior* **147**, 274-281.

9. Laguna L, Chen J (2016) The eating capability: Constituents and assessments. *Food Quality and Preference* **48**, 345-358.

10. Cichero JAY, Steele C, Duivestein J *et al.* (2013) The need for international terminology and definitions for texture-modified foods and thickened liquids used in dysphagia management: Foundations of a global initiative. *Current Physical Medicine and Rehabilitation Reports* **1**, 280-291.

11. Marcason W (2017) What is the international dysphagia diet standardisation initiative? *Journal of the Academy of Nutrition and Dietetics* **117**, 652.

12. Geeganage C, Beavan J, Ellender S *et al.* (2012) Interventions for dysphagia and nutritional support in acute and subacute stroke. *Cochrane Database Syst Rev.*

13. Rowe JW, Kahn RL (1987) Human aging: Usual and successful. *Science* **237**, 143-149.

14. Xu F, Laguna L, Sarkar A (2018) Ageing related changes in quantity and quality of saliva: Where do we stand in our understanding? *Journal of Texture Studies* **0**.

15. Methven L, Allen VJ, Withers CA *et al.* (2012) Ageing and taste. *Proceedings of the Nutrition Society* **71**, 556-565.

16. Laguna L, Hetherington MM, Chen J *et al.* (2016) Measuring eating capability, liking and difficulty perception of older adults: A textural consideration. *Food Quality and Preference* **53**, 47-56.

17. Sasaki H, Kasagi F, Yamada M *et al.* (2007) Grip strength predicts cause-specific mortality in middle-aged and elderly persons. *The American Journal of Medicine* **120**, 337-342.

18. Roberts HC, Denison HJ, Martin HJ *et al.* (2011) A review of the measurement of grip strength in clinical and epidemiological studies: towards a standardised approach. *Age and Ageing* **40**, 423-429.

19. Bohannon RW, Peolsson A, Massy-Westropp N *et al.* (2006) Reference values for adult grip strength measured with a Jamar dynamometer: a descriptive meta-analysis. *Physiotherapy* **92**, 11-15.

20. Cole KJ (1991) Grasp force control in older adults. *Journal of Motor Behavior* **23**, 251-258.

21. Goodwin AW, Jenmalm P, Johansson RS (1998) Control of grip force when tilting objects: Effect of curvature of grasped surfaces and applied tangential torque. *The Journal of Neuroscience* **18**, 10724-10734.

22. Kinoshita H, Bäckström L, Flanagan JR *et al.* (1997) Tangential torque effects on the control of grip forces when holding objects with a precision grip. *Journal of Neurophysiology* **78**, 1619-1630.

23. Diermayr G, McIsaac TL, Gordon AM (2011) Finger force coordination underlying object manipulation in the elderly – A mini-review. *Gerontology* **57**, 217-227.

24. Derler S, Schrade U, Gerhardt LC (2007) Tribology of human skin and mechanical skin equivalents in contact with textiles. *Wear* **263**, 1112-1116.

25. Thornbury JM, Mistretta CM (1981) Tactile sensitivity as a function of age. *Journal of Gerontology* **36**, 34-39.

26. Sarkar A, Ye A, Singh H (2016) Oral processing of emulsion systems from a colloidal perspective. *Food & Function* **8**, 511-521.

27. Sarkar A, Singh H (2012) Oral behaviour of food emulsions. In *Food Oral Processing*, pp. 111-137. Oxford, UK: Wiley-Blackwell.

28. Laguna L, Sarkar A (2017) Oral tribology: update on the relevance to study astringency in wines. *Tribology - Materials, Surfaces & Interfaces* **11**, 116-123.

29. Chen J (2009) Food oral processing—A review. *Food Hydrocolloids* **23**, 1-25.

30. Koc D, Dogan A, Bek B (2010) Bite force and influential factors on bite force measurements: A literature review. *European Journal of Dentistry* **4**, 223-232.

31. Helkimo E, Carlsson GE, Helkimo M (1977) Bite force and state of dentition. *Acta Odontologica Scandinavica* **35**, 297-303.

32. Ikebe K, Nokubi T, Morii K *et al.* (2005) Association of bite force with ageing and occlusal support in older adults. *Journal of Dentistry* **33**, 131-137.

33. Stone M, Shawker TH (1986) An ultrasound examination of tongue movement during swallowing. *Dysphagia* **1**, 78.

34. Ono T, Hori K, Nokubi T (2004) Pattern of tongue pressure on hard palate during swallowing. *Dysphagia* **19**, 259-264.

35. Steele CM (2013) Optimal approaches for measuring tongue-pressure functional reserve. *Journal of Aging Research* **2013**, 7.

36. Sakai K, Nakayama E, Tohara H *et al.* (2017) Relationship between tongue strength, lip strength, and nutrition-related sarcopenia in older rehabilitation inpatients: a cross-sectional study. *Clinical Interventions in Aging* **12**, 1207-1214.

37. Sakai K, Nakayama E, Tohara H *et al.* (2017) Tongue strength is associated with grip strength and nutritional status in older adult inpatients of a rehabilitation hospital. *Dysphagia* **32**, 241-249.

38. Hori K, Ono T, Nokubi T (2006) Coordination of tongue pressure and jaw movement in mastication. *Journal of Dental Research* **85**, 187-191.

39. MORIYA S, TEI K, YAMAZAKI Y *et al.* (2011) Relationships between perceived chewing ability and muscle strength of the body among the elderly. *Journal of Oral Rehabilitation* **38**, 674-679.

40. Eto M, Miyauchi S (2018) Relationship between occlusal force and falls among community-dwelling elderly in Japan: a cross-sectional correlative study. *BMC Geriatrics* **18**, 111.

41. Mingioni M, Mehinagic E, Laguna L *et al.* (2016) Fruit and vegetables liking among European elderly according to food preferences, attitudes towards food and dependency. *Food Quality and Preference* **50**, 27-37.

42. Laguna L, Mingioni M, Maitre I *et al.* (2016) Perception of difficulties encountered in eating process from European elderlies' perspective. *Journal of Texture Studies* **47**, 342-352.

43. Medin J, Windahl J, von Arbin M *et al.* (2012) Eating difficulties among patients 3 months after stroke in relation to the acute phase. *Journal of Advanced Nursing* **68**, 580-589.

44. Jacobsson C, Axelsson K, Österlind PO *et al.* (2000) How people with stroke and healthy older people experience the eating process. *Journal of Clinical Nursing* **9**, 255-264.

45. Laguna L, Barrowclough RA, Chen J *et al.* (2016) New approach to food difficulty perception: Food Structure, food oral processing and individual's physical strength. *Journal of Texture Studies* **47**, 413-422.

46. Laguna L, Sarkar A, Chen J (2015) Assessment of eating capability of elderly subjects in UK: a quantitative evaluation. *Proceedings of the Nutrition Society* **74**.

47. Laguna L, Sarkar A (2016) Influence of mixed gel structuring with different degrees of matrix inhomogeneity on oral residence time. *Food Hydrocolloids* **61**, 286-299.

48. Vandenberghe-Descamps M, Labouré H, Septier C *et al.* (2018) Oral comfort: A new concept to understand elderly people's expectations in terms of food sensory characteristics. *Food Quality and*

Preference **70**, 57-67.

49. IDDSI (2016) International dysphagia diet standardization initiative, www.iddsi.org.

50. Aguilera JM, Park DJ (2016) Texture-modified foods for the elderly: Status, technology and opportunities. *Trends in Food Science & Technology* **57**, 156-164.

51. Torres O, Andablo-Reyes E, Murray BS *et al.* (2018) Emulsion microgel particles as high-performance bio-lubricants. *ACS Applied Materials & Interfaces* **10**, 26893-26905.

52. Torres O, Tena NM, Murray B *et al.* (2017) Novel starch based emulsion gels and emulsion microgel particles: Design, structure and rheology. *Carbohydrate Polymers* **178**, 86-94.

53. Torres O, Murray B, Sarkar A (2017) Design of novel emulsion microgel particles of tuneable size. *Food Hydrocolloids* **71**, 47-59.

54. Torres O, Murray B, Sarkar A (2016) Emulsion microgel particles: Novel encapsulation strategy for lipophilic molecules. *Trends in Food Science & Technology* **55**, 98-108.

55. Sarkar A, Kanti F, Gulotta A *et al.* (2017) Aqueous lubrication, structure and rheological properties of whey protein microgel particles. *Langmuir* **33**, 14699-14708.

56. Boucher BJ (2012) The problems of vitamin D insufficiency in older people. *Aging and Disease* **3**, 313-329.

57. Keller H, Chambers L, Niezgoda H *et al.* (2012) Issues associated with the use of modified texture foods. *The journal of nutrition, health & aging* **16**, 195-200.

58. Farrer O, Olsen C, Mousley K *et al.* (2016) Does presentation of smooth pureed meals improve patients consumption in an acute care setting: A pilot study. *Nutrition & Dietetics* **73**, 405-409.

59. Cassens D, Johnson E (1993) Enhancing taste, texture, appearance and presentation of pureed foods improves resident quality of life and weight status. *Journal of the American Dietetic Association* **93**, A39.

60. Lipton JI, Cutler M, Nigl F *et al.* (2015) Additive manufacturing for the food industry. *Trends in Food Science & Technology* **43**, 114-123.

61. Dankar I, Haddarah A, Omar FEL *et al.* (2018) 3D printing technology: The new era for food customization and elaboration. *Trends in Food Science & Technology* **75**, 231-242.

62. Laguna L, Sarkar A, Chen J (2015) Assessment of eating capability of elderly subjects in UK: a quantitative evaluation. *Proceedings of the Nutrition Society (Joint Royal Society of Medicine-Nutrition Society Winter Meeting)* **74**, E167-E167.

Captions for Figures

Fig. 1. (Colour online) Schematic overview of eating capability measurements that provide design ‘inputs’ to food texture modifications, latter may act as ‘enabler’ to drive ‘output’ of optimised nutrient intake and eating capability can be negatively affected by ‘input’ conditions of chronic diseases and polypharmacy.

Fig 2. (Colour online) Devices used for measuring eating capability including JAMAR dynamometer for hand gripping force (a), Flexisensor with neoprene disc for finger gripping force (b), Semmes–Weinstein Monofilament (SWM) for touch sensitivity (c), Flexisensor with silicone disc for bite force (d), and Iowa Oral Performance Instrument for tongue and lip sealing pressure measurements (e); Copyright© 2015 Elsevier, Reproduced with permission (8).

Fig. 3. Age dependency of eating capability parameters, showing right hand gripping force (a), finger force (b), finger tactile sensitivity (c), bite force (d), tongue pressure (e) and lip sealing pressure (f) as a function of age in older adults from UK (n=103) (black bars) and Spain (n=100) (white bars); Copyright© 2015 Elsevier, Data used with permission (8).

Fig. 4. (Colour online) Relation of right hand gripping force with oro-facial muscle forces (maximum bite force (▲), maximum tongue pressure (●) and lip sealing pressure (■) of older adults in UK (closed symbols); (a) and Spain (open symbols) (b), respectively. Each data point represents the mean data of forces from participants in each of the age classes (years old) i.e. 65-70, 70-75, 75-80, 80-85, 85-90 and 90+. We have now mentioned this in caption of Figure 4 in the revised manuscript.Black lines show linear-regression best fits to the observed values except for lip sealing pressure relationship in Spain, latter shows a polynomial-fit. Copyright© 2015 Elsevier, Data used with permission (8) for (a) and Copyright© 2015 Cambridge University Press, Reproduced with permission (62) for (b).

Fig. 5. Relation among samples, number of chew and maximum force at break during oral processing by older adults (n=30) for model foods (hydrogels) with controlled mechanical properties with visual corresponding images (a) and food products (b). Nomenclatures 1κ and 2κ represent hydrogels containing 1 wt% and 2 wt% κ-carrageenan, respectively, M-κSAl represents mixed hydrogel containing 2 wt% κ-carrageenan + sodium alginate, B-κCAl represents hydrogel with structural inhomogeneity containing 1 wt% κ-Carrageenan + big calcium alginate beads (mean size 1210 µm) and S-κCAl represents hydrogels with structural inhomogeneity containing 1 wt% κ-carrageenan +

small calcium alginate beads of mean size 1210 µm. Copyright© 2016 Elsevier. Used with permission (16; 47).

Figure 1.

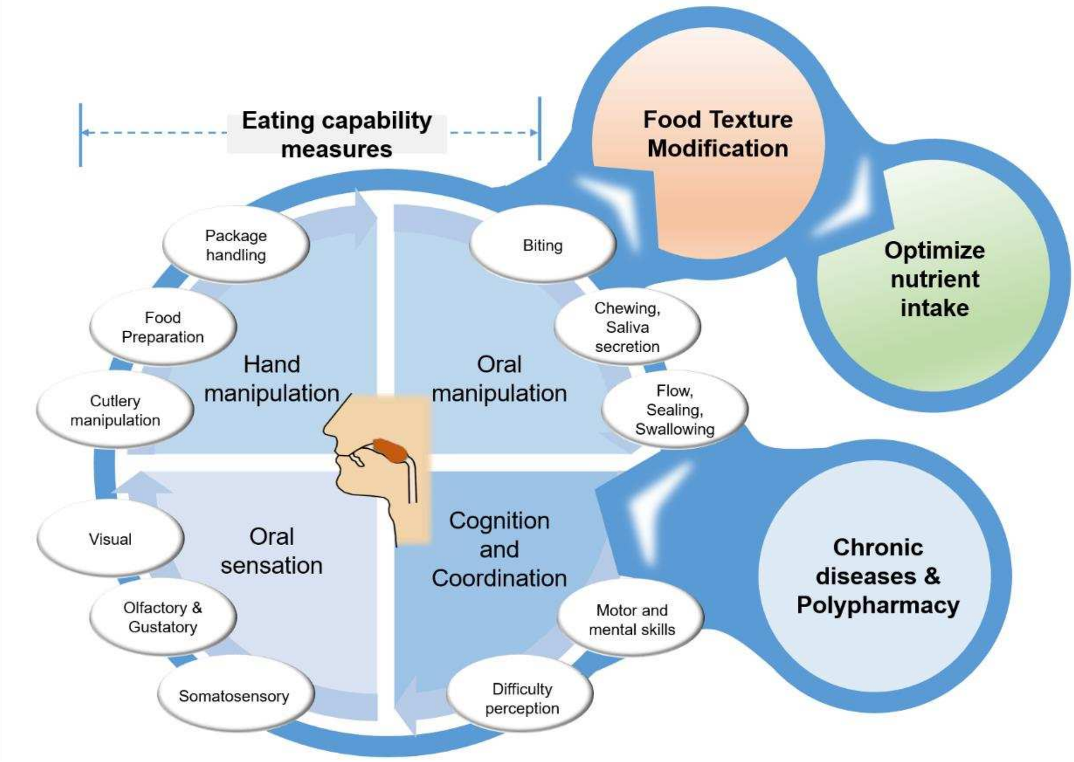

Eating capability measures
Food Texture Modification
Optimize nutrient intake
Chronic diseases & Polypharmacy
Package handling
Food Preparation
Cutlery manipulation
Hand manipulation
Biting
Chewing, Saliva secretion
Flow, Sealing, Swallowing
Oral manipulation
Visual
Olfactory & Gustatory
Somatosensory
Oral sensation
Cognition and Coordination
Motor and mental skills
Difficulty perception

Figure 2.

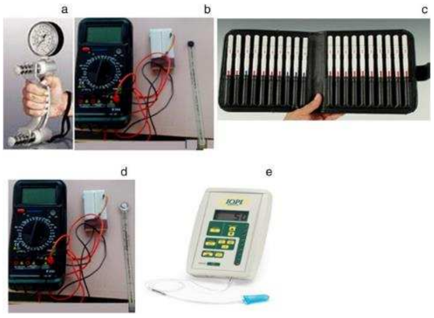


Figure 3.

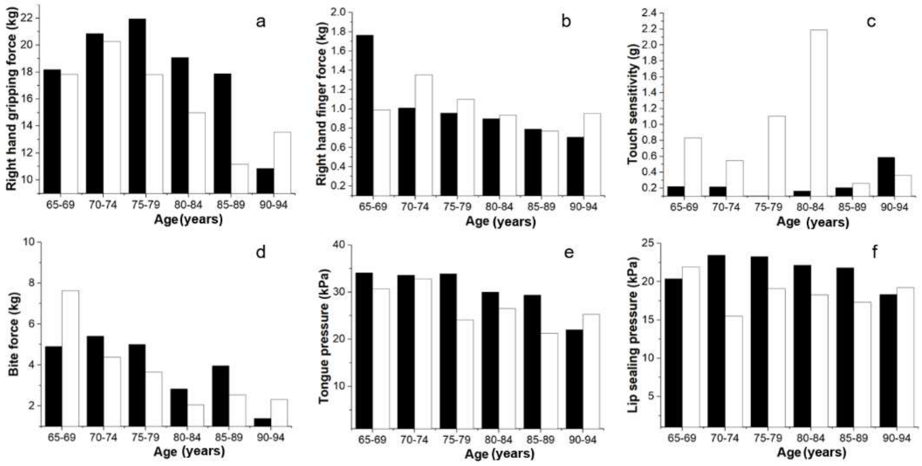

a
Right hand gripping force (kg)
10
12
14
16
18
20
22
65-69
70-74
75-79
80-84
85-89
90-94
Age (years)
b
Right hand finger force (kg)
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
Age (years)
c
Touch sensitivity (g)
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
2.2
2.4
Age (years)
d
Bite force (kg)
2
4
6
8
10
Age (years)
e
Tongue pressure (kPa)
10
20
30
40
Age (years)
f
Lip sealing pressure (kPa)
5
10
15
20
25
Age (years)

Figure 4.

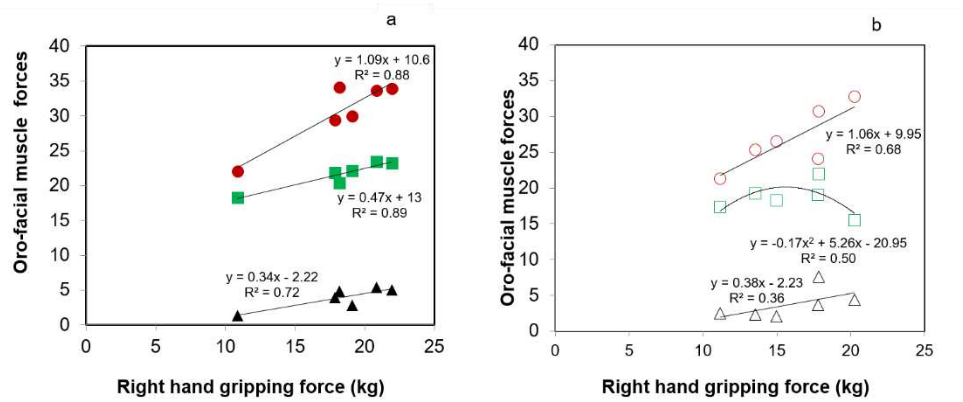
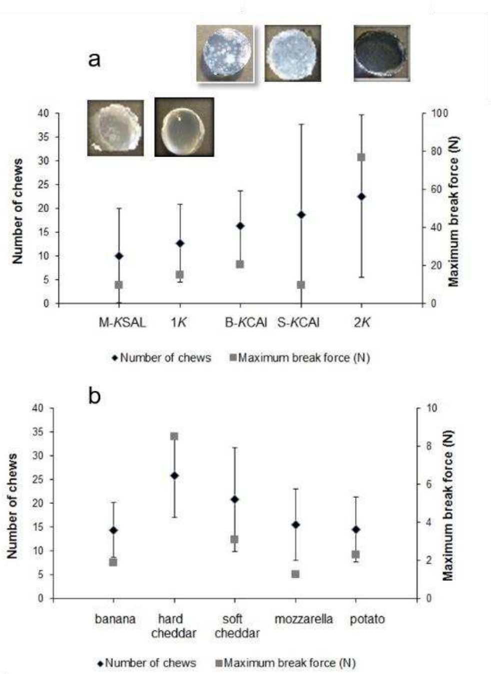

a
b
Oro-facial muscle forces
Right hand gripping force (kg)
y = 1.09x + 10.6
R² = 0.88
y = 0.47x + 13
R² = 0.89
y = 0.34x - 2.22
R² = 0.72
y = 1.06x + 9.95
R² = 0.68
y = -0.17x² + 5.26x - 20.95
R² = 0.50
y = 0.38x - 2.23
R² = 0.36
0
5
10
15
20
25
30
35
40

Figure 5.


a
Number of chews
Maximum break force (N)
40
35
30
25
20
15
10
5
0
100
80
60
40
20
0
M-*K*SAL
1*K*
B-*K*CAl
S-*K*CAl
2*K*
◆Number of chews
■Maximum break force (N)
b
Number of chews
Maximum break force (N)
40
35
30
25
20
15
10
5
0
10
8
6
4
2
0
banana
hard cheddar
soft cheddar
mozzarella
potato
◆Number of chews
■Maximum break force (N)