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Mastication: An Oral Physiology of Food Processing in Mouth

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Abstract

The objective of this study was to understand the concept of mastication in terms of its relation to neuromuscular activities, perception towards texture of food and changes in food properties. During mastication coordination between teeth, lips, gums, tongue, cheek, palate, salivary glands and muscle of the jaws is required. Mastication is one of the neurological and physiological based complex process, which involves the activities of facial, elevator and suprahyoidal muscles along with movement of tongue which results in rhythmic mandibular movements with breakdown of food. The pattern of human subject's chewing behavior during mastication also affects the perception of food texture. During mastication physical properties of food keep on changing in the oral cavity, so the mastication variables can be analyzed at different stages of mastication (early, middle and late). A number of methods are used for the analysis of mastication patterns. The study of mastication process has an important role in the food texture perception and its acceptance by the consumers.

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Introduction

The aim of this review is to understand the physics of food fracture and establish their relationship with mastication variables. In this review we understand the concept of mastication along with their classical and novel methods of measurement. This study helps in the designing of foods for people suffering with swallowing difficulties.

Process of mastication

Oral processing of food involves three different stages i.e. ingestion, mastication and swallowing. During ingestion of food, first food gets pressed against palate by tongue from which surface textural characteristics are obtained (Plattig, 1984). Mastication is combined effort of muscles action, tongue, teeth and saliva under neuromascular control. It is a process of making a food ready for swallowing. Togashi *et al.*, (2007) classified mastication parameters in to two parts rhythmic and irregular movement of the first molar during chewing of food with different texture. The rhythmic chewing is longer for tough foods and bigger sample while irregular movement are longer for foods which adhere to the teeth when chewing.

During mastication several muscles like facial, elevator and suprahyoidal work together. The tongue, cheeks and lips direct the food towards the surfaces of teeth. It is one of the complex process govern by sensory motor neurons which results in rhythmic movements of muscle and tongue and bring changes in the structure of food. These changes bring about various mechanical structural variations in food by several manipulations like cutting, shearing, grinding, mixing and kneading with the help of teeth.

The foods on degradation mix with saliva which is present inside the mouth and make the food moistens and convert it in to bolus which is easy to swallow (Fig.1). Food properties and oral physiology affects the process of mastication (Vanderbilt *et al.*, 2006).

During oral processing of semi-solid and solid foods, two kinds of opposite forces come into action, one which disintegrate the food while the other which adheres the food. During initial stages of mastication, fracture of food occurs while in later stages of mastication adherence of food occur which also allow the cleaning of mouth. During chewing some food particles adhere with mouth surface and produces friction which allow proper holding of the food and proper movement of the bolus by tongue in oral cavity. During this oral processing texture perception is developed based on neural feedback from various sensory receptors (Lucas *et al.*, 2004). During Chewing deformation rate was measured at high speed as compare to the instrumental analysis measured at low value (Tornberg, 1985).

A hypothesis called "breakdown path" was proposed by Hutchings and Lillford (1988). This theory is based on dynamic attributes for texture perception i.e. during real time in mouth oral processing of food. They explained 3D model for the actual fracture of food inside the mouth in which three dimensions of the model were structure of food, degree of lubrication of food and time.

They concluded that due to the differences in the breakdown path, variations were observed in the human subjects according to their preferences. These variations occur on the basis of consumer eating rate, age, physiology and eating occasions.

During the process of mastication, food gets differentiated in terms of chewing energy. Masseter muscles associated with high amount of chewing energy represent more number of chewing strokes (Sakamoto *et al.*, 1989). Chewing efficiency is based on occlusal surface or contact area and the force with which teeth come in contact with masticatory area (Manly, 1951). Chewing efficiency is calculated by a mathematical model based on linear operation which explains the distribution of the food particles during chewing as a function of chewing strokes. Chewing efficiency is related to muscle activity as well as dentition. The rate at which food is broken during chewing is a combine result of food selection as well as its breakage (Vanderbilt *et al.*, 1987).

There are various methods which were used for measuring chewing efficiency. Chewing efficiency was calculated by measuring the rate of breakdown of food and weight loss of food after specific numbers of chews. Human subjects show differences in their chewing efficiency as the rate at which food is broken during oral processing is varying from person to person. Due to these differences in chewing performance subjects can distinguished different food sample (Brown *et al.*, 1996). Heath (1982) explains two simple methods for calculating chewing efficiency. One method is based on calculation of sugar percentage comes out during the mastication of chewing gum after a specific number of chewing strokes and second method include measuring the dimension of food residual develop during chewing using calipers.

During oral processing foodis distributed into different sized particles like coarse, medium and fine. On the basis of volume of these different sized food particles two different methods optical scanning and sieving were used for measuring chewing efficiency. Both methods represent similar results for measuring the level of size reduction of food particles (Vanderbilt *et al.*, 1993). During the process of mastication the sum total of all muscle activity starting from first chew till swallowing represent as Mastication effort (Kohyama *et al.*, 2005). As chewing occur from both side of mouth different chewing pattern are obtained which is specific for an individual. Any particular modification in the act of chewing like giving someone particular direction of how to chew the food (left side and right side chewing) brings changes in the chewing pattern. Thus it is always recommended to follow free style normal habitual chewing behavior while recording the masseter muscle activities (Brown, 1994).

During chewing bolus moves from one side to another side of the mastication system (Brown *et al.*, 1994a). Long time is required for making a bolus which is easy to swallow (Kohyama *et al.*, 2000). During mastication, food undergoes various deformations with action of warm temperature through which texture is perceived (Mathevon *et al.* 1995). Salivary secretions start when food is placed inside the mouth, which moisten the food sample and make bolus ready for swallowing (Guinard and Mazzucchelli, 1996). During mastication under various types of forces food getsfragmented into smaller pieces, gets lubricated with saliva and makesa bolus which is required for the swallowing (Szczesniak, 2002). The water present in the saliva moistens the food while mucin present in them binds the masticated food into bolus for easy swallowing. Thus saliva help in mastication by moistens the food, in making of bolus, make food digestion easy by use of enzymes and helps in swallowing (Pederson *et al.*, 2002).

The adherence is required to form a sticky bolus which is finally swallowed. Adherence not only occurs between food particles but also to mouth surface which results in friction. This friction is required for the movement of food around the mouth with the help of tongue. Frictional work required during the process of chewing affects the sensory perception of food (Lucas *et al.*, 2004).During chewing of adhesive food tongue need high value of force which is require for their movement and making of a bolus (Shiozawa, 1999).Food particle size and its lubrication with saliva affect the frequency of chewing (Gonzalez *et al.*, 2002).

Hutchings and Lillford (1988) explained that during mastication, food gets fragmented to disrupt the structure so that its surface gets easily lubricated with saliva. During mastication of food, food size reduces which is moistened with saliva and releases flavors. Thus both taste and texture are perceived during the process of chewing. Mechanically, the salivary rate is calculated on a piece of parafilm where subject releases saliva at an interval of 30 seconds into pre-weighted dish and thus salivary flow rate is calculated (Vanderbilt *et al.*, 2006).

Swallowing of food occurs in three different stages. First stage is the oral stage where the food bolus is transferred from mouth to the oropharynx. In the second stage food bolus moves from oropharynx to the esophagus with the help of movement of tongue and jaw opening muscles. In the third and final stage, bolus moves toward stomach under the action of gravitational force and peristaltic movement (Kohyama *et al.*, 2007).

Role of muscles and nervous system in mastication

Mastication process is controlled by central nervous system which requires an external trigger for bringing the rhythmic movement (Kohyama *et al.*, 2008). Muscle activity required during mastication is generated due to the interaction between central nervous system with peripheral unit (Thextron, 1973). Mastication is the initial step of digestion.

It is very well synchronize neuro muscular based process which involves continuous movement of jaw with change in force. The mechanism of chewing regulation will be studied through response generated by mascular action due to the variation present in food consistency (Karkazis and Kossioni, 1997).

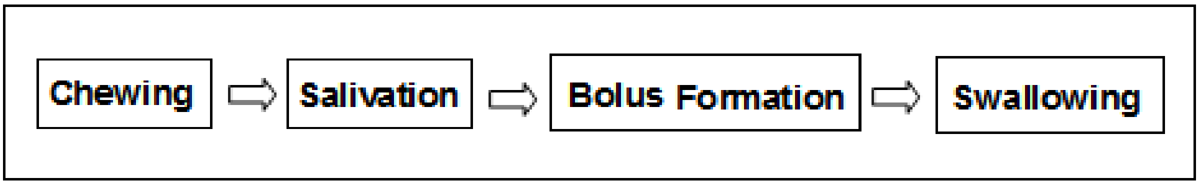

Fig. 1. Sequence followed during the process of mastication.

During chewing of food, mechanical responses which are generated depend on degree of fracture of food and mechanical resistance developed in the mouth due to both soft and hard tissues (Peleg, 1980). During oral processing the consistency of food brings the texture perception which depends on various factors like size, shape and hardness (Tyle, 1993).

Periodontal pressoreceptors and muscle spindles bring about positive feedback to the jaw closing muscles during the process of mastication (Vanderbilt *et al.*, 2006). Sensory nerve endings in periodontal membranes determine the force developed by the masseter muscles with the help of proprioceptors. Feedback generated from each chew decides the level of force required by the consecutive chew (Brown *et al.*, 1994b). As chewing process starts, complex series of feedback and feed forward control mechanisms also start which then further coordinate the action of motor neurons (Yeatman and Drake, 1973).

Cognitive psychology in terms of perceptual learning brings about behavioral changes which affect the process of chewing (Goldstone, 1998). Muscle spindles present in the jaw closing masseter and temporal muscles convey the information to the brain and thus maintain the magnitude of activities of jaw closing muscles required for the textural perception (Kohyama *et al.*, 2005).

Chewing behavior depends on the subject's sensory perception which regulates masticatory movements (Kawamura, 1964). Sensory systems are responsible for perceiving the texture of food and in bringing the modification in texture sensations (Christensen, 1984). Sensory nerve endings in oral mucosa governs the size, shape, surface properties of food and direct the action of tongue, lips and cheeks to form bolus by assembling the deformed fragments of food by orienting them at proper position between the teeth.

This procedure continues and elicits the oral comminuting during chewing (Brown *et al.*, 1994b).

During the formation of food bolus various sensory inputs modulate the motor nerves which bring mandibular movements from initial step of ingestion till final step of food swallowing. During mastication both opening and closing neurons work independently and brings production of the rhythm (Lund, 1991). Suprahyoid muscle activities are related with early stages of swallowing (Kohyama *et al.*, 1998). Mastication is rhythmically occurring in middle stage of mastication while in later stage it becomes irregular due to the formation of bolus (Kohyama *et al.*, 2014).

Effect of human behavior on mastication

Vinyard *et al.*, (2008) studied variation among primates in term of their muscle activity estimated through EMG. The variation arises due to change in food during chewing, bite location and the way in which muscles generate bite forces. This study plays an important role in evolution studies. The chewing patterns of different textured foods vary from person to person (Kemsley *et al.*, 2004). Younger subjects show shorter mastication time than elderly people (Kohyama *et al.*, 2002; Kohyama, 2004). The texture of food is governed by the masseter muscle activity during chewing (Karkazis and Kossini, 1997). Less consciousness is required during natural habitual chewing process (Stohler, 1986).

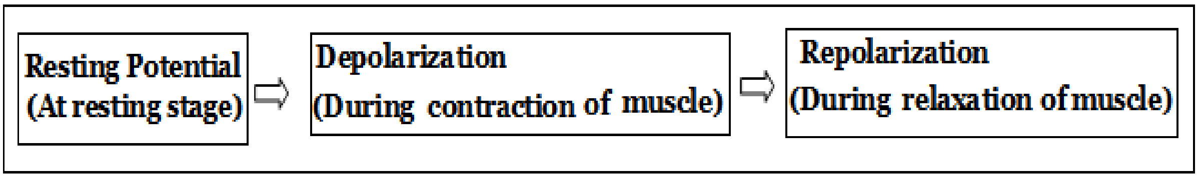

Fig. 2. Ion flow across the cell membranes during activation of muscles.

During mastication, eating at faster rate with incomplete chewing is not recommended. Brown *et al.*, (1994a) showed that chewing behavior of human subjects' changes if they chew the food naturally or under some given instruction. Trained subjects are more prone to the cognitive and perceptual learning through their adaptation to motor sensory skills and physio-anatomy (Ericsson and Lehmann, 1996). Humans can modify their chewing behavior to adjust with physical properties of foods (Hiiemae, 2004). Electromyographic results obtained from the masseter muscle activity were integrated and were found related to the oral force exerted by the muscles during mastication (Boyar and Kilkast, 1986a). Human subjects show maximum difference of chewing behavior in early stage of mastication, in which first chew shows greater variation.

The responses of human subjects with total denture were studied for various foods using EMG. During time progress the adaptation to denture increases the chewing efficiency in patients with total denture replacements (Tokmakci *et al.*, 2013). Veyrune and Mioche (2000) studied the response of human subjects with total denture for texture perception for meat using EMG. He concluded that texture perception is little altered while mastication but muscular adaptation to bolus is reduced in subjects with complete denture. Chewing behavior is specific for each individual as the source of variation in mechanics and functioning of system are more and the manner in which systems interact with food constituents are numerous (Ahlgren, 1966). Each human subject shows variation in terms of morphological characteristics of mastication system, in dental status and in efforts required for the breakdown of the food sample. So rather than examining the strategy which human apply during mastication we have to examine how much effort is involved along with degree of manipulation of food inside the mouth during chewing. Chewing patterns show differences among subjects but pattern for each subject remains consistent over different recording sessions (Brown *et al.*, 1994b). During chewing, variations occur at two different levels, first at muscle recruitment and its activation and second in the chewing sequence and its modification for different foods in terms of food breakdown to form bolus (Brown, 1994).

Human subjects show different chewing rhythm which was developed by central pattern generator in such a way that it affects chewing output by sensory feedback (Plesh *et al.* 1986). Brown *et al.*, (1994) explained that the major difference of chewing in between the human subjects depends on the chewing time and rate of muscle work during chewing. The rate of compression of solid foods is affected by differences in chewing rates between individual (Bourne, 1977). Human subjects exhibit difference in chewing efficiency, i.e. on the basis of their ability to rupture a portion of food in a given interval of time (Helkimo *et al.*, 1978). Human subjects also secrete different amount of saliva which also brings about variation in relation to the texture and chemical characteristics of foods (Pangborn and Lundgren, 1977)

During chewing variations are found between human subjects and food for number of chews, chewing motion and rate of food breakdown (Bourne, 1982). Chewing patternsareinter related to chewing efficiency. Difference in the pattern of chewing reflects the difference in the chewing efficiency with which food is fractured. Less muscle work is required for habitual chewing than one sided chewing (Mioche *et al.*, 1995). Subject chewing efficiency may get changed over time due to change in rate of secretion of saliva and changes in dentition (Brown and Braxton, 2000).

Felix *et al.*, (2008), studied EMG muscle activity in elderly patients suffering from swallowing problem and have fixed implant prosthesis. He concluded that amplitude of electromyographic decrease during swallowing which indicate adaptation to new condition of stability provided with complete denture patients.

Effect of food properties on mastication

Mastication parameters depend on the physical properties of food like its hardness, size, shape, texture, etc. During EMG the master muscles show higher amplitude in harder food as compare to the softer food and this indicates that chewing force and muscles movements may be strongly influenced by the texture of food, especially its hardness (Horio and Kawamura, 1989). The mastication of food with bigger size requires more chewing time with longer opening and closing phases (Miyawaki *et al.*, 2000). During chewing EMG activity is affected by texture of food, i.e. different food brings about different results for various EMG parameters (Karkazis and Kossini, 1997). Kohyama *et al.*, (2007) shows that cutting of same weight food does not bring about any change in the mastication pattern in respect to mouthful size block. However it can make the process of chewing easier by decreasing the weight of cut sample with same volume. Miyawaki *et al.*, (2000) studied chewing pattern in response to different size food products. He concluded that muscle activity changes according to the rate of change in the height of food bolus which is formed during mastication. Miyaoka *et al.*, (2013) studied the effect of physiological parameters of chewing for differentiate foods of different shape and textural properties.

During chewing of crispy food jaw decelerates as a result of resistance while accelerates as a result of disintegration of food. This breaking feature of crispy food brings about sensory perception Characteristics of food like amount of water, fat percentage and its hardness affects the process of chewing (Vanderbilt *et al.*, 2006). For mastication studies human subjectsare served with either constant weight or volume of food sample.

This brings natural mastication behavior whenever the human subjects consume food (Kohyama *et al.*, 2014). Kohyama *et al.*, (2007) concluded thatboth the amount of food sample and texture affects the mastication but not the swallowing characteristics. Swallowing occurs only upon the formation of bolus having suitable properties for swallowing.

Mastication of adhesive foods showed greater activity of muscles (Cakir *et al.*, 2012). During mastication the rate of chewing i.e. number of strokes for hard food are more as compared to soft food while duration of the chewing stroke is shorter for hard food than soft food. Thus there is inverse relationship between rate of chewing and duration of muscle contraction. Hard foods show greater amplitude of force than for soft food (Steiner *et al.*, 1974). The harder the food, the more is the chewing rate, muscle activity and relative contraction period while short is the cycle duration (Karkazis and Kossini, 1998). The acceptance of any food product depends on its ease with which it gets fractured and manipulated inside mouth and differences are generated due to difference in their interaction with food (Brown and Braxton, 2000).

All consumers do not like or dislike the same product (Helgesen *et al.*, 1997).

These changes may be related to anatomical, physiological and neuro physiological factors. Miyaoka *et al.*,(2013) found relationship between physiological parameters (chewing cycle, chewing time, amplitude and cycle duration) and textural characteristics (hardness, fracturability and adhesiveness) of food products in terms of physiological implications. Steiner *et al.*, (1974) found that chewing behavior of hard food differentiate from soft food in terms of shorter duration of chewing strokes and increase rate of chewing, higher frequency and amplitude of spikes in each strokes.

The number of chew, masticatory time and muscle activity per chew were more in harder rice with less degree of milled, cooked with least water ratio and more amylose content (Kohyama *et al.*, 2005; Kohyama *et al.*, 2014). Burst duration and muscle activity per chew were high and interburst duration was low in rice with high amylose content (Kohyama *et al.* 2016). Brown *et al.*, (1996) studied the variation among the human subject for the characterization of tenderness of meat. He found that sensory perception govern the tenderness of meat. Beef texture also evaluated by sensory profile, chewing patters and mechanical properties which show variation in terms of muscle composition, myofibrils status and cooking time at different rate of deformation, shear and dynamic tests (Mathoniere *et al.*, 2000). On changing the composition of food their sensory textural perception also change in terms of chewing behavior. Increased adhesiveness of food is associated with increased muscle activity, longer cycle duration while cheese with decreased fat associated with short cycle duration (Cakir *et al.*, 2011). Atherton *et al.*, (2007) designed various texture modified foods and thickened fluids which can be used as substitution food for individual suffering from dysphagia i.e. swallowing problem.

Methods of assessment of mastication

The forces involved during the masticatory cycle have been estimated using a variety of both extra-and intra-oral devices. Boyar and Kilcast (1986a) relate the integrated area of EMG with chewing force exerted during mastication. Morell *et al.*, (2014) explain various in vivo oral methods which can be used in field of food technology to mimic the natural condition during chewing in mouth.

This understanding is helpful in explanation of food dynamic changes which occur during mastication. The usage of acoustic-EMG based system for the analysis of food mastication parameters can measure the oral tactile perception in terms of electromyogram of both masticatory muscles and auditory signals which are generated during mastication and were used for differentiate among texture of food (Jessop *et al.*, 2006). Hiiemae (2004) used videofluorographic for showing different results for food with different consistency. There are various methods which are used for measuring the rate of mastication like measuring the sound produced during mastication, measuring mandibular speed, measuring food and tooth pressure (Watt, 1972). Kohyama (1998) designed a new pressure based sensor that can detect the force and contact area in real time using the multiple-point sheet sensor, which is a very thin and flexible pressure-sensing device.

Electromyography (EMG) technique is also used for measuring the rate of mastication which depends on the small potential generated by the action of flow (Fig. 2) of ions in the muscles (Brown *et al.*, 1994a, Brown *et al.*, 1994b; Boyar and Kilkast, 1986a; Rustagi*et al.* 2018a; Pratiksha*et al.*, 2018; Rustagi*et al.*, 2018b; Sodhi*et al.*, 2019; Kohyama *et al.*, 2014; Kohyama *et al.*, 2016). In dental science various methods were used for measuring mastication like gnathosonics, cinematography and the use of various electronic and intra-oral instruments (Boyar and Kilkast, 1986b).

Conclusion

During mastication food is first ingested in mouth where it is fractured and then mixed with saliva, so that food particles adhere with each other and form a bolus. During habitual chewing there is a rhythmic movement of jaw opening and closing muscles which are evoked by nervous system, triggered by some external stimulus with the help of neural feedback from various sensory receptors. Human perception for determining the food texture is dependent upon how effectively they can explain specific textural parameters. Mastication process is affected by food properties like shape, size and texture of food. Thus the process of mastication can be explained by the combined efforts of food scientists with oral physiologists.

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