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Review Article

A Review on Mastication and Related Factors

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Abstract

Mastication is an essential human function which is characterized by rhythmicity like respiration and locomotion. It involves complex biomechanical processes and is identified as the initial phase of digestion. During mastication, food is reduced to finer particles and mixed with saliva and a bolus is formed which is fit for swallowing. Mastication ensures nutrition in human beings. Dental deficiencies cause nutritional limitations especially in the old age. Prosthetic replacements restore masticatory function to some extent. Many physical, physiological and mechanical factors are involved in the process of mastication. Masticatory movements, the joints involved and the occlusal relations are interesting research areas even in the present times. This review provides an over view of the different factors related to the highly specialized area of mastication.

Keywords: Mastication; Chewing; Temporo-Mandibular Joint; Mandibular Movements; Occlusal Relations; Muscles of Mastication; Saliva

Introduction

Presence of teeth has been identified in our ancestors who lived seven million years ago. They had long jaw bones and their canines were very prominent. They had protuberant profiles (Figure 1). The posterior teeth of both sides were parallelly arranged and the dental arches were squarish. Posterior teeth were large and diastema was present to accommodate canines of opposing arches. When five million years passed, our ancestors had smaller jaw bones and teeth. Their profiles were more or less vertical. Present day human beings have smaller jaws and smaller teeth and the wisdom teeth do not find adequate space in the jaw bones and most of them are impacted. Cusps of teeth are more rounded and the dental arches are parabolic in shape (Figure 2). The evolutionary changes are attributed to lesser need of mastication because of the change in refinement of food [1].

Teeth of the ancestors

Our ancestors had large jaws and bigger teeth to manage chewing highly unrefined food which was available to them. But the present-day human beings need not chew food that hard because of the refined nature. One peculiar finding is that, the ancestral teeth had thin enamel whereas the present-day teeth have thicker enamel. Probably the ancestral teeth had limited duration of existence and the present-day human beings live longer and they have to chew food for a longer span. In the Paleolithic era (12000 years ago) the ancestral human beings lived for 33 years only. Seventy five percent of the deaths were caused by infections, diarrheal diseases and dehydration. Chewing food with teeth has occupied an important role in the human life only thousands of years ago [2].

Role of teeth in mastication

Human beings have four major types of teeth viz. incisors, canines, premolars and molars. Incisors are shovel shaped, situated in the anterior part of the dental arch and are used to cut the food material. Mandibular incisors make a sliding contact over the palatal surfaces of the maxillary incisors, when mandible makes a protrusive movement. Lower lip makes a controlled contact with the maxillary incisors and air is released to make pronunciation of 'f' and 'v' during speech. In occlusion when posterior teeth are in contact, between the upper and lower incisors, there exists a gap of 20 microns. In fact, this is a protective mechanism to keep the incisors in position preventing labial tipping. The force generated on incision is approximately 100 Newtons.

Canines have a cusp form and their roots are very long. Canines are intended to tear the tough food material. In the present generation of human beings, the tearing function is not prominently displayed. Canines have an important role in guiding the lateral excursive movement of mandible. In youngsters, when the mandible moves to one side, all the posterior teeth get disoccluded and hence the term canine protected occlusion. The heavy force applied on the canines, to be specific the guiding contact is between the palatal surface of the maxillary canine and the cusp of the mandibular canine, requires a heavy anchoring to the jaw bone and that is why the canines have longer roots. It is estimated that 140 N load is applied on canines. During the lateral excursion maxillary canines tend to move outward and the mandibular canines move inward and partly the load is transmitted through the adjacent teeth contacts. Maxillary canines do not get that advantage.

Premolars have two cusps and hence the name bicuspids. Premolars belong to the group of posterior teeth. They are placed between the canine and the molars. They crush and grind the food. The occlusal force applied on premolars is 222- 445 Newtons. On clenching, the force increases to an average of 660 N. Meat and carrots require a force of 70-150 Newtons in the premolar region for fragmentation.

The occlusal load applied on molars can vary in different individuals and there is a wide range like 107-156 to 654-665 Newtons. The occlusal force generated at first molar is generally greater than that on the second molar. When common food materials are chewed the force observed are as follows: Peanuts (39 N), Coconut (44 N), Carrot (673 N), Beef (675 N) [3].

Mechanics of mastication

Chewing is the first step in the digestive process. Chewing consists of the rhythmic process of opening and closing of the jaw, attempting to reduce the particle size of the food, moistening it with saliva and making it into a bolus and swallowing it [4]. The pattern of mastication starts with the eruption of teeth and when they make the contacts. As time passes, masticatory reflexes will be conditioned along with the emergence of proprioception through periodontal ligament and sensations through the joints, tongue and the mucosa. Mastication is a highly co-ordinated activity governed by conditioned reflexes [5].

Chewing happens with distinguishable movement patterns based on the consistency of food. While chewing hard food, lateral jaw movements are predominant whereas with soft food, predominant movement is vertical. Hard food requires grinding and hence the lateral movement which is not essential for soft food. Salivary flow is also increased while chewing which helps in the formation of bolus [6].

There are different phases for the masticatory process. When the food is taken towards the mouth, the mandible is lowered and advanced to start the (i) incision phase where the incisors act as shear cutters. Food is positioned by the tongue; mandible is protruded and the shearing action happens with the incisors. When the food is tough like meat, the canines are also required. In that case, the mandible moves laterally also. The next phase of (ii) crushing follows which happens over the premolars with several masticatory strokes or cycles. The food now passes to the molars and the (iii) grinding phase starts. This phase is characterized by predominant lateral movements of the mandible. After fine grinding, the food particles transform into a bolus and which is swallowed. When the bolus passes through the esophageal sphincter, the process of ingestion finishes [7].

Mastication is a cyclic process which has three stages-1. Opening of the jaw, 2. Closing of the jaw and 3.the occlusal phase. Duration of the masticatory cycle is approximately 600-900 milli seconds. Each phase takes almost one third of the total duration. The

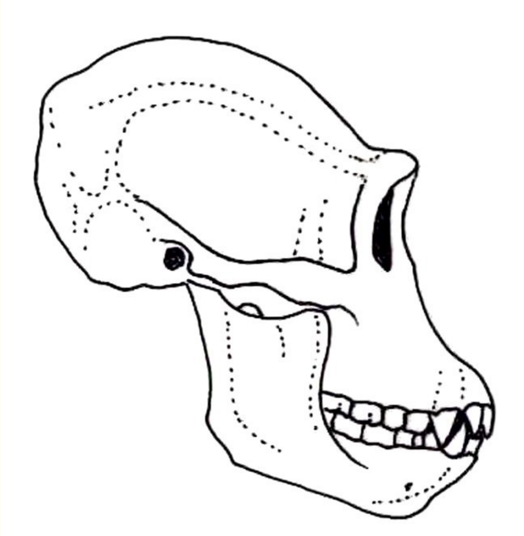

Figure 1: The profile of ancestors.

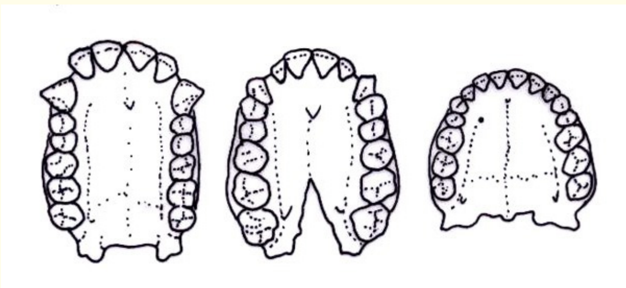

Figure 2: Evolutionary changes in the dental arches.

cycle is generated by the pattern generator situated in the brain stem and controlled by the sensations received from the periodontium, oral mucosa, masticatory muscles and the temporomandibular joints. In the beginning of the mastication, the amplitude will be high and then it decreases to a stable range [8]. Generally, four types of chewing patterns are observed viz. alternate bilateral chewing, simultaneous bilateral chewing, preferential unilateral chewing and chronic unilateral chewing [8]. If both sides are used in an alternate way, it is considered as physiological. Preferential unilateral chewing can result in asymmetric masticatory loading. The chewing cycle is affected by food texture, bite force, absence of teeth, restricted salivary flow and personality characteristics. Individuals who lost the posterior teeth (Kennedy Class I) will be using their anterior teeth to crush the food substance by protruding the mandible. Eventually anterior teeth will be attritioned, abraded, proclined and diastema will be evident between the maxillary anteriors [8]. Missing teeth obviously affects the masticatory efficiency because there is a considerable reduction in the contact area between the upper and lower teeth. Replacing the missing teeth with dentures can improve mastication, but manmade teeth cannot claim full replacement capability. Tooth loss makes the elderly individuals to increase the number of chewing cycles and they may swallow a large portion of the food without adequately chewing it [9,10].

Number and area of cycles

Number of chewing cycles have been evaluated in dentate individuals and in those who wear prosthesis. The individuals were asked to chew 3.5g peanut and swallow. Fully dentate individuals took 9-24 cycles before swallowing. In subjects with complete dentures the number of cycles went up to 67-90, with partial dentures 30-104 and with implant supported prosthesis 42-114. Increase in the number of cycles can be attributed to the progressive loss of periodontal proprioception [8,11,12]. Masticatory frequency in dentate patients has been calculated as 84.8±8.9 χψχλεσ περ μινυτε.

The area of masticatory cycle has been measured in different planes and the results obtained are as follows: Frontal plane - 43.8 ± 13.7 mm^2, Sagittal plane - 11.1 ± 4.8 mm^2, Horizontal plane - 10.9 ± 8.5 mm^2. With different studies, these values show great variations [13] (Figure 3).

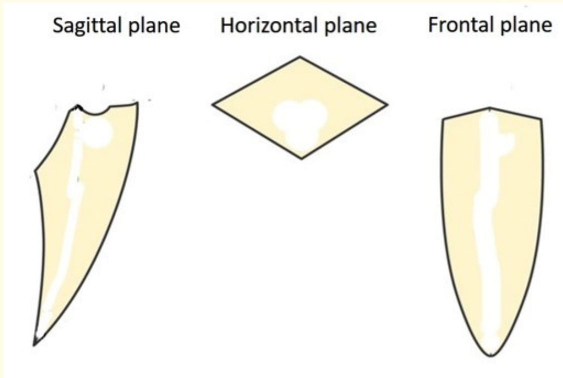

Figure 3: Mandibular movements recorded in sagittal, horizontal and frontal planes (Posselt).

Saliva and mastication

Saliva makes the oral environment moist and it gets mixed with the food particles. And it also provides adequate binding and helps in the formation of the food bolus. Saliva contains enzymes like amylase and lipase. Amylase breaks down complex carbohydrates (starch) into sugars which can easily be absorbed by the body. Lipase breaks down some portion of fats (triglycerides) in the mouth. Because of the activity of the enzymes, the viscosity of the saliva decreases. Lipase is also produced in the stomach and in the pancreas. The flavour of the food is released to the saliva where it is held for longer duration and enhances the sensory perception [14,15].

Mucins present in the saliva improves the lubrication quality and helps the bolus to pass through the oesophagus. Daily production of saliva is in a range between 0.5 – 1.5 litres. Unstimulated salivary flow is 0.3ml/min. During sleep it comes down to 0.1ml/min and during mastication it goes upto 3ml-5ml/minute [16,17].

Restricted salivary flow (hyposalivation) and subjective perception of dry mouth (Xerostomia) can cause difficulty to mastication, taste sensation and swallowing. Drugs like anti hypertensives and antidepressants can cause dry mouth. Radio therapy and chemotherapy in cancer patients can cause restricted salivary flow. Diabetic patients and elderly patients usually complain about dry mouth and denture wearers face retentive problems because of the reduced salivary flow [18].

Tongue

Tongue is muscular organ that is firmly anchored to the floor of the mouth. It has high quality blood supply and nerve supply. Excepting the root of the tongue, all other parts can move freely. Muscles and ligaments connect the tongue to the hyoid bone. Structure of the dorsum of the tongue consists of numerous papillae which have touch sensation and hence can identify the form and texture of the food. There are specialised papillae which can specifically sense the taste of the food. The under surface of the tongue is glossy and in the middle lingual frenum is seen. On both sides of the frenum, veins are visible. Sub lingual salivary glands are opening here near the floor of the mouth. The mucosa underneath the tongue can absorb medicaments. Sub lingually administered drugs are absorbed directly to the blood stream. (Nitroglycerine tabs or spray administered sublingually for chest pain is an example).

Tongue can move freely in all the directions and can change its shape. This capability helps to move the food in different directions, keep the food over the teeth in order to reduce the particle size. Cheeks assist the tongue in this function. The tongue movements press the glands and squeezes the saliva out. When the food is sufficiently masticated, tongue presses the food against the palate and directs the bolus towards the pharynx. Posterior part of the tongue has the immune system cells and is known as lingual tonsil. Another most important function of the tongue is the speech. Human beings can speak at a speed of 90 words per minute by making 20 different movements.

Tongue capability has become a measurable entity in the recent times. Usually, two types of tests are undertaken – 1. tongue-palate contact or tongue pressing capability 2. tongue movements during functions like swallowing. Iowa oral performance instrument (IOPI) is commonly used to measure the tongue pressure which consists of a compressible bulb. A more sophisticated instrument uses multiple sensors attached to a palatal plate. Tongue movement is precisely evaluated by ultra sound, video fluorography and MRI. The average maximum tongue strength in healthy adults is approximately 63 kilo pascals (kPa) in a range of 40-80 kPa [19-21] (Figure 4).

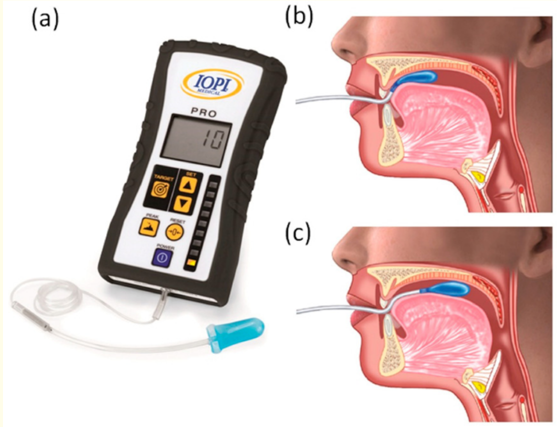

Figure 4: IOWA oral performance instrument.

Temporo-mandibular joint, muscles and movements

This joint is between the temporal bone which forms the superior portion and the mandibular condyle that forms the inferior portion. Between the articular surfaces, there is an interposing structure, the articular disc composed entirely of fibro cartilage. The disc is attached to the internal surface of the fibrous capsule of the joint and separates the articular surfaces. The disc stabilises the condyle and reduces the friction between the articular surfaces. The superior compartment contains 1.2 ml and the inferior compartment 0.9 ml of synovial fluid.

The lateral part of the joint capsule is thickened to form lateral ligament which prevents the posterior dislocation of the mandibular condyle. There are two extrinsic ligaments for the TMJ viz. Spheno-mandibular and Stylo-mandibular which limit the range of movements of the mandible. The spheno mandibular ligament limits the forward movement of the condyle when the jaw opens beyond ten degrees. In the closed position of the jaw, the ligament is slack and it becomes taut when the jaw is opened half way. The stylo mandibular ligament limits the jaw from protruding too far. (Figure 5,6).

The superior compartment allows for translatory movements whereas the inferior compartment allows for rotational movements of the jaw. The mandibular movements can be identified as follows

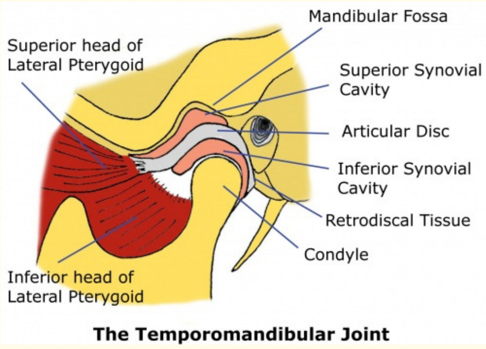

Figure 5: Organisation of TMJ.

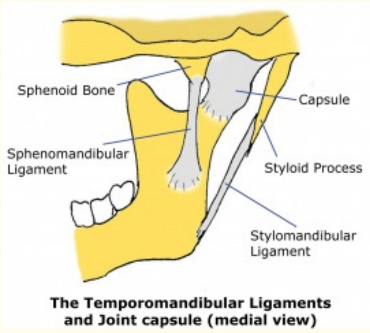

Figure 6: Ligaments of temporo-mandibular joint.

- **Protrusion:** Anterior movement of the mandible-predominantly lateral pterygoid muscles cause this.
- **Retrusion:** Posterior movement of the mandible which happens after protrusion-posterior fibres of temporalis, deep fibres of masseter, genio hyoid and digastric muscles cause this.
- **Lateral excursive movements:** Grinding and chewing of food happen because of this movement-Lateral pterygoid muscle moves the lower jaw from side to side. When the lateral pterygoid muscle contracts on the left side, along with the medial pterygoid muscle of the right side, the mandible moves to the right side (contra lateral side).
- **Depression:** Movement of opening the mouth-usually this is a gravity initiated movement but if there is resistance, the muscles facilitate-Lateral pterygoid, digastric, genio hyoid and mylo hyoid muscles cause depression.
- **Elevation:** Closing of the mouth, it is a strong movement and crushes the food-Temporalis, masseter and medial pterygoid cause elevation of the mandible (Figure 7).

Measuring masticatory efficiency

Mastication was subjected to scrutiny by analysing the subjective perception of satisfaction until 1950. In the recent past, many objective assessment methods were formulated and which belong

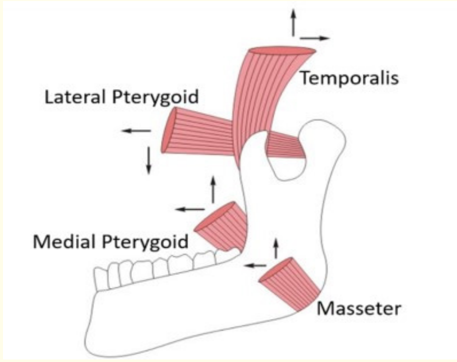

Figure 7: Muscles of mastication and mandibular movements.

to two classes- 1. Comminution technique and 2. Colorimetric technique. In comminution technique, a test material is administered for chewing under controlled conditions. Mastication is assessed according to the final particle size of the test material. Smaller the particle size, superior is the masticatory performance. In the colorimetric method chewing gum or wax of two different colours are provided to chew and periodically assessed for the degree of mixing. The samples are visually or digitally assessed. Both the methods are of objective quality and are reasonably reliable.

For comminution test, the test material is collected after subjecting it to predetermined number of chewing strokes or when the bolus is ready for swallowing. Measure of the particle size after a select number of chewing cycle indicates how well the subject grinds the food or fragments it. The specimen collected from the food bolus at the moment of swallowing indicates the physical property of the food like hardness, cohesiveness, moisture content and portion size. This also indicates the individual's general and oral physiologic status viz. condition of the dentition, force exerted during chewing, motility of tongue, flow rate of saliva and neurological status [22-24].

Edible and non edible substances are used for testing masticatory efficiency. Edible substances include peanuts, almonds, cocoa, carrot, hazel nut, chewing gums and gelatine gels. Non edible substances are silicone based materials like Optosil, Optocal plus and Cuttersil. Measured quantity of peanuts or carrot cubes are given to the subjects and allowed to chew for a desired time interval and the chewed material is expectorated and collected to measure the particle size distribution. The collected material is passed through multiple sieves with aperture ranging from 5.6mm to 0.5mm. The sample collected in each sieve is dried at 60^{0}C for 3 hours and the weight or volume is calculated. If finer particles are more, that indicate higher masticatory efficiency. This type of comminution test is simple and suited for dentate subjects [25] (Figure 8,9).

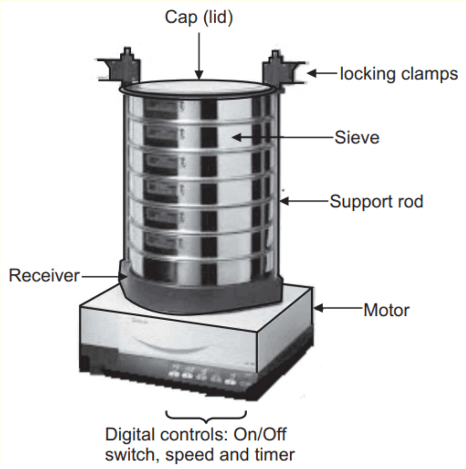

Figure 8: Sieve Shaker.

Figure 9: Different types of sieves.

If the subjects are unable to comminute, gum kneading method is suggested. Two differently coloured chewing gums or waxes are given as chewing specimens which are assessed for the degree of mixing at different time intervals. The mixed specimen is spread between transparent sheets and scanned. Photographs taken with a good quality mobile phone can be used in large scale assessment of masticatory efficiency. Hue-check View Gum® Test (Orophys, Bern, Switzerland) has been used and the quality is verified. The RGB values of the photographs are converted to Hue, Chroma, Value system. Variance of Hue is considered to indicate the degree of mixing. Smaller the variance of hue, greater is the mixing. Colour changing gums (Xylitol) are also available (Figure 10, 11) [18,26,27].

Leak proof poly vinyl chloride capsules containing pigment coated granules of erythrosine or adenosine triphosphate are also used for masticatory evaluation. The capsule is chewed for a specified time or cycles and the capsule is opened up and the content is dissolved in water. Only the detached pigment particles will be dissolved in water. The pigment quantity is assessed by spectrophotometry (Figure 12) [28-31].

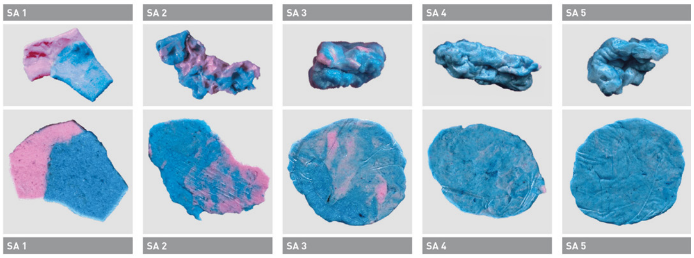

Figure 10: Chewing gum specimens at different stages of chewing.

Figure 11: Colour changing chewing gum.

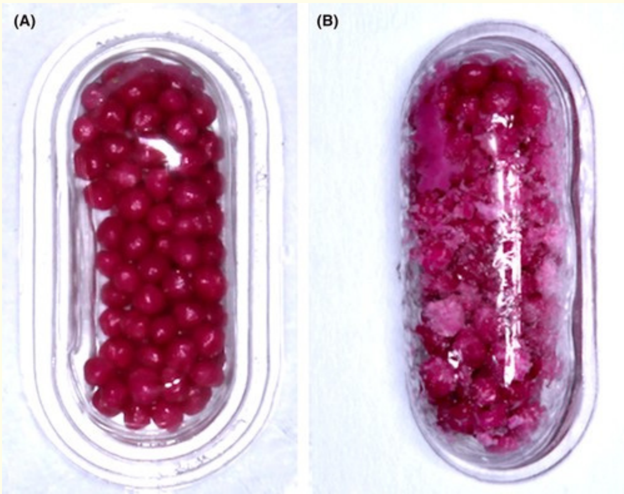

Figure 12: Pigment containing granules with capsule before and after chewing.

Figure 13: Nosey cup for individuals suffering from restricted neck movements.

Figure 14: Usage of Nosey cup.

Figure 15: Plate guard to prevent spillage of food.

Figure 16: Weighted cup for individuals who have hand tremors.

Figure 17: Stabilising electronic spoon for tremor patients.

Masticatory efficiency and chewing efficiency are used interchangeably and even though these two words can convey the same meaning. Precisely mastication is the process of chewing food for swallowing and digestion. Chewing means the deformation of food and similar materials that happens between the teeth and oral tissues. Chewing can be considered as part of mastication. With both the terms, the massage will be carried out in a similar dimension. Terminology presented in glossary of prosthodontic terms (GPT 9) on mastication are as follows

- **Mastication:** The process of chewing food for swallowing and digestion
- **Masticatory efficiency:** The effort required to achieve a standard degree of comminution of food
- **Masticatory performance:** A measure of the comminution of food attainable under standardized testing conditions
- **Masticatory cycle:** A 3D representation of mandibular movement produced during the chewing of food

Mastication and dentures

Individuals who use dentures generally avoid hard food stuffs because most of them perceive a limitation in masticatory efficiency. They also avoid adequate grinding of the food and they swallow when the particles are comparatively bigger. This may lead to nutritional deficiencies and gastrointestinal problems. Integration of implants to complete dentures, as a retainer or supporting device can definitely improve the functional efficiency of complete dentures. In comminution tests, natural dentition could perform mastication to the efficiency level of 71% whereas with complete dentures the efficiency obtained was 14%. With implant supported fixed mandibular prosthesis against fixed maxillary prosthesis, the masticatory efficiency obtained was 41% whereas for the same situation against removable maxillary prosthesis, the values came down to 31%. With implant retained mandibular over dentures, the values further came down to 27% [32].

Bite force values should be considered along with the masticatory efficiency. It has been observed that there is a positive correlation between the bite force and masticatory efficiency. Dentate individuals showed a bite force of 350-388N and with complete dentures the values were 50-55N. Maxillary CD and mandibular over denture produced a bite force in the range of 86-97N. Implants with single crowns produced a bite force of 224-254N. Implants do provide better bite force when compared to CD but it cannot restore the original functional values of dentate conditions [33].

Manipulation of food with hands

Distortions, diseases and injuries to hands can limit the food handling capability of an individual. They may experience difficulties in handling food packages, manipulating food on the plate and transporting it to the mouth using hands or cutlery and lifting a cup or a glass. Elderly individuals may find it difficult to exert force in a coordinated manner. Many compensating designs of utensils have been introduced like nosey cup for neck bending difficulties, weighted mugs and plate guards for tremor problems are some of the examples. An electronic spoon is developed for tremor patients which is fitted with a stabilising mechanism that is available with camera and mobiles for picture stabilising. The compensatory mechanisms will not fully restore functions but provide valued additions to the quality of life.

Role of vision, smell, taste, hearing and touch in mastication

Human beings first see the food and will be attracted to reach for it. With vision impairment, the first developed sensory contact is lost and the subjects do not take adequate food and suffer from malnutrition. It may also affect another sensory route-the smell. Elderly individuals with olfactory dysfunction may develop disinterest in food and food related activities. They may suffer from nutritional imbalance and their sugar intake is undesirably high. Five primary tastes identified are – sweet, sour, salty, bitter and umami (umami is a Savory, rich, meaty flavour in tomato, mushrooms, cured meats and soy sauce). Both smell and taste are interrelated because of their chemo sensory nature. Derangement in taste can affect food consumption and can cause nutritional disorder. The sound produced while taking crispy and crunchy food can have great influence on others. Hearing impairment can affect the eating experience and the pleasure received out of it. Food, taken inside the mouth, can provide the sensation of texture and the temperature. Complete and partial removable dentures can impair the sensations passed through the mechano-receptors and affect the food enjoyment. Mastication requires a fine-tuned sensory system so that individuals can enjoy the food and support the most vital physiological function [34-36].

Conclusion

Mastication is a complex and multifaceted process that integrates teeth, the temporomandibular joint, mandibular movements and the intricate interplay of sensory inputs. The evolutionary adaptation of teeth among ancestors highlights the importance of mastication in survival. The mechanics of mastication and the masticatory cycle showcase the precision and efficiency of this process, which is further assisted by saliva through the critical role of lubrication and enzymatic activity. For individuals using dentures, adjustments in masticatory efficiency have to be brought in by incorporating technological and clinical advancements. Moreover, the manipulation of food with fingers and the sensory feedback from taste, smell and texture underscore the holistic nature of mastication which changes the profile of simple chewing to a sophisticated physiological activity. A profound understanding of the multiple facets of mastication can have significant implications in improving general and dental health and can ensure essential nutrition and overall well-being.

The process of mastication has faced new dilemmas in the recent past. Long-term stay in space by astronauts, could present unique challenges to mastication due to reduced gravitational forces, changes in bone density and alterations in the muscle function, potentially making an impact on masticatory efficiency over a period of time. Another challenge is the change in the characteristics of human diets which become softer and highly processed. There is a possibility that the masticatory efficiency of future generations may decline along with deteriorated oral health. Changes in mastication may create unimaginable profiles for the human beings; may be our aesthetic norms might also change.

The food industry plays a significant role in these dynamics. The prevalence of ready-to-eat, highly processed foods require minimal chewing, potentially reducing the functional demand on masticatory structures. Conversely, these dietary shifts might stimulate innovations in food texture and nutrition to address emerging health concerns. Understanding these interdependencies is critical, as the interplay between diet, mastication, and industrial trends will shape not only individual health but also broader societal and evolutionary trajectories. Mastication related knowledge underscores the importance of maintaining a balance between convenience and promoting robust masticatory function to ensure long-term well-being.

Mastication cannot be considered as a simple locomotion of the jaw but it involves a highly coordinated activity of different systems that govern the human life. Mastication underpins the core function of survival and serves as an evolutionary link. We should understand the prevailing system and the future prospects of the process of mastication because it is an evolutionary link to the future generations. Let us conclude this review with an AI assisted literary creation (poem).

The Dance of Chew

- Our divine jaws played a vital role in
- Grinding roots and tender grains
- As foods evolve, and ease takes hold,
- Will jaws grow frail, or tales grow old
- Teeth shaped the path of growth
- Humans claim it as evolutionary path
- Let us honour the masticatory might,
- For every chew that holds life's delight.

Author Contributions

Conceptualization-K. Chandrasekharan Nair, Pradeep C Dathan, *Review of articles*-Bheemalingeswara Rao, T Mohan Kumar; *Initial draft preparation*: Viswanath Gurumurthy, T Mohan Kumar, *Review and editing*- K. Chandrasekharan Nair; *Supervision*– K. Chandrasekharan Nair.

All the authors have read and agreed to the published version of the manuscript.

Conflict of Interest

The authors do not declare any conflict of interest.

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