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The development of masticatory biomechanics from the prenatal to prepubertal period.

El desarrollo de la biomecánica masticatoria desde el período prenatal hasta el prepuberal

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Abstract

INTRODUCTION: Mastication is coordinated motor skill that is most effective through synchronized crosstalk between the teeth, bone and muscles. A combination of molecular signaling and central pattern generators govern the development and physiology of mastication. As primates, humans have evolved with the changing dietary shifts for their survival. The adaptive mechanisms in the involved structures allows us to puncture, pierce, cut, crush, grind, nip, incise, scrap, and strip different dietary textures.

OBJECTIVE: The objective of this review is to understand the developmental dynamics and rhythmogenesis of mastication in children from the point of view of myology, odontology, and evolutionary perspective.

RELEVANCE: This chronological review helps in understanding how the multi-faceted nature of the masticatory apparatus comes into being from the prenatal to the prepubertal period. It enables pediatricians and pediatric dental surgeons to understand the oro-motor development while intervening with any treatment involving muscle tonicity of the masticatory organ.

KEYWORDS: Mastication, Pediatrics, Pediatric Dentistry, Growth and Development, Masticatory Muscles.

Resumen

INTRODUCCIÓN: La masticación es una habilidad motora coordinada que es más eficaz a través de la diafonía sincronizada entre los dientes, el hueso y los músculos. El desarrollo y la fisiología de la masticación se rigen por una combinación de señalización molecular y generadores de patrones centrales. Como primates, los humanos han evolucionado con los cambios en la dieta para su supervivencia. Los mecanismos adaptativos de las estructuras implicadas nos permiten pinchar, perforar, cortar, triturar, moler, pellizcar, hacer incisiones, raspar y pelar diferentes texturas alimentarias.

OBJETIVO: El objetivo de esta revisión es comprender la dinámica de desarrollo y ritmogénesis de la masticación en niños desde el punto de vista de la miología, odontología y perspectiva evolutiva.

RELEVANCIA: Esta revisión cronológica ayuda a comprender cómo surge la naturaleza polifacética del aparato masticatorio desde el periodo prenatal hasta el prepuberal. Permite a los pediatras y a los cirujanos dentistas pediátricos comprender el desarrollo oro-motor al intervenir en cualquier tratamiento que implique la tonicidad muscular del órgano masticatorio.

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INTRODUCTION

Mastication or chewing is a semi-automatic, rhythmic act initiated by the central nervous system and fine-tuned by inputs from receptors embedded in the orofacial area.[1] It has played an unparalleled role in the survival of our species from an evolutionary perspective.

The earliest known mammal (Diademodon) to have teeth in intercuspation with a synchronized activity of muscles for chewing existed approximately 250 million years ago.[2] The genus Homo, with which modern humans associate themselves arose from the clade of mammals called primates. Since the time of Diademodon to Homo Sapiens, a shift in dietary perspectives spearheaded the list of characteristics that was survival for our mammalian ancestors. Gracilization, gape, and gomphodontia resulted in adaptive changes to our bones, muscles, and teeth that met the growing nutritional demands.[3]

Gracilization is the reduction in bone mass with evolution. There are two reasons for the reduction in the convexity of our jaws and the subsequent shortening of our faces. Firstly, the shift from foraging to cooking decreased our olfactory sensation. Secondly, to protect ourselves from higher-order carnivores in the food chain we had to develop a stereoscopic vision.[3]

Gape is the maximum extent of our mouth opening. Softening of our diet by cooking reduced the amount of force required to chew. But it never eliminated the essence of certain hard foods that required a substantial force to crack open. The jaw works by a lever principle from the temporomandibular joint. To increase the bite force, masticatory muscles repositioned themselves forward. This did not affect the muscle mass. The hybrid nature of the fibers of the masticatory muscles makes them moldable. Due to this feature, the gape reduction made these muscles boisterous and fatigue-resistant.[4,5]

Heterodontia is the dental characteristic of our species where each tooth has its specific function. But heterodontia could not have lasted if our masticatory apparatus had not adapted by placing teeth in sockets. This allowed the periodontium to equalize the stress distribution generated by masticatory loads. It is this characteristic feature that makes us one of the gomphodont species. Additionally, the adaptation of the occlusal surface of our molars from a tribosphenic molar model also led to various cuspal arrangements for the efficient grinding of food.[2] Readers can explore the works of Peter Ungar, John R. Lukacs, and Shara Bailey for better understanding.

What makes humans altricial mammals is their ability to nurture their newborns till physiological functions occur unaided. We are also diphyodonts, i.e., we acquire two sets of dentitions in our lifetime – deciduous and permanent. Physiologic mastication is a learned behavior rather than an acquired one. The function of deciduous dentition in this learning phase stipulates attention.[4]

Previous studies have focused on understanding the food fragmentation index. Fractional sieving methods help in analyzing the degree of breakdown of test materials. Some commonly used test materials are condensation silicone, artificial foods, bite registration wax, and xylitol gum with citric acid. Optical systems are more advanced methods that use scanned data, computer analysis, and readings of electromyography to understand masticatory efficiency.[6,7]

There is no paucity in the methods to test masticatory efficiency. But there does exist a dearth in understanding the sophisticated nature of the masticatory apparatus. This narrative review focuses on the dynamic development of our masticatory efficiency from the prenatal to the prepubertal period.

In Utero

Masticatory muscles start developing from the mandibular pharyngeal arch by the 7th week in utero. Gamma motor neurons innervate these jaw muscles by the 8th week. Involved neuronal systems include the peripheral and central trigeminal, facial, and hypoglossal cranial nerve systems. Reflex opening of the mouth develops as the nerve fibers instill the first functional action of the jaws by 9 to 10 weeks. Sucking motion via automatization occurs in the 12th to 14th week in utero.[8-11]

Molecular signaling by Sonic Hedgehog (Shh), Bone Morphogenic Proteins (BMP), and Wnt signaling initiates deciduous teeth calcification. Enamel knot is a transient structure that presents itself as a primary and secondary form in the late bud and the late bell stage respectively. It houses over 50 genes responsible for the differentiation and morphogenesis of each tooth. The Fibroblast Growth Factor (FGF) contributes to the proliferation of ameloblasts and odontoblasts. Furthermore, Notch signaling and Follistatin determine the morphology of each molar. Seven ligands of Wnt signaling, enamel knots, and homeobox genes code for the cuspal patterns for each tooth.[12]

Birth to 6 weeks

Breastmilk is the first source of nutrition that the child intakes by the guidance of orofacial musculature. This intake is through a suckling action. The lips and the tongue (pressed against the palate) form a negative pressure (vacuum) by sealing the oral cavity. The buccal fat pads, tensor veli palatini and the root of the tongue are responsible for the lateral and posterior seal. A compressive action then expresses the milk from the breast.[10]

The tongue is one of the fastest muscles to attain myogenic maturation. The myofibers of the tongue start developing from the 15th embryonic day. They mature at the time of birth to compensate for the functional need for suckling. The compression of the lips and tongue against the nipple stimulates the flow of the nipple. It is later drawn by the action of the dorsum of the tongue. This is often referred to as a rippling or stripping action.[8]

During this period, the approximate width, height, and length of the palate are 26 mm, 6.5 mm, and 23-25.5 mm respectively. These dimensions of the palate help in understanding the motility span of the tongue which creates an effective seal. By the sixth week, the breadth of the mouth when closed is approximately 34.1 mm and is 28.5 mm when open.[13] The palate also begins to discriminate between different flavors during this period. Feeding formula milk helps the infant learn the various flavor cues.[14]

Contraction of the facial and masticatory muscles is a physiological mandate. It stimulates cartilage growth, and forward growth of bone, and improves facial bulk.[13] The versatility of the infant's orofacial musculature immediately after birth is a testament to this period being the first visible growth spurt.

4-6 months

Before the infant reaches 6 months of age, the oral cavity and the pharynx work as a single unit. The jaw has by now learned the solitary action of elevation. The mechanoreceptors of the tongue are now capable of detecting runny, pureed foods. A reflexive action of up and down motion of the tongue indicates the onset of "mashing" of foods. Rudimentary chewing is the phrase used to define this process. The mashing movement also initiates the learning action of lip competency at 4 to 6 months. This period also marks the beginning of achieving lip pressure. It eventually plays a crucial role as a developmental landmark for mature swallowing patterns.

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The amount of lip pressure steadily increases till 3 years of age.[13,14]

6-12 months

The eruption of the primary lower central incisors and the resorption of the buccal fat pads at 6 to 8 months is a signal for the jaw musculature to attempt mastication. Eating maturity for soft foods is gradually established. In the process, the infant learns to stabilize the jaw.[14,15]

Infants are now weaned to semi-solid foods that they "munch" by raising the mandible. The lips can now pucker and curl inwards. Thus, the infant now has better control over guiding the food morsels inside the oral cavity.

The tongue learns to elevate its lateral surfaces. This allows the formation of a central groove on the tongue where the morsel is easily placed. The resulting bolus is better controlled by improved motor activity. The infant also begins to move the bolus to one side of the mouth. The combination of lip competency and jaw elevation in the absence of a rotary component construes the munching action. It is the earliest emergence of a chewing action, whose frequency ranges from 0.88 to 2.11 Hz.[11]

Weaning also signals a decrease in the Ba:Ca ratio and an increase in the Sr:Ca ratio. Barium fades off after contributing to the development of deciduous teeth. In contrast, strontium incrementally adds to the condylar growth process.[4]

1-3 years

The second growth spurt begins one year after birth. This phase of early childhood sees a full set of primary dentitions coincide with the developmental milestone of eating independently. It marks the beginning of a transitional phase of chewing. The child learns to chew dissolvable hard solids. This marks the commencement of learning to chew in a coordinated manner. This coordination involves the establishment of a prehensile hand.[3]

The tongue regulates the bite force. Its tip elevates intermittently without any protrusion or retraction. It takes nearly 10 months for the maturation of muscle coordination.[10,16,17]

Introduction of hard, non-dissolvable, and chewy food features at the age of 2 years. Jaw movements begin as muscle coordination synchronizes. This movement is an exploratory mechanism for the child. It learns new, mature, and balanced swallowing patterns for different food textures and consistencies. The bunodont morphology of posterior teeth is a license for humans to explore the different fabrics of diet.[2]

Concurrently, the range of motion of the tongue also increases. The action of the muscles of mastication is now synchronized. This is also the period where the myofibers of the masseter begin to near the completion of their maturation.[8,14]

Infantile swallow ceases and oral-motor skills level up. This is because of the maturation of peripheral sensorimotor pathways, after which, neural tissues enter a plateau phase as per Scammon's Growth Curve. An example of the improvement in oral-motor skills is the ability of children to bite the spoon using their lips instead of their teeth to stabilize their trunk while eating.[13]

4-6 years

Occlusion is a momentary stable condition depending upon an orderly and sequential application of forces upon the dentoalveolar units. An ideal or centric occlusion is a by-product of satisfying the swallowing reflex.[1]

The type of deglutition at the age of 4 years shifts from a suction-type to a dentition-type. Any malocclusion at this stage will decrease the masticatory efficiency. However, malocclusions are independent of the bite force. Bite force in this period ranges from 185-215 N. Furthermore, the mean tongue pressure of a 6-year-old equals the tongue pressure of individuals above the age of 70 years.[9,13,16,18]

The increased thickness of the masseter muscle (~ 9.47 mm) is a result of the increase in its functionality. Apart from its famous activity in working with the temporalis muscle for posterior chewing, the masseter is active even during incisal chewing.[13]

The role of lateral pterygoids is moderate and antagonistic in nature. Depressor muscles like mylohyoid, digastric, and geniohyoid contract more efficiently upon swallowing liquids.[14]

Children are now given more fibrous foods which trains them in understanding the role of each tooth while chewing. The jaws perform lateral excursions to grind the food. It is noteworthy to mention that children in this age group who have a unilateral posterior crossbite have a wider jaw angle opening (due to flat posterior occlusion and small overlap of incisors) while chewing. This makes them vulnerable to entering a reverse chewing cycle (chewing on the side of crossbite only). The ill effects of a reverse chewing cycle can result in dental and facial asymmetries.[7]

6-8 years

Growth is defined as an increase in size. The schooler now has a palatal length of ~43.6 mm and the length of jaws is ~55 mm. The length of the tongue increases from 6 cm to 9 cm since birth. The muscular spindles of the masseter are completely mature. This further amplifies the masticatory efficiency.[8,13]

Permanent teeth begin to replace primary teeth. This marks the beginning of the mixed dentition period. Parents should report any parafunctional oral habits they observe in their child. Bruxism and mouth breathing are two such habits that directly influence masticatory development. In the former, the occlusal surface of the teeth is worn down, thereby forming a flat occlusal plane and a shallow overbite. The muscles of mastication are thus forced into a chewing motion with an abnormal lateral excursion. Upon swallowing, the mandible moves posterior and upwards in a rocking motion. This physiologic motion is absent in mouth breathers. They display strong anterior forces of the tongue, minimal occlusal force, and mesial tipping of the long axis of the teeth. These asymmetries amount to reduced masticatory efficiency.[7]

9-11 years

The late mixed dentition coincides with the third growth spurt. It is usually observed at 8-11 years and 7-9 years of age in males and females respectively. Moreover, a difference in masticatory development in terms of sexual dimorphism is also observed. While the trituration of food is better in boys, girls have a better chewing rate. (14) According to Fulks et al, a natural chewing rate, irrespective of age is as fast as possible with minimal loss in performance.[19]

The shearing quotient reduces in this phase as functional units (teeth) perish in the shedding-eruption cycle. An increase in jaw size (especially the increase in posterior ramus height) compensates for the loss of teeth.[6]

12-14 years

Pre-pubertal period (females: 11-13 years; males: 14-16 years) marks the shift from mixed to permanent dentition. The increased number of cusps creates an average occlusal angle that controls the masticatory pattern. Teeth are physiologically depressed by 0.08 mm because of masticatory forces. Yet, the bulging of the periodontal ligament maintains the average occlusal angle.[20]

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The tongue influences the transverse growth of the palatal complex and the neutral zone that houses the teeth (functional matrix theory). This in turn modifies facial morphology. Occlusal forces are greater in people with short faces and lesser in people with long faces.[21, 22]

As the height of the ramus increases, the associated muscles adapt accordingly. A clinical evaluation of freeway space determines the physiological position of the mandible at rest. It also decodes a mandible characterized by stressed and tensed masticatory muscles prone to spasms. The normal range of freeway space is 2 mm posteriorly and 2-5 mm anteriorly.[23] Reading the work of Robert Mason can help the reader better their understanding of freeway space.

The tail-end of this period sees a shift in adult-type masticatory behavior. A power stroke is characteristic of this phase. The combined efforts of the masticatory muscles, vertical ramus height, facial form, and anterior and lateral crushing movements of the mandible generate this power stroke. It ensures the reduction of bolus in its most minimal form. This leads to faster hydrolysis of macronutrients and better uptake of micronutrients.[6,13] **Table 1**

RHYTHMOGENESIS OF MASTICATION

Central Pattern Generators (CPGs) are neural networks that function autonomously without any sensory input and govern coordinated movements. These include locomotion, respiration, sucking, and mastication.[24] Myokines are responsible for eliciting the stretch response in muscle spindles (of the muscles of mastication). Cell-to-cell signaling between myokines and osteokines then leads to bone remodeling. The amount of strain produced in this process is directly responsible for bone deposition and resorption. This is the mechanostat hypothesis.[2-4] Now that we understand the multi-faceted nature of masticatory development, here is a summary of how an adult eventually chews.

When the food is about to reach the oral cavity, the mouth opens by voluntary action. The rotational movement of condyles activates the masseter, anterior fibers of the temporalis, and the external pterygoid muscles. Voluntary closure follows and the anterior tongue presses upwards and backward. This seals the hard palate till the first premolars. The posterior tongue exerts a lateral force against posterior occlusion. The cheek muscles respond by exerting a negative pressure.

The action of the elevators inhibits when the lips close. The upper lip tenses and supports the anterior teeth (canine-to-canine) till the level of the vestibule. The lower lip contracts inwards and makes a catenary curve. It simultaneously moves up under the influence of the mentalis muscle and engages the incisal edges of the upper incisors. The pterygoid muscles also assist in this movement. The actions of the cheek, lower lips, and pterygoids mark the establishment of a suction.

The velocity of the mandible decreases upon closure. Its path shifts from straight to circular, to perform a masticatory pattern based on the food texture. The teeth slide into centric when they are at maximum inter-digitation. The contact of teeth initiates a stretch reflex in mylohyoid, digastric, and geniohyoid muscles. This loading stage sees the greatest occlusal force at the area of the molars. The most engaged muscles are the masseter and temporalis, followed by the medial and lateral pterygoid. The lateral pterygoids also support the suprahyoid muscles during abduction.

Deglutition occurs as the suction of the soft palate breaks from the posterior pharyngeal wall. This also equalizes the air pressure in the inner ear. This change in pressure allows the saliva to

Table 1. Chronological development of the masticatory apparatus (continued on next page)

AGE	EVENT
7th week in utero	Muscles of Mastication develop from 1st pharyngeal arch
8 weeks in utero	Innervation of jaw muscles begins
9.5 weeks in utero	Reflex opening of the mouth is seen
10-12 weeks in utero	Sucking movement acquired via automatization
14 weeks in utero	First evidence of calcification of primary teeth
Birth	Palatal width: ~26 mm Palatal Height: ~6.5 mm Palatal length: ~ 25.5 to 23.5 mm Length of jaws: ~ 30 mm Myofibers of the tongue are completely mature
6 weeks	Breadth of the mouth (closed): ~34.1 mm Breadth of the mouth (open): ~28.5 mm
4-6 months	Mashing of food by the tongue in an upward-downward motion (rudimentary chewing) Jaw motions: Only elevation Oral cavity and pharynx continue to work as a single unit
5 months	Lip pressure begins to develop (steady increase till 36 months)
6-7 months	Complete command over the maintenance of jaw stability
6-8 months	Buccal fat pads are resorbed Eating maturity accomplished for soft foods
8-10 months	Munching is established where food is crushed by raising the lower jaw without a rotary component. Infant begins to move semi-solid food textures to one side of the mouth Lips assist in food intake by beginning to curl inwards Puckering of the lips develops Lateral surfaces of the tongue can now elevate, thereby forming a central groove for better bolus control Labial closure, a developmental landmark towards mature swallowing is established.
12 months	Palatal width: ~32 mm Palatal Height: ~11.5 mm Transitional phase of chewing (beginner to intermediate) Improved stamina of chewing muscles
6 months – 2 years	Chewing time and chewing cycles gradually decrease
12-18 months	Establishment of coordinated chewing (AAPD) Postural and functional changes in tongue as tongue tip elevates intermittently with no extension/retraction/protrusion of tongue occurring Regulation of bite force
22 months	Maturity of muscle co-ordination reached
24 months	Chewy foods introduced to facilitate functionally balanced mature swallowing patterns
24 months – 30 months	Rotary Jaw Movements
34 months	Synchronized activity of muscles of mastication
35 months	Masticatory consistency is yet to be established for different consistencies and textures of food
36 months	Myofibers of masseter are yet to attain complete maturation
2 to 4 years	Role of the tongue increases in mastication as infantile swallow ceases Optimum chewing frequency develops after the age of 4

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Table 1. Chronological development of the masticatory apparatus (continuation)

AGE	EVENT
3 years	Peripheral sensorimotor pathways start maturing Initiation of acquisition of oral-motor skills Breadth of the mouth (closed): ~43.5 mm Breadth of the mouth (open): ~36.9 mm
4 years	Shift of deglutition method from suction-type to dentition-type
3 to 5.5 years	Bite force: 185-215 N
3 to 6 years	Masseter activity maximum in incisal chewing Temporalis and masseter more active in posterior chewing Moderate activity of depressors Swallowing liquids results in the contraction of depressors
5 years	Masseter thickness: ~9.47 mm
6 years	Beginning of mixed dentition growth spurt Palatal Length: ~43.6 mm Length of jaws: ~55mm Masseter thickness: ~10.03 mm Increase in tongue length from 6 to 9 cm (since birth)
7 years	Muscles spindles of the masseter are fully mature
8 years	Increase in masticatory efficiency
9-11 years	First difference in sexual dimorphism observed as food trituration improves in boys whereas the chewing rate increases in girls. Masticatory performance decreases due to the loss of occlusal functional units (shedding of primary and eruption of permanent teeth) in this phase of dentition
12-14 years	Shift to adult-type mastication behavior

wet and lubricate the throat and esophagus for the incoming bolus. Moreover, the drainage of nasal passages also occurs. It helps in maintaining an optimum respiration rate (18 per minute) and saliva production (1.3 ml per minute) even while swallowing. [1,14,20,21,25]

CONCLUSION

Chewing maturation is a product of learning behaviors and neuronal and psychosocial development. Kinetic changes seen at dental, skeletal, and muscular levels of the masticatory apparatus guide us in differentiating the abnormal from the normal. The gestalt of mastication helps in deducing how those ballistic movements can influence treatment protocols of the orofacial region.

FUTURE RESEARCH

This chronological review on the development of mastication can act as a guide for future researchers keen to study the elements of mastication in children. Future research can utilize this succinct guide to study the oro-motor developmental milestones, muscle tonicity and prediction of malocclusion for a myology perspective in children.

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