

BIOMECHANICAL AND HISTOMECHANICAL STUDIES OF THE MASTICATORY APPARATUS DEVELOPMENT

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Abstract: The human masticatory apparatus is a specialized multiunit biomechanical system. The masticatory apparatus is unique in its shape, functions, anatomical and morphological structure. In all stages of the masticatory apparatus development there are changes in its units according to varying mechanical load acting on them. Mechanical load is one of the governing factors of generation of masticatory apparatus units growth. Biomechanical and histomechanical studies such tissues and organs as bones, the enamel, the temporomandibular joint, the periodontal ligament, the palate and so on favours the view on role of mechanical factor in the masticatory apparatus functioning.

Key words: masticatory apparatus, multiunit biomechanical system, bone, enamel, periodontal ligament, temporomandibular joint, palate

Study of phylogenesis, ontogenesis and structure of the human masticatory apparatus, its various functions (food capture and holding, its mechanical and chemical treatment, forming of a food lump, movement of a food lump from the oral cavity to the throat and then to the esophagus, taking an active part in voice and speech formations, respiration, swallowing, facial expression, etc.) allows considering the masticatory apparatus as a specialized multiunit biomechanical system [7]. This system and all its units have been forming in the process of adaptation of living organisms to environmental changes. The peculiarities being intrinsic only to living tissues (for example, biological growth) play an important role in forming the masticatory apparatus and structure of its units.

The first mentions on this point date from the 19th century. In handbooks on anatomy the authors called the reader's attention to the direct relationship between structure and functions of different organs and tissues.

Folkman (1862) noted that bone growth was caused by pressure, however an excessive pressure retarded bone growth [14].

J. Wolff had stated the law of bone transformation that each bone function change was mathematically related with changes in bone architectonics and external form [8]. W. Ru (1883) had substantiated the theory of the "trajectorial" bone structure and had proved that the pressure was a biomechanical stimulus of bone growth [14].

A. Anichkin called attention to the fact that structure of all elements of the temporomandibular joints is changed with age and with changing functions of the dentofacial system [9].

S.A. Reinberg writes [16] that bone tissue is exceedingly living, changeable one. Bone is able to remodel and transform, it may adapt to changing environmental conditions.

G.A. Illisarov's clinical observations have reinforced the statement that tensile stresses may initiate and sustain bone growth.

Thus literature data as well as those of our clinicoanatomical, morphological and biomechanical investigations of masticatory apparatus functioning show ability of this

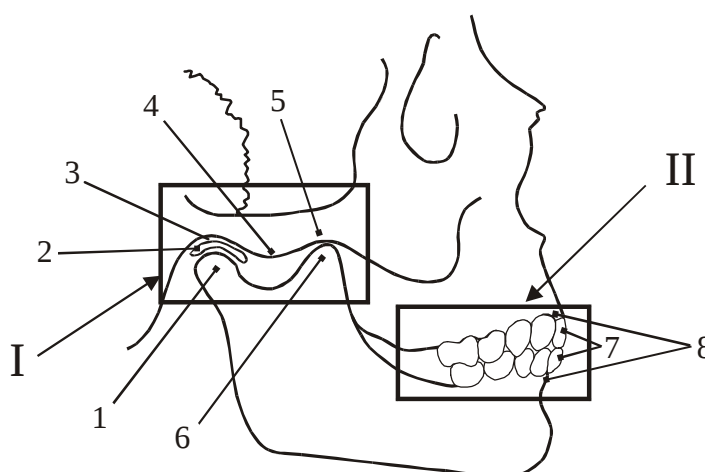


Fig. 1. Scheme of disposition of the frame units of the masticatory apparatus.

I. The osteomuscular unit in the region of the temporomandibular joints:

- 1 – the condyle; 2 – the disc; 3 – the temporal fossa; 4 – the articular tubercle;
- 5 – the zygomatic arch; 6 – the coronoid process.

II. The multiunit intermaxillary unit joined dental arches of the maxilla and the mandible

- 7 – the dental arches; 8 – the alveolar processes.

multiunit system to carry significant load, to transform and transmit it on the facial bones. Biomechanical models are of great importance in study of peculiarities of bone and soft tissues functioning taking into account their biological growth, time-varying and age-varying masticatory load.

Many tissues and organs (the teeth, the alveolar processes, the coronoid and condylar processes, the maxillary sinuses) of the newborn child's masticatory apparatus are germinal. Therefore a newborn child has no an articular joint between the mandible and the maxilla as well as contact between the lower and upper teeth. An increasing load is the generator of forming one of the frame units, namely the temporomandibular joint (Fig. 1). In the beginning a load is associated with sucking, after dental eruption a load is caused by chewing. The forming the temporomandibular joint is completed to 16 years when the permanent occlusion is formed. This fact substantiates the conclusion on importance of mechanical load to processes of growth and development of the jawbones and the joints between them.

Simultaneously with the temporomandibular joint forming the complex changes take place in the alveolar processes of both the mandible and the maxilla. They are connected with teeth eruption and arrangement, increase of the occlusion height. As a result the other frame unit (the intermaxillary unit) is formed by closed upper and lower teeth (Fig. 1).

It should be emphasized that the factors responsible for growth and development of the frame units, coordination and conjunction of their function are identical. Moreover there exist osteomuscular and neurohumoral links both between these frame units and with the central nervous system.

There are clinical, anatomotopographical and morphological evidences of influence of mechanical load on forming both organs and tissues in the masticatory apparatus. Of special interest is the process of the tooth crown development. The crowns of different teeth (the incisors, the canine, the premolar and molar teeth) are markedly distinguished, the amount and geometry of the roots also vary and depend heavily on the masticatory loads. A semielliptical shape of the maxilla's arch, a parabolic shape of the mandible's arch and their sizes are in consequence of mechanical loads as well. It is pertinent to note that the enamel is the hardest material in the human body [10].

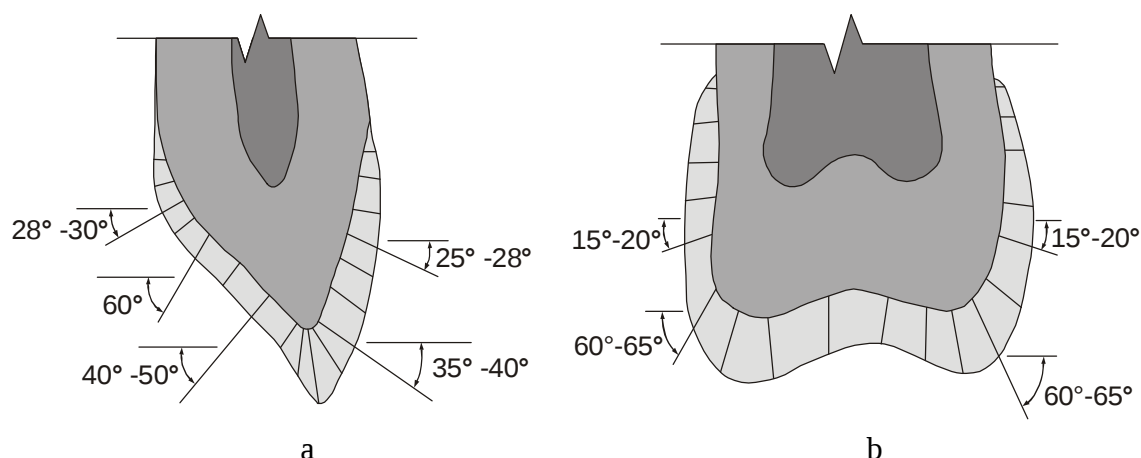


Fig. 2. The crowns of different teeth: a – the incisor, b – the molar

The role of functional load on structure of the hard dental tissues is thoroughly studied by analyzing the histograms in [11]. The authors have found out that directions of spiral-like twisting enamel prisms is not identical in different crown's regions (Fig. 2). In the neck region they are almost horizontally directed, in the middle of the crown they obliquely locate, and near the masticatory surface they are almost vertically directed. Moreover directions of the prisms appear to vary for different teeth.

Among numerous units of the masticatory apparatus the periodontal ligament is worthy of notice. The periodontal ligament is a dense connective tissue that surrounds the root of the tooth and attaches it to the alveolar bone.

The periodontal ligament plays a broad spectrum of functions. The primary functions are providing tooth support and blood supply. In literature, there is no disagreement concerning the role of the periodontal ligament in providing support for the teeth, but there is considerable controversy involving the mechanism by which this function is accomplished. The precise sequence of events that occurs in the periodontal ligament when force is applied to a tooth was not known.

Such a multifunction of the periodontal ligament depends upon its complex structure. The periodontal ligament consists mainly of collagen fibres, most of them being arranged into fibre bundles. Collagen fibres comprise 50% of the periodontal ligament by weight. Furthermore, the periodontal ligament also contains considerable amount of cells, nerves, vasculature, interstitial fluid [15].

To explain the mechanism of tooth support by the periodontal ligament we have conducted experiments in guinea-pigs [3]. It was experimentally shown that under a short-term load the periodontal ligament may be considered as a porous solid (collagen fibres, walls of blood and lymphatic vessels) containing a fluid (interstitial fluid, blood, lymph). Moreover the experiment provided to estimate the permeability coefficient of the PDL. It proved to be in the order of $10^{-8} \text{ m}^2/(\text{Pa}\cdot\text{sec})$.

We think that consideration of the PDL as a porous solid containing a free fluid might help to furnish insights into the mechanism and the nature of the providing tooth support by the PDL under load as well as other functions of the PDL.

That is why the authors use the Biot's poroelastic theory to model the PDL. As an example the behaviour of the interstitial fluid saturating and flowing through a deformable porous matrix was considered for the case of unconfined compression of such a porous medium [5].

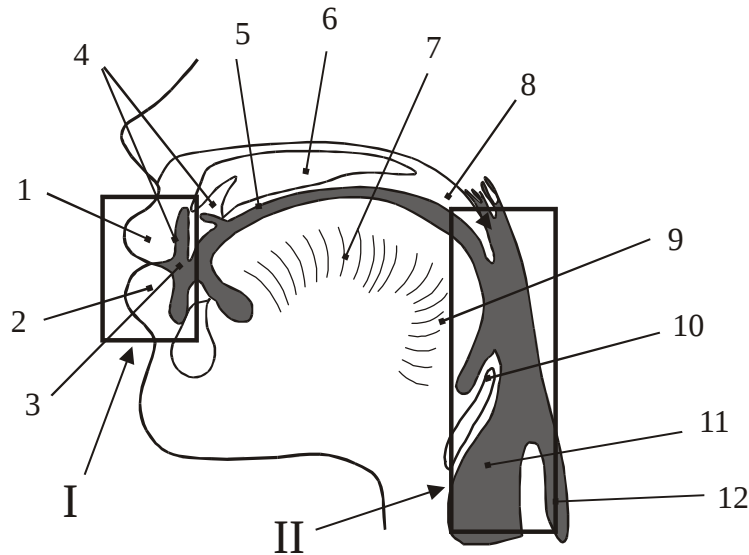


Fig. 3. Scheme of disposition of the auxiliary units of the masticatory apparatus.

I. The anterior oralolabial apparatus

1 – the upper lip; 2 – the lower lip; 3 – the mouth entrance; 4 – the teeth and the alveolar processes; 5 – the oral cavity; 6 – the hard palate; 7 – the tongue.

II. The posterior pharyngopalatine lock

8 – the soft palate; 9 – the tongue root; 10 – the epiglottis; 11 – the trachea; 12 – the esophagus.

Moreover from unified biomechanical grounds some problems were formulated and solved in which the teeth were considered to be loaded by functional, traumatic and orthodontic loads [2-6, 15]. In particular, the optimization problem of finding appropriate orthodontic forces was formulated and solved. By appropriate forces we denote forces which cause predesigned orthodontic tooth movement and satisfy some biological restraints. To achieve predesigned orthodontic movement of a tooth the exact mathematical definitions of concepts of a «center of resistance» and a «center of rotation of a tooth» were introduced and several corresponding theorems were proved.

The soft organs such as the lips, the cheeks, the soft palate, the tongue take an active part in chewing. Their activity and functions are controlled by the central nervous system and are dependent on state of chewing and mimic muscles. This units provide mouth opening, food capture, holding and approbation, its mechanical and chemical treatment, forming of a food lump which has the form and consistence suitable for movement from the oral cavity to the throat and then to the esophagus.

The oral cavity (*cavum oris proprium*) with the occluding teeth or without any tooth and the mouth entrance are the system of the communicating gaps which are surrounded by the walls and the protruding organs [12].

Thus the oral cavity and the mouth entrance can be considered as a single vestibulooral unit fitted with an special musculature (Fig. 3).

Food capture and holding is effected by the oralolabial apparatus. Its sphincter (*musculus orbicularis oris*) regulates mouth opening and closing. In the oral cavity a food is mechanically and chemically treated. Further a formed food lump moves to the tongue root and then through the complex posterior pharyngopalatine lock. This lock overlaps the entrance to the nasal cavity and the larynx and thereby promotes food movement to the esophagus.

In the pharyngopalatine lock functioning five conjugate muscles (*musculus tensor veli palatini*, *musculus levator veli palatini*, *musculus uvulae*, *musculus palatopharyngeus*, *musculus constrictor pharyngis superior*) take part. The oral and nasal cavities are separated

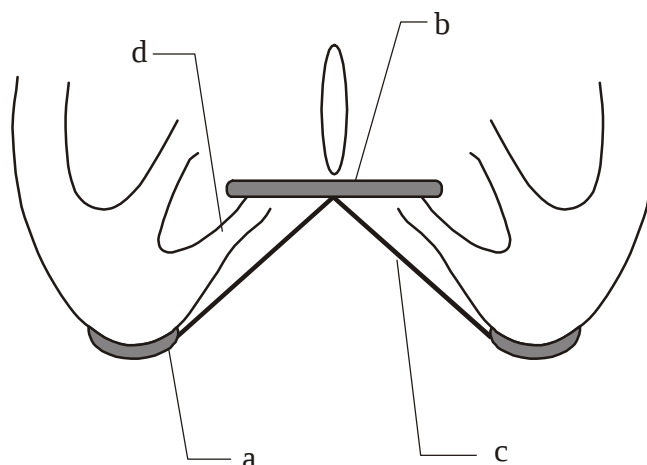


Fig. 4. Scheme of the mechanical apparatus in the case of the double-sided palate cleft: a) the teeth-gum plate; b) the nasal plate; c) the elastic ring; d) palate fragment.

by reflex contraction of the muscles of the soft palate. At the same time the entrance to the larynx is blocked due to pressure of the muscles of the tongue root to the epiglottis. As a result a food lump moves easily to the esophagus.

Congenital maxillary anomaly is one of the most commonly encountered disorders of the dentofacial system. It disturbs such vitally important functions as sucking, swallowing, breathing, speech and others.

We have elaborated the method of stepwise preoperative orthopedic reconstruction of the defective maxilla [17]. The key to this method is to bring down the hard palate fragments from the nasal cavity to the oral cavity. Fig. 4 schematically shows the apparatus after applying to the separated fragments in the case of the double-sided cleft.

Biomechanical analysis made possible estimating the optimal load developed the apparatus for successful treatment [1, 13].

Conclusions

The importance of biomechanical studies of the masticatory apparatus is beyond question. This system is unique in its shape, functions, anatomical and morphological structure. In the development of the masticatory apparatus it may be recognized typical stages such as germination, growth, development. In all stages the masticatory apparatus is changed in accordance with varying mechanical load acting on it.

At the moment it is clear that mechanical load is one of the governing factors of generation of masticatory apparatus units growth. Biomechanical studies allow objectively understanding the processes taking place in living tissues and individualizing the treatment of patients. It is especially important to diagnose and choose method of treatment of a very complex system, namely the masticatory apparatus.

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ИЗУЧЕНИЕ ДИНАМИКИ РОСТА И РАЗВИТИЯ ЖЕВАТЕЛЬНОГО АППАРАТА МЕТОДАМИ БИОМЕХАНИКИ И ГИСТОМЕХАНИКИ

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Изучение филогенеза, онтогенеза, структуры и функции жевательного аппарата, многогранность и специфичность выполняемых им функций (захватывание, удержание пищи, ее механическая и физико-химическая обработка, образование пищевого комка, проведение его в глотку и пищевод, а также активное участие в голосо- и речеобразовании, дыхании, глотании, мимической и пластической выразительности лица) позволяют рассматривать жевательный аппарат как специализированную полимодальную многоблочную биомеханическую систему, сформировавшуюся в процессе многоэтапных преобразований и приспособлений животных организмов к условиям окружающей их среды.

Это открывает возможности для новых методологических подходов как для разработки вопросов формообразования этой сложной системы, так и использования

методов математического моделирования функционирования ее отдельных блоков, затворов, клапанов, всей системы в целом под действием изменяющейся с возрастом жевательной нагрузки.

В период новорожденности ряд тканевых образований и органов жевательного аппарата находятся в зачаточном состоянии (зубы, альвеолярные отростки, венечный и суставной отростки нижней челюсти, верхнечелюстные пазухи); в этом возрасте у ребенка отсутствуют суставные сочленения между ветвью нижней челюсти и височной костью, между зубами верхней и нижней челюстей. Генератором процессов формообразования элементов височно-нижнечелюстного сустава (основного каркасного блока) является нарастающая нагрузка, изначально под давлением процесса сосания, а с прорезыванием зубов - акта жевания. Завершается моделирование основного каркасного блока к 16 годам - одновременно с установлением постоянного прикуса. Этот факт подтверждает значимость механической нагрузки для процессов роста и развития челюстных костей и их сочленений.

Одновременно с формированием основных каркасных блоков в области височно-нижнечелюстных суставов происходят сложные преобразования в альвеолярных отростках как верхней, так и нижней челюстей, связанные с прорезыванием, расстановкой зубов и подъемом высоты прикуса, что, в свою очередь, обеспечивает появление второго каркасного зубоальвеолярного блока, образующегося при смыкании между зубными рядами верхней и нижней челюстей.

Следует отметить идентичность факторов, генерирующих рост, развитие и формообразование основных каркасных блоков, координированность, сопряженность и взаимодействие их функций, наличие костно-мышечных и нейрогуморальных связей как между собой, так и с центральной нервной системой.

В жевательном аппарате имеют место отчетливо выраженные клинические, анатомо-топографические и морфологические признаки, отражающие влияние механической нагрузки на формирование как органических, так и тканевых структур. Это отчетливо видно по структуре, свойствам и поведению эмали, периодонта, неба. Кроме этого в зависимости от выполняемых функций четко разграничиваются форма коронок зубов (резцы, клыки, малые и большие коренные зубы), число, форма, размеры и геометрическое расположение корней зубов, форма и размеры зубных дуг (на нижней челюсти в форме параболы, на верхней - полуэллипса).

Для обеспечения выполнения всех компонентов акта жевания помимо основных каркасных блоков активная роль принадлежит вспомогательным механизмам: затворам, клапанам, то есть таким мягкотканым образованиям как губы, щеки, мягкое небо, язык, функции которых находятся под контролем центральной нервной системы, а также напрямую зависят от состояния жевательной и мимической мускулатуры.

Для целей биомеханического описания мы рассматриваем преддверие и полость рта как единый вестибуло-оральный блок, снабженный специальной мускулатурой и обеспечивающий прием, удержание, переработку и перемещение пищи.

Таким образом, в настоящее время доказана пусковая роль давления, которое является мощным генератором роста, перестройки и функционирования органов и тканей жевательного аппарата.

Разработка новой методологии с позиций биомеханики и гистомеханики для объективного изучения процессов, происходящих в живых тканях с учетом не только ростовых изменений, но и процессов остеогенеза, расширяет, углубляет и объективизирует исследования каждого индивидуального пациента в статике и динамике. Это особенно важно для диагностики, выбора метода лечения заболеваний такой сложной по конфигурации, анатомической форме, гистологическому строению и функциям системы - зубочелюстной системы. Библ. 17.

Ключевые слова: жевательный аппарат, многоблочная биомеханическая система, кость, эмаль зубов, периодонт, височно-нижнечелюстной сустав, небо

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