Human dentofacial system as an element of European megaproject “Virtual physiological human”: Modeling and analysis of pathologies

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Abstract

Because of complicated hierarchy of biological objects (molecules, cells, tissues, organs) forming interconnected functional systems, the human body is one of the complex objects of the scientific investigations. Technological breakthrough in the diagnostics and describing of in vivo processes and also development of mathematical models made possible an opportunity to obtain realistic simulations of normal and pathological events in the human body. The project “Virtual Physiological Human” is one of actual trends today in the contemporary science. This multi-disciplinary project unites mathematicians, biomechanicians, physicists, biologists, doctors, biochemists and other specialists from different countries of the world. The human dentofacial system is considered within the framework of this new approach. In given work, the connection of the dentofacial system with other systems of the human, causes the dentofacial system disturbance appearance, and possible consequences are considered. The following pathology is analyzed: deformation of the temporomandibular joint and internal carotid artery resulting in disturbance of brain blood circulation.

Keywords: Virtual physiological human, dentofacial system, multi-scale approach, pathologies of the dentofacial system.

1. Introduction

The relation between dental diseases and pathologies of different human organs was shown even in the seventh century before Christ by Egyptian and Greek physicians including famous Hippocrates. But, the mechanism of this relation was not studied. It seems likely that there are two mechanisms of this relation. One of them is realized by microbic factor which is especially appreciable at diseases of inflammatory character (for example, it is known the relation between dental periodontitis and myocardial infarction). The other mechanism discussed in this research is connected with mechanical factor (biomechanical pressure).

It is shown that mechanical factor has a pronounced effect on the formation (processes of phylogenesis and ontogenesis) and functioning of the development of the temporomandibular joint which is the youngest joint of the biological history of human, joint’s embryology rejects its phylogenesis. Some authors call this joint paladin of human joints [2].

2. Dentofacial system as one of the systems taking part in the virtual physiological human structure

The dentofacial system is a complex multilevel system. It is composed by hard and soft tissues forming complex multilevel substructures (units), the hard tissue units are the osteomuscular units in the area of the temporomandibular joints and the intermandibular units joining the dental arches of the upper and lower jaws (Fig. 1).

The soft tissue units are the anterior and posterior units (Fig. 2).
On examination, each of these units could be divided into smaller units. Perhaps, this dividing could be realized ad infinitum. For example, considering the periodontal ligament which enters into the intermandibular unit and has a thickness, on the average, only 0.2 mm, we can separate such tissues as the collagen fibres, blood and lymphatic vessels, nerves, cells, interstitial liquid. Each of these could be considered as a unit composed by smaller elements. It should be marked that the choice of units and level which would be used to research the dentofacial system depends on purposes of the concrete research.

The dentofacial system anomalies are the serious problems of human health, and they need in correct treatment. This treatment is impossible without the use of biomechanics, for example for the choice of force application points, their magnitudes, and directions for the orthodontic displacement.

Meanwhile, the dentofacial dysfunctions could lead to the pathology of the other systems of human that agrees with the view of unity and complexity of the human within the scope of virtual physiological human idea.

Table 1

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<th>The dentofacial anomaly consequences</th>
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<td>1. Aesthetic disturbances</td>
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<td>4. Breathing function disturbance (mouth breath)</td>
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<td>7. Predisposition to viral respiratory diseases</td>
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<td>8. ENT-disease development (ENT - ear, nose, throat)</td>
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Incorrect position of teeth as well as any disruption in the dentition can lead to abnormal function of other organs and body systems. Gastritis, cholecystitis and obesity, liver and pancreas, skin and endocrine diseases, deformities of the temporomandibular joint, parodontium diseases is only the partial list of the problems provoked by abnormal development of the dentofacial system [3].

Missing of teeth, maldevelopment of the mandible, traumas and hurts of the mandible cause the redistribution of loads in the dentofacial system (Fig. 3). As a result, teeth and temporomandibular joint suffer in many cases.

Displacement of the disk of the temporomandibular joint (sagittal displacement) (Fig. 4a) and medial displacement (Fig. 4b) are the most frequent mechanisms of redistribution of loads in the temporomandibular joint. The displacement of the disk can result in its bulging (formation of diverticulum) in different directions (Fig. 4).
Often, generated diverticulum can bring about serious consequences. Decrease of distance between the joint capsule and wall of the internal carotid artery occurs at medial displacement of the temporomandibular joint (Fig. 5).

The internal carotid artery is one of the four arteries which bring blood into the brain (two internal carotid and two vertebral arteries). At sufficiently big displacements of the temporomandibular joint inside, the diverticulum begins to irritate nerves, which braid wall of the internal carotid artery. This case can lead to stenosis of the artery or also its occlusion (possible stroke). Also, important thing is fact that pain syndrome of the temporomandibular joint can be generated at irritation of wall of artery. The irritation passes to sinocarotid zone, which regulates blood flow in the brain and also has influence on heart work.

Compensatory mechanism begins to work at disorder of cerebral blood circulation in internal carotid arteries. The mechanism consists of Willis’s circle (Fig. 6) and collaterals.

Willis’s circle is located in base of the brain and connects two internal carotid and two vertebral arteries in the circle. In norm, blood circulation in connecting of the circle is very slow.

Circle of Willis redistributes blood at disorder of vascular permeability of one of arteries. In this case, diameters of vessels and blood velocity in other arteries and collaterals increase. Note, in this case, expansible connecting arteries are not assigned in norm for large blood circulation. They are inflated and
their walls could not carry high value of pressure in some moment, then, it tends to rupture of wall, which tends to hemorrhagic stroke (blood fluxes into space between the brain and internal wall of the cranium).

Circle of Willis redistributes blood flow using communicating arteries in this case, if blood flow decreases or even stops into one of the arteries, and it does not leave the area of the brain without blood.

If circle of Willis is not close (often posterior communicating artery is absent), then collaterals are taken all of work for the restoration of cerebral blood flow with a deficiency of blood flow. The most common case is the increase of diameter of the ophthalmic artery.

For each person, the case of closed circle of Willis, the place of departure of the cerebral arteries from the internal carotid arteries, development of collateral arteries are unique. Accordingly, not all defense mechanisms are well developed in each person.

The chain of effects of malocclusion can lead to stroke (and often death of human). If it is broken, many pathological processes may not occur in the temporomandibular joint and the blood circulation into the brain.

Thus, the problem of treatment of malocclusion should be solved taking into consideration the temporomandibular joint. Modern methods (magnetic resonance imaging, computer tomography, condylography registration of movement of the disk at various movements of the lower jaw) and the use of the articulator (device for simulation of the proper occlusion by removing the wax forms of the dental arches) can allow us to simulate and restore malocclusion. In this case, the temporomandibular joint and movements of the disk at movements of the lower jaw will be in norm. Pain syndrome, overdistension of the facial and neck muscles and disorders of the cerebral circulation will not generate.

The problem of the relationship between change in the occlusion and accordingly the temporomandibular joint and cerebral blood circulation can not be considered by only dentists or only vascular surgeons. This problem should be solved within interdisciplinary approach. Only in this case, treatment will be complex and the consequences of interventions of medical specialists will not have adverse effects on systems of human organism.

The mathematical modeling of elements of the dentofacial system demands the statement and solution of appropriate initial boundary-value problem for continuum body with growing strain. The author’s experience shows that best results can be obtained at application of constitutive relation suggested by American biomechanician F. Hsu [4].

According to his supposition, the strain rate $\tilde{\xi}$ is additive sum of elastic strain rate $\tilde{\xi}^e$ and growth strain rate $\tilde{\xi}^g$

$$\tilde{\xi} = \tilde{\xi}^g + \tilde{\xi}^e,$$  \hspace{2cm} (1)$$

where elastic strain rate can be found according to Hooke’s law

$$\tilde{\xi}^e = \frac{d\tilde{e}^e}{dt}, \quad \tilde{e}^e = \tilde{C}^{-1} : \tilde{\sigma},$$  \hspace{2cm} (2)$$

here $\tilde{e}^e$ is tensor of elastic strain, $\tilde{\sigma}$ is stress tensor, $\tilde{C}^{-1}$ is fourth-order tensor of elastic compliance. Tensor of growth strain rate can be represented is the form:

$$\tilde{\xi}^g = \tilde{A} + \overline{\tilde{B}} \cdot \tilde{\sigma},$$  \hspace{2cm} (3)$$

where $\tilde{A}$ is tensor of congenital growth, $\overline{\tilde{B}}$ is fourth-order tensor describing influence of stress on the growth.
For isotropic body, this relation can be simplified:

\[ \tilde{\varepsilon}^g = A\tilde{I} + B\tilde{\sigma}, \]

where \( \tilde{I} \) is the identity tensor.

Coefficients \( A \) and \( B \) can be found from experiment. For example, for the hard palate of children of early age with the help of gypsum imprints, the authors found \( A = 0.0025 \) (1/month), \( B = 0.002 \) (mm\(^2\)/g \cdot month). After that, the boundary-value problem can be solved by traditional methods.

In should be noted the important fact that the dentofacial, circulatory and nervous systems of the human body are considered in this problem. It highlights the focus of the work within the concept of “Virtual Physiological Human”. This work may combine the efforts of dentists, vascular surgeons, neurosurgeons, and biomechanicians.

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References