〔Introductory paper〕

What is the Viscerocranium from the Standpoint of Vertebrate Evolution?

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Abstract

This paper investigates the functions and biomechanical properties of the viscerocranium from the perspective of phylogenic evolution. A new concept of the mechanical skeletal masticatory apparatus is proposed. Combined trilateral research in morphology (phylogeny-ontogeny), molecular genetics, and biomechanics, was reviewed in order to answer the question "What is the viscerocranium, i.e., face?" For this purpose consideration of the basic construction of vertebrates and evolution in vertebrate was studied. For an insight into the basic skeletal construction in the viscerocranium, especially in the masticatory structure, the biological and biomechanical properties of the tooth were also investigated.

Key Words: Viscerocranium, Trilateral research, Phylogeny-ontogeny, Evolution Molecular genetics, Biomechanics

1. Functions of the Face and Mouth, and the Concept of a Mechanical Supportive Organ System.

The "face" is called the viscerocranium in anatomical terms and is conceptualized as one organ unit. However, in traditional medicine, this portion of the skull is disassembled into many organs, and a treatment system is formed for each organ. Sensory and masticatory organs existing in this region have special functions peculiar to each organ, so that specialized treatment systems for each respective organ are indispensable, but the face has special functions of a higher order with these various organs integrated as a unit. With increasing progress in medicine, the higher order information functions of the face should also be cultivated as a new medical area. From olden times, the expression and complexion of the face have been thought to be important in the pathognomy in internal medicine; medical informative functions belonging to the face have also been taken for granted in surgery and clinical work in psychoneurotic departments, however they have not been studied systematically up to now. The viscerocranium was originally derived, as the name itself suggests, from the visceral muscle (smooth muscle) which existed in the respiratory visceral system of the branchial intestine and its auxiliary skeletal system. Therefore, the groups of facial expression muscles, masticatory muscles, and muscles controlling swallowing and vocalization were derived from these visceral smooth muscles. The skull and clavicle were derived from the dermal bone which originated from the armor, i.e., the complex of bone and dentin called aspidin, in the paleozoic era; in the mammal, a group of visceral muscles began to cover the outer layer of this dermal bone; on the other hand, the lingual striated muscle system developed in the oral cavity, thereby reversing the inside and the outside. Therefore, the branchial intestine can be seen systematically as a prolapsed mouth. Facial expression and complexion have been thought to be important in the pathognomy in internal medicine from ancient times because the color and condition of the visceral muscle of the prolapsed branchial intestine, that is, the expression of the viscera, could be

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detected in diagnosis. The emotions of joy, anger, and sorrow are expressed mainly in the face, but originally the effective organ for the emotional function of the brain is thought to have existed in the branchial intestinal respiratory system. This visceral muscle evolved into the masticatory, expression, swallowing, and vocalization muscles, therefore the expression of crying and laughing occurs in these areas. We human beings cry or laugh, twisting our bodies because the visceral muscle originating from the respiratory system is in close interaction with the body wall-based somatic respiratory muscle. A dog expresses joy and fear with its tail which interacts with the respiration. As stated above, the viscerocranium indicates the condition of an individual creature because it is an effective organ expressing mental and neurotic as well as somatic activities.

The stomatognatic system constituting the main portion of the face is equivalent to the digestive organ of the viscerocranium and is understood as a masticating apparatus. In addition, the face comprises the nasal cavity, paranasal sinuses, eyes as projections of the brain, and pinnae as sound wave introducing organs for the sense of hearing. By applying the concept of a mechanical supportive organ system to this stomatognathic unit with the dental arch as a masticatory apparatus, the causes of diseases can be clarified more easily, and treatment methods can become more reliable; also, conversion from symptomatic therapy, which has been dominant in the oral cavity region, to causal therapy becomes possible.

The masticatory mechanical supportive organ system has the following characteristics:

(1) If there is any structural defect in the organ system, the masticatory apparatus becomes defective, and diseases occur.

(2) Dentition and the shape of the jaw will come to have altered morphology and shape when external forces or deviated functions are applied over a long period of time.

(3) Both external forces and deviated functions applied to the mechanical organ are summari zed as habits, i.e., oral-perioral habits and they usually promote chain reactions. As a result, deformity occurs biomechanically in the skeletal supportive system.

(4) A disease results when the above-stated morphology and shape changes cause mechanical structural defects in some parts of the masticatory organs.

2. The Masticatory Organ and Phylogenesis

Here, in order to understand the characteristics of the masticatory organ as a mechanical skeletal system, it is necessary to clarify phylogenetically "What kind of archetype in the Paleozoic era developed into today's figure of a human being?" (Goethe). Lamarck thought that living beings have archetypes as basic forms; he proposed a concept of evolution in which those archetypes change with time. Through a study of invertebrates, he made "biologie" independent from natural history. The famous Goethe, who established "Morphologie," had a similar concept about evolution. Lamarck's and Goethe's conviction was later carried further by Haeckel. Haeckel integrated comparative anatomy (Cuvier, 1795) with embryology through his study of the ontogenesis of vertebrates, and set forth his famous Recapitulation Theory (Biogenetic Law) together with the new terms "Phylogenie" and "Ontogenie" based on observational studies. The new term "Recapitulation" proposed by Haeckel means in vertebrates, the main portion of development is seen as if it repeats phylogenesis in a short time after fertilization." Recapitulation theory was unable to explain neoteny, which was discovered later, and for this reason this theory has been almost entirely ignored in this century. Roux, who succeeded Haeckel, discerned the essentially important effects of mechanics such as gravity behind both ontogenesis and phylogenesis, and proposed a new scientific area of "Biomechanik". Through the introduction of biomechanics and molecular genetics, the relationship between ontogenesis and phylogenesis has been clarified and, at the same time, neoteny can now be easily explained as a genetic phenomenon. In the phylogenesis of vertebrates, the importanceof the viscerocranium seems evident. The organ characteristics and essential functions of the viscerocranium can be understood by clarifying how the basic system of archetypes in vertebrates has been modified, and what factors have driven this evolution. According to the late morphologist S. Miki, we can understand from what the face is derived (Fig. 1). Today, the evolution of vertebrates is considered to be dependent upon the characteristics of the skeleton of the collagen apatite complex (Halstead); and surveying the evolution of the oro-maxillofacial organ from the above mentioned viewpoint, a close relationship between the organ and biomechanics can be clearly discerned. The mysteries of the evolution of vertebrates lie in the biomechanical properties of apatite which is the characteristic material in vertebrates and, therefore, there is a possibility of demystifying evolution by investigations integrating phylogenesis, paleontology, morphology, molecular genetics, immunology, and biomechanics. The starting point of vertebrates was when Pterobranchia, having a cutaneous respiratory system, took the gill cleft into the intestine. Since this was the first step to the vertebrates, it can be seen as the primeval vertebrate revolution. And then the first overt vertebrate revolution is said to be the acquisition of teeth and jaws by the Acanthodii in the Silurian period. The second vertebrate revolution was the dramatic terrestialization from water that occurred in the Devonian period. By biomechanical response, a drastic conversion occurred not only from branchial to pulmonary respiration, but also in ossification of the cartilaginous endoskeleton. The third revolution which occurred subsequently was the birth of the mammals. The most important characteristic of a mammal is the acquisition of the lactation system of a suckling which after infancy becomes the masticatory organ. The mammalian revolution in energy metabolism by homoiothermal maintenance in small animals was induced and made possible by the mastication of foods. Thus, in the four epochs of the primeval, first, second and third revolutions culminating in the mammal which is the highest form in the animal kingdom, all

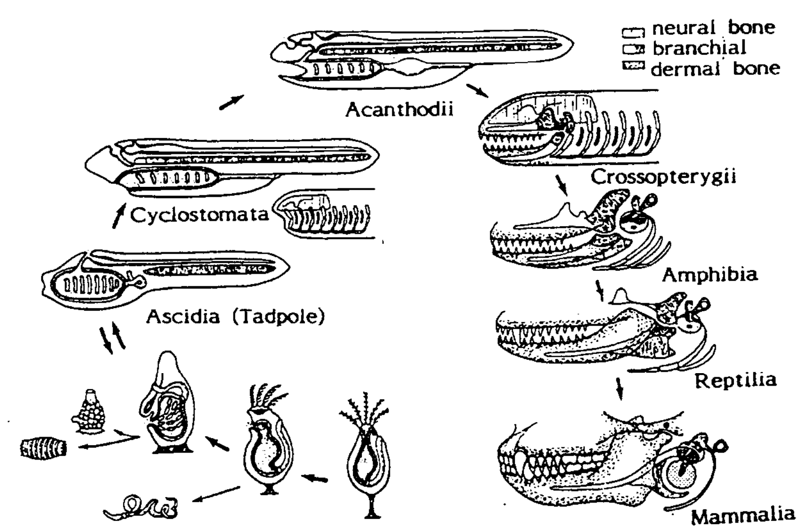

Fig. 1 Origin and Evolution of Jaw Metemorphosis of Branchia (S. Miki)

the revolutions occurred in the jaw, oral cavity and branchial-gut organs. From this it can be seen that evolution was led by the activities concerning the two kinds of vegetable-system functions (feeding-respiration and reproduction), and these activities are biomechanical responses.

Reviewing this evolutionary history, the process of the primitive Ascidian losing the opportunity to attach itself to a rock in its larval form thereafter, advancing to be a vertebrate in maturity - this process can be regarded as inheritance of a **lost character:** maturity is reached without those series of gene-actualizations for metamorphosis which are triggered by the biomechanics of attaching to a rock, and the function of the messenger RNA is in time abolished. When the whole process is inherited, this all-mouth organism is on its evolutionary way to becoming a vertebrate, eventually differentiating into the four sections of the face which represent organism, neck, chest and abdomen.

In this case, what is the face? Its origin is in the life organism itself of the primitive Ascidian which was constructed with almost all mouth having the gill cleft; gradually becoming differentiated, in the process of evolution, into the four sections, the face, neck, chest and abdomen.

3. Characteristics of the Tooth

The biological characteristics of the tooth as a functional organ of the masticatory system have not been reviewed conventionally. However, the tooth is most important mechanical organ in the viscerocranium, therefore, the understanding of their characteristics is essential in thinking about what the face is. So it will be briefly described below. The primeval material of the tooth and bone was a complex called aspidin which was the carapace of the agnatha. In response to biomechanical stimulation during ingestion, part of the aspidin developed around the mouth, thereby forming the teeth. At the same time the jaw separating from the branchial arches. Aspidin is a complex of dentin and bone tissue. It is known from studies on fossils that if the aspidin is broken, blood flows out and repairs the hard structure of the carapace. Therefore, it is also an original form of cutis and is considered to be a sensitive sensory organ protecting the organism. Most aspidin of carapace lost any sensitive sensory function and evolved into placoid scale, scale, hair and feather, but the aspidin developed in the oral cavity into a part of the masticatory organ while retaining its sensitive sensory function. Teeth are a precious inheritance transmitted with original form from five hundred million years ago to human beings. One of the basic functions of the teeth is as a sensitive sensory organ, derived from the armor of aspidins protecting the organism. When the carapace is invaded, it had to be immediately repaired, as the damage threatened life. Even in the human being, the teeth are able to distinguish 5μm and, if invasion strikes the dentin, an indefinable pain striking terror into the organism results. This is derived from a life memory belonging to the sensitive organ located at the center of archetypal life. The teeth are the most essential organ for life and were originally positioned as a more important organ in many vertebrates than is conventionally believed. The teeth are said to be the most essential organ for life in higher vertebrates (Cuvier). Because they are an unusual organ, tooth morphology was an area studied by distinguished scientists from two hundred years to several decades ago, and there is a huge accumulation of scientific knowledge in the fields of odontology in paleontology, phylogenesis, comparative morphology, animal taxonomy, anatomy, anthropology, genetics, and so on.

The archetype of teeth was already a complex organ ankylosed with bone structure as aspidin when the vertebrates began. Roots of mammalian teeth are covered with cementum, i.e., fibrous bone (Weidenreich), so even in the teeth of evolved mammals, we can now see their original form persisting in a changed mode. Teeth directly ankylosed to the bone called aspidine succeeded in fossil reptilia (dinosaurs) and are considered to have evolved through mammal type reptilia to gomphotic mammalian teeth during a period of a hundred million years. In this change, syndesmodial articulation was acquired at the outer layer of fibrous bony cement.

In spite of many distinguished studies of the tooth, there is still no answer to the question "What is the tooth?" One answer to this question may be that it is an organ which began as a sensorium for protecting the organism as stated above, which evolved into a functioning organ for mastication in mammals. Ultimately, the organ is understood as an important sensing organ for individual defense. On the other hand, skeletal organs such as teeth and mandibles have mechanical functions by means of their mechanical support structures. Therefore, the question, "What is the tooth?" should also be considered as a question concerning the mechanical characteristics of the tooth as a functioning organ for mastication. An adequate answer to this question was not possible from the scientific heritage on the tooth accumulated when Culmann, Meyer, Wolff and others began their studies, before Roux founded his new scientific area called "Biomechanik." Dental science has advanced today, and many studies are aggressively being carried out in diversified areas throughout the world but, unexpectedly, efforts at understanding "What is the tooth?" with respect to not only the essential functions of the organ but also to its biomechanical significance have hardly been made up to now. By integrating the empirical rules based on the knowledge obtained from paleontology and phylogenesis and the results of finite element analyses on the models of the artificial dental root, we may state that the tooth of a mammal is a special organ derived from an armor defending the organism; it has an optimization system for dispersing stresses; multiple masticatory forces borne by the **vehicle** of the teeth and then, through the shape of crown and root, the principal stress trajectories are converted and scattered in the periodontal ligament to the surroundings, and are borne by the jawbone cortex (Fig. 2). In this vehicle system, the periodontal ligament functions as a conversion

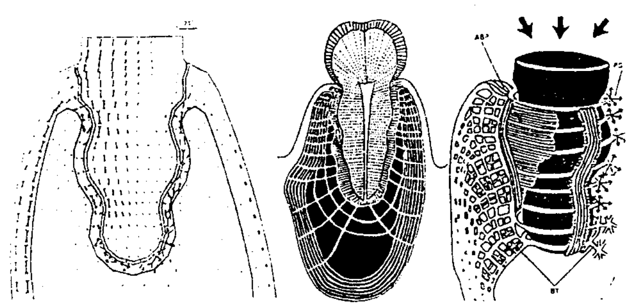

Fig. 2 Biomechanical construction of jawbone around a tooth

system for the principle stress trajectory, and the blood vessel system for nutrition functions as an elastic body for absorbing impact in cooperation with the gomphotic structure. From the above, it becomes possible to apply Wolff's law even to the mandible. The mandible having an optimization system essentially has a dental arch showing an occlusal plane and a parabola genetically aligning with a Monson's spherical surface, and can be seen to be designed genetically as a mechanics performing smooth masticatory cycles; and the mandible changes adapting to deviated motions over long-term function because of the optimization system of the same bone structure. The bone is remodeled in accordance with the function. When functional deviation continues over a long period of time, the deformation may become severe enough to disturb the performance of smooth masticatory cycles.

The tooth is empirically known to have an optimum shape system, but it has hardly any remodeling system. The tooth is an organ which takes optimum shape over a genetic span of time. Since the functions of teeth vary depending on their sites in the jawbone, therefore, the shape of the crown and root of teeth vary depending on the site according to the optimization system. Genetically, both the bone and tooth are considered to be organs having optimum morphology suitable for the general functions of their respective species, but the bone itself takes a functional adaptation in morphology so that the bone is deformed from its genetically restricted shape secondarily by applied external forces. When we consider the vehicle system of teeth, the vascular structure of the periodontium, and the morphology of the human mandible and root, it can be seen that the teeth have no mechanism for supporting a lateral force applied over a considerable period of time. Because of this, a tooth can be moved by a continuous lateral force of only 20 g to 70 g in orthodontics. When the biomechanical characteristics of the teeth and jawbone are known, the causes of malalignment, periodontal diseases, deformity of the jaw and face, tempor-omandibular arthrosis, habitual luxation of the jaw articulation and other disorders become evident biomechanically. From this, the characteristics of the digestive portion of the viscerocranium can be clarified, and the important role of the teeth in skeletal jawbones which regulate facial morphology can be understood.

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