Galen on Dental Anatomy and Physiology

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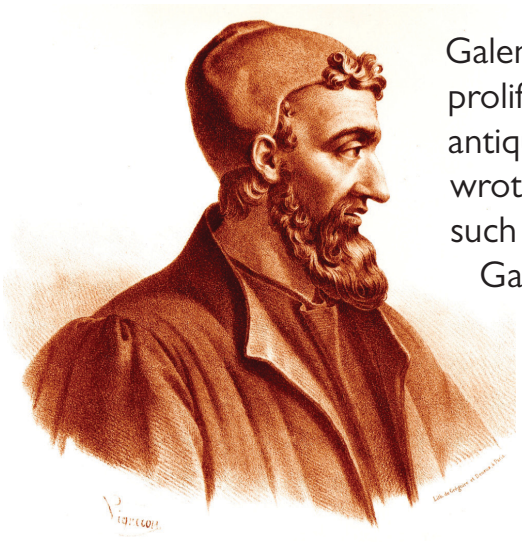

Fig. 1. Galen, Lithograph by Pierre Roche Vigneron (Paris: Lith de Gregoire et Deneux, ca. 1865)

Galen of Pergamum (129–ca. 210 CE) was the most prolific medical writer and greatest physician of antiquity, second only to Hippocrates. Although Galen wrote no treatise dealing exclusively with dental issues, such topics are nonetheless addressed throughout Galen's work. His work on human anatomy in general, and on dental issues in particular, is quite extensive. Galen specified the number of teeth in humans and their differences in shape and function. He believed that tooth formation took place *in utero*; and that teeth grew when the skull bones had consolidated their shape and strength. He recognized the innervation of teeth and claimed that only teeth among the hard tissues were provided with nerves, enabling them to have sensation. By modern standards, Galen would not be classified as a scientist; however, his observations of human anatomy, and especially of the oral cavity, still evoke our profound admiration.

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In the latter half of the 20th century, the proliferation of study in ancient medicine was unprecedented. New translations, monographs and commentaries on ancient medical texts, particularly on the Hippocratic and Galenic Corpora,[1] have appeared in medical conferences held worldwide, and in innumerable papers published in journals. Yet, against this admittedly remarkable scholarly activity on a global level, little is known about ancient dentistry. The aim of this paper is to examine Galen's (*Fig. 1*) contributions to ancient dentistry and, more specifically, to the anatomy and physiology of dentition, as well as to show that Galen decisively influenced the evolution of the dental art and left his permanent imprint on the Western dental tradition.

Galen of Pergamum (129 CE-ca. 210 CE) was the most important medical figure of the Roman imperial period, and second only to Hippocrates (ca. 460-370 BCE) as the greatest physician in all antiquity. As a medical author, Galen wrote extensively on every subject, his major concerns being anatomy, physiology, and therapeutics. He was also deeply engaged in the study of philosophy, in the theory and practice of rhetoric, and even textual criticism. Thus Galen was acknowledged by successive generations of scholars not only as an outstanding medical figure but also as a philosopher and philologist.

Oddly enough, there exists no specialized treatise on dental issues in the Corpus Galenicum, or, for that matter, in the whole body of ancient Greek literature. The absence of textbooks focusing exclusively on matters of dentistry does not necessarily mean that the ancients were ignorant of or indifferent to the aesthetics and therapeutics of teeth. On the contrary, for all ancient medical writers, the dentition and oral cavity in humans were matters of paramount importance. Their interest should be attributed mainly to the fact that the dental and periodontal pain and diseases were widespread as early as the Neolithic era.[2] As to Galen's own contributions in the field, these can be gleaned from his voluminous treatises, such as *De anatomicis administrationibus* (*On anatomical procedures*), *De ossibus ad tirones* (*On bones, for beginners*), *De usu partium corporis humani* (*On the utility of the parts of the human body*), *De compositione medicamentorum secundum locos* (*On the composition of drugs according to places*). Galen studied dental and oral issues more deeply and extensively than any other physician before or after his time in antiquity. He was the first ever in the history of dentistry to describe in minute detail the anatomy, physiology and treatment of diseases and injuries of the mouth and teeth.[3] The dental knowledge thus obtained was eventually incorporated into his own medical system, and even took on teleological, and indeed theological, dimensions.[4]

Dentists in Antiquity

The earliest dental references are found in the work of the Pre-Socratic philosophers, the founders of Western scientific thought. In the surviving literature of this period, the practice of dentistry as a separate specialty is for the first time attested to by the fifth-century BCE historian Herodotus in his *Histories.* By his account, there were many doctors in Egypt of specialized expertise, including oculists and dentists.[5] At a much later time, in the age of the Antonines (2nd c. CE), Galen makes repeated references to ὀδοντικοὺς ἰατρούς (tooth doctors), who alongside of ὀφθαλμικούς ἰατρούς (eye doctors) and ὠτικοὺς ἰατρούς (ear doctors) seem to have constituted the main specialties. Apparently there had developed a fierce controversy at the time among medical schools, and more especially between *Dogmatici* and *Empirici* about the individual specialties of medical art. In the treatise *Ad Thrasybulum liber, utrum medicinae sit an gymnastic hygieine* (*Treatise to Thrasybulus on whether health is part of medicine or gymnastics*) which was written at the request of his friend Thrasybulus, Galen addresses the question of whether hygiene should be included in medicine or in gymnastics. In this treatise he refers to the divisions of medicine. The division of medical specialties was made in three different ways according to: a) the kind of operation or medical act which the physician performed; b) the part of the body which the doctor treated; and c) the

material used to cure the disease, either pharmaco-therapeutically, or through herbs or certain foods as part of a diet. As a result, there were a) surgeons from the kind of operation that they performed; b) pharmaceutical or botanical physicians* from the medical material used, or c) dental or ocular doctors from the part of the body which they treated.[6]

Galen was all too keen to reject this fragmentary mode of reasoning in favor of a holistic one, in which all specialties should be conceived of as the constituent parts of a single art.

In another of his treatises, *De partibus artis medicativae* (*On the parts of medicine*), which has survived only in Latin and Arabic translations, Galen, while extolling the cities of Alexandria and Rome as the most prominent medical centers of his time, does not hesitate to take their doctors to task for their ever-growing tendency to subdivide existing specialties further, so that, ironically, there would eventually be more medical specialists than parts of the human body. Each disease would then have its own special doctor.[7] For Galen, a doctor is a servant of nature, and medicine is nature's first art; all doctors are united in serving a common cause, none other than restoring their patient's health.[8]

Dental Anatomy

Regardless of the existence or absence of specialized doctors for the treatment of tooth decay, it is certain that before Galen, and with the sole exception of Aristotle's inquiries,[9] that the anatomy of dentition had seen no remarkable progress. Galen, more than any of his colleagues, placed particular emphasis on the theoretical and practical training of any aspiring medical practitioner in anatomy. Knowledge of anatomy was extremely important because understanding the usefulness of the parts (such as those contained in the oral cavity), and also of the dentition, would play a key role in the successful treatment of disease. Otherwise, it would be impossible to diagnose the disease of an individual organ and therefore of the whole body.[10]

Since the early time of his apprenticeship to such great anatomists as Satyrus,[11] famous at that time for his skill in anatomy, Galen had amassed valuable anatomical knowledge, which he expanded in later years so that he could correct his predecessors' doctrines whenever he questioned their validity. His voluminous writings include *De anatomicis administrationibus*, his best treatise of anatomy, replete with excellent description of the bones, the muscles, the brain, the nervous system of the eye, the veins and arteries, and organs such as the heart, tooth, etc. Under the inspiration of Aristotle, he discusses issues of teleological anatomy in another work, *De usu partium corporis humani*, whereas in his introductory work, *De ossibus ad tirones*, dedicated to the anatomy of bones, there are significant observations on dental anatomy.

Galen did not acquire his brilliant anatomical knowledge from the dissection of humans, which he firmly opposed,[12] but as the result of strenuous and systematic dissections performed on animals. From the multitude of animals which he dissected, he preferred primates[13] and particularly a specific monkey, the Barbary macaque. He observed that primates present anatomical similarities with humans in the gut, muscles, arteries, veins and nerves;[14] however, the most important features of similarity were the canines.[15] Galen came to believe that the construction of the body of the Barbary macaque simulated sufficiently the utilitarian anatomical model that resembles humans because this species is inclined walk upright, and the fingers of the upper and lower extremities resemble those of man.

According to Galen, man has thirty-two teeth, allocated by half in each jaw. Each jaw contains the same number of teeth and thus the upper jaw has sixteen teeth, exactly what is found in the lower jaw.[16] The teeth differ depending on

*Others subdivided the specialty of pharmaceutical physician according to the substance used more frequently for the treatment of the diseases: ἑλλεβοροδότας (*hellevorodotas*) those who administered hellebore or οἰνοδότας (*inodotas*) those who administered wine to cure the illness from which the human organism suffered.

their shape and function, and are thus divisible into the categories of incisors, canines and molars. The incisors are four in each jaw; occupying the front part of the dentition, and having only one root.[17] Morphologically, they are described as acute and wide; functionally they serve to arrest and cut the food.[18] They take their name from the ability to cross and to cut the food in the same way that the chisel crosses.[19]

Next to the incisors, the canines are located on both sides of each jaw, four in number, and also have only one root.[20] Morphologically they are characterized as wide in their base, with their main task being to crush[21] food. Unlike the incisors that intersect, according to Galen the canines have as their mission to cause breakage.[22] Canines are the most distinctive teeth of the dentition; they took this name because they are similar to the teeth of dogs.[23]

Finally, Galen does not differentiate between premolars and molars. Molars are ten in the upper jaw and ten in the lower jaw, and are five in each half of the jaw. Galen notes that in certain people there are four molars in each half rather than five. Apparently he refers to cases of congenital absence, where the third molars or the second premolars do not form; this observation is in accordance with contemporary thought. He also speaks of rare cases of people with over-numbered molars, that is to say. six molars in each quadrant. Rightly, he highlights the fact that the mandibular molars have two roots, while the molars of the maxilla have three roots. Interestingly, the third molars or wisdom teeth, the second molar, and in extremely rare cases the first molar have four roots when they grow in the upper jaw and three roots when they are located in the lower jaw.[24]

Morphologically, Galen describes the molars as rough—perhaps due to the area of their occlusal surfaces—wide, hard and large. Molars are also called μύλαι (mylae), after the grinding of the food which comes to them, just as the millstones grind grains.[25,26] The term mylae (μύλαι) is used to describe not only the molars but also their occlusal surfaces, since they constitute the area of the molar where food is ground. In a passage of the treatise *De usu partium corporis humani* he states that the masseter muscles contract firmly to contact the teeth during mastication, to crumble what stands between them. In this way the food is ground by the mylae of molars as a consequence of the operation of the masticatory system. Thus the term mylae refers not only to molars but also to the occluding surfaces of the teeth during mastication, according to the modern view that grinding of the food is done by the mylae of the molars (ὑπὸ μυλῶν τῶν γομφίων λειοῦσθαι τὴν τροφὴν).[27]

Galen's descriptions of teeth are amazing. He mentions that nature developed molars with large middle roots and smaller ones adjacent to them (τὸ δὲ καὶ τῶν ριζῶν τὰς μέσας μὲν μεγίστας γενέσθαι, τὰς δ' ἑκατέρωθεν αὐτῶν ἐλάττους).[28] This remark refers to none other than the three-rooted molars of the upper jaw; the palatal root is bigger, while the two buccal roots are thinner. When viewed from the buccal surface of the tooth, they look as if they are placed on both sides of the palatal root.

Teeth and bones

Unfortunately, despite his exceptionally precise descriptions of teeth and their functional mission, Galen confined himself to the Hippocratic idea that teeth should be categorized as bones.[a] According to the author of the Hippocratic treatise *De carnibus* (*On Flesh*), teeth are bones, as they develop from the bones of the head and the jaws (ἀπὸ τῶν ὀστέων τῶν ἐν τῇ κεφαλῇ καὶ ταῖν γνάθοιν).[29] This situation is not unique, as Galen was influenced by Hippocratic views, and by personal observations of some anatomies of lower mammals. He believed that the mandible in humans developed bilaterally and was joined at the anterior symphysis. Misled by anatomical findings in dogs, where in fact there is contract between the bones of the lower jaw, (*Fig.* 2) he assumed these findings for humans as well.[b]

[a]Aristotle had the same opinion: the teeth have the same nature with bones, and moreover, they are made of bones: Aristotle, *De generatione animalium.* (II 745a 19 – 21).

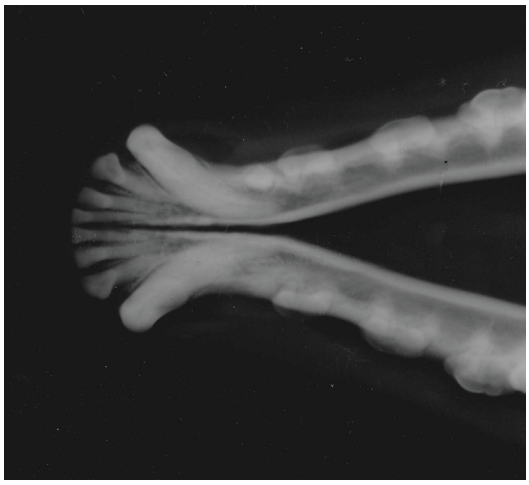

Fig. 2. Occlusal radiograph of the mandible of an 11-year-old Cocker Spaniel dog. The anterior joint is clearly visible.

Fig. 3. Occlusal radiograph of a human mandible..

Strangely enough, Galen refused to accept or even wonder about his own findings from the anatomy of monkeys. In short, he reaffirms that the contact is quite apparent in dogs, and admits that the simians, who are anatomically the most similar to humans, have a single bone of the lower jaw. He ultimately concludes, as Hippocrates did, that in humans the lower mandible (*Fig.* 3) is a bilateral bone, which unites at the symphysis according to the pattern found in dogs.[30]

In Galen's lifetime, a fierce controversy arose among physicians as to the real nature of teeth and their relationship to human organs. The situation was amply testified by Galen's unusually extensive references to the issue, and his arguments in favor of the nature of teeth as bones. To convince the reader, he uses a brief introductory treatise addressed to aspiring students of medicine, *De ossibus ad tirones*. It contains preliminary knowledge of anatomy, specifically the bones and their role in shaping the human skeleton. The treatise was written during Galen's first stay in Rome, (winter 162 CE-summer 168 CE), a period when he tried hard to make a name for himself.[31] He uses the process of the *reductio ad absurdum* (reduction to the absurd) to prove firmly and irrevocably that teeth do not fall into any other category of organs but bones. For Galen, teeth are not cartilages, arteries, veins, or nerves, nor do they belong in the class of fat, hair, flesh or gland. Therefore, if they are not otherwise classified, they must be classified as bones.[32]

Galen's views on how the teeth are joined to the jaw bones are of particular interest. The ligament of a tooth is made on the φατνίον (alveolus), the Greek diminutive of φάτνη, or trough, the timber structure which holds animal feed. The alveolus is essentially a well in the bone that provides shelter for the roots of teeth; they are part of the bone of the jaws. The exact description that Galen uses for alveolus is that it is a delicate process (*apophysis*) of the jaw bone.[33] The teeth are linked to the bone (γεγόμφωνται), as they are nailed in the wells of the alveolar processes which are called sockets.[34] The ligament of the teeth in the alveoli of the jaws is a kind of joint, as it is trapping the two parts.

For the description of the joint of bones, Galen uses the name ἄρθρον (articulation), which dates to the time of Hippocrates. He then goes on to discuss the typology of joints and their individual classes. He outlines two basic types of joint constructions: the διάρθρωσις (diarthrosis) and συνάρθρωσις (synarthrosis). Diarthrosis is the

[b]The view that the lower jaw was a two-part bone and the two parts were jointed at the level of the chin was widespread; however it was in doubt. According to the author of the pseudogalenic treatise *Ascripta medicus seu introductio* (XIV. 721,18-722,1 Kühn): "The lower jaw according to some ones consists of two bones which are jointed at the chin, according to some others, of one."

structure that allows movement of the bones joined. In contrast, synarthrosis is the articulation where the movement of the jointed bones is extremely limited and is seen faintly and difficultly, given the particular nature of the joint.[35] Both diarthrosis and synarthrosis he subdivides into various types of joints.

In this case synarthrosis is interesting, as teeth are jointed with the alveoli of the jaws by this type, since normally the teeth exhibit little mobility. Further, synarthrosis is divided into three separate sub-categories: suture, gomphosis and harmony. A typical example of suture articulation is the joint of the bones of the head.[36] The joint by harmony is a simple joint in which the bones adapt perfectly in a line, "snapping" together very well between them.[37] Examples of harmony are the joints of the bones of the upper jaw or of the bones of the head. Based on his dissecting findings from many skulls Galen also said that not in all skulls, nor all the joints of the same skull, were sutures; but in the same skull one could observe a joint that was partly suture and partly harmony.

Gomphosis is presented last, which is synarthrosis by nailing. For example, the roots of the teeth are joined to the alveoli of upper and lower jaw, like nails (γομφία, *gomphia*) nailed into a surface. In this way teeth are "nailed" in the alveoli.[38] Since gomphosis as synarthrosis restricts the movement of teeth, he considers that this kind of articulation approaching a symphysis. However, Galen avoids designating it as symphysis, because the teeth are not permanent structures, rather, they erupt and are shed.[29] The description of the dentition as an automatic mechanical process is the only reference about this issue.

Galen's argument is identical with that of Aristotle, who himself admits that even if the teeth are in contact with bones, they are not attached to them; as a result they can erupt again when shed. Galen and Aristotle also shared perceptions of the stage at which tooth formation (odontogenesis) occurs. According to Aristotle, the teeth are not created in the first stage of creation of the embryo when all the bones are created, but later.[40] Galen in his turn considers that odontogenesis occurs when the fetus is still in gestation. He times the development of the teeth as after the fourth of the periods into which he divides the development of the embryo from its initial conception. The teeth grow after the formation and strengthening of the skull bones, which are the last created during osteogenesis. The structure of teeth, as that of eyes,[41] can be described as imperfect, since in the newborn the teeth are still hidden in the alveoli and the eyes are closed.[42]

Teeth, in order to perform their function, should be supported and held very tightly in their place. This is accomplished by the alveoli themselves, by the tooth–jaw joint, and by the tissue that surrounds the teeth, which are referred to as gums.[43] Primarily, however, it is achieved with strong ligaments that surround the alveoli and particularly the root of the teeth.[44]

At the same time, the powerful ligament performs another mission. It allows insertion (κατάφυση) of nerves in teeth,[45] keeping the roots of teeth attached within the sockets. Galen was first in the history of dentistry to refer to the nerves of teeth, and thus occupies an exceptional position in the Pantheon of the pioneers of dentistry, considering his time when he acted and the means that were available to him.

Teeth Innervation

The existence of nerves in humans allows for sensation and movement. According to Galen's anatomical observations, the brain is the source of nerves,[c] but nerves may grow both directly from the brain and the spinal cord.[46] He describes the existence of seven syzygies (συζυγίαι) of brain

[c]In terms of the medical teaching of Galen, the three main organs of the human organism were the brain, the heart and the liver; these were the source from where three kinds of vessels derived. The brain is the source of nerves, the liver the source of veins where the venous blood was circulated. Finally, the heart is the source of arteries which carry the arterial blood. This theory is the basis for the three-part form of the human body physiology; its roots are found in the Platonic theory of three parts of the soul. Further, in Koutroumpas D. Galen's Pharmacology. PhD Thesis. Athens: University of Athens. 2010: 58-66.

nerves, the third one of which (trigeminal nerve) is responsible for the innervation of the whole face and the oral cavity, including teeth. Galen says:[47]

> The beginning of nerves in all of the muscles and indeed in all other parts that are in the face is the third branch of a syzygy of nerves originating from the brain. They reach the temporal and masseter muscles, and certainly these that are inside the mouth, and the teeth, and the lips, and the nose, and to all the skin around the face (Nature) has distributed the nerves, since the bones are perforated to provide space, as it is necessary to pass each one of the split branches. In each part of the human body goes the necessary nerve branch for sensation or movement so that neither less nor more comes from the branch of the nerve, but each nerve has precisely the necessary volume for the needs of the part it serves.

It is a matter of importance to specify the nature of nerves that are inserted into the roots of teeth, because it is by reason of their nature that the functions they are going to perform are established. There are two kinds of nerves;[d] the hard nerves that are responsible for motion (motor nerves) and soft nerves responsible for sensation (sensory nerves). The soft sensory nerves do not have the ability to induce motion; accordingly, the hard motor nerves have no sensation. All hard nerves grow from the spinal cord and all soft nerves grow from the brain.[48]

In order that sensation and movement of the muscles of the lips by the same nerve could be justified, Galen was forced to propound the solution of the nerve's texture changing along the course of the third branch. So, the trigeminal nerve (third branch nerve according to Galen), on account of its growing from the brain should be purely sensory; however, as it traverses the lower jaw and comes out in the region of canines, it is converted to motor function.[49] Regardless of the theoretical acrobatics which Galen employed to explain the nature of innervation, he recognized nerves of teeth in order to overcome practical issues. All teeth[e] are equipped with soft nerves from the brain and the nerves allow them to have clear sensation.[50]

In conclusion, all teeth and gums have nerves from the third branch of trigeminal nerve. Both the upper and the lower jaw have foramina through which the large nerve branches pass. The nerves grow from the brain and come into the teeth. In the lower jaw, the trigeminal nerve passes through the mandibular canal and gives large nerve branches to the molars, whereas the other teeth and gums are supplied with small and delicate branches. The mandibular canal also penetrates the region where the two parts of the lower mandible merge; at least Galen assumed this occurs. In the upper jaw, following a similar path, the nerves reached the back of the cheek and from there they proceed to the molars and the gums, supplying large and delicate branches respectively.[51] In this way, the teeth as well as the soft tissue around them are provided with sensation.[52]

Galen believed that only the teeth among bones had nerves, because they are naked inside the oral cavity. In view of their special mission

[d]Galen implies that between these two basic categories is a third one that stands in the middle between the others. From the study of the relevant passage it is clear that it is a theoretical concept without practical value, since he does not mention any specific function of this intermediate nerve category; certainly he doesn't mention any organ which is innervated by this intermediate nerve category.

[e]Hoffmann-Axthelm incorrectly reports belief in the *absence* of nerves from all teeth (Hoffmann-Axthelm W. *History of Dentistry*. Chicago: Quintessence Publishing Co. 1981:75-76). However this view is based on misunderstanding of the text: (III. 865,17-866,5). Hoffmann-Axthelm seems to have a serious problem understanding the ancient Greek text, as the references he gives are usually irrelevant and incorrect. This problem is also highlighted by Macfarlane P. in "Teeth in the Hippocratic Corpus." XIIIth Colloquium Hippocraticum, University of Texas, Austin, August 11–13, 2008.

[f]Until today, Macfarlane gave us the best analysis on the topic of tooth sensitivity to cold and hot as it is presented by the Hippocratic writers and Aristotle. Macfarlane P. "Teeth in the Hippocratic Corpus." XIIIth Colloquium Hippocraticum, University of Texas, Austin, August 11–13, 2008.

to act in mastication, teeth are obliged to cut and break; they are resistant to erosion, abrasion and pathological lesions. They are highly exposed to the hot and cold as well. The teeth have sensation so that, due to the feeling of pain, the animal can sense an upcoming risk for the integrity of the teeth and the other parts of the oral cavity and can react to protect them. According to Galen, the teeth, due to their innervation, have sensory ability and along with the tongue are designated for the perception of flavors.[53] That is why soft nerves are implanted in the teeth; it is thanks to them that teeth turn out to be sensory organs. By acknowledging that teeth are sensory organs, Galen was able to solve the puzzle of toothache in the presence of hot or cold,[f] an issue which had been obsessing the Hippocratic writers, the members of the Peripatetic school, and perhaps Aristotle himself, if we are to accept that he was the author of the treatise *Problemata* (*Problems*).[g]

Bones and teeth were regarded by Galen as the hardest and the driest parts of the human organism. Elementally, they were characterized as Earthy, because they constituted a foundation on which the body would be built.[54] According to an ancient theory dating back to Empedocles, a fifth-century BCE Greek philosopher from Sicily, both the microcosm and the macrocosm consist of four fundamental material elements, which he called ῥιζώματα (rizomata, "masses of roots"); namely, water, air, earth and fire.[55] However, while all substances are composed of these four fundamental elements, each simple body in its own turn is the combination of two of the four primary contraries: the earth is cold and dry, water is cold and moist, air is warm and humid and the fire is warm and dry. This theory was Aristotle's answer to the inquiry into the physical world's primary constituents, the elemental substances into which everything in the world could be resolved.

Galen, for his part, incorporates in his medical teaching the dominant philosophical views about the principles of nature; the physical world (such as minerals, rocks, etc.) and even man are the result of the intermixture of the four fundamental elements.[56] Each one of the elements (water, earth, fire or air) gives a distinctive quality to the body. Likewise, all living organisms are the product of different blends of elements.[57] Teeth, as bones, are earthy, and thus formed by mixing the qualities of cold and dry, which raises the question: How can teeth be sensitive to cold, if their composition involved the quality of cold? Similar questions were raised in the treatise *Problemata*, which has come down to us under the name of Aristotle. Its author wonders why teeth are more susceptible to cold than to warm. In this case, also, the question rests on the fact that the specific nature of the tooth is cold, as there is the quality of cold during the formation of the tooth substance (οἱ δὲ ὀδόντες ψυχροί).[58] Similar questions are raised in several treatises of the Corpus Hippocraticum, such as *Aphorismi* (*Aphorisms*), *De carnibus* (*On Flesh*), and *De humoribus* (*Use of Liquids*).[59] For example, the author of *Aphorismi* argues that cold is hostile to the teeth (τὸ ψυχρὸν πολέμιον), as it is also hostile to the bones, the nerves, the brain and spinal cord. He considers that warm is friendly to all these categories of tissues and organs.[60]

Galen embraces this view in *Commentary on Hippocrates' Aphorisms,* and tries to uphold it by argument. Teeth and the other organs mentioned in this aphorism are, by their nature, the coldest parts contained in any animal body. Since they are completely bloodless, they have no blood vessels and

[g]The treatise *Problemata* is included in the Aristotelic corpus. Although it is one of the most extensive works of the collection, its authorship is in doubt. The treatise was written in the middle of the 3rd century CE; contemporary research has shown that it contains genuine Aristotelic material, however it also incorporates views of the members of the Lyceum, who were familiar with the views of Aristotle. See: Touwaide A. The Aristotelian School and the birth of theoretical pharmacology in ancient Greece. In: "The Pharmacy." *Windows on History*. Pötzsch, R. (ed.) Basel: Roche. 1996: 328–329.

[h]Internal heat is Galen's concept of the constant internal temperature of the body which is necessary for the survival of the organism. On the contrary, its absence signals the discontinuation of the vital functions of the organism resulting to death. Keeping the internal heat at the necessary level is of vital importance for the organism. The heart is considered to be the focus center of the internal heat.

consequently they are not supplied by any amount of internal heat,[h] which would protect them to some extent from changes in temperature. They are affected by the excessive use of cold, sometimes less, and sometimes adversely, as they are not supplied by internal heat to counteract the effect of cold; conversely, warmth is more friendly to them as they are cold by their nature and the effect of the warmth is counterbalanced.[61]

As previously mentioned, Galen gave a satisfactory answer to the problem of heat and cold by putting forward the view that the teeth have nerves, in order that they may feel pain, cold, heat, and so on. Hot and cold are two qualities which cause pain when they come into contact with the tooth. The same response to each occurs in cases of tooth disease (when teeth have decayed or become black or worn). Teeth that do not tolerate cold or warm are suffering, and the patient reports feeling pain within the tooth, i.e. inside. Galen is puzzled by this observation, as he himself witnessed such an incident firsthand. He states that once, when he suffered from toothache, he observed that the tooth was not only painful but it pulsated, in a manner similar to inflammatory soft tissue. That fact surprised him since teeth by their consistency are of a stony hard substance.[62] So he distinguishes two types of pain: one that comes from the gums, and another that comes from the heart of the tooth. In fact, he has to agree with his colleagues that the tooth itself aches and that the nerve that grows into the root suffers the pain (τοῦ καταφυομένου νεύρου τῇ ῥίζῃ τοῦ ὀδόντος ὀδύνην γενέσθαι).[63]

Since the time of Galen, a dispute had been going on about whether the tooth, being a bone, was aching; their main feature, the hard and stony structure, did not justify the occurrence of pain. The stimulation of pain was caused either by an erosion of the tooth or from contact with cold or warm. Galen, based on his own experience of toothache, distinguished two cases: in one case he felt his very tooth was aching, and it pulsated as the inflamed soft tissues in other parts of the body did; in the other case, he was able to tell that the pain was not from the tooth but from the inflamed gums.

Galen studied cases where there was no apparent inflammation in the alveoli, yet the teeth were painful. This painful feeling, he surmised, was due to nerves (ἐν τῷ νεύρῳ συμβαίνει γίνεσθαι).[64] He supposed the phenomenon was the same even if the teeth were extracted from the oral cavity; the pain remained as the result of nerve inflammation.[65]

Tooth nutrition

Ironically, while being the leading anatomist of antiquity, who performed careful and accurate dissections of animals, Galen had not realized the existence of the dental pulp. He was convinced, of course, that inside the tooth grew soft nerves (καὶ τοῖς ὀδοῦσιν ἐνέφυ νεῦρα μαλακά). The teeth were the only bones which involved sensory nerves, and perhaps they had a role similar to that of bone marrow that contributed to the nutrition of the bones. Like Aristotle,[66] Galen believed that the teeth grow continuously throughout a man's life to compensate for the wear of friction during mastication. Of course it would be impossible for the teeth to grow if for some reason nourishment stopped.[67] This observation he based on the phenomenon of continuing eruption of teeth in which each tooth erupts until it meets the contralateral tooth (antagonist). In cases of a missing antagonist, the tooth over-erupts giving the illusion of growth.

According to Aristotle, the teeth are formed and grow in size because of food distributed in the jaw bones.[68] However, it is not clear for Galen how sufficient food comes into the teeth and contributes to their growth. Teeth are included in bones, therefore they should follow a similar process to that of osteogenesis. According to the Galenic medical teaching, the bones, like the other soft parts, are formed from blood.[69] Osteogenesis (bone formation) as a process lasts too long, because changing of the blood to bone is a major process.[70] Bones need marrow for their nutrition, in the same way that soft parts need blood. Marrow is thus contained within the bones. In the spongy bone, marrow is spread all over the small cavities that they form, while in the hollow bones marrow fills the bone canals.[71] Teeth are a special category, where only soft nerves grow into their roots, and these nerves

ought to be performing a similar role to that of the bone marrow. Aetius, interpreting Galen, reached a similar conclusion, as the waste of the nerves is responsible for the nutrition and development of teeth.[72]

Galen mentions the existence of bone marrow in the lower jaw (γένυς δὲ ἡ κάτω μυελὸν μὲν ἔχειν).[73] He also repeatedly declares that arteries and veins are distributed in each jaw, throughout the oral cavity and throughout the head.[74] Veins are more interesting to him than arteries, as they transfer the nutritive materials necessary for the nutrition of organs. Initially, the food that is consumed goes to the stomach where it will undergo a special treatment of conversion in a broth that is eventually assimilated by the body.[75] Then the broth is transported through veins,[76] to the liver for further processing and the production of blood.[77] The resulting blood from the liver, which is rich in nutrients, is conveyed via the veins throughout the organism for its final nutrition.[78] Somehow the veins pass nutritive materials into the bone marrow for the nutrition of the bones. In a similar manner, Galen supposed, teeth should be nourished as well.

Teleology

The anatomy of the mouth and especially of teeth was the subject of admiration for the great doctor from Pergamum, who believed that nothing in nature is futile (μάτην μὲν γὰρ οὐδεν ὑπὸ τῆς φύσεως γίνεται).[79] He thus colored the physiology of the oral cavity with an aura of teleology. For Galen, everything created by nature had a functional purpose,[80] and although he was not himself a Christian, the dental references in his work are a doxology of the wisdom and of the providence of the Creator. Galen's conception of teleology is completely different from the secondary teleology that Aristotle attributed to the teeth.[81] Nature, or the Creator, works nothing in vain, as the structure of the body is perfectly adapted to its functions. For example, in humans one canine erupts in each half of the jaw, while in lions, wolves and dogs many more erupt on each side. This is because Nature knew well that it created man as a peaceful, political animal, and that man's power is not based in strength but in wisdom. This is why Nature created double incisors in man, and even more molars, in order to meet the higher needs of mastication.[82]

As man has small teeth in the jaws appropriate only for food, the temporal muscle is accordingly small. He does not need an excessive muscle size to support large jaws, as in lions and dogs, which need to have powerful jaws in order to survive. Man does not prevail over other animals with his bite, but with the power of reason, and the subtle dexterity of his hands. Therefore, Galen concludes, one admires the art by which Nature provided for and created everything according to its value.[83]

The creation of teeth with symmetry and equality, Galen concluded, constituted the work of a skilled craftsman. The regularity and the rate at which the two jaws were built are worthy of admiration and acknowledgement of a unified order, where the symmetry of the upper jaw with the lower, the right with the left, is to be found not only among the teeth but also the alveoli and roots, the nerves, ligaments, arteries and veins.[84]

The anatomical and functional construction of the mouth, and especially of the dentition, rightly led Galen to express his admiration: "If someone choreographed a dance with thirty-two dancers moving with rhythm, we would praise his art; since Nature set the sum of teeth so well-decorated, should not we praise it, too?"[85]

Ancient Greek medicine and dentistry reached it pinnacle with Galen. Clearly he cannot be considered a scientist according to the modern standard of empiricism, but his anatomical descriptions and oral observations continue to make an impression, even in modern dentistry.[86]

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References

1. Nutton V. The fatal embrace: Galen and the history of ancient medicine. *Sci Context*. 2005; 18(1):111-121.

2 . Mitsis FJ & Taramidis G. Alveolar bone loss on Neolithic man on 38 skulls of improvement with regard Khirokitia's (Cyprus) inhabitants. *J Clin Periodontol.* 1995; 22 (10): 788-793.

3. Tsoukanelis Al. *Stomatology in the world throughout ages, edition in Greek*. Athens: Tsiveriotis 1994; I. 152.

4. Musiteli S. Pagine di odontoiatria e di odontologia nel mondo antico. *Med Secoli*. 1996; 8(2): 207-235.

5. Herodotus. *Historiae* (II. 84,1-5).

6. Galen. Ad *Thrasybulum liber, utrum medicinae sit an gymnastices hygieine.* (V. 846,14 –17 and 849,14-533, 18 Kühn).

7. Galen. *De partibus artis medicativae.* (24,36-25, 68 Schöne).

8. Galen. *Ad Thrasybulum liber, utrum medicinae sit an gymnastices hygieine.* (V. 851,12-18 and 853,10-854,1 Kühn).

9. Guerini V. *History of Dentistry: From the most ancient times until the end of the eighteenth century.* Philadelphia and New York: Lea & Febiger, 1909; 65.

10. Galen. *De sectis ad eos qui introducuntur.* (I. 95,17-96,5 Kühn).

11. Galen. *De anatomicis administrationibus.* (II. 224,15-225,2 Kühn).

12. Galen. *De temperamentis.* (I. 632,6 Kühn.).

13. Galen. *De anatomicis administrationibus.* (II. 532,5-533,4 Kühn).

14. *Ibid.* (II. 222,2-223,16 Kühn).

15. *Ibid.* (II. 533,6-18 Kühn).

16. Galen. *De usu partium corporis humani.* (III. 868,18-869,2 Kühn).

17. Galen. *De ossibus ad tirones.* (II753, 9-10 Kühn).

18. Galen. *De usu partium corporis humani.* (III. 869, 2-3 Kühn).

19. Galen. *De ossibus ad tirones.* (II. 754, 5-6 Kühn).

20. *Ibid.* (II. 753, 9-10 Kühn).

21. Galen. *De usu partium corporis humani.* (III. 869, 3-6 Kühn).

22. Galen. *De ossibus ad tirones.* (II. 754, 6-10 Kühn).

23. *Ibid.* (II. 754, 3-5 Kühn).

24. *Ibid.* (II. 753, 12-18 Kühn).

25. Galen. *De usu partium corporis humani.* (III. 869, 6-10 Kühn).

26. Galen. *De ossibus ad tirones.* (II. 753, 18-754,3 Kühn).

27. Galen. *De usu partium corporis humani.* (III. 854, 11-17 Kühn).

28. *Ibid.* (III. 871,17 872,1-Kühn).

29. Hippocrates. *De carnibus.* (VIII. 598,7-8, Littré).

30. Galen. *De anatomicis administrationibus.* (II. 439,18-440,7 Kühn)

31. Koutroumpas D. *Galen's Pharmacology* (PhD thesis). Athens: University of Athens, 2010; 37–38.

32. Galen. *De ossibus ad tirones*. (II. 752, 14-753,8 Kühn).

33. Galen. *De usu partium corporis humani*. (III. 872, 10-13 Kühn).

34. Galen. *De ossibus ad tirones*. (II. 754, 9–12 Kühn).

35. *Ibid*. (II. 734, 17-735,11 Kühn).

36. *Ibid*. (II. 737, 5–10 Kühn).

37. *Ibid*. (II. 737, 738, 1, 16-Kühn).

38. Galen. De anatomicis administrationibus (II. 336, 2-11 Kühn).

39. Galen. De ossibus ad tirones (II. 738, 1-6 Kühn).

40. Aristoteles, De generatione animalium (II. 745b 4–7).

41. Galen. De foetuum formatione libellus (IV 673,16-674,1 Kühn).

42. Galen. De semine (IV. 637,10-14 Kühn).

43. Galen. De usu partium corporis humani (III. 743,17-744,1 Kühn).

44. *Ibid*. (III. 872,14-873,13 Kühn).

45. *Ibid*. (III. 873,10-13 Kühn).

46. Galen. De nervorum dissectione (II. 831, 1-9 Kühn).

47. Galen. De usu partium corporis humani (III. 864,5-18 Kühn)

48. *Ibid*. (III. 740,7-741,9 Kühn).

49. *Ibid*. (III. 741,12-742,17 Kühn).

50. Galen. De ossibus ad tirones (II. 754, 12-14 Kühn).

51. Galen. De usu partium corporis humani (III. 743,17-744,13 Kühn).

52. Galen. De anatomicis administrationibus (II. 432,2-9 Kühn).

53. Galen. De usu partium corporis humani (IV. 271,9-272,6 Kühn).

54. Galen. De ossibus ad tirones (II. 733,2-4 Kühn).

55. Diels H & Kranz W. Die Fragmente der Vorsokratiker: griechisch und deutsch, Greek edition, Athens: D. Papadima. 2004: 556-566.

56. Galen. De elementis ex Hippocrate (I. 456,9-457,5 Kühn).

57. Galen. De temperamentis (I. 559,1-3 Kühn).

58. Aristoteles, Problemata (III. 963b 28-29).

59. Macfarlane, Teeth in the Hippocratic Corpus, XIIIth Colloquium Hippocraticum, University of Texas, Austin, August 11-13, 2008

60. Hippocrates, Aphorismi (IV. 538,3-4 Littré).

61. Hippocratis, Aphorismi et Galen eos cemmentarii (XVII. B. 803,8-13 Kühn)

62. Galen. De compositione medicamentorum secundum locos (XII. 848,9-849,5 Kühn).

63. *Ibid*. (XII. 849,5-15 Kühn).

64. *Ibid*. (XII. 854,16-855,2 Kühn).

65. *Ibid*. (XII. 849,12-850,6 Kühn).

66. Aristotle. De generatione animalium (II. 745a 25-31).

67. Galen. De compositione medicamentorum secundum locos (XII. 850,11-851,3 Kühn).

68. Aristoteles, De generatione animalium (II. 788b 34-789a 4).

69. Galen. De naturalibus facultatibus (II. 83,6-9 Kühn).

70. *Ibid*. (II. 21,9-17 Kühn).

71. *Ibid*. (II. 212, 9-17 Kühn).

72. Aetii Amideni, Libri Medicinales V-VIII (CMG VIII. 431,8-25 Olivieri).

73. Galen. De ossibus ad tirones (II. 733, 12 Kühn.).

74. Galen. De usu partium corporis humani (III. 861, 9-13 Kühn).

75. Galen. De temperamentis (I. 655, 4-6 Kühn).

76. Galen. De usu partium corporis humani (III. 270,1-269,1 Kühn).

77. *Ibid*. (III. 299,5-18 Kühn).

78. Galen. De anatomicis administrationibus (II. 542,14 543,5-Kühn).

79. Galen. De usu partium corporis humani (III. 857,3-4 Kühn).

80. *Ibid*. (III. 736,1-2 Kühn).

81. Leunissen M. & Gotthelf, What's Teleology Got To Do With it? A Reinterpretation of Aristotle's Generation of Animals V. Phronesis 2010; 55:325-356.

82. Galen. De usu partium corporis humani (III. 877,1-13 Kühn).

83. *Ibid*. (III. 846,6-14 Kühn).

84. *Ibid*. (III. 873,18-874,10 Kühn).

85. *Ibid*. (III. 871,3-6 Kühn).

86. Shklar G & Brackett CA. Galen on oral anatomy. *J Hist Dent*. 2009; 57(1):25-28.