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INTRODUCTION

The aim of this article is to present the state of scientific knowledge that prevailed in the Modern Age concerning the nature and origin of teeth, particularly, the acquisition of this knowledge by Spanish authors and their contributions to the subject.

In the Modern Age, ideas about the nature and origin of the teeth were inherited from the Greco-Roman past and from the contributions made from the Renaissance onward. All of these ideas were directly related to the theories about the constitution of physical matter and the human body which existed in Greece from the 5th century BC. Empedocles of Agrigentum (*ca.* 495-430 BC) originally developed the theory that nature consists of the combination of four 'roots', called 'elements' by Aristotle (384-322 BC)—earth, water, air, and fire—with each of these elements being a combination of two qualities. Thus, water is wet and cold, air is dry and cold, fire is dry and hot, and earth is wet and hot. These ideas were developed in the fourth and fifth centuries BC by the authors of **Corpus Hippocraticum**, who observed that blood clots were formed by four clearly differentiated layers, which they identified as 'humours'. These authors' theories assumed that the constitution of the body's health or illness depended on the balance among these four humours, related to the elements and qualities of matter at the same time. The four cited humours were 'blood' which belongs to the air element, 'phlegm', which belongs to water, 'choler' or 'yellow bile', which corresponds to fire, and 'melancholer' or 'black bile', which corresponds to earth.

With regard to this theory, the Hippocratic writings contain numerous references to teeth and their formation. The theory was completed thanks to the work of Aristotle, considered to

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The Nature and Formation of Teeth According to Spanish Authors from the 16th to the 18th Centuries

be the father of comparative anatomy. He studied the dentition of numerous animals and also established the theoretical grounds of the causes of odontogenesis and the physical nature of teeth. Aristotle supported the theory that natural objects and events are affected by four different causes: The 'material' cause is the matter or substance of which something is formed; the 'efficient' cause is the principle of change; the 'formal' cause is the form; and the 'final' cause is the natural objective that produces the causes or processes. His embryological ideas also incorporated the epigenetic theory that living beings gradually adopt their final shapes from an undifferentiated mass affected by a formal cause (the configuring force of male semen), from certain vital forces acting as efficient causes, and from maternal blood, which provides the material cause. All of these components are regulated by the final objective (cause).

These ideas were followed by Roman authors such as Galen and Celsus. The work of Galen (131-201 AD) influenced medieval Christian and Muslim authors. Together with the work of Celsus (30 BC-50 AD), Galen's was one of the most important references for the professional experts of the Renaissance.

Until this time, important contributions had referred to the knowledge of only odontology and the health sciences. The most relevant innovations were introduced by Vesalius, in his work **De humani corporis fabrica** (1543), which described the first detailed studies in dental anatomy, including the pulp chamber. The first modern studies on dental embryology are attributed to Fallopius and Eustachius (Gysel, 1971, 1977; Donahue, 1978).

We have studied the works of numerous Spanish scientists of the 16th, 17th, and 18th centuries, and among the most outstanding authors was Montana de Monserrate (*ca.* 1480-1558). He studied in Italy and France before becoming a professor of anatomy at the University of Valladolid; his work **Libro de la anatomía del hombre** (1550) introduced to Spain the Vesalian anatomical iconography. Valverde (1525-*ca.* 1588) studied in Padua as a disciple of Realdo Colombo and was one of the doctors who attended Pope Paul IV. He published consecutive editions of his work **Historia de la composición del cuerpo humano** (1556) widely throughout Europe, in Spanish, Italian, and Latin. Francisco Martínez (*ca.* 1520-1585) was a soldier, priest, and a dentist for King Philip II of Spain; his work **Coloquio breve y compendioso sobre la material de la dentadura** (1557) was a reference text in odontology. The remaining noteworthy authors (Carbon, *ca.*

Table. Summary of Early Spanish Scientists' Contributions to the Nature and Formation of Teeth

Author	Date	Concept	Contribution
Montana de Moserrate	1550	Content of the pulp chamber and its physiological functions	They observed the presence of a nerve inside the pulp chamber, to which they attributed dental sensitivity. This represents the first detailed study on pulp tissue and its physiological functions.
Juan Fragoso	1572		
Hidalgo de Agüero	1604		
Valverde	1556	Embryologic origin of permanent dentition	He observed an embryonic trace in adult teeth. This can be considered as a forerunner of the current idea of dental germs stimulating the development of the alveolar process.
Francisco Martínez	1557	Scientific knowledge of Odontology	He published the first scientific textbook entirely dedicated to the oral cavity and teeth.
Porras	1716	Morphological differences between teeth and bones	Evidence around the absence of periosteum in the teeth.
Martin Martínez	1730	Morphogenesis of the permanent teeth	They carried out some of the first approaches to the embryology and chronology of the process. They used some anatomic research to describe the germ and the changes occurring in the follicles.
Martin Martínez	1730		
Fernando Velasco	1744		
Juan de Dios López	1752		
Francisco Puig	1768		

1465-1554; Daza, *ca.* 1503-1596; Juan Fragoso, *ca.* 1530-1597; Hidalgo de Agüero, 1530-1597; Martin Martínez, 1684-1734; Porras, fl. 1716; Francisco Puig, fl. 1768; and Fernando Velasco, fl. 1744) were all prestigious doctors or dentists who occupied relevant posts in administration and university teaching. Thanks to the study of their biographies and literature, we can affirm that they were experts in the medicine and odontology of their time. The contributions of Monserrate and other authors are summarized in the Table.

THE NATURE AND ORIGIN OF TEETH ACCORDING TO AUTHORS OF THE 16TH AND 17TH CENTURIES

Based on the works of Spanish authors of the 16th and 17th centuries, we can establish that the discussion revolved around two closely related questions: first, the physical nature of teeth (Are they bone or not?) and, second, odontogenesis (Are teeth developed from maternal blood or paternal sperm?). In the 18th century, the discussion shifted toward the differences between bones and teeth, and the particular process of dental morphogenesis.

The link between the tooth and bone is easy to establish, based on, or as emerging from, the hardness of teeth. If teeth are of osseous matter, they have a spermatic origin, as does bone. Therefore, teeth develop before birth as bones, and following birth, they simply grow. However, this theory met with difficulties in attempts to explain the appearance of a new dentition subsequent to birth. In all the literature studied,

corresponding to the 16th and 17th centuries, authors unanimously defended the osseous nature of teeth (with certain clarifications) and discussed authors who were "against this doctrine" without citing them explicitly.

Doctor Montana de Monserrate (1550) was the first author who applied Aristotelian teleological thinking (that natural events and objects have a final objective involved in their causes) when he described teeth as 'bones made for chewing'. In the work of Juan Fragoso (1572), also a doctor, we find a translation from such teleological thinking into the Christian doctrine, with his statement that the great hardness of teeth 'was granted by the Creator and it is so that they do not break along with the food'.

Another doctor, Hidalgo de Agüero (1604), supported the erroneous general idea that teeth change, even in old age. However, he summarized the physiological differences between teeth and bones by stating that teeth have feeling,

due to 'the small nerve, like marrow, that they have inside'. Here, Hidalgo was actually reflecting widespread ideas, previously set forth by Montana de Monserrate (1550), about the nerve that emerges through the dental apex. We must remember that Vesalius had described the pulp chamber only three years previously, in 1547, but the precise description of its content would be studied and circulated thanks to the works of Fallopius (1561), Eustachius (1563), and Juan Fragoso (1572) in Spain.

Considering teeth as bone led most authors to assert that teeth were formed from seminal matter or, at least, that their nature was different from that of blood. This posture, however, encountered difficulty in attempts to explain the second dentition. Juan Valverde (1556), one of the most relevant post-Vesalian anatomists, challenged this problem by claiming that teeth are 'spermatic parts of the body', and therefore 'do not grow again after falling out'. He stated that nobody is born without permanent teeth, although they cannot be seen because they are covered by the gums. This idea was not new. It had classic precedents, such as the studies of the encyclopedist Celsus, who found that the deciduous teeth are pushed out by the permanent ones, and Galen, who explained the extrusion of teeth with the erroneous idea of their continuous growth. The most immediate precedent was stated by Vesalius in his work *De humani corporis fabrica* (1543), in which he gathered the doctrines of previous authors. He concluded that the temporary tooth was an appendage of the permanent tooth, and that both types of teeth were a biological unit, similar to the epiphysis

and diaphysis of long bones (Gysel, 1971). A few years after the publication of Juan Valverde's work, Fallopius (**Observationes anatomicae**, 1561) still claimed that teeth originated in two periods: before and after birth. In contrast, Eustachius (**Libellus de Dentibus**, 1563) observed, in the human fetus, two types of teeth: the calcified temporal teeth and the permanent teeth, still mucilaginous. He also believed, like Juan Valverde, that the beginnings of all teeth already existed before birth.

The belief in the existence of permanent teeth before birth was still difficult to support. Nevertheless, certain authors set forth alternatives or modifications to the aforementioned theories. Carbon (1541), a doctor residing in Majorca, tried to explain the second dentition by reconciling both doctrines, the first based on the spermatogenic origin of teeth, and the second based on their sanguineous origin. He wrote that teeth are formed from blood retained in the jaw, and that this blood preserves spermatogenic properties, thus enabling new teeth to regenerate after the loss of the old ones. Daza (1584), one of the most significant Spanish surgeons, suggested that teeth are formed from the nutritive matter discarded by the nerves, which accumulates in the gums, becomes dense, and is converted into bone and tooth, thus preventing them from being worn away. With this theory, Daza updated the aforementioned widely accepted ideas proposed by Galen, regarding the continuous growth of teeth.

Doctor Francisco Martínez studied the problem in more depth. His work **Coloquio breve y compendioso sobre la materia de la dentadura** (1557), published in its first edition in the form of a dialogue and in consecutive editions as a treatise, is the first scientific work entirely dedicated to the mouth and teeth. This work connected with Aristotelian causality ideas, stating that the cause of tooth formation is natural heat. The formal cause 'is the aspect of the bone, which makes it different from the other parts of the body', and its material cause is blood, a mixture of the four humours. Following Empedocles and Aristotle, Francisco Martínez stated that the qualitative differences between teeth and the surrounding tissue can be explained by the different contributions of each of the four elements, with their particular characteristics, to each of the anatomical parts. Thus, teeth are hard, white, cold, and dry, as is bone, because it was mostly the element earth that intervenes in their constitution.

REVISION OF THE SUBJECT IN THE 18th CENTURY

In the 18th century, authors offered no original ideas regarding the nature of teeth. Authors still unanimously thought that teeth were bones with certain anatomical and physiological differences in comparison with the other bones of the body. Thus, Porras (1716) and later Martín Martínez (1730) explained that teeth are bones, but due to the absence of periosteum, dental sensitivity is caused by the presence of a nerve that enters the roots. This idea differs only slightly from the one offered by Hidalgo de Agüero (1604) over 100 years earlier. However, in the debate concerning morphogenesis, authors seemed to acquire a more precise knowledge of the process. Martín Martínez (1730) referred to mucus in the alveolus that curdles and hardens. The same idea was supported by Fernando Velasco (1744), although with more precision: 'A mucilaginous seminal matter appears in the alveolus at the very moment of formation, enclosed within small follicles, which hardens and

grows until it breaks the gums.' Following this trend, Juan de Dios López (1752) used direct anatomical research to describe the changes occurring in the gums and follicles that eventually form the tooth germ. However, it was Francisco Puig (1768) who offered a more detailed description of the whole process, using fundamentally epigenetic explanations of dental formation, but with purely mechanistic theories regarding the growth and loss of teeth. He stated that the matter that served as an embryo for teeth is the mucous contained in a membranous follicle, whose ossification gradually propagates until the tooth is entirely formed. This process is immediately followed by the ossification of the roots, which deepen in the alveolus until they reach the osseous barrier, which stops their development. It should be noted that this was the first text to examine the development of teeth in such detail, and that its author set forth in a precise manner the sequence of events leading to the formation of the whole tooth, including the osseous limit to the extension of the root, and the degree of ossification of the different dental areas at the moment of birth.

CONCLUSIONS

The level of knowledge of Spanish doctors and dentists from the 16th to the 18th centuries was similar to that of other European experts. The Spanish scientists passed on their knowledge of the past and rapidly embraced innovations, but they also made original and outstanding contributions to the science.

Montana de Monserrate (1550), and later other authors, explained the difference between teeth and other bones, pointing out the presence of a small nerve inside the tooth. This explanation was offered shortly after the description of the pulp chamber by Vesalius (1543), and before the explanation of its content by Eustachius (1563).

The work **Coloquio breve y compendioso sobre la materia de la dentadura** (1557), by Francisco Martínez, is the first scientific monograph dedicated to odontology. The author added his own experience and interpretation of the problems related to this study, which represents an excellent summary of the dental knowledge of the time.

The ideas of Carbon (1541) and Daza (1584), concerning morphogenesis and the regeneration of teeth, are reminiscent of those of Fallopius (**Observationes anatomicae**, 1562), who wrongly claimed that the second dentition formed subsequent to birth. Theories of the spermatogenic nature of teeth, sustained by some authors such as the anatomist Juan Valverde (**Historia de la composición del cuerpo humano**, 1556), contradicted others and supported the origin of permanent teeth already existing in the embryo. Thus, Juan Valverde is a forerunner of the ideas disseminated later by Eustachius in his work **Libellus de Dentibus** (1563), with an authentic experimental base.

The contributions made by Valverde and Eustachius to the understanding of the permanent configuration of teeth developed from mucous in the gums would be followed up again by Spanish authors in the 18th century.

For a better appreciation of the importance of these Modern Age authors' contributions, it is critical to understand the limitations in both theory and technique that they experienced. Actually, discussions around the spermatogenic or hematological origin of teeth were primarily an attempt to establish a theoretical framework to discuss observations of embryonic and post-natal development of human teeth, when technical resources were limited to low-potency optical microscopy.

It was not until the 19th century, with the invention of achromatic lenses allowing for higher-magnification microscopy, that the cellular theory could be formulated providing a correct interpretation of direct embryological observations.

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