# MJSS

# MONTENEGRIN JOURNAL FOR SOCIAL SCIENCES

Volume 2, 2018. Issue 1.

CIP - Каталогизација у публикацији
Национална библиотека Црне Горе, Цетиње

**COBISS.CG-ID 32743952**

**ISSN 2536-5592**

**Publisher**

Center for Geopolitical Studies

Časopis ***Montenegrin Journal for Social Sciences*** upisan je u evidenciju medija, Ministarstva kulture Crne Gore pod rednim brojem ***782***.

MJSS
MONTENEGRIN JOURNAL FOR SOCIAL SCIENCES

**Volume 2, 2017. Issue 1. Podgorica June 2018.**

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**Montenegrin Journal for Social Sciences is indexed in:** CEOL-Central and Eastern European Online; Google Scholar; Index Copernicus; CiteFactor; Scientific Indexing Services (SIS); ISRA-Journal impact factor; Electronic Journals Library; ROAD; General Impact Factor; OAJI - Open Academic Journals Index.

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**Prepress and print:** Pro file – Podgorica

**Circulation:** 200 copies

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**Montenegrin Journal for Social Sciences indeksira se u sledećim naučnim bazama:** CEOL-Central and Eastern European Online; Google Scholar; Index Copernicus; CiteFactor; Scientific Indexing Services (SIS); ISRA-Journal impact factor; Electronic Journals Library; ROAD; General Impact Factor; OAJI - Open Academic Journals Index.

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**Priprema i štampa:** Pro file – Podgorica

**Tiraž:** 200

# SADRŽAJ:

**Review**

# DENTAL ANTHROPOLOGY: AN OVERVIEW OF CURRENT APPLICATION AND TECHNIQUES

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***ABSTRACT:***

Dental anthropology, as a subfield of biological anthropology, is a study of dentitions of past and present populations. The aim of dental anthropology is to give answers to some significant questions in anthropology. Those questions are usually regarding diet, health, and biological relations of individuals and populations. To answer these as well as may other research questions, dental anthropologists study development, microstructures, eruption, number, size, morphology, modifications, wear, and tooth pathologies, using a range of micro- and macroscopic techniques. This text gives a brief review of techniques used in dental anthropology currently, and their application in anthropological and archaeological research.

***KEY WORDS:***

Dental anthropology; Teeth; Archaeology

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***SAŽETAK:***

Dentalna antropologija je subdisciplina biofizičke antropologije i bavi se istraživanjima zuba i vilica,  kako drevnih, tako i savremnih populacija. Cilj dentalne antropologje je da odgovori na neka od važnih antropoloških pitanja o ishrani, zdravlju i biološkom srodstvu individua i populacija. Da bi odgovorili na ova, kao i ostala istraživačka pitanja, denatalni antropolozi izučavaju razvoj, strukture, temo izbijanja, broj, veličinu i oblik, modifikacije, istrošenost, kao i patologije zuba uz pomoć niza makroskopskih i mikroskopskih metoda. Ovaj rad daje pregled osnovnih principa i tehnika dentalne antropologije, kao i njihove primene u savremenim antropološkim i arheološkim istraživanjima.

**KLJUČNE RIJEČI**:
Dentalna antropologija; Zubi; Arheologija.

***Introduction***

Teeth are the hardest calcified components of the body, and throughout a lifetime of an individual they are recording numerous significant data. Once when they are recovered from archaeological sites, they can almost serve as time capsules preserving relevant information even in very harsh environments. The data we can found analysing teeth can help with getting an insight into the lifeways of past and present people. Dental and jaw pathological conditions can provide date on health, living conditions, nutrition and hygiene of individuals and entire populations. At the same time, metric, and especially morphological characteristics of teeth, can shine a light on aspects of the origins of people, and in some cases, morphological traits can even help us to establish biological relationship between individuals. By improving, developing and applying dental anthropology techniques, our ability to collect these data and present them properly will only increase (Irish, Nelson, 2008).

Dental anthropology is a study of human dentitions. The work of Albert Dalhlberg and his colleagues in 1930s and 1940s can be considered as the origin of the discipline (Hillson, 2009). The term „dental anthropology"has been in use since 1958 (Brothwell, 1963). Dental anthropology has been developed since, and the body of dental anthropological work is growing consistently. Such an interest in this filed is largely due to unique chemical and physical characteristics of teeth which enable them to be preserved in various archaeological sites. Teeth are from bones by their biological characteristics, structure, and function, and, as Hillson suggested, they cannot be considered as parts of bony skeleton in a narrow sense (Hillson, 2009).

In the more recent years there are several publications serving as milestones of dental anthropology progress. One of those is Dahlberg's (1991) "Historical perspective of dental anthropology" in Kelley and Larsen's edited volume *Advances in Dental Anthropology* (Kelley, Larsen, 1991). Several years later, Scott (Scott, 1997) wrote a peace on history of dental anthropology titled "Dental anthropology" for yet another edited volume, History *of Physical Anthropology* (Spenser, 1997). Dahlberg was a dentist, but he also did significant amount of pioneering work in dental anthropology. Therefore, in his paper he gave an overview on development of both oral biology and dental anthropology. On the other hand, Scott, as a physical anthropologist, is mostly focused in his text on ways in which tooth research can be used to answer questions important for physical anthropology. Other significant reviews of history of dental anthropology, although focused on certain geographic areas, can be found in work of Brown (1992, 1998) and Kossa (1993). There are numerous textbooks, research manuals and guides for dental anthropology published since. The ones with the most significant impact and widespread use among dental anthropology students and professionals are edited volumes *Advances in Dental Anthropology* (Kelley, Larsen, 1991) and *Technique and Application in Dental Anthropology* (Irish, Nelson, 2008), and Hillson's book *Dental Anthropology* (2012).

## Structure, form and function of teeth

Teeth are complex calcified structures found in mouth of many vertebrae and their primary function is to break down food. A tooth comprised generally of two main parts: a crown and root(s). The crown of a tooth is usually the part above the gum, whilst the roots are placed in the bony sockets *(alveolae*) of upper and lower jaws. A human tooth is formed of three mineralized tissues (enamel, cementum, and dentine), and a soft tissue called dental pulp. Enamel is hardest dental tissue and most highly mineralized substance of the body, and it covers tooth crowns. The roots are coated with a thin layer of bone-like cementum. Underneath these two coating layers lies dentin which forms the main structure of every tooth. Dental pulp is contained within the pulp chamber and root canals deep inside the tooth. Dental pulp contains dentine cells, and blood and nervous vessels. Although the dental pulp is most active during development and eruption of the tooth, it remains productive throughout of life, forming secondary dentine and, within certain limits, even tertiary dentine, as a response to stimuli such as caries, trauma, and tooth movement.

Humans are diphyodont as well as other mammals. That means that we develop two sets of teeth during our lifetime. The first set of primary or deciduous, also known as "milk" or "baby", teeth starts its eruption about age of six months. There are usually 20 deciduous teeth in humans and they start to be replaced by their permanent counterparts around the age of six years. There are 32 teeth in permanent dentition[2] and they are usually fully erupted by the age of 21 years. Depending on their position in jaws as well as their function teeth are classified as incisors, canines, premolars and molars. Although there are several different notation systems to refer to a specific tooth, the most commonly used is FDI World Dental Federation notation[3] system.

2 A complete set of different types of teeth arranged in two rows

3 https://www.fdiworlddental.org/

*Mastication*

Teeth can be used as tools or a "third hand" in a number of activities (Radović, 2013) People often modify their teeth for aesthetic reasons, but primary function of teeth in all mammal species is mastication. Mastication is the process of cutting, crushing and grinding food in mouth, during which food is being mixed with saliva and prepared to be swallowed. It is considered that mastication plays a key role in the increase of "digestive efficiency without which high rate of metabolism associated with homeothermy in mammals could not be sustained" (Berkovitz et al. 2009, p. 95). Interestingly, some experiments showed that mastication is not necessarily the same key factor for increase of digestive efficiency in humans (Farrell, 1956) as it is for other mammals. This can be explained by the fact that people in modern societies select, grow and prepare foods that are readily digestible.

Mastication is a complex process, and its complexity varies from species to species. In humans it starts with vertical movement of mandible (lower jaw) after which food is being shared by lateral to medial movements of mandible. This initial cutting and crushing of food does not necessary require full occlusion[4] of the teeth. Only after the food is being softened, the upper and lower teeth can start grinding the food in a movement similar to a pestle and mortar action. The whole process of mastication is supported by two main muscles, *m. temporalis* and *m. masseter*, as well as the tongue movements, and its being enabled by functional anatomy of all the other structures in oral cavity.

*Growth, wear and age estimation*

There are a quite a few macro- and microscopic age estimation techniques based on growth and development of teeth. Growth is a process of increasing in size and maturity, but not all body parts are growing at the same mode and tempo. Growth will not occur at the same tempo for each individual; it is different for females and males; it is also highly variable process on interpopulation level; and it is influenced by genetic factors as well as environment. Furthermore, bones will keep on remodelling[5] even after they reach the full-grown size, but teeth stay very little altered structurally after they are fully erupted.

4 Occlusion is contact between the upper and lower teeth when they approach each other, as occurs during mastication.

5 Bone remodelling is a lifelong process of tissue turnover where cells continuously break the mature tissue down and form a new bone tissue.

The tempo of tooth development and growth is widely studied in archaeological human populations. Numerous techniques involving radiographic studies and histological analyses as well as recording the stages of tooth development macroscopically have been in used to establish standards for dental age estimation (Massler, 1941; Moorres, Read 1964; Hillson, 1979; Rose et al., 1978; Cook, 1981; Goodman, Rose, 1990; Antoine et al., 1999). It is of uttermost importance to have modern comparative data available on teeth development stages when try to estimate individual age in archaeological material. However, even with all the data available, when using teeth to estimate an individual's age, one is only estimating her or his dental age (Hillson, 2009, p. 2012-2013). Dental age refers to a stage of development and eruption of one's teeth. Dental age can be different from skeletal age as teeth and bones grow at different mode and tempo. When trying to estimate age from archaeological material based on biological development of teeth and bones, one can only estimate dental or skeletal age of observed individual, but not their chronological age.

After eruption, teeth undergo the process of ageing. Ageing is a biological stage in a life cycle of an individual most commonly characterized by changes in collagen and the loss of calcium in the skeleton. Unlike the bones, enamel and dentine in the teeth do not remodel and there is no age-related loss of calcium from the dental tissues (Berkovitz et al., 2009, p. 378). However, after tooth has erupted it start to wear almost immediately. Tooth wear is caused by grinding of teeth against each other as well as contact with food, external objects, cheeks, and tongue (Hillson, 2009, p. 214). This process may occur during mastication, but it also occurs at other times, even during sleep (e.g. sleep bruxism[6]). The results of wear are most apparent on the occlusal[7] surfaces of the teeth, but sometimes it is also visible at the contact points of teeth from the same jaw (interproximal wear). There are three types of tooth wear: attrition, abrasion and erosion. Attrition is related to food mastication, so it occurs at the contact points of the teeth, and the wear facets are characterized by scratches that follow masticatory movements of the jaws. In contrast, abrasion is mechanical wear of tooth which occurs due to interaction with objects other than tooth-tooth contact. Abrasion scratches are more randomly orientated. Finally, dental erosion is a type of wear seen as irreversible loss of tooth structure due to acid attack but not of bacterial origin. The most common cause of erosion is the intake of acidic food

6 Bruxism is excessive teeth grinding or jaw clenching. It is an oral parafunctional activity, and it is unrelated to normal function such as eating or talking.

7 Occlusal surface is a surface of a tooth that comes into contact with a tooth in the other jaw.

and drinks (e.g. pH below 5.0–5.7). The rate of wear may depend on many factors: the overall morphology of the crown, developmental defects, the structure of the tooth's hard tissue, the chewing mechanism, diet, and non-feeding behaviours (using the teeth as tools, bruxism *etc*.). In archaeological material attrition is the most commonly recorded type of tooth wear.

When analysing archaeological specimen, it is relatively easy to estimate age of a dentition of up to about 20 years of age. On the other hand, that task becomes harder when dealing with isolated teeth or older individuals.  Some information concerning age can be obtained by studying the attrition patterns of teeth, most precisely by observing the patterns of dentine and cement exposure in the occlusal wear facets. Furthermore, X-rays can be used to estimate the amount of dentine formation and the reduction in the size of pulp cavity. Histological analyses can be applied too, so one can estimate the amount of translucent dentine and the thickness of cementum in the roots. When analysing each of the mention features, the first step is to estimate the score, and then to obtain a total score for the observed tooth. When compare such a score against the existing appropriate standards, it is possible to get an estimate of dental age. It appears that the most reliable feature for the age estimation so far is the amount of translucent dentine in the root (Berkovitz et al., 2009, p. 381).

### *Size and Shape*

In order to record and make schemes of series of tiny variations in teeth shape we do make a distinction between metrical and non-metrical variations in tooth shape. "Metrical" variations are those which could be measured directly, using measuring instruments. "Non-metrical" variations are traits in tooth forms for which we are currently only recording their presence or absence, the degree of their development, and in which form they appear in tooth. The tendency in dental anthropology is to develop appropriate measuring system even for these non-metrical variations in teeth. However, it is hard to establish such a system which will be able to clearly define measuring points for very variable traits in tooth form.

### *Odontometry*

Odontometry is measurement and study of tooth size.  There are a number of precisely defined pints on tooth from which the measurements can be taken. The purpose of measuring teeth in this way is to obtain more information on human phenotypic variation. The primary aim of odontomery is to establish certain homologous structures which are present in teeth of every individual, with the same functions and relations with other adjacent structures. This might seem as a simple task, but taking measurements from teeth can be quite problematic for researchers. Teeth are not simple flat structures, and the shape varies between different individuals. For this reason, great caution is needed when defining reference points for measurements. Hillson (Hillson, 2009, p. 260) also noted that care is essential not only when measuring teeth, but also when interpreting the results of odontometric studies.

First measurements of primate teeth were taken by Owen in 1845 (Hillson, 2009, p. 260). Numerous studies on human teeth were carried out ever since and they showed that size of human teeth was changing through time and it is highly variable in modern humans too. Furthermore, one of the main trends in the evolution of *Hominidae*, which includes humans, has been the reduction in jaw and teeth size. However, it has not been fully understood yet in which proportion the size of teeth is determine by genes and in which proportion is influenced by environmental factors. It is quite clear, though, that tooth size is not determined by only one gene, so it cannot be simply inherited or not by the offspring. At the contrary, tooth size is affected by genes which are present on both X and Y chromosomes (Potter, Nance, 1976; Potter et al., 1976) and which expression could be determined by environment.

The size of tooth crown is defined by two diameters: maximum mesiodistal crown diameter (length) and maximum buccolingual crown diameter (breadth). Maximum mesiodistal crown diameter is the maximum distance between two parallel planes, tangential to the most mesial and most distal points of the crown side. Maximum buccolingual crown diameter is the maximum distance between two parallel planes, tangential to the lingual and to the buccal crown sides (Hillson, 2009, p. 261-262). There are a few more measurements which could be taken from a tooth, such as crown height, root length, root diameters etc., but to date these measurements have not been widely used by dental anthropologists.

### *Tooth morphology*

The purpose of observing and recoding variation in shapes and structures of tooth crown (as opposed to metric traits) is to establish a genetic proxy for population history reconstruction (Scott, 2013). In many studies on humans it has been proven that shape and size of certain non-metrical variations in teeth depend strongly on an inheritance component (Sofaer et al., 1972; Biggerstaff, 1973, 1975, 1976; Berry, 1978; Nichol, 1989; Sharma, 1992). Furthermore, when it comes to cusps[8] development it seems that the same genes or group of genes are in control for both sides of dentitions and for the molars on each side. It appears that there is, also, no or a very little evidence of sexual dimorphism for non-metrical dental traits (Portin, Alvesalo, 1974; Aas, 1983; Harris, Bailit, 1980).

The system which has been mostly used for recording non-metrical dental variations is the Arizona State University Dental Anthropology System (ASUDAS) developed by Christy G. Turner, II and students (Turner et al., 1991). Hence, a large number of non-metrical dental traits that can be scored in teeth derived from almost two centuries of the research, but only a few of them are recognized across the discipline. One can usually record and /or score the following variations: shovel-shaped incisors, lower premolar lingual cusps, molar main cusps, lower molar fissure patterns, additional cusps of molars, and root numbers.

## *Dental pathology*

### *Caries*

Dental caries is a chronic complex bacterial infection that results in losses of minerals from the tooth that is affected by the infection. Despite the complex nature of caries development, main causes of this infection are bacteria and eating habits which enable the development of the disease (Loesch, 1985). This disease is as old as humankind, and the prevalence of caries tends to increase in periods of economic prosperity in a society. A significant increase in prevalence of caries in Europe was during the expansion of the Roman Empire in antiquity, and most probable cause for that was the frequent consumption of cooked food (Radović, 2013a, p. 956).

Caries is a very important condition of the teeth that should be recorded in the analysis of archaeological material. Hence, the results obtained in such analyses are highly related to the way they have been recorded. In modern populations, dental caries is strongly associated with individual age, as the nature of caries lesions and its incidence are successively changing with age of observed individuals. Furthermore, premolars and molars are more susceptible to caries, as well as teeth in the lower jaw than those in the upper jaw. Tooth wear, which again depends on individual age and diet, can obscure caries lesions. When dealing with archaeological samples, one must bear in mind that the presence of tooth chipping, fractures and irregular

8 Dental cusp is a hard eminence on occlusal surface of a tooth. Depends on type of the tooth, the number of cusps can vary from one to five normally.

wear may be closely related to caries. The additional challenges when recording caries in archaeological material are diagenetic changes and various preservation of different parts of the dentition. For all these reasons, it is difficult to establish a single standard for the examination of caries of a dental collection, which would be suitable for testing it on any other archaeological collection.

Together with the study of tooth wear patterns and the stable isotopes analyses, the examination of the epidemiology of caries in many ways give an insight into the ancient diet. To get comparable and reliable results when examining archaeological caries, it is of uttermost importance to use standardised methods. Hillson (Hillson, 2001, p. 249–289) offers the most detailed recording system so when analysing caries in archaeological material.

*Dental calculus*

Dental calculus is mineralized plaques that adhere to the surface of the teeth. In living individuals, the calculus deposits are covered by non-mineralized plaque, which is precisely that pathologic agent which causes paradontal changes, inflammation of the gingiva, or bone degeneration around the alveolar sockets. Dental calculus can be very useful when it comes to archaeological material. Firstly, it is a very resistant mineralized deposit that can be preserved together with the hard tissue. Secondly, for anthropologists who study human skeletal remains, dental calculus is useful source of information on periodontal diseases in ancient populations. Finally, dental calculus is also useful in the study of ancient diet, because it is reminiscent of specific factors involved in human nutrition in the past (Cristiani et al., 2016). The researchers agree that the main cause for the formation of dental calculus is the alkaline environment in the oral cavity, which increases the precipitation of minerals from the surrounding oral fluids. It is also considered that diet rich in proteins causes an increase in alkalinity in the oral cavity, which contributes to the formation of dental calculus.

Dental calculus comprises an organic and inorganic component. The organic matrix is composed of about 15 -20 % dry matter, then amino acids, peptides, glycoproteins, proteins, carbohydrates and lipids. The inorganic component is composed primarily of calcium and phosphorus, but also of carbon, sodium, magnesium and fluoride. Depending on the place where it is located in the oral cavity, dental calculus can be supragingival or subgingival. These two types of calculus also differ in their composition and structure. The supragingival calculus is usually located on the lingual surface of the lower incisors and on the buccal surface of the upper first molars. It is called supragingival, because it forms on the tooth surface above the gingiva edge. The subgingival calculus is always formed on diseased teeth and on the surface of the tooth root.

*Dental defects –hypocalcification and hypoplasia*

Hypocalcification defect of tooth crown surface recognized as white opaque patches in the translucent enamel. Hypocalcification of the enamel is caused by episodic disruptions during the crown maturation. Enamel hypoplasia is an enamel defect which result from disturbance in enamel matrix secretion. When possible to observe it macroscopically, it is seen in forms of grooves and/or pits in the tooth enamel. A general standard for recording these two dental defects is available (the Developmental Defects of Enamel index) and it has been developed by Fédération Dentaire Internationale (FDI). The causes of maturation defects of enamel are not understood yet and they are not very often seen in archaeological material. On the other hand, hypoplastic defects are very common in archaeological samples and they are well studied. The terminology for distinction between different types of enamel hypoplasia has been given by Hillson and Bond (Hillson, Bond, 1997). A few recording systems were developed together with methods in which the measurements should be taken (Massler et al., 1941; Buikstra, Ubelaker, 1994; Reid, Dean, 2000).

Enamel hypoplasia defect of a tooth crown caused by some general disorders. Disorders that can cause such a defect in the process of secretion of enamel matrix are sometimes hereditary, but in most cases, they are caused by many different factors such as nutritional deficiencies and childhood diseases accompanied by extremely high fever. In archaeological dentitions these defects are indicators of Selyean stress (Goodman et al., 1988; Goodman, Rose 1990; Larsen, 1997; Hillson, 2009).

*Chronology, diet, climate and origins*

Some dietary habits of ancient populations and individuals can be obtained by studying tooth wear patterns and dental caries as we saw above. However, more particular information regarding the type of food consumed (e.g. plants vs. meat; type of plant material consumed; fish or “flesh”) can be determined from analyses of isotopes[9] present in teeth as well as in bones. The interpretation of the results of such analyses can additionally help in collecting the information about chronology,

9 Isotope are atoms of the same element with a same number of protons, but different number of neutrons.

climate and place of origin. The most commonly studied isotopes are carbon, nitrogen, oxygen, and strontium.

*Carbon*

The longest-lived unstable radioisotope of carbon is $^{14}C$, with a half-life of 5730 +/- 40 years (the Cambridge half-life). This is also the only carbon radioisotope found in nature.  For these reasons it has been used extensively as a dating technique in archelogy.

Carbon has also two known stable isotopes which are $^{12}C$ and $^{13}C$. They are incorporated into plants during the process of photosynthesis. When eating those plants, a human or an animal incorporates these isotopes in the amino acids of their structural proteins and in the carbonate present in hydroxyapatite crystals of their mineralized tissues. Stable carbon isotope values for marine plants is different from those of terrestrial plants. Therefore, different values will be measured for individuals which consumed marine plants in comparison to ones feeding on terrestrial plants. Furthermore, carnivores feeding on the meat of marine herbivores will have isotope levels different from land carnivores.

*Nitrogen*

Nitrogen found in nature consist of two stable isotopes, $^{14}N$ and $^{15}N$. Same as with stable carbon isotopes, they are used to reveal dietary information from the bone collagen. These values help to distinguish between carnivores and herbivores, as well as marine and terrestrial feeders. $^{15}N$ values in teeth and bones can also be used to determine the approximate time of weaning. It appears that breastfed children have higher nitogen-15 levels in their collagen than their mothers.

*Oxygen*

Oxygen has two stable isotopes ($^{16}O$ and $^{18}O$), and they are incorporated into the structure of the hydroxyapatite crystallite through the drinking water intake. The heavier isotope, oxygen-18, is associated with the drinking water from warmer, tropical climate nearer the oceans, while the lighter isotope, oxygen-16, is associated with cooler environments further away from the ocean. By measuring the values of these two isotopes from tooth enamel, we can obtain the information about the environment during the period of crown formation. By measuring their values across a section of a single tooth, we might be able to obtain the information about an individual's movement during childhood (Berkovitz et al., 2009, p. 382). Examination of oxygen-16 and oxygen-18 can also help in distinguishing between local and non-local individuals from a single burial site.

*Strontium*

Strontium is present in the soil and it gets incorporated into the hydroxyapatite crystallite from the plants and through the food chain. Even though, it can be used for diet reconstruction as well as an absolute ageing technique, it is mostly used as an indicator of the place of origin of the sample. The ratio between two of the strontium stable isotopes, $^{87}Sr$ and $^{86}Sr$, is the indicator of the geology of an area. By measuring those ratios from tooth enamel, one can obtain significant information about an individual's movements during the early childhood, while the same measurements taken form adult bone and dentine, due to their remodelling, provide information on more recent movements of the observed individual.

*Conclusion*

During the last few decades, archaeology has shifted from the place of being strictly considered as a social science to being more multidisciplinary in its scope. That can be seen, not only in developing new fields in archaeology, such as archaeometry, but also in broader range of the questions which can be answered, and in obtaining the results which can be tested. For these reasons, dental anthropology is tightly connected to archaeological research. As we saw in this paper, dental anthropological research can help in gaining significant information about people in the past. We can use teeth to find out in which period people lived in, or to find out more about their origins, their dietary habits, their life expectancy and many other life history data.

By widening the spectrum of the research questions and with the increasing number of techniques available to answer those questions, the possibility of making more significant errors in interpretation is broadening too. The most common mistakes the researchers in dental anthropology are making, when applying methods listed above, can be broadly clustered in problems with: sample size and control; sample contamination; conformation bias with sampling and interpreting the results, and "overfitting" models to the available data; improper understanding of biology of the samples, and an underestimation of the limitations of the equipment used to obtain data. Some of these problems are easily avoidable by getting an adequate training or just by following the established research protocols, and by using appropriate standards. Yet, there are many big unknowns surrounding the relationship between human teeth, behaviour, environment, and biology more widely. These unknown complexities require us to take a cautionary research stance. Anthropological research questions cannot be simply answered by uncritically obtaining new results from exciting new high-performance equipment. It is up to us to carefully design continually better research questions with all the limitations of the above approaches I have outlined in mind, if dental anthropology is to progress as the truly dynamic and innovative discipline that it has previously been.

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