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HUMAN DENTAL BUCCAL MICROWEAR AND PALEODIET RECONSTRUCTION

ABSTRACT: Researches on the pattern of buccal dental microwear (striations) in relation to diet and dietary habits have been solidified after the year 1980. The density of striations, orientation, and length are discriminate variables in reconstructing paleodiet. Populations who depended more on meat consumption tended to have a lower density of striations with a higher percentage of vertical striations. On the other hand, individuals who depended on more plant consumption tended to have higher density of striations with more horizontal ones. In contrast to occlusal dental microwear, buccal microwear is practically a proxy for the lifetime diet of an individual without any effect of non-masticatory factors, and thus can be used to construct diet, dietary behavior, climatic fluctuations, and maybe to estimate the age at death and sex. By comparing buccal dental microwear to the other techniques used in reconstructing paleodiet, the technique is reliable and shows a great potential in dietary reconstructions.

KEY WORDS: Dental - Buccal - Microwear - Paleodiet

INTRODUCTION

Dietary reconstruction of past human populations has recently become more acknowledged in the archaeological lexicon. Bioarchaeologists perceive diet as culturally constructed and thus governed by human behaviors (Alrousan 2009, Alrousan, Pérez-Pérez 2012, Lalueza et al. 1996, Twiss 2012) but at the same not divorced from its environmental context, which may affect the distribution and availability of food resources (Alrousan 2009, 2011, Pérez-Pérez et al. 2003). Accordingly, diet would have reflected the social status of an individual; people of higher social status frequently consumed better quality and quantity of food (Ambrose et al. 2003, Jankauskas, Kozlovskaia 1999, Joyce 2010, Pérez-Pérez, Lalueza 1992, Schutkowski 1995). Furthermore, diet played a major role in the evolution of the genus Homo (Leonard et al. 2007). For example, meat consumption was attributed to the brain size enlargement millions of years ago. Food production and consumption have been considered as chief factors in shaping societies' structure and settlement pattern (sedentary vs. mobile) especially in the absence or modest technological
innovations (Smith 1995). Human buccal dental microwear is one of the useful techniques in reconstructing past diet and dietary behaviors. In light of this, this paper tries to shed more light on the buccal dental microwear technique.

**PALEODIET RECONSTRUCTION**

Paleodiet reconstruction entails several methods; they could be classified depending on the source of information, into two main categories: indirect and direct methods. The indirect methods are based on the evidence that is found or excavated in archaeological sites such as grinding stones, sickles or mortars (Smith 1972, Twiss, 2007). Food remains such as plant and cereal remains provide good information about the paleodiet and the interaction between humans and the surrounding ecology (Richard 2002, Twiss 2007).

The direct methods include the evidence that leave signatures on the skeletal and dental remains. One of the major techniques associated with the direct methods is the use of chemical analysis of bone. Bone chemistry provides a strong evidence for reconstructing diet of a given skeletal materials, and can be divided into two types: trace elements and stable isotopes analyses. The main trace elements that can be analyzed in the human skeletal remains are Sr, Zn, Mn, Mg and Br (Elias 1980, Elias et al. 1982, Ubelaker 1994, Schutkowski 1995). The biochemistry, physiology and turn over of these elements are well-known (cf. Al-Shorman 2013, Larsen 1997). Trace element analysis is affected by many uncontrolled factors, such as food preparation technique, cooking process, storage materials, age and sex, as well as post-mortem diagenesis which is the most important (Al-Shorman 2013, Larsen 1997, Price et al. 1992). The use of the stable isotopes usually includes two of them: carbon ($^{13}$C) and nitrogen ($^{15}$N) (Ambrose 1987, Buikstra 1992, Chisolm 1989, Greenlee 1998, Hogue 2000, 2003, Hogue, Peacock 1995, Hutchinson et al. 2000, Larsen et al. 1992, Lynott et al. 1986, Schoeninger, Schurr 1998). The analysis of these stable isotopes is affected by the composition of the burial soil, postmortem diagenesis, and climate (Lösch et al. 2006). Furthermore, the isotopic analysis does not reflect single diet consumption but the cumulative intake over the individual’s life span (Grine et al. 2002). The chemical techniques require tedious preparation methods of the skeletal materials and/or teeth, and also necessitate strict control over the variables mentioned above.

Many dental features, such as rate of attrition, alveolar resorption, and calculus may provide only a general view of past diet and/or subsistence economy (Rose et al. 1991, Fyfe et al. 1992, Larsen et al. 1990 and 1991, Hillson 2000, Eshed et al. 2006, Alrousan, Abu Dalo 2013), where the reliance on them in reconstructing the paleodiet is risky. There are certain diseases that left marks on the skeletal remains and are linked to certain food intake and/or insufficient intake. Cribra orbitalia, for example, is a well-known sign of iron deficiency anemia (Walker et al. 2009), dental caries is also correlated with the consumption of carbohydrate diets (Alrousan, Abu Dalo, 2013, Larsen 1984). Rickets is a disease that is caused by vitamin D deficiency and causes osteomalacia (Pitt 1988), scurvy results from vitamin C deficiency and alters the texture of the bone surfaces (Ortner 2003). These metabolic disorders only reconstruct certain food and/or food items but not the whole diet.

**WHY DENTAL MICROWEAR?**

As mentioned previously, the above methods in paleodietary reconstruction are either limited to certain food consumption or only provide general clues on the past diet. Coupled with postmortem diagenesis, the nature of the human bone especially the physiological turn over may stand as an obstacle in the process of reconstructing paleodiet. The alternative method that might stand more reliable is the use of dental microwear. Teeth are valuable tools in dietary reconstruction since teeth are the most preserved human remains in the archaeological assemblages, and there are directly related to food processing. In order to reconstruct the diet using teeth, microscopic and gross analysis are used, where they rely on the modification of tooth enamel during the life of individuals.

The interaction between the enamel and food material ends with dentine exposure; a term that is known as dental wear or gross wear, which is an informative indicator of paleodiet (Alrousan, Abu Dalo 2013, Eshed et al. 2006). Both forms of wear and percentage of dentine exposure is an indicator of the interaction between tooth and food during a chewing cycle. For example, agriculturists tended to have higher percentage of dentine exposure with an oblique form, while hunter-gatherers had a lower percentage of dentine exposure with a flat form of attrition (Eshed et al. 2006, Formicola 1987, Molnar 1971, 1972, Scott
Dental attrition occurs also due to tooth-to-tooth contact which increases the percent of dentine exposure (Hillson 1996). Besides, using teeth as tools also increases the percentage of dentine exposure and the form of exposure (Al-Shorman, Khalil 2006, Macchiarelli 1989), which may mislead results interpretations. Dental microwear has the potential to establish and consolidate the relationship between diet, subsistence economy and tooth size. The progressive reduction of tooth size in the genus Homo is a worldwide phenomenon. For example, Hunter-gatherers populations have large dentition compared to agriculturists (Brace 1963, Brace, Mahlar 1971, Calcagno 1986, 1989, Macchiarelli, Bondioli 1986, Pinhasi et al. 2008), which means that their diet was unprocessed with low percent of cereal components: a thing that could be reconstructed using dental microwear.

**DENTAL MICROWEAR METHOD**

Dental microwear is the microscopic examination of teeth enamel surfaces including striations and pits (Grine et al. 2002, Puech 1976, 1979, Ungar, 1992). The interaction between enamel surfaces and abrasive materials or particles in diet, usually harder than enamel, is responsible for the formation of dental microwear pattern. Hardness of the abrasive particles is measured by Mohs scale (1824) on a range from 1–10. Dental enamel is scored on a range from 4.5–5 as well. Therefore, any particle that exceeds this range tends to form a microwear features, during mastication process with presence of abrasive particles tend to form pits and striations on the occlusal surface, but only striations on the buccal. These abrasive particles can be classified as either intrinsic or extrinsic. The intrinsic particles are found within the food especially plants; for example, silica particles (opal phytoliths) (G gel et al. 2001, Laloeza, Pérez-Pérez 1994, Piperno 1988). The extrinsic particles usually introduced to diet during food processing; for example, sand, dust, grits, ash ... etc. (Alrousan 2009, Alrousan, Pérez-Pérez 2008, 2012, Alrousan et al. 2013; Romero et al. 2012, 2013, Teaford, Lytle 1996, Ungar 1992).


In order to standardized microwear analysis and quantification, Kay (1987) introduced numerical Fourier transformations as an analytical tool. Recent studies used confocal light microscopy to measure microwear features (Boyde, Fortelius 1991). Then, semi-automated image analysis procedure was used to identify individual features on a computer screen using...
a mouse-driven pointer (Ungar 1995, Ungar et al. 1991). This software was developed by the paleoanthropologist Peter Ungar at University of Arkansas. After generations of this software, microware 4.02, (the occlusal dental microwear analysis) took its way to be one of the main methods of dietary reconstruction (Alrousan 2011, El-Zaatari 2008, Schmidt, 2001). The occlusal microwear pattern is distinguished by two features: striations defined as linear features that have a length to width ratio not exceeding 4:1, and pits that are shorter than the former (El-Zaatari 2008, Grine et al. 2002, Teaford, Walker 1984). The hardness of diet is proportionally related to the number of microwear features, pits and striations on the occlusal surface of teeth (Alrousan 2011, Mahoney 2006, Schmidt 2001).

The buccal microwear was first studied by the French odontologist Pierre-Francois Puech, who suggested that the number, the length and the orientation of the microwear striations on the buccal surface are characteristics of diet. He also suggested that longer vertical striations are characteristics of a major meat diet, while longer horizontal striations is a characteristic of a major plant diet (Puech 1976, 1979, Puech et al. 1980, 1986). The striation is defined as a linear feature that equals or exceeds in length 10 micrometer (Galbany et al. 2005, Romero et al. 2012). The number of horizontal striations increases by increasing plants consumption, while the number of vertical striations increases by increasing meat consumption (Alrousan, Pérez-Pérez 2012, Lalueza et al. 1996).

By the 1980s, the vestibular dental microwear took its way as a tool in dietary reconstruction, dietary adaptation, and dietary behavior. The University of Barcelona was considered as the center for buccal microwear analyses. Started by many PhD dissertations (for example Pérez-Pérez 1990), and followed by many published researches (Lalueza et al. 1996, Pérez-Pérez et al. 1994, 1999, 2003, Romero et al. 2013). This group studies the dietary evolution in human lineage, modern hunter-gatherers and primates employing an experimental approach.


The interpretation of dietary reconstruction is done using the above variables. The harder diet tends to have a higher number of total striations than that of softer diet (Alrousan 2009, Alrousan, Pérez-Pérez 2008, Pérez-Pérez et al. 1999, 2003). The length of striations is negatively correlated with the number of striations, because the increasing in the number of striations tends to cut the previous striations (Romero, De Juan 2007). Meat diet tends to make more vertical striations, while plants tend to make more horizontal ones. Therefore, many indices were developed to characterize the diet using the number of horizontal and vertical striations (Alrousan, Pérez-Pérez 2012, Lalueza et al. 1996). The large value of this index is related to high percentage of plants in diet. The length of horizontal and vertical striations was used as another index (Pérez-Pérez et al. 1994). The higher value of this index is also correlated with higher percentage of plant consumption.

PROBLEMS: CASTING AND POSTMORTEM DAMAGE

Dental microwear studies depend on molding and casting teeth in order to preserve the original teeth. But during the process of molding and casting many problems were faced. For example, it would destroy the weak enamel due to taphonomic effects. The presence of pits on the buccal surface may be due to methodological error during molding and casting (Figure 2). Before examination the casts under scanning electron microscopy, it should be covered with gold using a high temperature, that may be affects
the surface of the casts by wrinkles or waves and make the surface unsuitable for microwear analysis (Estebaranz et al. 2006).

One of the major problems of analyzing dental microwear is the inter and intra-observer error (Galbany et al. 2005, Grine et al. 2002). But the instant of error might be reduced using the standardized technique and the experience of the investigator (Galbany et al. 2005). Other factors that may interfere with microwear method are the taphonomic process and postmortem alterations that may change the pattern of dental microwear, the presence of acid in the soil surrounding the skeletal remains and the medium particles of soil (King et al. 1999). To overcome these factors, diagenetic teeth can be determined according to King et al. (1999), Martinez and Perez-Perez (2004), Perez-Perez et al. (2003), and Teaford (1988). An example of postmortem alteration is the presence of large number of parallel striations (Figure 3). The experience of the investigator is also necessary for recognizing the taphonomic process in the teeth. Thus the affected teeth must be excluded, which reduced the number of the individuals in the final sample.

BUCCAL VS OCCLUSAL

In comparing the two faces of dental microwear studies: occlusal and buccal, the term turn-over enters the first issue of comparison. Turn-over is defined as the changing in dental microwear pattern through the time. The occlusal dental microwear shows a high turn-over character and the pattern changes in just few minutes and reflects the last food consumed, last supper effect (Teaford, Oyne 1996), and also the pattern changes seasonally. On the other hand, buccal face shows long term stability, and it is known as accumulative process depending on the age, time since eruption, and it is not affected by seasonal changes (Alrousan 2009, Perez-Perez et al. 1994). Therefore, buccal dental microwear may also used as age estimations technique (Pinilla et al. 2011). Recent experimental study measured the turn over and the stability of buccal dental microwear showed that the buccal dental microwear pattern exhibit a long-term stability that makes this technique a reliable method used to reconstruct overall dietary habits and dietary adaptations of ancient human populations (Romero et al. 2012).

Tooth-to-tooth contact may affect and infer the pattern of occlusal dental microwear (Every 1974). This contact might remove enamel flakes (Rensberger 1978), prism-sized chips (Walker 1984), and hydroxyapatite crystallites (Teaford, Walker 1984). Recent studies on stillborn guinea pigs indicate the presence of pits in the enamel, even though the pigs are not exposed to abrasive diet (Perez-Perez et al. 2003, Teaford, Walker 1983), and the presence of pits is due to anomalous ameloblast-sized enamel that is projected under the tooth surface (Boyed 1989).

Tooth use by ancient populations as a tool in their daily lives is not uncommon and affected the occlusal...
surface (Macchirelli 1989, Minoizze et al. 2003). This consequently affected the pattern of the occlusal surface by changing it and masking certain features (Al-Shorman, Khalil 2006, Minozzi et al. 2003). The buccal surface is not affected by this phenomenon making it more reliable in dietary reconstruction. Occlusal dental microwear pattern differs from one tooth to another and from one jaw to another; even the same tooth has a different pattern from facet to another depending on the function of the facet during mastication of food (Mahoney 2006, Schmidt 2001). Accordingly, the number of the individuals that enter the final sample will be limited due the preservation condition of the same part of the facet.

The pattern of buccal microwear shows no significant difference among the post-canine teeth considering tooth position, jaw or side (Alrousan 2009, Pérez-Pérez 1990, Pérez-Pérez et al. 1994). As a result, the number of individuals who enter the analysis will increase. Excluding the third molar, each adult individual has 16 choices of teeth. The standard method of buccal dental microwear relies on micrographs using SEM with 100X magnification (Figure 4) of the middle third of the buccal surface then treats the image using Adobe Photoshop®, and cropping 0.56 mm square of large surface area that allows choosing the best preserve enamel (Figure 5). Then each micrograph is digitized using a special software (Sigma Scan pro 5 by SPSS) giving the slope and length of each striation. Using a special formula the slope is converted into an angle. Using SPSS the results are analyzed to yield the microwear pattern of each tooth.

NEW 3D AUTOMATIC TECHNIQUE

A new technique was recently developed to quantify occlusal dental microwear pattern, it is known as microwear texture analysis using confocal microscopy and scale-sensitive fractal analysis that is characterized by many useful features. First, it is automated and thus eliminates inter and intra-observer error, quick, cheap, and suitable for analyzing a large number of individuals (Scott et al. 2005, Ungar et al. 2003). The automatic technique was also used on the buccal surface to reconstruct paleodiet using interferometric microscopy, although the automatic procedures are useful techniques in both buccal and occlusal surfaces, it need a more training to different microwear pattern, taphonomical features and post-mortem alterations (Estebaranz et al. 2007).

It has been proved that the buccal dental microwear analysis is a reliable technique in reconstructing diet, dietary behavior, and dietary attributed factors of ancient human populations. Therefore, bioarchaeologists use this type of enamel surface analysis under scanning electron microscope. For example, Lalueza and Pérez-

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**FIGURE 4.** Micrograph.

**FIGURE 5.** Cropped micrograph.
Pérez (1993) investigated the buccal dental microwear pattern of a Neanderthal child and suggested that its diet was similar to that of carnivores. Pérez-Pérez et al. (1994) were able to reconstruct the weaning time using buccal dental microwear using the density of striations on the buccal surface. Modern populations were also investigated to establish a dental microwear pattern comparable to ancient populations of the same subsistence economy (Lalueza et al. 1996). Diet texture, sex and age were proved to be strongly related to the pattern of buccal microwear (Pérez-Pérez et al. 1999). In addition, it was noticed that the climatic fluctuations left imprints in the pattern of buccal microwear (Pérez-Pérez et al. 2003). Food processing techniques play an important role in the introduction of abrasive materials in diet that can be investigated using buccal microwear analysis (Alrousan, Pérez-Pérez 2008, Romero, De Juan 2007). Alrousan (2009) analyzed a large collection of teeth of hunter-gatherers (Mesolithic and Natufian) and agriculturists (Neolithic) populations from Near East and the Iberian Peninsula, the later population tended to have harder diet due to introduction of cereals to diet with grits from food processing. The varied NH/NV index of the Natufian samples is probably a reflection of cultural preferences, which was supported by archaeological findings (Alrousan, Pérez-Pérez 2012). Experimentally, the turn-over of buccal microwear of living population is a dynamic and continuous process during the life of an individual (Romero et al. 2012). Recently, the correlation between buccal microwear pattern and stable isotopes was measured using a Mesolithic sample from Spain, no correlation was found may be due to the effect of food processing techniques in buccal microwear pattern (Alrousan et al. 2013)

CONCLUSIONS

The examination of buccal surface under the scanning electron microscope to extract paleodiet information has many advantages in a comparing with occlusal surface; the buccal surface is far away from non-masticatory effect such as tooth use as a tool, long term turn-over, and buccal dental microwear pattern shows no significant variation in post-canine teeth that allows increasing the number of individuals in the sample of study. Although the automatic procedures are useful techniques used to avoid inter and intra-observer error and it is faster technique than that of the semi-automated one, but also these techniques lack discriminations between the microwear pattern and postmortem alterations. For the previous reasons, biological anthropologists use buccal microwear analysis in reconstructing paleodiet and dietary behavior of ancient human populations. But this technique is still in its infancy stage, further studies need to be conducted especially on the experimental techniques and taphonomical effects.

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