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HUMAN DENTAL BUCCAL MICROWEAR AND PALEODIET RECONSTRUCTION

ABSTRACT: Researches on the pattern of buccal dental microwear (striations) in a 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, Kozlovskaya 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

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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 microweaer. 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

1979, Smith 1972, Smith 1984). 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, Macchirelli 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, Lalueza, 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).

Dental microwear studies are either relied on the analysis of dental enamel occlusal surface (Alrousan 2011, El-Zaatari 2008, Gordon 1982, 1984, Mahoney 2006 ,Schmidt 2001, Teaford, Walker 1984), or the buccal surface (Alrousan, Pérez-Pérez, 2008, 2012, Alrousan *et al.* 2009, 2012, 2013, Lalueza, Pérez-Pérez 1993, Pinilla *et al.* 2008, Pérez-Pérez *et al.* 1994, 1999, 2003, Romero, De Juan, 2007, Romero *et al.* 2012, 2013). The lingual side is not included due to the movement of the tongue inside the jaw, which works as a polishing tool. Microscopic analysis entails the reconstruction of diet and dietary behavior of ancient human populations (Alrousan 2009, 2011, Alrousan, Pérez-Pérez 2008, 2012, Hojo 1989, Mahoney 2006, Molleson *et al.* 1993, Pérez-Pérez *et al.* 1994, 1999, 2003, Romero, De Juan 2007, Schmidt, 2001, Unger, Spencer 1999); the diet of the *Australopithecines* and early *Homo* (Estebaranz *et al.* 2008, 2012, Martinez *et al.* 2004, 2008); primate diets and ecology (Galbany 2006, Galbany *et al.* 2009, Teaford, Runestad 1992, Ungar 1992), and experimental studies focusing on improving the methods of analyzing dental microwear (Teaford, Oyne 1989, King *et al.* 1999, Galbany *et al.* 2005, Grine *et al.* 2002, Romero *et al.* 2012). Recent studies on microwear surpass the reconstruction of diet and dietary habits to reconstruct more complex aspects, such as, food processing (Alrousan, Pérez-Pérez, 2008, Alrousan *et al.* 2013 Teaford, Lytle 1996), mastication behavior and biomechanics (Gordon 1984), and non-dietary use of teeth (Al-Shorman, Khalil 2006, Lauleza, Frayer 1997, Minozzi *et al.* 2003).

The first microwear study on the occlusal surface was carried out by Dahlberg and Kinzey (1962) on samples from modern and archaeological teeth using light microscopy. Then after almost a decade, the first occlusal dental microwear analysis of non-human primates using optical light microscopy was published by Walker (1976). The analyses of dental microwear pattern started as a qualitative technique by counting microwear features (Grine 1981, Puech 1979, Walker 1981, Walker *et al.* 1978). Then analytical quantitative techniques were developed to acquire more reliable interpretations of dental microwear (El-Zaatari, 2008, Gordon 1982, 1984, Grine 1986, 1987, Grine *et al.* 2002, Mahony 2006, Schmidt 2001, Teaford 1985, 1986, Teaford, Walker 1984). These studies identified new variables such as teeth position, facet type, and the orientation of wear facet that may affect the pattern of dental microwear.

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 occulsal 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 hardiness 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). This group studies the dietary evolution in human linage, modern hunter-gatherers and primates employing an experimental approach.

Buccal dental microwear pattern is characterized by 15 variables depending on the orientation of the striations (*Figure 1*): Vertical, Horizontal, Meso-distal, and Disto-mesial, then the sum of all striations: total number of striation. Each type of striation is characterized by three variables: number, length, and standard deviation of length (Alrousan, Pérez-Pérez 2008, 2012, Estebaranz *et al*. 2012, Galbany *et al*. 2009, Lalueza *et al.* 1996, Martínez *et al.* 2008, Pérez-Pérez *et al.* 1994, 1999, 2003, Romero *et al*. 2013).

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.

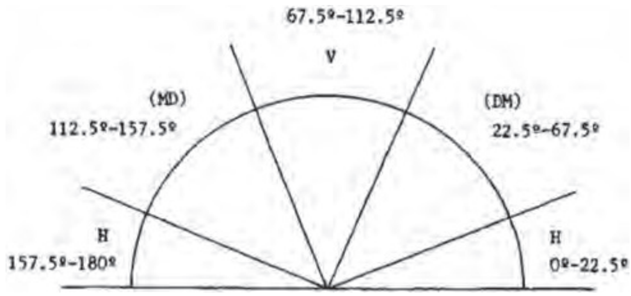

FIGURE 1. Orientation of striations after Pérez-Pérez *et al.* (1994).

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).

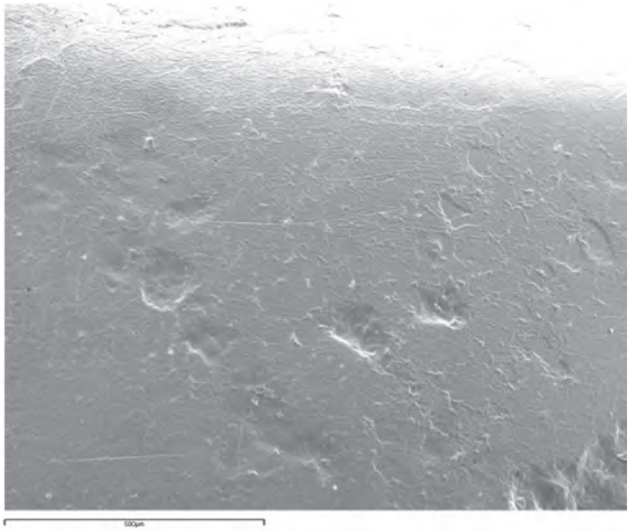

FIGURE 2. Pitted buccal surface.

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), Martínez and Pérez-Pérez (2004), Pérez-Pérez *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.

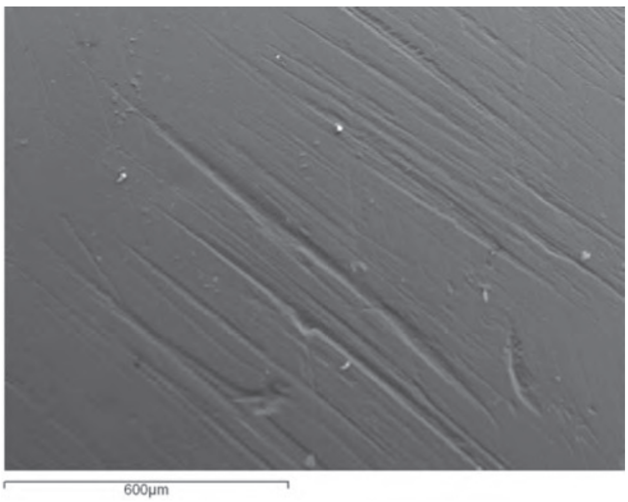

FIGURE 3. Non-dietary parallel striations.

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, Pérez-Pérez *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 (Pérez-Pérez *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 interfermetric 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-

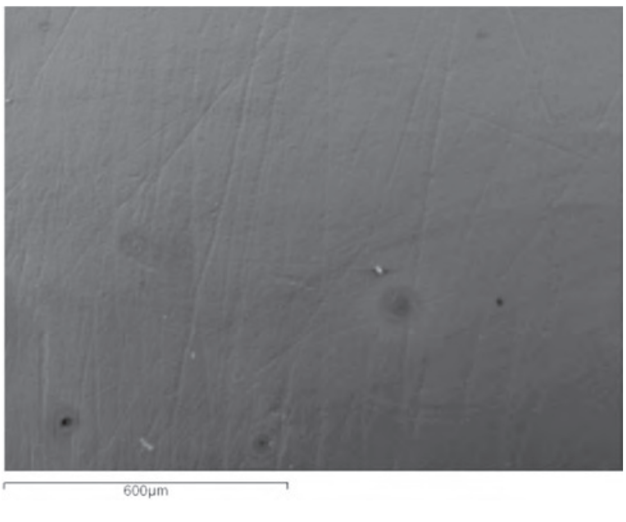

FIGURE 4. Micrograph.

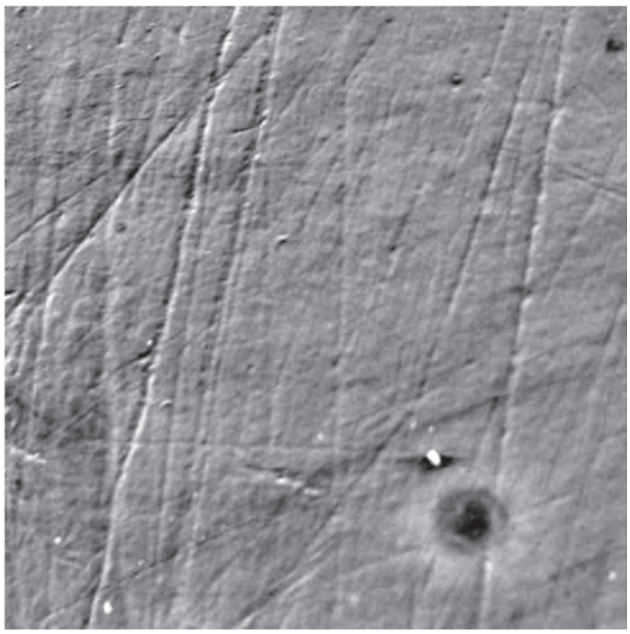

FIGURE 5. Cropped micrograph.

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.

REFRENCES

ALROUSAN M., 2009: *The Mesolithic-Neolithic Transition in the Near East: Biological implications of the shift in subsistence strategies through the analysis of dental morphology and dietary habits of human populations in the Mediterranean area 12,000–5,000 B.P.* PhD. Dissertation of Physical Anthropology. University of Barcelona, Spain.

ALROUSAN M., 2011: Dental Microwear and Dietary Adaptation of the People of Ya'amun During the Middle/Late Bronze Age. In: M. El-Najjar (Ed.): *Ya'amun An Archaeological Site In Northern Jordan*. Pp. Yarmouk University Press.

ALROUSAN M., PÉRÉZ-PÉRÉZ A., 2008: Non-Occlusal microwear of the last hunter-gatherer from Near East and Europe. In: A. J. Nogués, S. Pinilla (Eds.): *Gene, ambiente y enfermedades en los poblaciones humanas*. Pp. 45–59. University of Zaragoza Press.

ALROUSAN M., PÉRÉZ-PÉRÉZ A., 2012: Buccal Dental Microwear as an Indicator of Dietary Habits of the Natufian People from El Wad and Kebara. In: M. P. Perry (Ed.): *Bioarchaeology of the Near East and Eastern Mediterranean.* Pp. 165–179. Perry.

ALROUSAN M., ABU DALO A., 2013: Reflections on Human Skeletons from Tall Abu Al-Kharaz. In: P. M. Fischer, T. Bürge (Eds.): The Swedish Jordan Expedition 2011 and 2012 at Tall Abu al-Kharaz. Fourteenth and Fifteenth Seasons: Preliminary Results. *Opuscula. Annual of the Swedish Institutes in Athens and Rome* 6: 307–338.

ALROUSAN M., AL-SHORMAN A., GALBANY J., PÉRÉZ-PÉRÉZ A., 2013: Buccal dental microwear and stable isotopes of El Collado: A mesolithic site from Spain. *Bull Int Assoc Paleodont* 7, 1: 4–11.

AL-SHORMAN A., 2013: *The Chemistry of Archaeological Human Bones*. Deanship of Scientific Research and Graduate studies. Yarmouk University, Jordan.

AL-SHORMAN A., KHALIL L., 2006: The Evidence of Weaving at Khirbit Yajuz. *International Journal of Dental Anthropology* 8: 1–9.

AMBROSE S. H., 1987: Chemical and isotopic techniques of diet reconstruction in eastern North America. In: W. F. Keegan (Ed.): *Emergent Horticultural Economics of the Eastern Woodlands*, vol. 27. Pp. 87–107. Southern Illinois University Occasional Paper.

BOYDE A., 1989: Enamel. In: B. K. B. Berkovitz, A. Boyde, R. M. Frank, H. J. Hohling, B. J. Moxham, J. Nalbandian, C. H. Tonge CH. (Eds.): *Teeth: handbook of microscopic anatomy.* Volume V/6. Pp. 309–407. New York: Springer Verlag.

BOYDE A., FORTELIUS M., 1991: New confocal LM method for studying local relative microrelief with special references to wear studies. *Scanning* 13: 429–30.

BRACE C. L., 1963: Structural reduction in evolution. *American Naturalist* 97: 185–195.

BRACE C. L., MAHLER P. E., 1971: Early Holocene changes in the human dentition. *American Journal of Physical Anthropology* 34: 191–204.

BUIKSTRA J.E., 1992: Diet and disease in late prehistory. In: J. W. Verano, D. H. Ubelaker (Eds.): *Disease and Demography in the Americas*. Pp. 87–101. Smithsonian Institution Press, Washington.

CALCAGNO J., 1986: Dental reduction in early Holocene Nubia. *American Journal of Physical Anthropology* 70: 349–363.

CALCAGNO J., 1988: Human dental reduction: Natural selection or the probable mutation effect. *American Journal of Physical Anthropology* 77: 505–517.

CALCAGON J., 1989: *Mechanisms of Human Dental Reduction: A Case Study from Post-Pleistocene Nubia. Lawrence*: University of Kansas Publications in Anthropology 18.

CHISOLM B. S., 1989: Variation in diet reconstruction based on stable carbon isotope evidence. In: T. D. Price (Ed.): *The Chemistry of Prehistoric Human Bone*. Pp. 10–37. Cambridge University Press, Cambridge.

DAHLBERG A., KINZEY W., 1962: Etude microscopique de l' abrasion et de l' attrition sur la surface des dents. B*ulletine du Groupement International pour les Recherches Scientique en Stomatologie* 5: 242–251.

ELIAS M., 1980: The feasibility of dental strontium analysis for diet-assesment of human populations. *American Journal of Physical Anthropology* 63: 1–4.

ELIAS R. W., HIRAO Y., PATTERSON C. C., 1982: The circumvention of natural biopurification of calcium along nutrient pathways bye atmospheric inputs of industrial lead. *Geochimica et Cosmochimica Acta* 50: 1941–1949.

ESHED V., GOPHER A., HERSHKOVITZ I., 2006: Tooth Wear and Dental Pathology at the Advent of Agriculture: New Evidence from the Levant. *American Journal of Physical Anthropology* 130: 145–159.

ESTEBARANZ F., GALBANY J., MARTINEZ L., PÉREZ-PÉREZ A., 2007: 3-D interferometric microscopy applied to the study of buccal dental microwear. In: S. E. Baily, J.-J. Hublin (Eds): *Dental Perspectives on Human Evolution.* Pp. 391–403. Springers.

ESTEBARANZ F., GALBANY J., MARTINEZ L., PINILLA B., PÉREZ-PÉREZ A., 2006: Nota metodológica: Alteración del patrón de microestracion dentaria por el efecto wrinkle. *Rivista española de Antropología Física* 26: 115–121.

ESTEBARANZ F., GALBANY J., MARTINEZ L., TURBON D., PÉREZ-PÉREZ A., 2012: Buccal dental microwear analyses support greater specialization in consumption of hard foodstuffs for Australopithecus anamensis*. Journal of anthropological science* 90: 1–24.

ESTEBARANZ F., MARTINEZ L., GALABANY J., PÉREZ-PÉREZ A., 2008: Análisis del patrón de microestriación dental de Australopithecus afarensis. In: A. J. Nogués, S. Pinilla (Eds.): *Gene, ambiente y enfermedades en los poblaciones humanas*. Pp. 127–141. University of Zaragoza Press.

EVER R. G., 1974: Thegosis in prosimians. In: R. D. Martin, A. Walker, G. A. Doyle (Eds.): *Prosimian biology*. Pp. 579–620. London: Duckworth.

FORMICOLA V., 1987: Neolithic Transition and Dental Changes: the Case of an Italian Site. *Journal of Human Evolution* 16: 131–239.

FYFE D. M., CHANDLER N. P., WILSON N. H. F., 1992: Alveolar bone status of some pre-seventeenth century inhabitants of Taumako, Solomon Islands. *International Journal of Osteoarchaeology* 3: 29–35.

GALBANY J., 2006: *El patró de microestriació dental de primats Catarrhini: un model ecològic per primats fòssils i homínids*. Ph.D. Dissertation. Universitat de Barcelona. Barcelona, Spain.

GALBANY J., ESTEBARANZ F., MARTINEZ L., PÉREZ-PÉREZ A., 2009: Buccal microwear variability in extent African Hominiodea: taxonomy verus ecology. *Primates* 50: 221–230.

GALBANY J., MARTINEZ M., LÓPEZ-AMOR H. M., ESPURZ V., HAIALDO O., ROMERO A., DE JUAN J., PÉREZ-PÉREZ A., 2005: Error rates in dental buccal microwear quantification using Scanning Electron Microscopy. *Scanning* 27: 23–29.

GORDON K. D., 1982: A study of microwear on chimpanzee molars: implications fordental microwear analysis. *American Journal of Physical Anthropology* 59: 195–215.

GORDON K. D., 1984: Hominoid dental microwear: complications in the use of microwear analysis to detect diet. *Journal of Dental Research* 63: 1043–1046.

GREENLEE D. M., 1998: Prehistoric diet in the central Mississippi River Valley. In: O'Brian, M. J., Dunnell, R. C. (Eds.): *Changing Perspectives on the Archaeology of the Central Mississippi River Valley*. Pp. 299–342. The University of Alabama Press, Tuscaloosa.

GRINE F. E., 1981: Trophic differences between "gracile" and "robust" australopithecines: a scanning electron microcope analysis of occlusal events. *South African Journal of Science* 77: 203–30.

GRINE F. E., 1986: Dental evidence for dietary differences in *Australopithecus* and *Paranthropus* – a quantitative-analysis of permanent molar microwear. *Journal of Human Evolution* 15: 783–822.

GRINE F. E., UNGAR P. S., TEAFORD M. F., 2002: Error rates in dental microwear quantification using scanning electron microscopy. *Scanning* 24: 144–53.

GÜGEL I., GRUPE G., KUNZELMANN K-H., 2001: Simulation of dental microwear: characteristic traces by opal phytoliths gives clues to ancient human dietary behaviour. *American Journal of Physical Anthropology* 114: 124–138.

HILLSON S., 1996: *Dental Anthropology*. Cambridge: Cambridge University Press.

HILLSON S., 2000: Dental pathology. In: M. A Katzenberg, S. Saunders (Eds.): *Biological Anthropology of the Human Skeleton*. Wiley-Liss, New York.

HOGUE S. H., 2000: Burial practices, mortality, and diet in east-central Mississippi: a case study from Oktibbeha County. *Southeastern Archaeology* 19: 63–81.

HOGUE S. H., 2003: Corn dogs and hush puppies: diet and domestication at two Protohistoric farmsteads in Oktibbeha County, Mississippi. *Southeastern Archaeology* 22: 85–195.

HOGUE S. H., PEACOCK E., 1995: Environmental and osteological analysis of the South Farm site (22OK534), a Mississippian farmstead in Oktibbeha County, Mississippi. *Southeastern Archaeology* 14: 31–45.

HUTCHINSON D. L., LARSEN C. S., NORR L., SCHOENINGER M. J., 2000: Agricultural melodies and internal harmonies in Florida and Georgia. In: Lambert P. M. (Ed.): *Bioarchaeological Studies of Life in the Age of Agriculture*. Pp. 96–115. The University of Alabama Press, Tuscaloosa.

JANKAUSKAS R., KOLOZLOYSKAYA M., 1999: Biosocial Differentiation in Lithuanian Iron Age population. *Anthropologie* (Brno) 37: 177–185.

KAY R. F., 1987: Analysis of primate dental microwear using image processing techniques. *Scanning Microscopy* 1: 657–62.

KING T., ANDREWS P., BOZ B., 1999: Effect of Taphonomic Procees on Dental Microwear. *American Journal of Physical Anthropology* 108: 539–373.

LALUEZA C., FYRAYER D., 1997: Non-dietary Marks in the Anterior Dentition of Krapnia Neanderthals. *International Journal of Osteoarchaelogy* 17: 133–149.

LALUEZA C., PÉREZ-PÉREZ A., 1993. The diet of the Neanderthal Child Gibraltar2 (Devil's Tower) through the Study of the Vestibular Striation Pattern. *Journal of Human Evolution* 24: 29–41.

LALUEZA C., PÉRÉZ-PÉRÉZ A., 1994: Dietary information through the examination of plant phytoliths on the enamel surface of human dentition. *Journal of Archaeological Science* 21: 29–34.

LALUEZA C. PÉREZ-PÉREZ A.,TURBBON D., 1996: Dietary inferences through buccal microwear analysis of middle and upper Pleistocene human fossils. *American Journal of Physical Anthropology* 100: 367–387.

LARSEN C. S., 1984: Health and Disease in Prehistoric Georgia: The Transition to agriculture. In: M. N. Cohen, G. J. Armelagos (Eds.): *Paleopathology at the origins of agriculture*. Pp. 367–392. New York: Academic Press.

LARSEN C. S., 1997: *Bioarchaeology: Interpreting Behavior from the Human Skeleton.* Cambridge University Press, New York.

LARSEN C. S., SCHOENINGER M. J., HUTCHINSON D. L., RUSSWL K. F., RIFF C. B., 1990: Beyond demographic collapse: biological adaptation and change in native populations of La Florida. In: D. H. Thomas (Eds.): *Columbian Consequence. Archaeological and Historical Perspectives on the Spanish Borderland East*, vol. 2. Pp. 409–428. Smithsonian Institution Press, Washington.

LARSEN C. S., SCHOENINGER M. J., VAN DER MERWE N. J., MOORE K. M., LEE-THROP J. A., 1992: Carbon and nitrogen isotopic signatures of human dietary change in the Georgia Bight. *American Journal of Physical Anthropology* 89: 197–214.

LARSEN C. S., SHAVIT R., GRIFFEN M. C., 1991: Dental caries evidence for dietary change: an archaeological context. In: M. A. Kelly, C. S. Larsen (Eds.): *Advances in Dental Anthropology*. Pp. 179–202. Willey-Liss, New York.

LEONARDO W. R., SNODGRASS J. J., ROBERTSON M. L., 2007: Effects of Brain evolution on Human Nutrition and Metabolism. *Annual review of nutrition* 27: 311–327.

LÖSCH S., GRUPE G., PETERS J., 2006: Stable Isotopes and Dietary Adaptations in Humans and Animals at Pre-Pottery Neolithic Nevali Cori, Southeast Anatolia *American Journal of Physical Anthropology* 131: 181–193.

LYMAN R., 1994: *Vertebrate Taphonomy.* Cambridge. Cambridge University Press.

LYNOTT M. J., BOUTTON T. W., PRICE J. E., NELSON D. E., 1986: Stable carbon isotope evidence for maize agriculture in southeast Missouri and northeast Arkansas. *American Antiquity* 51: 51–65.

MACCHIRELLI R., 1989: Prehistoric "Fish Eaters" along the Eastern Arabian Coasts: Dental Variation, Morphology, and Oral Health in the Ra's Al-Hamra (Qurum, Saltanante of Oman, 5th–4th Millennia BC). *American Journal of Physical Anthropology* 78: 575–594.

MAHONEY P., 2006: Dental Microwear from the Natufian Hunter-Gatherers and Early Neolithic Farmers: Compasions Within and Between Samples. *American Journal of Physical Anthropology* 130: 308–319.

MARTINEZ L., PÉREZ-PÉREZ A., 2004: Post-Mortem Wear as Indicator of Taphonomic Processes affecting Enamel Surfaces of Hominine Teeth from Laetoli and Olduvai (Tanzania): Implications to Dietary Interpretations. *Anthropologie* (Brno) 42: 37–42.

MARTINEZ L., ESTEBARANZ F., GALBANY J., PÉREZ-PÉREZ A., 2008: El Patrón de Microestriación Dentaria en los Primeros Homo. A. J. Nogués, S. Pinilla (Eds.): *Gene, ambiente y enfermedades en los poblaciones humanas*. Pp. 227–235. University of Zaragoza Press.

MINOZZI S., MANZI G., LERNIA S., TARLI S., 2003: Nonalimantary Tooth Use in Prehistory: An Example from Early Holocene in Central Sahara (Uan Muhuggiag, Tadrart Acacus, Libya). *American Journal of Physical Anthropology* 120: 225–232

MOHS F., 1824: *Pyramidales Mangan-Erz.-Grundriss der Mineralogie*, vol. II. Pp. 484–486.

MOLLESON T., JONES K., JONES S., 1993: Dietary change and the effect of food preparation on microwear patterns in the Late Neolithic at Abu Hureyra, Northern Syria. *Journal of Human Evolution* 24: 455–468.

MOLNAR S., 1971: Human Tooth Wear, Tooth Function and Cultural Variability. *American Journal of Physical Anthropology* 34: 175–190.

MOLNAR S., 1972: Tooth wear and culture: a survey of tooth functions among some prehistoric populations. *Current Anthropology* 13: 511–526.

O'CONNOR T., 2000: *The Archaeology of Animal Bones*. Stroud: Sutton.

ORTNER D., 2003: Metabolic Disorders. In D. Ortner (Eds): Identificacion of Pathological conditions in human skeletal remains. Pp. 383–418. San Diego: Academic Press.
PÉREZ-PÉREZ A., 1990: *Evolución de la Dieta en Cataluña y Baleares desde el Paleolítico hasta le edad Media a partir de Restos Esqueléticos.* Ph.D. Dissertation. University of Barcelona.Spain.
PÉREZ-PÉREZ A., LALUEZA C., 1992: Social stratification and differential access to meet through trace element analysis. *Anthropologie* (Brno) 30: 185–188.
PÉREZ-PÉREZ A., CASTRO J., ARUAGA J., 1999: Non-occlusal Dental Microwear Analysis of 300,000-Year-old Homo heildbergensis Teeth from Sima de Los Huesos (Sierra de Atapuercar, Spain). *American Journal of Physical Anthropology* 108: 433–457.
PÉREZ-PÉREZ A., ESPURZ V., DE CASTRO J. M. B., DE LUMLEY M., TURBON D., 2003: Non-occlusal dental microwear variability in a sample of Middle and late Pleistocene human populations from Europe and the Near East. *Journal of Human Evolution* 44: 497–513.
PÉREZ-PÉREZ A., LALUEZA C., TURBON D., 1994: Intraindividual and intragroup variability of buccal tooth striation pattern. *American Journal of Physical Anthropology* 94: 175–187.
PINHASI R., ESHED B., SHAW P., 2008: Evolutionary Changes in the Masticatory Complex Following the Transition to Farming in the Southern Levant. *American Jurnal of Physical Anthropology* 135: 136–148.
PINILLA B., GALBANY J., ESTEBARANZ F., MARTIENZE L., ALROUSAN M., PÉREZ-PÉREZ A., 2009: La influencia del clima en la dieta de H. neanderthalensis y H. sapiens: Microestriación Vestibular y fluctuaciones climáticas. In: A. J. Nogués, S. Pinilla (Eds.): *Gene, ambiente y enfermedades en los poblaciones humanas*. Pp: 573–586. University of Zaragoza Press.
PINILLA B., ROMERO A., PÉREZ-PÉREZ A., 2011: Age-related variability in buccal dental-microwear in Middle and Upper Pleistocene human populations. *Anthropological Review* 74: 25–37
PIPERNO D., 1988: *Phytolith analysis: an archaeological and geological perspective*. San Diego: Academic Press.
PITT M., 1988: Rickets and Osteomalacia. In: D. Rensnick, G. Niwayama (Eds.): *Diagnosis of bone and joint disorders.* Pp. 2086–2119. Philadelphia: WB. Sounders.
PRICE T., BLITZ J., BURTON J., EZZO J, 1992: Digenesis in Prehistoric Bone: Problems and Solutions. *Journal of Archaeological Science* 19: 513–529.
PUECH P., 1976: Recherche sur le mode d'alimentation des hommes du Paleolithique par l'étude microscopique des couronnes dentaires. In: H. de Lumley (Ed.): *La Préhistoire Française I*. Pp. 708–709. Centre National de la Recherche Scientifique.
PUECH P., 1979: The diet of early man: evidence from abrasion of teeth and tools. *Current Anthropology* 20: 590–592.
PUECH P., ALBERTINI H., MILLS N., 1980: Dental destruction in Broken-Hill man. *Journal of Human Evolution* 9: 33–39.
PUECH P., CIANFARANI F., ALBERTINI H., 1986: Dental microwear features as an indicator for plant food in early hominids: a preliminary study of enamel. *Human Evolution* 1: 507–515.
QUINTERO L., WILKE P., 1995: Evolution and economic significance of naviform core-and blade technology in the southern Levant. *Paléorient* 21, 1: 7–33.
RENSBERGER J.M., 1978: Scanning electron microscopy of wear and occlusal events in some small herbivores. In: P. M. Butler, K. A. Joysey (Eds.): *development, function and evolution of teeth*. Pp: 415–437. London: Academic Press.
RENSBERGER J. M., 2000: Pathways to functional differentiation in mammalian enamel. In: M. Teaford, M. Meredith Smit, M. W. J. Ferguson (Eds.): *Development, function and evolution of teeth*. Pp. 252–268. Cambridge: Cambridge University Press.
RICHARDS M., 2002: A Brief review of the Archaeological Evidence for Paleolithic and Neolithic Subsistence. *European Journal of Clinical Nutrition*. 56. doi:10.1038/sj.ejcn.1601646.
ROMERO A., DE JUAN J., 2007: Intra- and Interpopulation Human Buccal Tooth Surface Microwear Analysis: Inferences about Diet and formation Processes. *Anthropologie* (Brno) 45: 61–70.
ROMERO A., GALBANY J., DE JUAN J., PÉREZ-PÉREZ A., 2012: Short and long-term in vivo human buccal dental-microwear turnover. *American Journal of Physical Anthropology* 148: 467–472.
ROMERO A., RAMIREZ-ROZZI F.V., DE JUAN J., PÉREZ-PÉREZ A., 2013: Diet-related buccal dental microwear patterns in Central African Pygmy foragers and Bantu-Speaking farmer and pastoralist populations. PLoS ONE 8(12): e84804.doi:10.1371/journal.pone.0084804
ROSE J. C., MARKS M. M., TIESZEN L. L., 1991: Bioarchaeology and subsistence in the central and lower portions of the Mississippi Valley. In: M. L. Powell, P. S. Bridges, A. M. Mir (Eds.): *What Mean These Bones? Studies in Southeastern Bioarchaeology*. Pp. 7–21. The University of Alabama Press, Tuscaloosa.
SCHOENINGER M. J., SCHURR M. R., 1998: Human subsistence at Moundville: The stable isotope data. In: V. J. Knight., V. P. Steponaitis (Eds.): Archaeology of the Moundville Chiefdom. Pp. 120–132. Smithsonian Institution Press, Washington.
SCHUTKOWSKI H., 1995: What you are makes you eat different things-interrelations of diet, status and sex in the early medieval population of Kirchheim unter teck, FGR. *Human Evolution* 10: 119–130.
SCOTT R., 1979: Dental Wear Scoring Technique. *American Journal of Physical Anthropology* 51: 203–218.
SCOTT R. S., UNGAR P. S., BERGSTROM T. S., BROWN C. A., GRINE F. E., TEAFORD M. F., WALKER A., 2005: Dental microwear texture analysis shows within-species diet variability in fossil hominins. *Nature* 436: 693–695.
SCHMID T. C. W., 2001: Dental microwear evidence for a dietary shift between two nonmaize-reliant prehistoric human populations from Indiana. *American Journal of Physical Anthropology* 114: 139–145.

SMITH B., 1984: Patterns of molar wear in hunter-gatherers and agriculturists. *American Journal of Physical Anthropology* 63: 39–56.

SMITH P., 1972: Diet and Attrition in the Natufians. *American Journal of Physical Anthropology* 37: 233–238.

SMITH P., 1995: People of the Holy Land from Prehistory to the Recent Past. In: T. E. Levy (Eds): *The Archaeology of Society in the Holy Land.* Pp. 58–74. New York: Facts on File.

TEAFORD M., 1988: Scanning Electron Microscope Diagnosis of Wear Patterns and Artifacts on Fossil Teeth. *Scanning Microscope* 2: 1167–1175.

TEAFORD M., LYATLE J., 1996: Brief Communication: Diet-Induced Changes in Rates of Human Tooth Microwear: A Case study Involving Stone-Ground Maize. *American Journal of Physical Anthropology* 100: 143–147.

TEAFORD M., OYEN O., 1989: In Vivo and In Vitro Turnover in Dental Microwear. *AmericanJournal of Physical Anthropology* 80: 447–460.

TEAFORD M., RUNESTAD J., 1992: Dental micowear and diet in Venezualan primates. *American Journal of Physical Anthropology* 88: 347–364.

TEAFORD M. F., WALKER A., 1983: Dental microwear in adult and still born guinea pigs (Cavia porcellus). *Archives of Oral Biology* 28: 1077–1081.

TEAFORD M. F., WALKER A., 1984: Quantitative differences in dental microwear between primate species with different diets and a comment on the presumed diet of Sivapithecus. *American Journal of Physical Anthropology* 64: 191–200.

TWISS K., 2007: The Neolithic of southern Levant. *Evolutionary Anthropology* 16: 24–35.

TWISS K., 2012: The Archaeology of food and Social Diversity. *Journal of Archaeological Research* 20: 357–395.

UBELAKER D., 1994: *Human Skeletal Remains Excavation, Analysis, Interpretation*. Smithsonian Institute.

UNGAR P., 1992: *Feeding behaviour and dental microwear in Sumatran anthropoids*. PhD. dissertation, State University of New York at Stony Brook.

UNGAR P., 1995: A semiautomated image analysis procedure for the quantification of dental microwear. 2. *Scanning* 17: 57–9.

UNGAR P., BROWN C. A., BERGSTROM T. S., WALKER, A., 2003: Quantification of dental microwearby tandem scanning confocal microscopy and scale-sensitive fractal analyses. *Scanning* 25: 185–193.

UNGAR P., SIMON J. C., COOPER J. W., 1991: A Semiautomated Image Analysis Procedure for the Quantification of Dental Microwear. *Scanning* 13: 31–6.

UNAGR P., SPENCER M., 1999: Incisor Microwear, Diet, and Tooth use in Three Amerindian Populations. *American Journal of Physical Anthropology* 109: 387–396

WALKER A., 1981: Diet and teeth. Dietary hypotheses and human evolution. *Philosophical Transactions of the Royal Society London B, Biological Sciences* 292: 57–64.

WALKER A., 1984: Mechanisms of honing in the male baboon canine. *American Journal of Physical Anthropology* 65: 47–60.

WALKER A., HOECK H. N., PEREZ L., 1978: Microwear of mammalian teeth as an indicator of diet. *Science* 201: 908–910.

WALKER P. L., 1976: Wear striations on the incisors of cercopithecoid monkeys as an index of diet and habitat preference. *American Journal of Physical Anthropology* 45: 299–308.

WALKER P., BATHURST R., RICHMAN R., GJERDRUM T., ANDRUSKO V., 2009: The causes of porotic hyperostosis and cribra orbitalia: A reappraisal of the iron-deficiency-anemia hypothesis. *American Journal of Physical Anthropology* 139: 109–125.

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