Contents

List of Figures and Tables .................................................................................................................. iii

In Memoriam Rui Boaventura (February 10th 1971 – May 28th 2016) ........................................ vi
Ana Catarina Sousa, Tiago Tomé, Ana Maria Silva

Foreword to the XVII UISPP Congress Proceedings Series Edition ........................................ ix
Luiz Oosterbeek

Introduction ....................................................................................................................................... x
Tiago Tomé, Marta Díaz-Zorita Bonilla, Ana Maria Silva and Claudia Cunha

Tomb 3 at La Pijotilla (Solana de los Barros, Badajoz, Spain): A Bioarchaeological Study of a Copper Age Collective Burial ........................................................................................................ 1
Marta Díaz-Zorita Bonilla, Charlotte A. Roberts, Leonardo García Sanjuán and Victor Hurtado Pérez

On the applicability of the assessment of dental tooth wear for the study of collective prehistoric burials .......................................................................................................................... 11
Luíz Miguel Marado, Claudia Cunha, G. Richard Scott, Tiago Tomé, Hugo Machado and Ana Maria Silva

Cova de Can Sadurní (Begues, Barcelona). Towards the definition of a multiple funerary model inside caves during the middle Neolithic I in the northeast of the Iberian Peninsula ............................................................................................................................ 21
Manuel Edo, Ferran Antolín, Pablo Martínez, Concepció Castellana, Remei Bardera, María Saña, M. Mercè Bergadà, Josep Maria Fullola, Chus Barrio, Elicínia Fierro, Trinidad Castillo and Eva Fornell

Mora Cavorso Cave: a collective underground burial in Neolithic central Italy ......................... 33
Mario F. Rolfo, Katia F. Achino and Letizia Silvestri

Bioarchaeological approach to the Late Neolithic and Chalcolithic population of Cameros megalithic group (La Rioja, Spain) .............................................................................................. 41
Teresa Fernández-Crespo

Anthropological and taphonomical study of human remains from the burial cave of El Espinoso (Ribadedeva, Asturias, Spain) ................................................................................................. 55
Borja González Rabanal, Manuel Ramón González Morales and Ana Belén Marín Arroyo

Diet and ritual in the western Mediterranean Copper Age: human and animal stable isotopes from the collective burial at S. Caterina di Pittinuri (Sardinia, Italy) ........................................... 67
Luca Lai, Ornella Fonzo, Elena Usai, Luca Medda, Robert Tykot, Ethan Goddard, David Hollander and Giuseppa Tanda

The artificial caves of Valencina de la Concepción (Seville) ............................................................ 79
Pedro M. López Aldana and Ana Pajuelo Pando
Multiple burials in pit graves from Recent Prehistory at Southwest of Iberia:
The cases of Monte do Vale do Ouro 2 (Ferreira do Alentejo),
Ribeira de S. Domingos 1 and Alto de Brinches 3 (Serpa) .......................................................... 91
Tânia Pereira, Ana Maria Silva, António Valera, Eduardo Porfirio

Bioarchaeological analysis at the Copper Age site of Valencina de la Concepción
(Seville, Spain): The PP4-Montelirio sector .................................................................................. 103
Sonia Robles Carrasco, Marta Díaz-Zorita Bonilla, Virginia Fuentes Mateo and
Leonardo García Sanjuán

Assessing spatial dispersion of human remains in collective burials: A GIS approach
to the burial-caves of the Nabão Valley (North Ribatejo, Portugal) .............................................. 119
Tiago Tomé, Claudia Cunha, Ana Maria Silva, Luiz Oosterbeek and Ana Cruz
List of Figures and Tables

*M. Díaz-Zorita Bonilla* et al.: *Tomb 3 at La Pijotilla (Solana de los Barros, Badajoz, Spain): A Bioarchaeological Study of a Copper Age Collective Burial*

**FIGURE 1. MAP OF LA PIJOTILLA** .......................................................... 2  
**FIGURE 2. PLAN OF TOMB 3 AT LA PIJOTILLA** .......................................... 3  
**FIGURE 3. CIRBRA ORBITALIA AFFECTING THE RIGHT ORBIT, GRADE 2 (ID 6887)** ................................................................. 6  
**FIGURE 4. DENTAL ABSCESS CAVITY (ID 10400)** ..................................... 7  
**TABLE 1. RADIOCARBON DATES FOR LA PIJOTILLA** .................................... 8  
**TABLE 2. ESTIMATION OF AGE AT DEATH AT LA PIJOTILLA** ....................... 9  
**TABLE 3. SEX ESTIMATION AT LA PIJOTILLA** ........................................... 4  
**TABLE 4. STATURE CALCULATION AT LA PIJOTILLA** ................................ 5  

*L. Miguel Marado* et al.: *On the applicability of the assessment of dental tooth wear for the study of collective prehistoric burials*

**FIGURE 1. TOOTH WEAR ON DIFFERENT UI1 SUBSEQUENTLY LESS AFFECTED BY TOOTH WEAR** .................................................... 12  

*M. Edo* et al.: *Cova de Can Sadurní (Begues, Barcelona). Towards the definition of a multiple funerary model inside caves during the middle Neolithic I in the northeastern of the Iberian Peninsula*

**FIGURE 1. LOCATION OF THE SITES MENTIONED IN THE TEXT AND SITE PLAN OF COVA DE CAN SADURNÍ** .................................................. 22  
**FIGURE 2. EAST PROFILE OF THE EXCAVATION AREA** ................................ 23  
**FIGURE 3. INDIVIDUAL 1 (INH1) AND INDIVIDUAL 2 (INH2)** ....................... 24  
**FIGURE 4. HYPOTHETICAL RECONSTRUCTION OF THE SHROUD OF INDIVIDUAL 1** ......................................................... 24  
**FIGURE 5. RADIOCARBON DATES BASED ON HUMAN BONE SAMPLES** ........ 26  
**FIGURE 6. HYPOTHETICAL RECONSTRUCTION OF THE EVOLUTION OF THE FUNERARY EVENTS IN THE CAVE** ...................................... 27  
**FIGURE 7. MATERIALS ASSOCIATED TO THE BURIALS OR LIKELY TO BE CONSIDERED AS FUNERARY OFFERINGS** ......................... 28  
**TABLE 1. RADIOCARBON DATES ON HUMAN BONE SAMPLES** ..................... 29

*M.F. Rolfo* et al.: *Mora Cavorso Cave: a collective underground burial in Neolithic central Italy*

**FIGURE 1. 1- THE LOCATION OF MORA CAVORSO CAVE IN THE SIMBRUINI MOUNTAINS; 2- PLAN OF THE CAVE WITH LOCATION OF THE ARCHAEOLOGICAL TEST PITS** .............................................................. 34  
**FIGURE 2. 1, 3- THE HUMAN BONES FOUND ON THE FLOOR OF THE LOWER ROOM; 2, 4- THE HUMAN BONES FOUND ON THE FLOOR OF THE UPPER ROOM** ................................................................. 35  
**FIGURE 3. PLAN AND STRATIGRAPHY OF THE LOWER ROOM (1) AND UPPER ROOM (2)** ..................................................... 36  
**FIGURE 4. ARCHAEOLOGICAL REMAINS FROM UPPER ROOM (4-5) AND LOWER ROOM (1-3)** .................................................... 37

*T. Fernández-Crespo*: *Bioarchaeological approach to the Late Neolithic and Chalcolithic population of Cameros megalithic group (La Rioja, Spain)*

**FIGURE 1. MAP OF CAMEROS REGION REVEALING THE LOCATION OF LATE NEOLITHIC AND CHALCOLITHIC BURIAL SITES** ....................... 42  
**FIGURE 2. IMAGE SHOWING THE COMMON FRAGMENTED, DISARTICULATED AND COMMINGLED STATE OF BONES** ........................................ 43  
**FIGURE 3. RADIOCARBON DATES FROM THE MEgalithic GRAVES UNDER STUDY** ................................................................. 44  
**FIGURE 4. SHAPE OF MORTALITY RATES [q(x)] FROM CAMEROS MEgalithic GRAVES** ................................................................. 48  
**FIGURE 5. EVIDENCE OF Spondyloarthritus OR VERTEBRAL FUSION FROM Peña Guerra II** ............................................................... 49  
**FIGURE 6. PICTURE SHOWING THE POSITIONING OF A GROUP OF SKULLS BY THE ORTHOSTATES OF THE SECONDARY CHAMBER OF Peña Guerra II** ..................................................... 50  
**TABLE 1. DISTRIBUTION BY AGE OF THE INDIVIDUALS RECOVERED FROM THE CAMEROS MORTUARY SITES UNDER STUDY** .................. 47
S. Robles Carrasco et al.: Bioarchaeological analysis at the Copper Age site of Valencina de la Concepción (Seville, Spain): The PP4-Montelirio sector

Figure 1. Map of Valencina de la Concepción (Sevilla) .......................................................... 104
Figure 2. Map with structures with and without human bone remains at the PP4-Montelirio sector .......................................................... 104
Figure 3. LEH at 21, individual 2 from Structure 10.035 .......................................................... 108
Figure 4. Dilaceration of the root (teeth 13) from Structure 10.003 ........................................ 109
Figure 5. Unusual alteration in enamel (tooth 21) at Structure 10.055 ..................................... 110
Figure 6. Possible case of ‘dens invaginatus’ on tooth 22 from individual 1 at Structure 10.044. .......................................................................................................................... 111
Table 1. List of structures with bioarchaeological analysis ...................................................... 106
Table 2. List of teeth with LEH .................................................................................................. 108
Table 3. List of teeth with possible ‘Dens invaginatus’ .............................................................. 109
Table 4. List of teeth showing enamel alteration ...................................................................... 109

T. Tomé et al.: Assessing spatial dispersion of human remains in collective burials: A GIS approach to the burial-caves of the Nabão Valley (North Ribatejo, Portugal)

Figure 1. Location of CDV and GRO .................................................................................. 121
Figure 2. Global spatial dispersion of skeletal remains .......................................................... 122
Figure 3. Adults versus non-adults skeletal remains distribution .......................................... 123
Figure 4. Spatial dispersion by skeletal region at CDV ......................................................... 124
Figure 5. Spatial dispersion by skeletal region at GRO .......................................................... 124
Figure 6. Differential dispersion patterns for upper and lower limb bones at GRO ............... 124
On the applicability of the assessment of dental tooth wear for the study of collective prehistoric burials

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Abstract

Teeth are a very important resource in Biological Anthropology. One of their many uses is the evaluation of dental wear, which can document both masticatory and non-masticatory behavior. The objectives of this work are to 1) present a protocol for scoring evidence of non-masticatory activity applicable to all kinds of contexts (including commingled collective burials), 2) suggest interpretation tools, and 3) use simple, time-saving and accessible procedures.

Procedures addressing oral alterations, a new trait – cingular continuous lesions (CCL) – and statistical analysis are described. This method will complement archaeological knowledge on past populations’ cultural, ritual or work-related tooth uses.

Keywords

Bioarchaeology; extramasticatory dental wear; teeth as tools; dental lesions

Résumé

Les dents sont très importantes pour l’anthropologie physique. Un de ses uses est l’usure dentaire, qui peut documenter les comportements masticatoires et non-masticatoires. Les objectifs de ce travail sont 1) la présentation d’un protocole de registre des évidences d’activités non-masticatoires applicables à contextes diverses (notamment les enterrements collectifs mélangés), 2) la suggestion de outils d’interprétation et 3) l’use des méthodes simples, accessibles et rapides.

Méthodes pour adresser les altérations orales, un nouvel trait – cingular continuous lesions (CCL) – et testes statistiques sont décrits. Cette méthodologie complèment la connaissance archéologique de l’use dentaire en fonctions culturelles, rituelles et de travail.

Mots-clés

Bioarchéologie; usure dentaire extra-masticatoire; les dents comme outils; lésions dentaires

Introduction

Teeth are the most important resource in Paleoanthropology: 1) when dental tissues (almost entirely mineral) have matured, they do not remodel – so any changes in their shape are resultant of their use
or of the lesions they suffered, which do not undergo biological reparative actions (Hillson 2005); 2) teeth are the most resistant of human tissues, and endure most taphonomic conditions (Hillson 2005, Scott 2008, Scott and Turner 1988, Silva 2002), hence they are a remarkable source of information on archaeological populations.

One of the most common ways tooth shape is changed is through dental wear, i.e. the progressive loss of superficial dental tissues as crowns are exposed to environmental agents. Wear is also one of the ways in which tooth use molds the evolution of dental characteristics (tissue qualities, anatomy, morphology) (Kaidonis 2008). Contact with other teeth (attrition); contact with food, tongue and cheeks or other objects (abrasion); and the chemical dissolution of tooth tissue (erosion) are forms of wear (Hillson 2005, Kaidonis 2008, Soames and Southam 2005), although erosion is not wear, stricto sensu (since the loss of tissue is related to chemical reactions, not mechanical contact: Molnar 2011). Wear can occur in any extragingival part of the tooth, such as on the occlusal or incisal parts (the most distant from the roots), on the interproximal facets (that directly contact neighboring teeth), on the lingual/palatal and buccal/labial surfaces (that face the interior and vestibular portions of the mouth, respectively), on the cervical portion, near or at the enamel-cement junction and, in cases when teeth suffer extreme tooth wear, the roots themselves will endure loss of its exposed surfaces as a result of tribological (relating to relative movement of teeth) forces (Figure 1).

From early on, tooth wear was studied in past populations to interpret dietary habits and, most commonly, to estimate age at death (Rose and Ungar 1998). Alongside other data from analyses of varying degrees of technological complexity and of oral lesions, dental wear is still used to help reconstruct past human diets (Forshaw 2014). However, dental wear does not solely result from masticatory activities, and can occur when teeth are used as a third hand or as tools in labor, cultural or ritual activities (Molnar 2011); this non-masticatory tooth use has also been studied for several decades (e.g.: Hylander 1977, Molnar 1972, Turner and Machado 1983).

The value of teeth and their capacity for conservation are both high (see above). However, the poor conservation of other elements – and, occasionally, of teeth themselves – in some archaeological contexts (like collective prehistoric burials with commingled remains) can still make researchers’ jobs difficult. When human remains are no longer attributable to a set of anatomically connected bones and teeth, the paleoanthropological analysis is limited in several ways and requires specific approaches in order to collect bioanthropological data: estimation of minimum number of individuals (MNI), age at death, stature, sex, individual biological affinities, individual social status, systematic

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**Figure 1.** Tooth wear on different UI1 subsequently less affected by tooth wear, from worn tooth roots (after complete crown obliteration) to slight alterations caused by dental wear. Numbers above each tooth correspond to occlusal wear grades, according to Molnar (1971) and Smith (1984).
paleopathological analysis, association between characteristics on different skeletal or oral elements, etc. (see, for example, Silva 2002, Tomé 2011).

There are many examples of studies concerning patterns or traits of non-masticatory tooth wear in prehistoric (Fiorenza et al. 2011, Molleson 1994, Molnar 2008, Molnar 1971, 1972, Waters-Rist et al. 2010), historic (Scott and Jolie 2008, Scott and Winn 2011) and recent or contemporary (Berbesque et al. 2012, Clement et al. 2008, Wood 1992) samples. These studies of non-masticatory wear tend to focus on individuals; their application on loose teeth is rare and usually occurs in small samples or as a small part of a given sample (see Bonfiglioli et al. 2004, Liu et al. 2010, Minozzi et al. 2003, Pechenkina et al. 2002).

Molnar (2011) addresses the need for a standard methodology for scoring non-masticatory wear, which should include careful morphological characterization and description, as well as visual documentation. Despite this need for systematization, there is also the need for new methodology to enable and adapt to the study of loose teeth.

Molnar’s (1971) attempt to standardize not only the scoring of occlusal wear, but also the recording of wear variations derived from non-masticatory tooth use, was the main influence for the presentation that originated this work.

The authors aimed at creating a laboratory protocol to: a) score dental wear on all exposed tooth surfaces, b) score specific wear signs related to non-masticatory tooth use, and c) other score alterations to teeth and/or bone that can be related to the application of massive occlusal forces or the use of teeth as tools (such as hypercementosis, chipping and bone exostoses). This method is applicable to both in situ and loose teeth, and only requires the use of 10x magnifying glass, when needed. Although designed to address commingled human remains, this approach could also be employed on large samples of individual inhumations.

The objectives of this study are 1) to present a methodological protocol for scoring non-masticatory dental wear (and other morphological or pathological alterations related to strenuous use of the dentition); 2) to suggest statistical approaches to assist the interpretation of the subsequent results; and 3) to accomplish the former objectives with simple, time-saving and accessible procedures.

Scoring methodology

1) Occlusal wear

Occlusal wear is scored using Smith’s (1984) eight-graded scale, which has three versions for a) molars, b) premolars and c) incisors and canines. This method, despite its wide use and the schematization of the three different types of progressive occlusal wear patterns (also inspired by Molnar’s 1971 work), is somewhat incomplete: Smith’s scale does not account for possible wear inclinations, only for plane occlusal wear. This scale is very helpful – the thoroughly illustrated and described grades make this a relatively easy to apply method, which describes the general effect of occlusal wear (e.g.: Berbesque et al. 2012, Machicek and Zubova 2012) – but does not discern masticatory from non-masticatory wear and ignores the other tooth surfaces.

2) Non-masticatory wear

Following Molnar’s 1971 intent to complement the scoring of occlusal wear, signs of wear most likely derived from non-masticatory activities are also contemplated, using a five-graded ordinal scale applied to all vertical tooth surfaces (buccal, lingual, mesial and distal), which are scored separately:

1 – Wear is slight – the only physical effect is polishing of the surface and/or the obliteration of the natural and/or hypoplastic lines of enamel deposition;
2 – Significant loss of enamel – sometimes obliteration of morphological features such as the *cingulum* and/or *tubercula* occurs;
3 – Dentine is exposed on more than half of the surface;
4 – The pulp chamber is exposed by semi-vertical to vertical wear;
5 – The observed surface is destroyed by semi-vertical to vertical wear.

This kind of vertical wear has been found to be related with the use of teeth as tools (Liu *et al*. 2010, Molnar 2011, Pechenkina *et al*. 2002). The use of loose teeth impedes the verification of wear facets on antagonistic teeth or the exclusion of instances of malocclusion (as recommended by Sarig and Tillier 2014), which could demonstrate these wear patches’ masticatory origin. This hindrance should however not be relevant when analyzing samples of sufficient size.

3) **Curved/notched wear**

Instances of curved (convex) or notched (concave) wear are commonly identified with non-masticatory tooth use (Bonfiglioli *et al*. 2004, Minozzi *et al*. 2003, Molleson 1994, Scott and Jolie 2008, Waters-Rist *et al*. 2010), since these are particular and unusual forms of dental wear. To characterize the variations within these forms of atypical wear (when present; in absence of convex/concave wear, the score for any tooth is 0), a nominal scale with four types was defined:

- **‘Rou’** – Rounded – tooth wear is convex on the occlusal/incisal surface;
- **‘BL’** – Bucco-lingual – tooth wear is concave on the occlusal/incisal surface. Direction of wear suggests the movement was from buccal to lingual;
- **‘LB’** – Linguo-buccal – tooth wear is concave on the occlusal/incisal surface. Direction of wear suggests movement was from lingual to buccal;
- **‘MD’** – Mesio-distal – tooth wear is concave on the occlusal/incisal surface. Direction of wear suggests movement was from mesial to distal (and/or vice-versa).

4) **Cingular continuous lesions (CCL)**

This type of lesion was not previously characterized or described, to the knowledge of the authors. It corresponds to a continuous lesion found around the most protruding part of the *cingulum* of upper incisors. The lesion is a usually narrow and shallow strip of missing enamel that arches between both lingual margins of the tooth. Sometimes this strip is enlarged towards the cement-enamel junction, presumably because of the strain put upon the remaining thin enamel band. The origin of this mark – that is tentatively named ‘cingular continuous lesion’ (CCL) – is abrasion, possibly through holding or processing fibers or thread. CCL was seen by one of the authors (AMS) in several Neolithic/Chalcolithic samples and was later scored by the authors on a Late Neolithic to Bronze Age sample.

CCL should be scored as present or absent at least on anterior teeth, although it may present itself on other teeth in future research.

5) **Hypercementosis**

Hypercementosis is the deposition of extra cement beyond the typical limits of the roots. This causes an alteration of the appearance of the root to the naked eye (greater root thickness, presence of nodules and rough appearance). Among its several possible etiologies (like continuous dental eruption, disruption of cementum deposition by cementicles, reaction to inflammatory processes and systemic factors) is stress caused by occlusal forces (Bürklein *et al*. 2012, Pinheiro *et al*. 2008).

Sometimes, the large occlusal forces that can cause hypercementosis can be associated to the use of teeth as tools (Hylander 1977, Waters-Rist *et al*. 2010). Therefore, hypercementosis’ associations with other variables that could be related to non-masticatory wear will inform on its etiology and may provide further evidence on how large were the occlusal forces implemented on a given non-
masticatory dental function. Hypercementosis should be scored as present or absent on every observable root.

6) Chipping

Enamel is hard and not very flexible, so it is a brittle material. Chipping results from applying force with a large hard object near the occlusal edge of a tooth (Constantino et al. 2010). It has been associated with either masticatory activities such as eating hard or frozen foods (Constantino et al. 2010, Scott and Winn 2011) and with the use of teeth as tools (Belcastro et al. 2007, Bonfiglioli et al. 2004). Scoring chipping and small fractures of teeth and testing these variables for associations with other non-masticatory activity lesions can further inform on their etiology and help understand both dietary habits and cultural, ritual or work-related use of teeth.

To score chipping, the number of small fractures on each tooth should be counted and registered.

7) Bone exostoses

Bone exostoses (mandibular, maxillary and palatine tori) can occur on either or both lingual and buccal aspects of the mandible and maxilla, and on the hard palate (Hauser and De Stefano 1989). The etiology for tori has been under debate and authors have proposed several different causes for this excessive bone growth. Genetic, environmental and functional etiologies have been proposed singly or in some combination as causative agents in the formation of tori (Halffman and Irish 2004, Hassett 2006, Hauser and De Stefano 1989). However, clinical and anthropological data (García-García et al. 2010, Halffman et al. 1992, Hassett 2006, Hylander 1977) suggest that multifactorial etiology might be involved in their development, once genetic predisposition for the development of this kind of morphological alteration is triggered by external environmental and/or functional factors (Hassett 2006). When strong masticatory forces are involved in the formation of tori, other symptoms might be observed in association with the bony outgrowth, namely: severe tooth wear, chipping and hypercementosis (Halffman et al. 1992, Hassett 2006, Hylander 1977).

Anthropological studies that link bone exostoses with non-masticatory dental use in past to contemporary samples are common (e.g.: Halffman and Irish 2004, Halffman et al. 1992, Hylander 1977, Pechenkina et al. 2002).

The presence of probable mandibular and maxillary tori should be registered (as two separate variables). The observation of adult individuals only is recommended, so as to limit cases to those most likely related to the use of strong masticatory forces. Associations with chipping, hypercementosis and, above all, non-masticatory tooth wear, will inform on the possible etiology of these bony outgrowths for each sample.

Statistical tests and interpretation

This section merely attempts to suggest how to approach the data in the statistical perspective. It is not the authors’ intention to limit further analysis, or indicate there are no other possible valid and informative tests or approaches. The following ideas are meant as a simple guide to less statistically inclined researchers, to provide a start to statistical interpretation of the set of data collected.

It should be noted, before any analysis is undertaken, that there may be teeth or surfaces that will not be observable, due to destruction or obstruction. This impossibility should be properly annotated – with a number or symbol to correspond to the reason any surface or tooth could not be scored – and this data should be filtered out before any valid variable can be tested.

Data can be analyzed as occurrences per tooth, by tooth pair, by general sample, and by sections of the dentition: anterior, posterior, upper, lower, left and right dentitions. It may also be useful to
separate these sections further (e.g.: superoanterior, lower left dentition) after possible patterns are detected.

To compare the results between samples or between sections of the dentition data are reported as averages (occlusal wear) and presence frequencies (CLL, hypercementosis, mandibular and maxillary tori), which in some cases (non-masticatory wear, curved/notched wear and chipping) need to be dichotomized (presence is defined as any grade above 0). Sometimes it may be useful to report grade frequencies for non-masticatory or curved/notched wear, or frequencies of chipping incidences, instead of dichotomizing those data. That allows associations between any given variable and a specific type of wear or number of chipping incidences to be tested.

The detection of statistically significant wear/lesion patterns, the use of two statistical tests is recommended. To detect different variable distributions between two dental sections, the chi-squared ($\chi^2$) test for independence (a parametric test) is recommended. To determine if a dental section presents significantly higher variable values than another section (e.g.: anterior vs. posterior teeth), the Mann-Whitney U non-parametric test, a rank-sum statistic, is recommended. The two subsamples should be considered different if both these tests ($\chi^2$ and Mann-Whitney U) provide a significant result between two sets of data for any variable.

The association between variables can be tested using Kendall’s $\tau$ rank correlation coefficient. Data should not be dichotomized, since correlations will be more precise if the variation in the subsamples compared is fully documented. The resulting coefficients will be positive if the variables behave similarly (e.g.: the value in variable X tends to be high when the value in variable Y is high), negative if their variation is opposite (e.g.: the value in variable X tend to be low when the value in variable Y is high) and null if the variables are randomly distributed in relation to one another. Kendall’s $\tau$ results between 0.25 and 0.4 (or -0.25 and -0.4) are recommended as moderate (positive or negative) correlations. Coefficients above 0.4 (or below -0.4) should be considered strong (positive or negative) associations.

The analysis of the data and statistical tests’ results should take into account the archaeological context from which the sample hails and the known facts, as gathered from archeological (and/or historical) research. Ethnographic research and previously reported archaeological parallels are also valuable, as they can illustrate how certain tasks were realized and the part teeth could have played in those tasks. These sources can be very useful if the environmental and archaeological contexts are similar.

The patterns observed with the application of the proposed methods and statistical analyses should then be interpreted in light of the known limitations and possibilities. Contexts also provide useful questions to inform data interpretation (e.g.: did males or females perform a certain task?). Differences in the distribution of a given variable or the association between two variables can correspond to expected activities or merely generate further questions. Only further (preferably standardized) work on non-masticatory dental use wear and lesion patterns can help to continuously shed light into otherwise nearly invisible labor, cultural and ritual activities from past populations.

Conclusions

Past human and hominid populations have long used their teeth to help with their activities, in many occasions on a daily basis. Teeth can be used to hold pieces of string, a smoking pipe or a nail. Eskimos are known for towing large game (such as seals) by ropes using their teeth while their hands are used for rowing small boats. Teeth can process materials (like sinew or fibers), by chewing on, or cutting them. These and many other activities (and eating habits or needs) leave marks on teeth. The systematic study of these wear or lesion patterns (how they are distributed on a given dentition or on any sample) can be very informative on past populations and their relationship with the environment and with one another.
Bioarchaeologists often depend on inexpensive, fast to apply and easy to reproduce methods that can help put together and contribute to the information on a given site. The authors attempted to provide one such method. The proposed variables and tests can be entirely applied on commingled human remains from collective burials or on well identified, complete individual burials. This method can also be applied to populations from prehistory to near contemporaneity. In cases when the research hypothesis so dictates, some variables can be set apart and different (or no) statistical tests can be chosen.

The method introduced here is subject to changes as future research clears how non-masticatory tooth use affects some of the lesions included. The application of this approach in diverse archaeological contexts and the findings it provides will contribute to its amelioration. This method provides another way for anthropological data to support archaeology and the knowledge of past populations’ non-alimentary dental use and, to some degree, their eating habits.

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