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Title: Characterizing Evulsion in the Later Stone Age Maghreb: age, sex and effects on mastication

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Abstract:

This paper assesses the earliest evidence for widespread dental modification in Northwest Africa. The intentional modification of teeth has implications for an individual's appearance, sense of identity and perceived status. The range of modifications reported varies from alterations of shape or color to the complete removal of healthy teeth (evulsion or ablation). The availability of well-dated collections reveals that Northwest Africa was the first region where the custom of tooth evulsion was widely practiced.

Analysis of Iberomaurusian (Late Stone Age, n=77) and Capsian dental material (n=12) shows that evulsion was present in most male and female individuals (>94%). The most common Iberomaurusian practice involved removal of both upper central incisors (around 65%) although removal of fewer, none and more teeth was also recorded. Observations of the extent of alveolar remodeling of different sockets revealed that teeth were frequently removed at different ages, suggesting that the cultural significance was age transgressive and may have related to an event that individuals experienced more than once. During the Capsian period the prevalence of evulsion was lower in males than in females, but when present more teeth were removed with evulsion frequently involving both mandible and maxilla. Tooth wear analysis shows that evulsion affected not only the appearance of the individual but also the functioning of the masticatory complex.

Introduction

Intentional dental modification was, and still is, in some populations, highly important for individual and/or group identity. The variability in intentional modification observed throughout the world varies from coloring, filing the teeth to obtain predetermined shapes to the crowns, the introduction of dental inserts and inlays and the intentional removal of teeth, referred to as ablation, avulsion or evulsion (Cook, 1981; Hrdlička, 1940). Tooth evulsion or ablation is a culturally established behavior involving the intentional removal of teeth, typically from a highly visible location within the dental arcade (Domett et al., 2013). This form of dental modification has been reported from archaeological and ethnographic contexts around the world (Alt and Pichler, 1998; Bonfiglioli et al., 2004; Cook, 1981; Domett et al., 2013; Finucane et al., 2008; Hadjouis, 2002; Hrdlička, 1940; Humphrey and Bocaege, 2008; Mower, 2009; Pietrusewsky and Douglas, 1993; Raynal et al., 2010; Stojanowski et al., 2014; Tayles, 1996). The research presented here is based on direct observations of evulsion practices in adults from Northwest African archaeological sites from the Capsian and Iberomaurusian (Late Stone Age).

A number of studies have investigated associations between the presence, type and extent of dental modification seen in the archaeological record, and social differentiation or occupation (Alt and Pichler, 1998; Cook, 1981; Domett et al., 2013; Durband et al., 2014; Hrdlička, 1940; Mower, 2009; Pietrusewsky and Douglas, 1993; Tayles, 1996; Williams and White, 2006). For example, among the Jomon of Yoshigo, Japan (3500-2300BP) different patterns of evulsion were recorded and found to vary with strontium isotope ratios. This suggested that there were differences in cultural practices amongst the Jomon and group membership would have been evident from the appearance of the anterior dentition (Kusaka et al., 2011).

Other research has focused on the cultural transmission of the practice over time (Alt and Pichler, 1998; Bonfiglioli et al., 2004; Cook, 1981; Finucane et al., 2008; Hadjouis, 2002; Hrdlička, 1940; Humphrey and Bocaege, 2008; Kangxin and Nakahashi, 1996; Mower, 2009; Pietrusewsky and Douglas, 1993; Stojanowski et al., 2014; Tayles, 1996). A recent paper by

Stojanowski (2014) looked at the chronological and geographical distribution of evulsion patterns across north and central Africa during the Late Pleistocene and Early Holocene. During the Late Pleistocene tooth evulsion was restricted to the Maghreb, and the presence of tooth evulsion at the site of Gobero (southern Sahara) by 9.5 kya indicates a cultural or biological connection between these regions. Over time influx of other populations increased the complexity of this behavior at Gobero resulting in the removal of an increased number of teeth and a focus on males (Stojanowski et al., 2014).

Both archaeological reports and ethnographic accounts can contribute to a better understanding of the cultural significance and techniques underlying dental modifications. A variety of reasons have been given by different cultural groups to explain the removal of teeth. These range from initiation rites, to intimidation of enemies, language pronunciation to the mourning of loved ones (Konnild, n.d. unpublished; MacDonald, 1999; Marcellino, 1972; Mower, 2009).

The methods used in dental modification also varied widely. In Hawaii, where teeth were removed each time a tribal leader died, incisors were knocked out with a stick and rock resulting in the frequent presence of residual roots (67% of cases) within the jaw (Handy and Pukui, 1989; Pietrusewsky and Douglas, 1993).This traumatic technique differed from the extractive techniques reported throughout Africa. In the Sudan, deciduous tooth germs were removed before the infant reached one month using fishhooks and metal wires (Konnild, n.d. unpublished). In the Upper Nile, an iron spike was used to loosen the anterior teeth from their sockets to enable their removal. This would likely have resulted in the removal of the whole tooth, rather than just the crown (Konnild, n.d. unpublished). The Nuer in Namibia still practice an extractive approach whereby the teeth are loosened alongside the root using a fine blade (Willis et al., 2008). The extraction takes place without anesthetic and the individual is not allowed to show emotion or pain. Regardless of the underlying technique, tooth evulsion could not have been achieved without causing a degree of pain and a risk of infection.

Evulsion of the anterior teeth would have resulted in a highly visible change in the facial characteristics of the individual (Balzeau and Badawi-Fayad, 2005; Briggs, 1955b; Hadjouis, 2002; Marchand, 1936). The absence of teeth in the anterior jaw also results in an alteration in the pronunciation of language and other sounds. There are no reported examples of evulsion of the posterior teeth among recent populations, which probably relates primarily to the reduced visibility of modification at the back of the jaw and may also reflect a greater difficulty in the extraction of larger teeth with multiple roots. Molars and premolars are more susceptible to tooth decay than incisors and canines due to the more complex occlusal surface and fissure pattern (Hillson, 2008) and in archaeological material tooth absence due to evulsion would be difficult to distinguish from tooth loss due to disease once the alveoli are fully remodeled. Dental modification in archaeological assemblages is usually recognized on the basis of high prevalence and consistent patterning within a sample (Mower, 2009). Single instances of tooth evulsion are often considered to be accidental occurrences.

The presence of tooth evulsion during the Iberomaurusian – a period spanning approximately 21,160 Cal BP to ca. 12,000 CalBP (Barton et al., 2013; Bouzouggar et al., 2008) – has been recognised since the onset of archaeological excavations at Late Pleistocene site in the Maghreb (Balout, 1954; Briggs, 1955a). The earliest reported example of tooth evulsion is an isolated adult female skull from Taza, Eastern Algeria, from deposits dated between 16,100 and 13,800 BP (Medig et al., 1996; Meier et al., 2003). Previous accounts of tooth evulsion in North West Africa (Briggs, 1955b; Chamla, 1978; Ferembach, 1985; Humphrey and Bocaege, 2008) reported the widespread occurrence of evulsion of the upper central incisors during the Iberomaurusian, but the sites that are well dated are from the later part of the Iberomaurusian and it is not known exactly when the ritual was introduced. Tooth evulsion continued into more recent periods but became less prevalent and also more variable in terms of the number of teeth and tooth types involved by the Neolithic. A recent review evaluated the occurrence of tooth evulsion at archaeological sites across the region based on accounts published over a period of more than 120 years (Humphrey and Bocaege, 2008). The level of reporting varied widely ranging from detailed accounts of individual cases to a brief mention of presence of absence of tooth evulsion in an unspecified number of individuals. Further limitations were poor dating of sites, uncertain attribution of human remains to cultural levels and inconsistent reporting between authors, such that many sites could not be included in the review (Humphrey and Bocaege 2008). The most recent analysis of the distribution of evulsion in North Africa

(Stojanowski et al 2014) considered a broader geographical and temporal spread, but also relied on published sources for many locations.

The current study focusses on the patterning, process and implications of tooth evulsion in dental samples associated with Iberomaurusian and Capsian industries in Northwest Africa. Unlike other recent studies, this research is based on direct observation of the dental material. Specifically the research aims to document the extent of variation in the patterning of tooth evulsion and possible associations with period, sex and age at death, as well as its effect on tooth wear.

Materials and Methods

This study is based on direct observation of human skeletal material securely associated with Iberomaurusian or Capsian sites from Morocco, Algeria and Tunisia (Table 1, Figure 1). The Iberomaurusian sample originates from three sites: Taforalt in Morocco (15,000-13,000 CalBP (Humphrey et al., 2014)), Hattab (8,900 +/- 1100 BP (Barton et al., 2008)) and Afalou in Algeria (between 14,910 +/-180 Cal BP and 11,450 +/-230 CalBP (Hachi et al., 2002)). The sample included recently excavated skeletons from the Iberomaurusian levels at Grotte des Pigeons at Taforalt (Humphrey et al., 2012). The Capsian sample came from Ain Dokkhara (6580 +/- 100 BP (Chamla, 1973)), Site 12 (8,591 - 8,973 CalBP) and Khanguet el Mouhaad (7170 ± 80). The other Capsian material is from undated deposits but securely associated with Capsian technology: Mechta el Arbi, Ain Meterchem, Koudiat-el-Kherouba, and Grotte des Hyenes. The sample included in a high proportion of isolated mandibles and whole or half maxillae and for this reason, each part of the study utilized a slightly different sample in order to maximize sample size (Table 1).

Sex determination was only possible for those individuals where relevant parts of the skull or post-crania were preserved. Sex was determined using standard methods described in Buikstra and Ubelaker (1994). Based on observations of pubic symphysis morphology, auricular surface morphology, ectocranial suture closure, and sternal rib end changes, the sample was divided into three age categories: young adult, middle adult, old adult, and an undetermined age category (Buikstra and Ubelaker, 1994). Where the first permanent molar (M1) was preserved, age was also characterized by M1 wear stage (ranging from 1-10) for dental only samples (Scott, 1979; Smith, 1984). This M1 wear score was used as a relative age seriation technique, rather than to study differential wear patterns for which we used the technique described below.

Frequencies of absence and presence of evulsion were recorded based on the observation of at least one preserved maxilla for each individual. The absence of at least one anterior tooth with signs of remodeling in the alveoli was considered evidence for the presence of evulsion. An alveolus can show signs of remodeling even if the tooth was not intentionally removed. A number of factors including loss due to dental disease, age-related or traumatic loss (accidental or violent) can lead to the absence of a tooth (Cook, 1981; Hrdlička, 1940; Lukacs and Hemphill, 1990; Lukacs, 2007; Merbs, 1968; Russell et al., 2013; Tayles, 1996). It is possible these factors affected certain individuals in the sample and that the presence of evulsion is therefore overestimated. Anterior teeth are rarely affected by caries (Hillson, 2008) so although antemortem tooth loss (ATML) associated with oral pathology is present during the Iberoumaurusian and Capsian, this is unlikely to contribute to overestimation of the prevalence of incisor evulsion. Absence of teeth can lead to mesial drift of the adjacent teeth and/or compensative eruption of the previously occluding teeth into the gap left by the removed teeth (Briggs, 1955b; Marchand, 1936) although this is not necessarily indicative of deliberate removal. Typically the process used in tooth evulsion does not leave enduring visible signs on the skeletal and dental material making it more difficult to make a distinction between deliberate and pathological absence of the teeth (Tayles, 1996). In certain cultures residual roots are present in the jaw following tooth evulsion because only the crown is removed (Handy and Pukui, 1989; Pietrusewsky and Douglas, 1993). For this study it was assumed a tooth was lost post-mortem if no remodeling was observed but the tooth was missing. This may lead to an underestimation of the presence of evulsion if the intervention occurred shortly prior to death.

The pattern of evulsion was analyzed to look at trends in the number of teeth and the tooth type being removed. Only those individuals preserving both left and right maxilla were included in these analyses. All alveoli were observed and those showing signs of remodeling were counted as evulsed teeth. Chi square analysis was performed in SPSS to look at the effect of sex and age category on the evulsion patterns observed within the samples. Degrees of freedom for each analysis may be different due to different sample sizes and valid categories.

The age at which tooth evulsion is practiced has bearing on its cultural meaning and on the extent of subsequent tooth movement and remodeling of the facial structure. Previous studies have attempted to ascertain the age at which evulsion occurred based on the age distribution of individuals with and without evulsion within a series, the amount of wear on opposing teeth (revealing whether the occluding tooth was present for long enough to cause wear) or the extent of drift and the degree of inclination of teeth retained in the same jaw (Briggs 1955). Here a new approach based on estimated age at death in adults and the extent of alveolar remodeling is used. Alveolar remodeling was recorded for each socket in order to assess whether tooth removal was carried out at a similar age in each individual and whether the intervention was carried out at as single event or different teeth were removed at different times. An alveolus without remodeling was attributed to post-mortem tooth loss and was not recorded as evulsion. Alveolar remodeling was categorized in four phases (Figure 2).

- Phase 1: Tooth missing, leaving an empty cavity in which there are hints of remodeling.
- Phase 2: Remodeling underway but the alveolus is still visible.
- Phase 3: Remodeled to a full level contour but not smooth yet (still actively remodeling).
- Phase 4: tooth missing, with full remodeling of the jaw to leave a level contour.

Healing of a socket following tooth extraction involves a predictable series of events. As is the case with other bone fractures, the removal of a tooth from a socket firstly results in the formation of a coagulum (blood clot). The coagulum is subsequently replaced by a provisional connective tissue matrix, and this matrix is then replaced with trabecular bone and lamellar bone and filled with bone marrow. During this healing process a bridge of cortical bone is formed and closes the socket (Cardaropoli et al., 2003). Several studies have looked at the rate at which this alveolar resorption occurs. In some dog studies, full alveolar remodeling is complete after 6 months (Cardaropoli et al., 2003) but some human experimental studies have noted that no examples of complete remodeling had occurred after 12 months of post-extraction monitoring of patients (Hansson and Halldin, 2012). A recent study by Morgan (2012) found that it takes at least 29 weeks in humans for sockets to be fully healed, which was defined on the basis of bone presence throughout the cavity left by tooth extraction (Morgan, 2011). Other research has found variability in the early phases of bone remodeling in humans (Trombelli et al., 2008), which implies that the rate and duration of remodeling of the alveolar sockets may vary between individuals. Whether there is a difference in alveolar resorption between adjacent teeth extracted simultaneously is at present unknown. Nevertheless, it is expected that differences in remodeling between teeth that were removed at different ages will become less visible after a period of months or years and will be fully obliterated when the process of remodeling is complete. Therefore, the frequency at which differential timing of evulsion occurred would be underestimated if individuals with all tooth sockets fully remodeled were included. Only those with undergoing active remodeling in at least one socket were retained in this analysis.

In addition to characterizing the pattern and timing of tooth evulsion, the effect of evulsion on tooth wear was investigated. Left and right sides were combined in order to increase sample size and because there tend to be few differences between sides (Hillson, 2001). Tooth wear was evaluated using dentine proportions as this approach is most suitable for a poorly preserved sample where age estimation is often impossible. Occlusal surface areas and dentine proportions were calculated based on pixel counts of occlusal photographs of the specimens using ImageJ (Schneider et al., 2012). The total tooth area was traced first. Next, the surface area of all exposed dentine patches was traced. Dentine proportion for each tooth was calculated as the total area of exposed dentine divided by the area of the occlusal surface. In order to compare wear patterns independent of age the dentine proportion was divided by the wear ratio on the first molar (Clement et al., 2012). Tooth wear ratios are then presented in graphs with the M1 wear ratio (solid line) as a baseline against which to compare the wear of the other teeth. According to the expected pattern, tooth wear of all other teeth should be less than the wear on the M1 and the wear ratios should to be closely linked to the eruption sequence of the permanent teeth (Figure 3). Despite the lack of information on wear angle, this method has been demonstrated to work well on both historical (Clement et al., 2008) and archaeological (Clement et al., 2012) collections. Although this method allows for the inclusion of partial dentitions, it does rely on the presence of the M1 for standardization. For this reason, sample size was reduced for these analyses. A total number of 48 maxillae and 48 mandibles were included in the analyses. These were not necessarily pairs.

Chi square analyses and frequency analyses were performed using the SPSS statistical package.

Results

Frequency and sex differences

To investigate how widespread evulsion was within the Iberomaurusian, all individuals for which at least one side of the maxilla was preserved were observed (Table 2). Of a total of 77 individuals, 73 individuals (94.8%) have evulsion of at least one central incisor and/or additional anterior teeth. Males and females show similar frequencies with 29 out of 32 males and 17 out of 18 females missing anterior teeth (X^2=2.620, d.f.=2, P=0.270) corresponding to 90.6% and 94.4% of males and females respectively. All individuals in the sample for which sex was not assessed (N=27) exhibited evulsion. The frequency of maxillary tooth evulsion was lower (66.7%, N=8/12) during the Capsian with 62.5% of males (N=5/8) and 100% of females (N=3/3) affected. One Iberomaurusian mandible had at least one lower incisor missing. In the Capsian five out of nine individuals had evulsion of the lower incisors in addition to the upper incisors.

The two largest Iberomaurusian assemblages are those from Taforalt and Afalou with 41 and 34 individuals respectively (Table 3). At Afalou, 97.6% of all individuals (N=40/41) had evulsion (100% of males N=18/18 and 87.5% of females N=7/8 and 100% of unsexed N=15/15 individuals). At Taforalt, 76.9% of males (N=10/13) and all females (N=10/10) had evulsion and all unsexed individuals had evulsion. This suggests an opposite pattern of male and female bias in these sites but these differences between sites were not statistically significant for the sample as a whole (N=75, X^2=1.501, d.f.=1,P=0.221) and for the sexes (Taforalt: N=34, X^2=5.315, d.f.=2, P=0.070; Afalou: N=41, X^2=4.228, d.f.=2, P=0.121).

Evulsion pattern

All individuals for whom both left and right maxilla were present (N=54) were analyzed to look at trends in the number of teeth and the tooth type being removed as part of the evulsion process (Table 1). The results show there is some diversity in evulsion patterns during the Iberomaurusian and Capsian.

The most prevalent pattern during the Iberomaurusian (N= 32 out of 49 individuals = 65.3%) was the removal of both central incisors (L I1 + R I1) (Figure 4). An unexpectedly high proportion of individuals (N= 11 out of 49 = 22.4%) exhibits absence of only one central incisor on either right or left side. One individual had both left incisors removed but had the right incisors intact. Two individuals had three incisors removed and two individuals showed an absence of all four upper incisors (Figure 4). For those individuals in the sample for which sex could be assessed and an evulsion category was possible, there was no significant effect of sex on the pattern (N=49, X^2=9.992, d.f.=12, P=0.617).

Evulsion patterns were compared for the Iberomaurusian samples from Afalou and Taforalt for which both left and right maxilla were preserved. The most prevalent pattern in both samples was the removal of both left and right central incisors (N=17/26 for Afalou and N=14/20 for Taforalt). Patterns in which more than two teeth were removed, was more prevalent in Afalou but there was no significant difference between Taforalt and Afalou in evulsion pattern (Figure 5) (N=47, X^2=4.206, d.f.=6, P=0.649).

Of the Iberomaurusian maxillae only 45.5 % (N=35/77) had an associated mandible. The mandible of Taforalt VIII-2, presented a both first incisor alveoli that were almost fully remodeled. Although the maxilla presented evulsion, it was not well enough preserved to assess the phase of alvaeolar remodeling. None of the other Iberomaurusian mandibles presented evulsion.

Eleven out of twelve Capsian individuals had a preserved mandible. All female maxillae but only three of the seven males showed evulsion. The individual of unknown sex had no evulsion. The most prevalent pattern in the Capsian was the removal of all eight incisors (both upper and lower). One individual (the Mechta type male) had only lower and upper central incisors removed and another individual had no maxillary evulsion but lacked a lower left central incisor (Table 1).

Age at tooth removal

Since removal of two upper central incisors is the prevailing pattern during the Iberomaurusian, age distributions were examined to give an indication of whether individuals with none or only one central incisor removed (Total>28%, N=15/53) had not yet attained this typical pattern due to their age.

Age was characterized by M1 wear stage (1-10) for dental only samples and by age category (young, middle, old adult and undetermined) using skeletal and dental characteristics where possible. Samples were analyzed separately according to both ageing techniques. There was no significant difference in evulsion patterns between the four age categories within the Iberomaurusian whole sample (N=53, X^2=25.508, d.f.=21, P=0.226), nor was there a difference within the sample from Taforalt (N=24, X^2=13.087, d.f.=15, P=0.596). Individuals with fewer than two central incisors removed were not necessarily the youngest. When the M1 wear stage was used there are also no differences in evulsion patterns between the age categories assessed by M1 wear stage (N=53, X^2=55.053, d.f.=56, P=0.511) for the Iberomaurusian sample or for the Taforalt sample (N=24, X^2=28.442, d.f.=30, P=0.547).

There is no significant difference in evulsion patterns between age categories using the M1 wear stages within the sample from Afalou (N=27, X^2=40.674, d.f.=36, P=0.272), but there is a significant difference between the skeletal age categories (N=27, X^2=30.674, d.f.=18, P=0.031), although the association between the variables is moderate (Cramer's V = 0.615, P=0.031). The association may be the result of the Middle Adults having the most variable pattern compared to the Young and Old Adults.

The extent of alveolar remodeling also reflects the timing of tooth removal in the individual's life. Phases of remodeling were recorded for each alveolus and the difference in the number of phases between different alveoli analyzed. Those individuals with fully remodeled alveoli were excluded (N=20). The most frequent observation was that there was at least one remodeling phase difference between alveoli. Alveoli exhibited a difference of one phase in 43% of individuals (N=9/21) and two phases in 14% of individuals (N=3/21). In 43% of cases there was no difference between left and right alveoli (N=9/21). The absence of a difference between left and right is likely due to simultaneous extraction of both teeth. Nonetheless, in the majority of cases (12/21) there was a difference of either one or two phases between alveoli indicating that there was an alveolar rim that was fully remodeled or almost fully remodeled on one side while the other side showed an earlier phase of the remodeling process.

Effect of evulsion on tooth wear

The effect of evulsion on tooth wear was assessed by calculating ratios of exposed dentine relative to enamel on the occlusal surface of the mandibular and maxillary teeth (see Methods). Only those individuals with evulsion that preserved both the mandible and maxilla were considered (n=24).

Compared to the expected tooth wear pattern (see Figure 2) the individuals show relatively high wear ratios for the canine and third premolar (Figure 6). Sample size for the first incisor (UI1) consists of only three individuals and this tooth exhibits considerable variability in its wear. The fairly normal wear of the remaining incisors but increased wear on the canine and premolar is particularly striking compared to the expected wear pattern and suggests compensatory use of the canine and premolar by these populations.

The results of the tooth wear analysis also reveal a clear deviation from the expected tooth wear pattern in the mandible (Figure 7). Increased tooth wear, relative to the M1 is visible in the canine in particular. Remarkable here is the low wear of the incisors which is most likely the result of the lack of occlusion in those individuals with evulsion, supporting the suggestion that the canines are used as incisors.

Discussion

This study on the distribution of the practice of tooth evulsion in 77 Iberomaurusian and 12 Capsian individuals from Northwest Africa has provided extensive new information on this cultural practice and has generated some additional questions.

In the sample studied here the frequency of central incisor evulsion was near universal with 94.8% of the sample showing evidence for the deliberate removal of at least one tooth. Considering the scarcity of evidence for evulsion in North Africa prior to the Late Pleistocene and its absence throughout the rest of the region during the Late Pleistocene (Humphrey and Bocaege, 2008; Stojanowski et al., 2014), this observation would suggest that the practice of dental evulsion originated during the Iberomaurusian. This is the earliest time period in which widespread evulsion has been documented in archaeological series. The oldest evidence from Taza dates to the middle of the Iberomaurusian but relates to a single isolated skull. Although the Taza skull is an isolated find, the pattern of evulsion compares to that of other individuals from the same cultural period and region suggesting that this was a deliberate intervention rather than an accidental occurrence. Recent re-dating of the two large Iberomaurusian assemblages from Afalou (dating back to 13,120 CalBP (Hachi, 2006; Humphrey et al., 2012)) and Taforalt (ca. 15,000 to 12700 CalBP (Barton et al., 2013; Bouzouggar et al., 2008; Humphrey et al., 2014)), indicates that evulsion was widespread amongst these hunter-gatherers of Northwest Africa by at least 15,000 years ago. The evidence from Gobero would suggest the practice spread to the Sahara region by the early Holocene (9500 cal BP (Sereno et al., 2008; Stojanowski et al., 2014)). Other early populations where evulsion was common date back to the Late Natufian (13-11600 CalBP (Belfer-Cohen et al., 2005)) in the Levant where evulsion has been reported at Ain Mallaha, El Wad, Nahal Oren, Kebara and Shukbah (Bocquentin, 2008, 2011; De Groote et al., 2014; Eshed et al., 2006).

Although there is some variation in the number and type of teeth removed during the Iberomaurusian, the prevailing pattern was for both left and right central incisor to be removed. Some 22% of individuals present evulsion of a single central incisor. Although alveolar resorption rates are not fully understood at present, the relatively high proportion of individuals exhibiting a difference in alveolar resorption between sockets may imply that those with a single extraction had not yet undergone the event at which the second incisor was removed. Alternatively, differences in the number of teeth removed may reflect evolving practices or differing traditions within the group. If the intervention was undergone on separate occasions, the cultural significance may relate to circumstances that affected people experienced on more than one occasion. The lack of correlation with sex and age would suggest that evulsion was a practice carried out universally within the community. Although the Capsian sample is small and results must therefore be considered with caution, the prevailing pattern was for all eight incisors to be removed. In the Capsian, it is also clear that it is primarily females who underwent evulsion although some males also showed evulsion. Differences in the extent of alveolar remodeling indicated that in the Capsian teeth were also removed at different times. In one case, Mechta 5, the three removed teeth displayed three different remodeling phases. Only two residual roots were observed: one in an unsexed adult from the Iberoumaurusian period (Afalou 14) (Figure 8) and one in the Capsian male 4-254 from Grotte des Hyenes pointing towards an extractive rather than traumatic extraction in the majority of cases.

The ethnographic record offers an important insight into the origins and purpose of tooth evulsion, but the specific social meaning of tooth evulsion is difficult to determine in past populations (Kangxin and Nakahashi, 1996). The lack of sex differences during the Iberomaurusian suggest that the practice relates to an event experienced by both males and females. The hiatus in the timing of removal of different teeth in one individual suggests that the evulsion may signify an event that some individuals experienced more than once and at different times in their lives.

A possible reason for the introduction of widespread evulsion could be increased exposure to tetanus (Cook, 1981; Willis et al., 2008). The Iberomaurusian and Capsian people consumed snails frequently (Lubell, 2004a, b; Taylor et al., 2011), and may have been exposed to tetanus spores from soil. The existence of a gap in the dentition due to evulsion would have enabled affected individuals to drink water and other liquids while presenting lockjaw. This has been suggested as a reason for extraction from the Nilotic (Kenya) and other African populations (Fedders and Salvadori, 1981; Handler, 1994; Hinde and Hinde, 1901; Humphreys, 1954; Willis et al., 2008).

In addition to producing a visible change in the frontal aspect of the individual, evulsion of the anterior teeth affected tooth wear patterns. Wear ratios in hunter gatherers from the Middle Paleolithic through the Epipaleolithic were high for the anterior teeth in some periods (Clement et al. 2012). The mean wear ratio in the Iberomaurusian sample is similar to that found in the Upper Paleolithic and Epipaleolithic sample studied by Clement et al. (2012) (Figure 9), with high wear of the canine and incisors relative to the posterior teeth, but the Iberomaurusian sample exhibits fewer cases with high wear ratios in the lower central incisors. This is caused by the lack of occlusion with the upper incisors. The Iberomaurusian sample also exhibits higher wear ratios in the canines and third premolars when compared with the samples included in the previous study (Clement et al 2012). This observation suggests that the canine and third premolars were used more frequently in this sample than expected for a hunter-gatherer group, and this heavier usage could be regarded as a compensation for the absence of incisal occlusion. This demonstrates that evulsion would have disrupted normal occlusion patterns within the dentition and may have compromised mastication.

Conclusion

The evidence from the Iberomaurusian represents the earliest example for the widespread practice of dental modification globally. Our analyses show that its prevalence during the Capsian remained high. The most frequent pattern observed in the Iberomaurusian was removal of two central incisors, although some 25% of individuals presented with only a single missing central incisor. In the Capsian it was most common for all eight incisors to be removed both in the mandible and the maxilla. Tooth evulsion would have had a striking and immediate impact on a person’s appearance and speech and been disadvantageous for mastication. Tooth wear patterns indicate that the removal of the central upper incisors lead to the increased reliance on the third premolar, and the canine during mastication.

The origin and purpose of tooth evulsion in these periods is difficult to determine but needs to be consistent with the lack of age and sex patterns and the hiatus in the timing of removal of different teeth in some individuals. Based on the difference in remodeling between alveoli it is evident that both Iberomaurusian and Capsian individuals would undergo evulsion on separate occasions, possibly separated by many months or even years. An underlying reason may have been to divide the experience of pain either by limiting the pain experienced during each intervention or to multiply the experience. Alternatively it may imply that individuals experienced the underlying cause for evulsion more than once in their lifetime. This would have been the case in Hawaii where teeth were removed following the death of a tribal leader (Pietrusewsky and Douglas, 1993). In some cases more than two teeth were removed which may indicate that some people experienced the cause and or process of tooth evulsion more than twice. The lack of a correlation with sex would indicate that both males and females were subject to the same tradition, at least during the Iberomaurusian. The random age distribution suggests that removal of a tooth signified an event that each individual experienced at different times in their lives such as marriage, childbirth, illness or death of a close relative or other significant person within the community.

Tooth evulsion may have been practiced as a preemptive measure in case of the occurrence of lockjaw due to tetanus, which would have prevented normal food intake. The affected individual could have imbibed liquids through the gap in the dentition produced by prior tooth removal. The frequent consumption of snails by Iberomaurusian and Capsian people may have increased exposure to soils containing tetanus spores. Whether teeth were removed prophylactically and whether this practice became a tradition that subsequently spread across North Africa and was given different meanings remains a question.

In the studied sample, only a single residual root was observed. The absence of residual roots within the jaw implies that the method employed for removal of the teeth was extractive and aimed to remove the whole tooth. A technique, such as the use of a spike to loosen and subsequently remove the tooth may have been utilized here (Willis et al., 2008). The extractive technique implies that teeth could not have been removed during lockjaw but may have been removed prior to any occurrence. It is surprising though that despite the ability to remove teeth; this population did not extract teeth infected by caries more frequently.

The abandonment of the practice, probably during the Neolithic, (Chamla, 1978; Humphrey and Bocaege, 2008; Sereno et al., 2008) may imply either cultural assimilation with incoming non-practicing populations or population replacement.

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