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ORIGINAL ARTICLE

Extramasticatory dental wear reflecting habitual behavior and health in past populations

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Abstract In skeletal remains, teeth are valuable sources of information regarding age, diet, and health. Dental wear is especially helpful in reconstructions of dietary patterns in populations of varying subsistence. In past societies, teeth have also been used as "a third hand" or as a "tool." The present article examines this type of dental wear and traits attributed to habitual behavior during prehistoric and historic times. Terminology and classification of habitual dental wear are described mainly by appearance, for instance, notching, grooving, cuts, scrapes, and polished surfaces, and their characteristics are illuminated by different case studies. Secondary health effects caused by the extramasticatory use of teeth, such as periapical lesions, tilting, skeletal changes at the temporomandibular joint, chipping, and antemortem tooth loss are also examined. During the examination of extramasticatory dental wear, information should be recorded on morphology, size, frequency, intensity, and location within the dental arch, as well as descriptions and detailed photographic documentation. The advantage of using a low- to medium-resolution microscope in all dental examination is emphasized. By categorizing the wear marks, characteristics are emphasized rather than an exact causing agent. In this way, tentative analogies for the origin of different extramasticatory wear, and consequently for human behavior in the past, can be avoided.

Keywords Tooth abrasion · Tooth attrition · Teeth as tools · Dental lesions · Antemortem tooth loss

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Introduction

Investigations of dental remains continue to contribute valuable data that assist dental anthropologists and bioarchaeologists with interpretations of past health patterns, life ways, and human behavior. The teeth and jawbones are generally well preserved and provide excellent opportunities for a wide range of anthropological techniques, as well as for reliable sampling for various chemical analyses. Different dental features offer detailed information on health status of past populations, such as linear enamel hypoplasias, calculus formation, periodontal disease, caries, and periapical lesions [1–9].

Oral health and dental wear, in particular, have also been studied in relation to diet and dietary trends [10–13]. In this way, Smith [10] studied the relationship between tooth wear and temporal dietary changes in hunter–gatherer populations and agriculturalists. Comparisons of molar occlusal wear plane angles showed significant differences between the two groups, and these differences were attributed to the tougher and more fibrous diet of foragers.

Tooth wear is frequently used as a technique for aging skeletons. Although most researchers agree on the imprecision of a universally valid method, dental wear will continue to be an accepted component of a multifactorial approach in assessing age in skeletal remains (at least at a population specific level). Several systems have been developed for recording occlusal wear [10, 14–18], of which some are utilized in age estimations.

In both human and animal archaeological remains, various forms of tooth wear have been recorded, and relationships between tooth wear and subsistence, food preparation, and the habitual use of teeth have been well established. Expressions such as "using teeth as tools" and "a third hand" have been used to describe dental traits in prehistoric samples in reconstructions of human habitual behavior. Extramasticatory dental wear and related features examined at Ajvide, a Swedish Middle Neolithic site from the island of Gotland in the Baltic Sea, showed that this hunter–gatherer population used their teeth intensively in a variety of ways. The extramasticatory use of teeth also resulted in effects of the oral health, and a correlation was noted between dental wear patterns and the chipping of teeth. Differences were also observed between the sexes in the habitual use of teeth [19, 20] (see below).

Several reviews on dental anthropology have dealt extensively, with most topics relating to dental wear, including extramasticatory traits [3, 6, 7, 21–27]. The present article deals with the large variety of extramasticatory gross dental wear as well as associated pathologies and trauma. The patterns are viewed as reflections of past life ways, behavioral patterns and cultural practices, on both an individual and a collective level. Suggestions are offered for means of recording, documentation, and presentation of extramasticatory dental wear. Information on atypical dental wear can additionally be of interest and provide new insights for clinicians as it may be linked to other oral conditions seen in clinical cases today.

Terminology and classification of wear

As the degree of wear increases with age, *macrowear* (or gross dental wear) is generally applied in techniques for assessing biological age [16, 18]. Within zooarchaeology, dental *mesowear* is studied by light microscopy on the occlusal surface to reconstruct animal (paleo)diets [28]. In dietary reconstructions, dental *microwear* analysis (DMA) is employed in which dental traits are studied under a scanning electron microscope (SEM) with a resolution of approximately 500× (0.1–0.2 μm). Scratches and pits are recorded on the occlusal surface of selected facets of the molars and analyzed with the computer software *Microwear* [29–33].

Within the dental sciences and dental anthropology, distinctions are also made between *attrition, abrasion*, and *erosion*. *Attrition* is defined as a reduction of tooth mass at the occlusal surface (enamel or dentine) owing to frictional tooth-to-tooth contact, during food mastication (although not caused by food), but also from jaw clenching or tooth grinding (*bruxism*) [23, 34–36]. *Abrasion* is described as the wear of occlusal surface, caused by external components, such as food mastication or extramasticatory dental use [34, 37]. Although, Alt and Pichler [7] regard the distinction between attrition and abrasion as of minor importance as the abrasive processes in dental remains overlap and are difficult to differentiate aetiologically. *Erosion* should not really be conceived as dental wear, but as a chemical predepositional or postdepositional processes affecting tooth exteriors. It is generally visible on the entire tooth surface, including the occlusal plane [38, 39]. With some experience, it should pose no difficulty to confidently differentiate between erosion and attrition or abrasion during the examination of archaeological dental assemblages.

The process of dental wear begins with enamel loss and is followed by secondary dentin deposition [6]. Thus, wear is strictly speaking intentional or unintentional attrition or abrasion and caused by human (or animal) activity. The term *wear* is extensively used and accepted as a collective term that also includes marks on teeth that are not strictly speaking wear. It is in this wide sense that the term will be employed in the present article.

Distinctions are made between unintentional (passive) and intentional (active) habitual dental wear. Unintentional modifications include dietary, parafunctional, occupational, traumatic, and habitual dental marks, as well as erosion. Intentional modifications include deliberate extractions (ablation), filing, decorating, and early dentistry. The characteristics of unintentional dental traits are described in detail elsewhere [7, 26]. In the present article, the terms habitual or extramasticatory dental wear are mainly used as they are considered the most suitable, and only unintentional dental wear and associated features are included.

Extramasticatory dental wear and inferred activities: examples and case studies

Accounts of extramasticatory dental wear are often presented in case studies [6, 7, 25, 26, 31]. While these cases are highly interesting, the following descriptive overview is intended to encourage a more systematic approach to recording and describing these changes. Hopefully, this will contribute to a wider understanding of the phenomenon and thus lead to coherent interpretations of behavioral patterns in general and their significance for living conditions of past populations in particular. As dental anthropologists and paleopathologists can never typify dental wear types according to activity or cause, the most suitable way is by description and location.

Notching and grooving

Notching has been described as “an indentation involving the tooth’s incisal/occlusal edge, sometimes extending across all the surface” (Fig. 1a) [40]. In an assemblage from Taforalt in Morocco, Bonfiglioli and coworkers [41] observed notching in 6 % (n=2) of the male individuals and none among the females. Similar changes have also been recorded in modern clinical Italian cases of carpenters, tailors, and shoemakers, etc, [40] as well as modern examples of “pen-biting”. Dental notching has also been recorded in skeletal remains from the Neolithic to Medieval

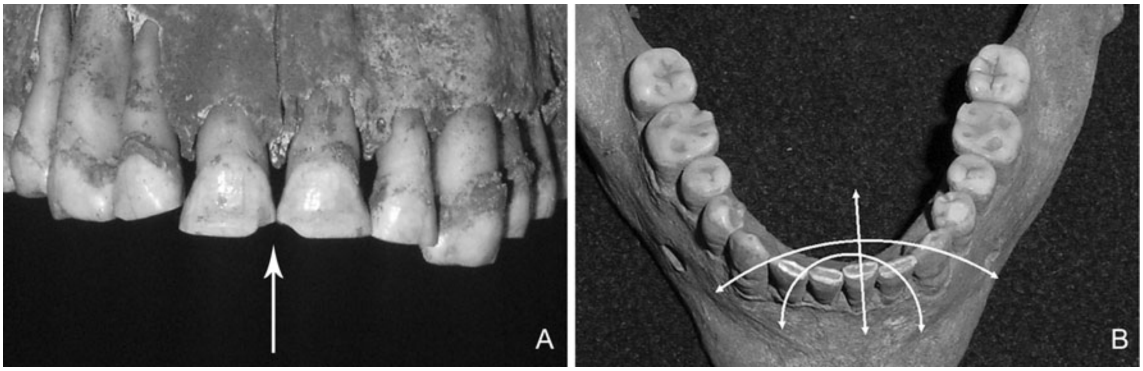

Fig. 1 Notching of the upper central incisors in a 25- to 30-year-old female at Ajvide (**a**), schematic illustration of reported distributions of grooving in anterior teeth (interproximal excluded) (**b**)

times in England [42] and the United States [43, 44]. Some of these notches or grooves also appear comparable with some of those found in individuals that have smoked clay pipes [45]. The common denominator is a mark on the occlusal surface of the tooth caused by a rounded object held between the teeth.

Occlusal grooving appears as single or multiple well-defined grooves on anterior teeth [6, 46]. The grooves have been observed in dentitions from different time periods and geographical areas [46–48] and have been attributed to the working of willow strands, fibres, and sinews. The grooves appear both in an anterior–posterior and lateral (involving multiple teeth) direction. In most instances, they appear occlusally; however, on occasion, they appear lingually as well [44]. However, the causative action appears to be similar (Fig. 1b).

Cuts, scrapes, and polished surfaces

Cuts (or scrapes) on the labial surfaces of anterior teeth (Fig. 2a) have been recorded by several researchers [49–54]. For the most part, the cuts have been attributed to the "stuff and cut" activity, i.e. the clenching of a substance (e.g., a piece of meat) between the anterior teeth, while cutting it off with a sharp tool [50]. Researchers have also explored these marks in order to establish handedness of fossil hominids as well as modern humans [52, 53].

Clear single (or few) horizontal cut-marks were also visible in the Middle Neolithic dental sample from Ajvide on Gotland, Sweden (Fig. 2a). The marks occur in incisors and canines, the most commonly affected teeth being the upper central incisors, followed by the lower incisors. The features occur in both males and females, however, with slightly higher frequencies in males [20]. In addition, in the same sample, vertically oriented scrapes, abrasions, and striations were noted on labial surfaces at the occlusal margin (Fig. 2b). These vertical striae were noted in both males and females (although with different patterning; see below) and on all teeth except the molars [20]. The orientation and appearance of these marks (and other dental wear patterns) clearly suggest extramasticatory use of teeth at Ajvide.

Another type of extramasticatory dental wear is the LSAMAT (lingual surface attrition or abrasion of the maxillary anterior teeth), which is lingually oriented flat striations or polished areas. This wear occurs on well-defined

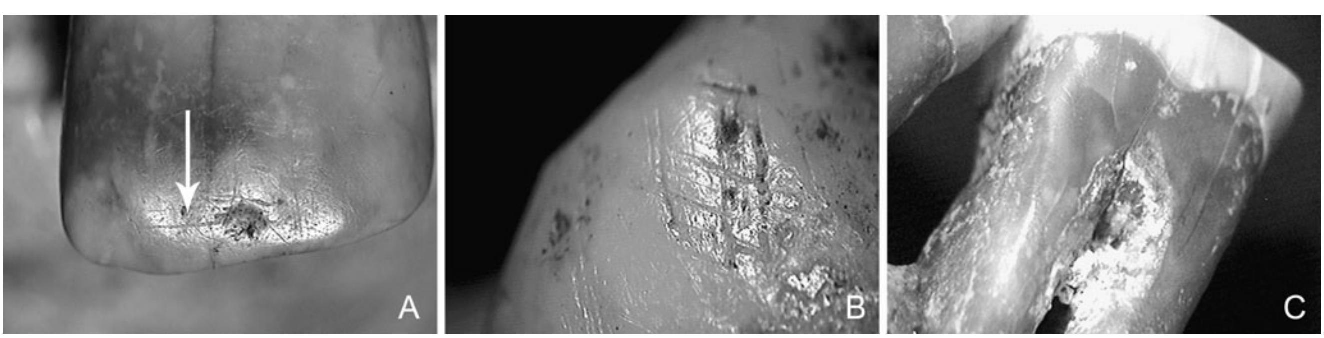

Fig. 2 Horizontal cut mark ("stuff and cut") on upper central incisor of 17- to 19-year-old male from Ajvide (**a**), scrapes on inferior canine of 30- to 40-year-old male from Ajvide (cross patterning is coincidental) (**b**), and polished lingual surface on lower second molar of the approximately 50-year-old "Granhammar" man (**c**)

areas of the lingual surface and with no equivalent wear on antagonist teeth [7, 55–59]. The wear is attributed to the processing of animal skins or preparations of plant or fibre materials [6]. Polished labial facets on lower incisors have been ascribed to the use of labrets (lip plugs) in Inuit, Aleut, and Native American populations [7, 60–63]. Recently, well-defined areas of striated and polished wear were also recorded in the dentition of a Bronze Age (800 B.C.) male from middle Sweden. Tools for leather working were found together with the skeleton, leading to the interpretation that this was a leather craftsman, who processed leather in his mouth (Fig. 2c) [64].

Interproximal grooves and striations

Interproximal wear facets are present between adjacent teeth and are caused by tooth to tooth contact and friction during mastication [6]. The facets are not to be mistaken for interproximal grooving (Fig. 3a) [20, 26, 40, 47, 56, 65–68].

Interproximal grooves are generally located at or near the cementoenamel junction on the approximal surfaces of all teeth (Fig. 3a, b). They are commonly found on adjacent teeth, but also occur unilaterally. They have been reported as occurring most frequently in premolar and molar teeth [26, 68]; however, in the Swedish Middle Neolithic sample Ajvide, they were recorded in all tooth types except the molars [20]. A similar pattern was also observed by Schulz among prehistoric populations from the Stone Lake site in California [47].

Brown and Molnar [66] interpret interproximal grooving as the result of stripping animal sinews between clenched posterior teeth in an aboriginal sample (19th century) from Australia. They use images [66, see Fig. 5] showing a craftsman stripping kangaroo sinew for the making of a spear thrower, as evidence to support their theory. Conversely, the rather sharp morphology of the groove margins suggests that they are caused by a more solid, nonflexible object with a defined shape [66], for instance, a thin wooden implement. The angles of the grooves imply that the worked material would have been drawn in a straight lateral rather than anterior direction (which would have been covered by soft tissues). It seems more probable that sinews would produce a rounder, smoother, and more polished appearance. In addition, it is unlikely that the spaces between the teeth were large enough to insert the sinews, which were a few millimetres thick. The use of the anterior teeth and the positioning of the sinew by the craftsman in the images provided do not correspond to the grooves observed in the skeletal remains [66].

While observations of interproximal grooves are fairly common, the equivalent but less obvious feature, interproximal striae are rarely recorded, although they occur in the same regions and represent the same behavior (Fig. 3b). Brothwell [21] interpreted these marks as antemortem erosion, and Wallace [69] considered the changes as remnants of dietary grit in food and drinks during swallowing. The image shown in Wallace's article, however, indicates that the wear is clearly man-made and occurs on a limited area of the tooth. Had the cause been grit, all teeth and the entire tooth surfaces would have been affected.

Differences in the habitual use of teeth as regards to population, sex, and age

A significant element of bioarchaeology and paleopathology is comparing patterns observed in different populations, sites, age groups, and between the sexes, etc. Dental wear and extramasticatory wear are no exception. No extensive systematic comparisons of habitual wear patterns between different populations or sites have so far been carried out. However, such a study would preferably involve a standardized method of recording extramasticatory dental wear, something which may hopefully be realized in the near future.

The circumstances are less complicated as regard to comparisons between the sexes and, to some extent, different age groups. Studies of age-related differences have shown that some activities causing habitual wear started at 10–11 years of age [55]. At Neolithic Ajvide, several types of dental wear, for example, interproximal features, were shown to increase with older age, while the "stuff and cut" wear frequencies decreased. This was attributed to an increased skill with age of the use of the cutting tool [19, 20].

Far more studies have examined the diversity of habitual wear, and thus behavioral variability, between the sexes [46, 47, 70–73]. Some of these investigations show differences in the presence or intensity of wear between males and females. This was also the case at Ajvide, where certain wear types exhibited differences in their position (i.e., tooth type). The vertical striae wear occurred in higher frequencies in the incisor areas in females, while males exhibited higher incidences in the canine regions. This was true for both the upper and lower dentitions (Fig. 4) [20].

Lesions resulting from extramasticatory dental wear

Extramasticatory use of teeth also had effects on people's health in the past. This is evident in the links made between pathological changes and general dental wear as well as extramasticatory wear patterns. Pathological changes include periapical lesions, lingual tilting, chipping, antemortem tooth loss, and temporomandibular changes. Some of these health hazards may potentially even have contributed to premature death.

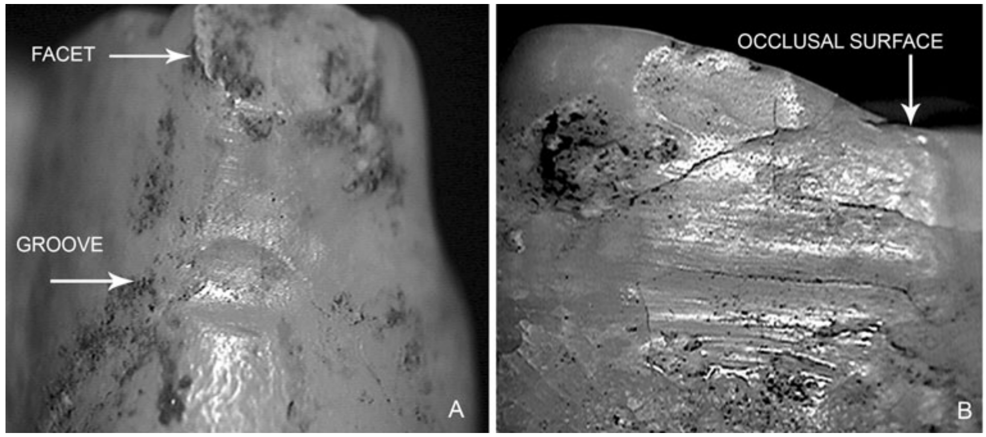

Fig. 3 Interproximal facet (*top*) and groove (*bottom*) (**a**) and interproximal striations (**b**). Both teeth from 40- to 50-year-old males from Ajvide

Periapical lesions

A periapical lesion is initiated by a pulpal infection (pulpitis), leading to the spread of bacteria through the apical foramen. The lesion is usually caused by caries, severe wear, or dental trauma. The bacteria spread through the root canal or through fine line cracks in the occlusal surface and into the periapical region through the apical foramen or alongside the root. In the case of an acute inflammatory reaction, resorbed bone around the apex of the root leaves a cavity for granulation tissue to form (chronic periapical inflammation). The formation of pus in the space between the tooth apex and the bone caused the tooth to rise from its alveolus. Although these lesions are usually benign, they can result in severe pain [3, 74–77].

Several studies have shown a correlation between dental wear, periapical lesions, and dental tilting [20, 74, 75, 78]. Because of the severe attrition, the pulp is exposed, thus giving access to bacteria to enter (Fig. 5).

Lingual tilting

When severe attrition is placed on a tooth, the force will bring the tooth to dislocate itself from its original position in the jaw (Fig. 5). The emergence of periapical lesions in areas of affected teeth is most likely a contributing factor in this process. This has been referred to as "severe attrition syndrome" [79]. Clarke and Hirsch's study of 1,200 individuals suggests that functional strain and reduced bone support caused the lingual tilting and that in life, the roots protruded through the bone of the jaw and the surrounding living tissues. Clarke and Hirsch [74] conclude "Dislocation appears to provide a satisfactory outcome for the natural progression of attrition, perforation, abscess development, and loss of tooth support."

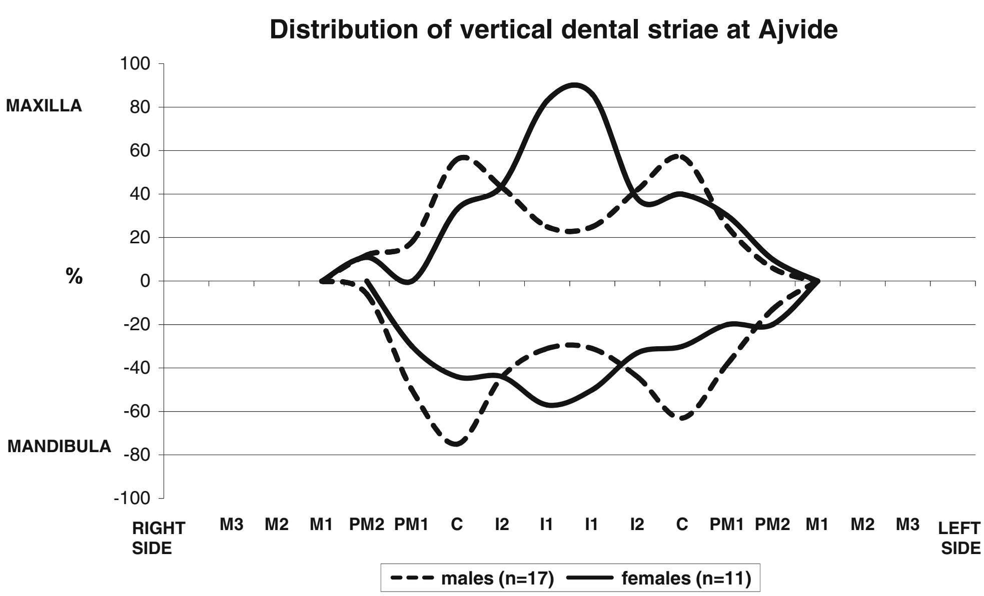

Fig. 4 Sex differences of vertical striations (scrapes), showing high frequencies in the central dentition in females, and in the canine region in males (Ajvide)

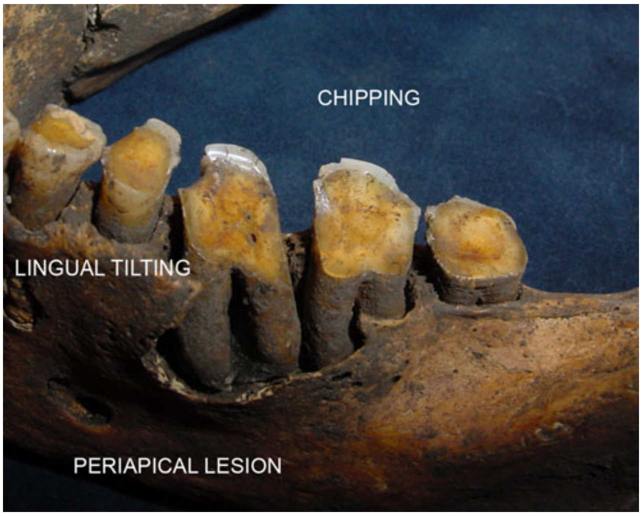

Fig. 5 Lower jaw of 40- to 50-year-old male from Ajvide showing a periapical lesion at the first and second molars, lingual tilting of the first molar, and chipping of the premolars and molars. Note also the small aperture of the pulp chamber on the first molar

TMJ

There are reports of a positive correlation between heavy dental wear and osteoarthritic changes in the temporomandibular joint [71, 80–83], and Turner and coworkers [84] emphasize the use of joint changes in the TMJ for determining bilateral asymmetry in tooth wear. Others are less enthusiastic about conclusions drawn about habitual behavior from osteoarthritic changes [20, 85, 86]. At Ajvide, rates of excessive dental wear are high, although there are very few instances of osteoarthritic changes at the temporomandibular joint.

Chipping (microfractures)

Chipping has been described as "an ante mortem irregular crack, involving enamel or enamel and dentine, situated on the buccal, lingual or interproximal edge or crest of the tooth." (Fig. 5) [40]. Severe crushing of hard materials and/or the presence of seeds and gravel in the food is believed to be the cause of these microfractures in the enamel and dentine [87, 88]. Small lesions often occur in prehistoric contexts and are generally found in all regions of the dental arch [26, 89]. Correlations have also been noted between the occurrence of chipping and certain habitual wear patterns, suggesting a common causative action [20].

Antemortem tooth loss (AMTL)

Antemortem tooth loss may have a number of explanations, such as dietary, nutritional, or traumatic factors. One of the primary causes is also attrition [9, 89] and commonly in association with excessive wear or habitual behavior [71, 90–92]. In general, frequencies of AMTL due to heavy attrition and caries affect the posterior dention, while loss of teeth in the anterior arch is caused by extramasticatory behavior [89, 93]. Anterior teeth are lost as they are not as well attached in the jaw as teeth with multiple roots. In addition, caries affects anterior teeth to a lesser degree, making habitual behavior a more likely interpretation of AMTL in this section of the jaw.

Discussion

The distinction between nonmasticatory and masticatory wear may not always be clear. In the present article, masticatory or "normal" wear has been described as wear caused by the chewing of foodstuffs for immediate consumption. This distinction is important as food preparation practices may involve chewing in order to soften or alter substances that may be consumed at a later stage. One of the most evident characteristics of the extramasticatory wear is that it can be identified by a regularity, or patterning that is not present in normal mastication. Striations or other markings are generally present in a limited area and occur in parallel patterns. To enable comprehensive comparisons and interpretations of extramasticatory wear and habitual behavior, the development of a more detailed and systematic descriptive documentation methodology is suggested.

Methods of recording extramasticatory dental wear

Standards for recording methods have been developed for microwear [29, 30] and general occlusal wear [10, 15–18]. However, extramasticatory wear and features are often recorded as curiosities. This is to be expected, as a large variety of features can occur on practically every surface of all tooth types. Apart from descriptions and documentation, no standard methodology has previously been formulated for recording these.

A fundamental technique is the systematic examination of teeth under a microscope with low to moderate magnification, which reveals small dental features that are not observable to the naked eye. However, as we are not dealing with microwear, the optimal resolution is approximately 10–50 times, which gives an overview of the whole feature. A digital camera with high resolution and connected to a microscope is also essential for documentation purposes.

Recording of extramasticatory dental wear should include information on morphology, size, frequency, intensity, and location within the dental arch as well as descriptions and detailed photographic documentation. By categorizing the wear marks, the feature is emphasized rather than the activity that caused it. The proposition is that similar implements were used for similar actions, thus leaving similar marks; i.e., sharp objects leave cut marks, coarse hard objects such as twigs or bones leave scrapes, and softer materials such as leather produce more polished surfaces. Obviously, this is a general assumption, not a universal one; however, the descriptive approach can lead to more comparable data between different dental samples. In addition, the use of a database programme is useful, enabling an overview of the material as well as the option of extracting specific data.

One trait; one task?

Linking certain dental features to specific tasks and activities is problematic, although in some cases, historical accounts corroborate the habitual behavior indicated by dental wear patterns [6]. A range of activities have been suggested in the literature, such as basket working, stripping branches, softening sinews, cutting of pieces of meat, hide preparation, leather working, etc. These are all very probable tasks, although others may be just as plausible or even “correct.” This is a general problem within the archaeological sciences. However, refraining from making interpretation and offering explanations (though tentative) is a rather disencouraging alternative. Detailed descriptions and clear documentation are essential in order to increase the possibilities of interpopulation comparisons of dental patterns. The danger lies in assigning dental wear a special activity, without offering a well-founded argument for the interpretations made. Some changes, for example, notches, may be just a habit of keeping a small wooden stick clenched between the teeth, occasionally chewing on it.

Experiments on teeth with a variety of abrasive materials such as stone, bone, wood, leather, etc., could also lead to clues on the type of action that produced the wear and the time it may have taken to form. In microwear studies, the “last supper” term is applied as the wear was formed during the time just preceding death, thus representing recent events [94]. This is of importance also in macrowear, as activities may have been ongoing since childhood [55] or be one single act, such as the stuff and cut feature. Once the “new” wear covers the “old,” that information is lost.

As previously stated, many different terms exist for these dental markings. This may not present a problem, as long as their meaning and interpretation are clear. The general suggestion is to avoid potentially socially loaded (in today’s society) expressions, such as *occupational*, *stress*, or *mutilation*, in descriptions of, for instance, interproximal wear. The word mutilation is better suited in the case of intentional filing of teeth or ablation.

Teeth are visible during life, whereas bones, evidently, are not. This provides dental anthropologists with a direct link to the past as it enables them to observe what was also clearly seen when the individual was alive. This is significant for interpretations of past human behavior.

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Conflict of interest The author declares that there is no conflict of interest

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