Reading the dental record : a dental anthropological approach to foodways, health and disease, and crafting in the pre-Columbian Caribbean
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Chapter 2 Dental Anthropology

2.1 Dental Anthropology

The term 'Dental Anthropology' first appeared in an article published in 1900 by German physician, anthropologist and ethnographer G.H.T. Buschan (1863–1942), but it was not until much later that the term became widely used in scholarly circles (Scott and Turner 1988). During the 1960's dental anthropology was established as an important sub-discipline of physical anthropology and human osteology. Broadly speaking, dental anthropology is defined in this research as 'the study of teeth in order to understand the biology and behaviour of past and living hominid populations', however creating a more specific definition of this field of research can be a tedious exercise, as numerous scholars' attempts to do so have resulted in many different definitions (Rodríguez Flórez 2003). This difficulty in defining the subject matter of dental anthropology is partly due to the fact that it has come to encompass a large number of sub-disciplines and research topics, ranging from dental metrics and morphology to the cultural treatment of teeth (Intentional Dental Modification).

In general, behaviour is recorded in the teeth in four ways: through dental wear, dental pathology, intentional dental modification, and developmental defects. Interpreting these modifications is complicated; particularly when more than one of these factors is at work. The study of biology and behaviour from hominid teeth is based on a number of physical aspects of the teeth which make them a durable and informative source of information. Firstly, teeth have a very distinct anatomy and physiology, which enables them to be readily identified even when (severely) fragmented. Physiological condition (e.g., similarities and differences) is often used to distinguish groups and individuals within a population. For example, metric and non-metric variation in dental morphology is used in diagnosing age, sex and geographic origins. Secondly, the sequence of juvenile dental development is clear and generally the same for all modern humans (although there is some variation between populations), which means juvenile human remains can be reliably identified and aged by their teeth. Thirdly, teeth are comprised of hard tissues, which are very durable and often survive in the archaeological record for far longer than other remains. Teeth are the only hard bodily tissues which come into direct contact with the environment, and once they have formed, teeth generally do not remodel. Therefore, intentional and unintentional modifications of dental tissues tend to remain visible, unless they are removed by later modification. Such modifications of the teeth can inform us about patterns of dietary and cultural behaviour. Finally, teeth can be relatively easily studied in living populations. The ability to compare past dental morphology or modifications with those in living populations is vital for understanding the biological and cultural behaviour that caused them (Hillson 1996).

Dental wear is commonly divided into masticatory wear, which comprises all forms of dental wear which occur as the result of food mastication, and non-masticatory

wear, or non-alimentary wear, which comprises all non-food related dental wear. Patterns of masticatory wear can thus be used to reconstruct diet and subsistence strategies, whereas non-alimentary wear can inform us on other activities involving the teeth (e.g., the use of the teeth as tools or intentional dental modification). Dental pathology is the study of dental disease, and its development and consequences. Generally this involves anything which causes a tooth or the entire dentition to be malformed or damaged, with the exception of dental trauma, although the latter is often included in dental pathology studies. Dental diseases are directly related either to the individual genetics and physiology of an organism, or the environment. The most common diseases affecting the teeth and surrounding bone are related to the accumulation of dental plaque, which is mostly related to diet and oral hygiene (Hillson 1996). The methods, approaches and problems associated with the study of foodways, health and disease, and craft activities in dental anthropology are discussed in more detail further on in this chapter.

2.2 History of the Field

In the late 19th and early 20th century interest in the study of teeth in (physical) anthropology arose, under the influence of Darwin's theory of evolution. The variation in tooth form – previously only used for taxonomic classifications – attracted new interest as Darwin's theory directed research toward racial and evolutionary issues. This culminated in the work "The Origin and Evolution of the Human Dentition" (1922) by William King Gregory, which distinguished stages of dental evolution from fish to humans and confirmed the evolutionary relation between apes and humans (Gregory 1922; Scott 1997; Scott and Turner 2008).

Other foundational efforts were made on the subjects of dental paleopathology and dental wear, with John H. Mummery (1847–1926) being the first to recognize the link between an increase in caries rate and a growing reliance on refined foods, while Paul P. Broca (1824–1880) developed the first method for scoring human dental wear (Broca 1879; Mummery 1870; Scott 1997; Scott and Turner 2008).

Pioneering scholar Aleš Hrdlička (1869–1943) was the first to recognize morphological differences between human groups of different geographical origins during the 1920's and 1930's. His discovery of shovel-shaped incisors in Mongoloid races was the first evidence for the Asian origin of Native Americans. In the same period, Rufus W. Leigh demonstrated the relation between different subsistence economies and different patterns of dental wear and pathology (Hrdlička 1920; Leigh 1925; Scott 1997; Scott and Turner 2008).

With the introduction of the modern evolutionary synthesis in the late 1930's and early 1940's dental genetics became one of the main subjects in dental research. This period was also characterized by increasing interest in human dental variation based on ethnographic research (e.g., Moorrees 1957; Pedersen 1949).

In 1945 an influential scholar in the field of dental research, Albert A. Dahlberg (1908–1993), published "The changing dentition of man", contributing greatly to

the understanding of dental evolution. In the late 1940's and early 1950's Dahlberg started taking casts of contemporary Pima Indian dentitions, leading to the first morphological characterizations of American Indian dentitions, based on over 8,000 individuals. The casts he made served as three-dimensional references for scholars world-wide (Dahlberg 1951; Rose and Burke 2006; Scott 1997; Scott and Turner 2008).

In 1963 Don R. Brothwell published "Dental Anthropology", a product of a meeting of the Society for the Study of Human Biology in 1958, which served to define the field of Dental Anthropology. It also introduced the term 'Dental Anthropology' for common use in scholarly circles (Brothwell 1963; Rose and Burke 2006; Scott 1997).

From the 1960's onward much research focussed on the morphology and shape of fossil hominid teeth, in order to understand the evolution from the Australopithecines to Homo sapiens (Scott 1997; Scott and Turner 2008). This period also brought more detailed analyses of the morphological traits associated with different ancestral groups of humans. Furthermore, researchers came to realize more fully the value of studying dental paleopathology and dental wear patterns (to understand dietary shifts through time) and intentional dental modification (to understand social and cultural reasons for the modification of the teeth in an ethnographic context).

In the 1985 the Dental Anthropological Association (DAA) was founded, and in 1988 the DAA held a symposium at the annual meeting of American Association of Physical Anthropologists, named "Horizons of Dental Anthropology", which resulted in another pivotal volume "Advances in Dental Anthropology" (Kelley and Larsen 1991). Since its publication, and especially in the last few years, the amount of ground-breaking work being done in Dental Anthropology has increased tenfold. Different perspectives and approaches to the study of teeth have been brought together, and more innovative research is being done. The range of dental anthropological research done today is increasing rapidly, not least in the field of archaeology, where researchers are becoming increasingly aware of the value of such studies (Rose and Burke 2006; Scott 1997).

2.3 Diet

2.3.1 Dental pathology and diet

As described above, John H. Mummery was the first to discover the relation between dental pathology and diet. He observed an increase in caries rate over time in prehistoric dental material from ancient Britains, Egyptians, and contemporary aboriginal groups, and concluded that this was due to the increased consumption of soft, refined foods (Mummery 1870; Rose and Burke 2006; Scott 1997). The association between dental pathology and diet and subsistence strategies, later termed the "Economics of Dental Pathology" (Scott and Turner 1988), remains an

important research focus in dental anthropology.

Rufus W. Leigh described in detail the relation between dental caries, periapical and alveolar abscesses, periodontal disease, dental attrition and certain diets and food processing types. He demonstrated a correlation between a high caries percentage and a diet based mainly on maize and other carbohydrate rich plants, and he interpreted the frequent occurrence of abscesses in agricultural groups as resulting from the higher rate of attrition (due to the use of stone mortars) and caries in these groups. He also linked high prevalence of periodontal disease to an agricultural diet and a sedentary lifestyle (Leigh 1925). Until Leigh's work the adoption of agriculture was considered to be the most advanced stage of development in human history, however he demonstrated that this technological change had major impacts on the (dental) health of the population.

Caries

The increase in caries rates over time, observed worldwide, has been attributed to a shift toward a more carbohydrate rich diet (Cohen and Armelagos 1984; Klatsky and Klatell 1943; Larsen 1995; Larsen et al. 1991; Littleton and Fröhlich 1993; Meiklejohn et al. 1984; Milner 1984; Turner 1979). In most areas this shift coincides with important sociopolitical and cultural developments often associ-
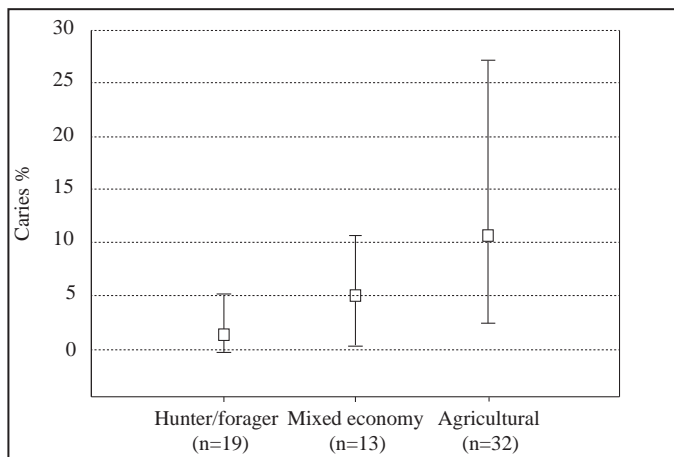

Figure 2.1 Caries rate per subsistence type (Turner 1979), after Lukacs (2008) (Hayley Mickleburgh).

ated with the adoption of agriculture, however, research has shown that less pronounced changes in diet and food processing techniques can result in differences in caries rates (Larsen 1997).

It has generally been accepted in the field of dental anthropology that the 'hunter-gatherer/forager' diet is associated with a very low caries percentage, while 'mixed economies' and 'agricultural economies' have much higher caries rates in comparison. Worldwide reviews of caries frequencies in hunter-gatherers/foragers, mixed

economies, and agricultural economies have found that hunter-gatherers have less than a 2% caries rate, mixed economies about 5%, and agricultural economies 10% or more (Koca et al. 2006; Larsen et al. 1991; Powell 1985; Scott and Turner 1988; Turner 1979; see Figure 2.1).

Contrary to these data, high caries rates have been documented for some prehistoric and contemporary hunter-gatherer/forager groups (e.g., Lubbell et al. 1994; Sealy et al. 1992). The consumption of carbohydrate rich plants from non-agricultural sources could be the cause, since some non-agricultural diets are comprised of large amounts of (non-domesticated) plant foods (Hardy 2007). Exchange of food with agricultural groups, or low levels of fluoride in the local water sources, are others explanation for the inflated caries rates in some hunter-gatherer/forager groups (Larsen 1997; Lukacs 1990; Sealy et al. 1992; Walker and Hewlett 1990).

Even so, the categories of caries frequencies distinguished by Turner (1979) still generally hold true, although other work has indicated that the aetiology of caries is much more complicated than originally thought. For example, some research has shown a correlation between the degree of occlusal wear of the teeth and the percentage of caries. A study by Maat and Van der Velde (1987) determined that the rapid wear of the teeth decreases the chances of cavity formation, refuting the idea that heavily worn teeth are more exposed to carious lesions. Other research, however, has indicated that heavy dental wear and the presence of dental caries are independent variables (Larsen 1995; Meiklejohn et al. 1988; 1992).

Furthermore, food processing techniques have been indicated to be highly influential in the formation of carious lesions. Soft, boiled foods with a sticky consistency tend to facilitate bacterial growth in areas of the mouth where food remains are easily retained; usually between adjacent teeth or in the fissures of occlusal cusp patterns (Larsen 1995; Powell 1985).

Moreover, research on sex differences in caries prevalence has demonstrated that in various cultures and subsistence systems females tend to be significantly more frequently affected by caries than males (Kelley et al. 1991; Larsen 1997). These differences have frequently been explained as the result of gender-based differences in food processing and consumption (Larsen 1983; Larsen et al. 1991; Lukacs 1992; Lukacs and Pal 1993; Sealy and van der Merwe 1988; Walker and Hewlett 1990). Often gender-based differences in labour division are thought to be the cause of such differences. However, more recent research suggests that biological differences between males and females may be the cause of higher caries rates in females (Lukacs 1996; Lukacs 2008; Lukacs and Largaespada 2006). Women's reproductive biology and associated hormonal fluctuations cause changes in the immune response system (Cheyney 2007), dietary preferences (Vallianatos 2007) and saliva composition during pregnancy (Laine 1988), which in turn make women more susceptible to dental caries.

Still, some research has shown no significant differences between male and female caries rates, while others have shown that in some cases males have significantly higher caries rates than females, indicating that the relation between caries preva-

lence and sex is far from straightforward (Burns 1979; Clarkson and Worthington 1993; Larsen 1997; Powell 1988; Walker et al. 1998).

Differential caries prevalence has often been observed between the members of different social groups, indicating dietary differences between them. Studies of social status in various cultural settings have found that high-status individuals often have very different caries rates than lower class individuals. In some cases high-status caries rates are elevated, due to the consumption of more refined, carbohydrate rich foods than other groups (Valentin et al. 2006), whereas in other cases the higher classes show lower caries rates, due to the consumption of larger proportions of meat and fish (Cucina and Tiesler 2003; Hodges 1985; Walker and Hewlett 1990).

Caries location is partly related to the type and consistency of foods. Highly abrasive diets that are rich in carbohydrates are expected to produce mainly interproximal caries, since these locations can harbour plaque while in other parts of the dentition it is removed during mastication (Caglar et al. 2007; Lubell et al. 1994; Vodanovic et al. 2005). Diets comprised of soft, sticky starches are expected to produce mostly CEJ and occlusal surface caries, since soft, sticky foods encourage the accumulation of plaque and – the bacteria that thrive in plaque – around the gingiva, while sticky food remains become trapped in the occlusal fissures of molars and premolars (Lubell et al. 1994). Smooth surface caries are generally attributed to the consumption of large amounts of sugars. Some research has suggested that CEJ caries and root caries may be more strongly associated with the consumption of starches, the consumption of sugars is related to both CEJ and occlusal caries, although the precise relation is complex and poorly understood (Lingström et al. 2000; Waldron 2009).

Dental caries are usually associated with a high rate of ante-mortem tooth loss (AMTL), as the destructive effects of carious lesions frequently lead to the exfoliation of the teeth. This means that the 'true' percentage of dental caries in a population is unknown (see also section 2.2.1).

Other dental pathologies are also indicative of prehistoric diets. Often they are closely linked with the formation and aetiology of dental caries, which means the complete picture of dental pathology, or the 'pathology load', should be taken into account in reconstructions of prehistoric diets (Listi 2007; Lubell et al. 1994; Lukacs 1989).

Calculus

Dental calculus is a hard, yellowish to brownish-black deposit on teeth formed largely through the mineralization of dead bacteria in dental plaque by the calcium salts in salivary and sub-gingival secretions. In prehistoric dental material, calculus is often fragile, and easily detaches from the teeth, but in life calculus is very hard and strongly attached. The formation of calculus is generally classed as a dental disease, which is heavily influenced by oral hygiene and dietary makeup. It is this link with the constitution of the diet which enables dental anthropologists to

use the presence and severity of dental calculus as an indicator for diet. However, as poor oral hygiene was fairly ubiquitous in prehistoric societies, such interpretations based on the presence of calculus should be treated with care. Furthermore, it is extremely important to keep in mind that the formation of dental calculus is a very complicated process, which involves many other causative factors, such as age, sex, fertility, hormonal imbalances, hereditary predisposition, salivary constitution, mineral composition of drinking water, and fluid intake (Hillson 1996; Lieverse 1999).

Although the mineralization process of dental calculus is still not fully understood, it is generally agreed that microorganisms that thrive in dental plaque play an important role in initiating mineralization. At the base of a plaque deposit, which is an anaerobic environment, mineralization of dead bacteria occurs under the influence of minerals present in the saliva. Subsequently, calcium phosphate crystals are deposited among and on the bacteria in the dental plaque. An important factor in the formation of calculus is the alkalinity of the oral environment, with is known to facilitate precipitation of minerals from the saliva (Hillson 1996; Lieverse 1999). The fact that diets which are high in protein increase the alkalinity in the oral environment is thought to be a good indication that diet and calculus formation are related (Hillson 1979). The reason for this link between protein and alkalinity is thought to be the fact that microorganisms in the mouth produce ammonia – which is very alkaline – when metabolizing urea levels in oral fluid. Protein consumption results in increased urea levels in the saliva, and therefore indirectly leads to increased alkalinity in the oral environment.

Following the reasoning above, a high protein diet would lead to (higher) calculus formation, and therefore the presence and amount of dental calculus is indicative of the protein content of the diet. Still, research to try and understand this relationship more fully has led to contradictory results, as high carbohydrate diets have been shown to facilitate the formation of calculus too. In the latter case it is important to consider the abrasivity of the carbohydrates involved, as soft, sticky carbohydrates tend to lead to increased plaque formation.

In a study on the relationship between diet and dental calculus, Angela R. Lieverse concluded that the role of high protein consumption must be re-evaluated. Furthermore, she suggested that "[d]ietary reconstruction based on the presence and frequency of dental calculus should be combined with as much other associated data as possible" (Lieverse 1999:230). Nonetheless, numerous studies in anthropology have used the presence and severity of dental calculus to understand dietary patterns, many of which have proven to be fruitful. Specifically, changes in calculus rates over time are considered to be a valuable indication of shifts in diet or food preparation techniques.

Other factors also need to be taken into account when studying the effect of diet on dental calculus. The relationship between dental calculus and other oral diseases, namely, is crucial in understanding its aetiology. The relationship between dental calculus and periodontal disease is an important subject of study in clinical

research, and dental calculus has long been thought to be the primary cause for periodontal diseases (White 1997).

Dentists distinguish two different types of calculus: supragingival and subgingival. Supragingival calculus is located above or along the gingival margin, or gums, whereas subgingival calculus is located in the gingival pocket on the surfaces of the roots of the teeth. Supragingival calculus is most frequently located on the lingual surfaces of the mandibular incisors and the buccal surfaces of the maxillary first molars, due to their proximity to the salivary ducts. Furthermore, the different types also differ somewhat in chemical composition and structure. Subgingival calculus is usually more heavily mineralized, which in theory would lead to better preservation in the archaeological record (Hillson 1996; Lieverse 1999; White 1997).

Whereas supragingival calculus is not always associated with periodontal disease, subgingival calculus is. Numerous studies have indicated a clear association between subgingival calculus and gingivitis (inflammation of the gums), which is most likely the result of the formation of a periodontal pocket at the gingival margin, due to the detachment of the periodontal ligament by subgingival calculus build up, and subsequent inflammation and lesions of the gingivae. In later stages, when chronic gingivitis leads to periodontitis, gum recession eventually results in alveolar bone loss. Bone resorption can eventually lead to tooth loss, as the teeth become increasingly detached from supporting tissues (Hillson 1996; Lieverse 1999; White 1997).

As periodontal disease is associated with alveolar bone resorption (and as a consequence also with CEJ and root caries) and ante mortem tooth loss, it is clear that calculus build up is of significant influence on the overall state of the dentition. The complex aetiology associated with calculus formation is of paramount importance in dietary studies of calculus.

Another important relationship between calculus and other oral diseases to be taken into account is the 'caries-calculus inverse relationship'. The caries-calculus inverse relationship theory is based on the assumption that because calculus formation is a mineralization process, and carious lesions are the result of a demineralization process, the absence of calculus would be a useful predictor of caries, and perhaps even vice versa. Although earlier research found no indication for a relationship between calculus and caries, some researchers have suggested that the relationship may have been obscured by other factors which contribute to the caries and calculus rate observed in clinical trials (Duckworth and Huntington 2005; Schroeder 1969). For example, the fact that the prevalence of both calculus and caries increases with age and the fact that both conditions tend to be strongly related to poor oral hygiene, could have concealed the true relationship between the two. Duckworth and Huntington (2005) conducted a large scale clinical study that indicated the presence of an inverse relationship, suggesting the presence of calculus is a good indicator of lower caries rate, however the exact causes of this relationship remain unclear.

Research on dental calculus in living populations has focussed mainly on the consequences of different oral hygiene habits and on the development of chemical mineral inhibitors which can be added to toothpastes and mouthwashes in order to counteract calculus formation (White 1997).

The distribution of the calculus deposits throughout the dentition and on the surfaces of individual teeth, although known to be related to dietary practices, follows a particular 'natural' pattern in all humans (Bergström 1999; Corbett and Dawes 1998; Jin and Yip 2002; Parfitt 1959; Schroeder 1969; White 1997). This 'natural pattern' of supragingival calculus build-up in the dentition is largely determined by the location of the salivary ducts in the mouth. As minerals in the saliva are responsible for the deposition of the mineral component of dental calculus, the teeth and roots closest to the salivary ducts are more frequently affected, as they are bathed in saliva more often and thus suffer from greater calculus accumulation than the other teeth. Generally, the lingual surfaces of the lower front teeth and the buccal surfaces of the upper back teeth are most prone to natural calculus build-up. Of course, individual hormonal differences, which can affect the chemical composition of the saliva, and oral hygiene practices, influence the pattern of calculus build-up. In people who practice regular and thorough cleaning of the teeth, calculus accumulation is mostly restricted to the subgingival pockets and the supragingival surfaces of teeth closest to the salivary ducts. Those who practice poor or no dental cleaning are more prone to larger supragingival accumulations throughout the dentition, although the teeth closest to the salivary ducts are still more heavily affected (White 1997). Exceptionally poor oral hygiene may result in large calculus deposits throughout the entire dentition, masking the natural pattern of calculus accumulation. In addition, deviation from the natural pattern of calculus deposition may be the result of non-dietary behavioural patterns that affect the processes of mineralization which underlie the formation of calculus.

AMTL

Ante mortem tooth loss (AMTL) is of course not a disease of the dentition, but rather it can be the result of numerous ailments and diseases, or traumatic injury, which may be intentional (i.e., removal of teeth for aesthetic reasons) or unintentional. AMTL is very common in prehistoric dentitions, and is therefore often dealt with in palaeopathology as a pathological condition or disease. The 'aetiology' of this condition is far from straightforward. Dental caries and periodontal disease are usually the cause of AMTL, especially in populations with carbohydrate rich diets. In diets traditionally associated with hunter-gatherer/foragers, which generally have less carbohydrates and less refined foods, AMTL is traditionally associated with rapid dental wear and resulting pulpal exposure (which may lead to infection and eventually loss of the tooth). While all human groups, regardless of their subsistence type, suffer from AMTL, there is a marked tendency for higher AMTL rates in populations that consume refined, carbohydrate rich diets (Larsen 1995; Larsen 1997; Scott and Turner 1988). A high degree of AMTL in a skeletal

population may considerably affect the analysis and interpretation of dental pathology, as the cause(s) of AMTL are difficult or even impossible to discern. A high rate of AMTL may significantly distort true caries frequencies, for example, as a large number of teeth may (or may not) have been lost due to caries, but cannot be included in the calculation of caries frequencies. In order to deal with the effects of AMTL on interpretation of caries percentage in a population, a number of researchers have come up with various (mathematical) methods to calculate the true caries percentages (Duyar and Erdal 2003; Erdal and Duyar 1999; Lukacs 1995).

2.3.2 Dental wear and diet

Why do the teeth grow to the end of our life, and not the other bones? Because otherwise they would be consumed with chewing and grinding (Aristotle 4th century B.C.).

Macrowear
Dental wear in humans is for a large part related to age, as the older an individual becomes, the longer the teeth will have been used in mastication, and the more worn they will be. Next to the age-related component in degree of dental wear, the degree of molar wear has been attributed to food preparation techniques (i.e., grinding, baking, boiling), the physical properties of the food (i.e., tough, unrefined, fibrous, versus soft, sticky, refined), and the inclusion of sand and grit in the food, for example in marine diets or in sandy (desert) environments. The first to notice the relation between the degree of dental wear and particular subsistence patterns was Rufus W. Leigh. He observed that groups who relied mainly on stone ground maize had very high degrees of wear, while groups with a high proportion of meat in the diet had much lower degrees of wear. Groups with a mainly vegetarian diet (including maize), who did not stone grind their food, were found to have a much lower rate of wear than those who used mortars, but a higher rate of wear than those who consumed a large amount of meat. In this way he demonstrated that the degree of dental wear is related to both the type of food and the processing techniques (Broca 1879; Leigh 1925). Next to the use of stone grinders, which introduces tiny particles of stone to the food, high rates of wear have since been related to the consumption of tough, fibrous plant foods or sandy, gritty marine foods, the consumption of dried or frozen meat and fish, and the inclusion of sand, grit, and ash in baked foods (bread). Lower rates of wear are associated with the consumption of soft, refined foods without stone particles, and boiled foods (Cucina and Tiesler 2003; Eshed et al. 2006; Jurmain 1990; Kaifu 1999; Larsen 1997; Macchiarelli 1989; Molleson and Jones 1991; Molnar 1972; Powell 1985; Rose and Ungar 1998; Sealy and van der Merwe 1988; Smith 1984; Walker and Erlandson 1986).
The decline in mean degrees of molar wear over time has been attributed to the transition from hunter-gatherer subsistence to agricultural subsistence practices

(Hinton 1981; Lubell et al. 1994; Molnar 1971a; Powell 1985; Rose et al. 1991; Smith 1984). This difference is the result of both changing diet composition and changing food preparation techniques, which shift from tough, abrasive foods to soft, refined, sticky foods (Larsen 1995). Some research has found high mean degrees of molar wear associated with marine food consumption. In the latter case it is thought to be the grit adhering to these foods, and sometimes the consumption of dried fish or fish with bones that cause this high rate of wear (Costa 1980; Jurmain 1990; Eshed et al. 2006; Littleton and Frohlich 1993; Macchiarelli 1989; Pedersen 1949; Sealy and van der Merwe 1988; Sealy et al. 1992; Smith 1972; Walker 1978; Turner and Cadien 1969). One study has even found parallels between human and canine dietary shift toward greater marine food consumption. In both cases the degree of wear increased as the proportion of marine food in the diet grew (Clark 1997). Despite this, some studies have shown that both hunter-gatherers/foragers and agriculturalists can have extremely high rates of wear, although the aetiology of the wear differs drastically (Deter 2006; Scott and Turner 1988). Overall, however, research has shown that mean degrees of wear tend to decline as shifts toward an agricultural subsistence economy take place (Benfer and Edwards 1991; Molnar 1971a; Pastor 1992; Powell 1985; Walker 1978). Recent research by Deter (2009) on occlusal dental wear in hunter-gatherers and agriculturalists from three North American late Archaic (3385 ± 365 cal. B.C.) and late Anasazi – early Zuni agricultural sites (~ A.D. 1300) has confirmed earlier reports that hunter-gatherers have a higher degree of occlusal surface wear, especially in the anterior teeth (Kaifu 1999; Molnar 1971a). However, Deter also found that differences in degree of wear along the dental arch can be attributed to the eruption sequence of the teeth. Thus, the teeth that erupt early on (such as the first incisors and the first molars) are inevitably more worn than teeth that erupt in later stages, since they spend a longer amount of time in functional occlusion (Deter 2009).

Research on dental wear in northwest Mexico has shown that degrees of dental wear can change drastically over time solely due to changes in food processing techniques, while the diet remained stable (Watson 2008). This means that certain dental wear patterns can only be linked indirectly (through processing techniques) to certain food types.

Comparison of the degree of dental wear in skeletal populations to reconstruct diet remains complex, due to the relation between dental wear and age. Age estimation in skeletal populations is based on changes in the skeletal frame during life, and is often restricted to broad age categories. The completeness and preservation of the skeletal material may severely affect the preciseness of aging, but perhaps more importantly, when comparing populations with differing age profiles it is hard to determine whether differences are the result of diet and food preparation techniques, or due to the differing age profiles. This problem can sometimes be avoided by comparing intra-individual rates of wear. The rate of wear is measured using the difference in degree of wear between the permanent molars: M1, M2, and M3. This is possible due to the fact that these teeth erupt at approximately 6-year intervals

in all humans, which means inter-individual and inter-group comparisons can be made (Chattah and Smith 2006; Scott and Turner 1988; Smith 1972; Watson 2008; Watson et al. 2011).

Direction and shape of occlusal wear

The direction of molar wear, i.e., the angle of the occlusal surface, has been shown to become increasingly oblique as the proportion of processed (e.g., ground, boiled) foods in the diet increases (Eshed et al. 2006; Lubell et al. 1994; Smith 1984). Smith (1984) studied molar wear patterns in five hunter-gatherer and five agricultural groups from around the globe, and found that agriculturalists tend to have more obliquely worn molars than hunter-gatherers. The greater the reliance on agricultural foods over time, the greater the wear angle was found to be (Smith 1984). Soft, agricultural foods allow for more contact between occluding teeth without lateral excursion, which causes attrition increasing the natural angle and positions of the molars in the alveolar bone. Lower molars tend to be slanted buccally, while upper molars (with the exception of the third molar) tend to slant lingually. The upper lingual cusps and the lower buccal cusps are worn on both sides and thus more rapidly in a normal dentition where there is a slight overbite, causing sloped surfaces when the wear progresses. Tough, fibrous foods, and foods with large amounts of grit and sand contaminants require what is called 'puncture-crushing', where the teeth do not meet, and more intense chewing and lateral movement of the teeth which abrades the tooth crown more evenly and results in a more flat and rounded wear of the occlusal surface (Lubell et al. 1994; Smith 1984). Another study found that hunter-gatherers tend to have labially rounded wear of the anterior teeth, most likely associated with the use of these teeth as tools, whereas agriculturalists tend to have more cupped wear in the anterior teeth. In general, anterior teeth are also more worn in hunter-gatherers than agriculturalists. Furthermore, hunter-gatherers tend to have larger interproximal wear facets, due to slight movements of adjacent teeth as the result of the heavy mastication of non-processed foods (Hinton 1981, 1982).

Smith (1984) also found that agriculturalists have a higher proportion of cupped molar surfaces than hunter-gatherers, which she attributes to the presence of small particles from grinding implements in the refined agricultural diet. Similarly, Lubell et al. (1994) found that the shift from the highly abrasive Portuguese Mesolithic marine dominated diet with sand and grit to the more refined Neolithic diet with processed agricultural foods led to a change from flat molar wear to cupped molar wear. Contrastingly, Deter (2009) found no evidence of difference between hunter-gatherer and agriculturalist cupping. Her sample of three North American late Archaic (cal. 3385 ±365 B.C.) hunter-gatherer sites (n= 306) and late Anasazi–early Zuni agricultural sites (~ A.D. 1300) (n= 87) displayed cupping in many of the hunter-gatherers and agriculturalists. The reason for this apparent contradiction may lie in variation in the constitution of the hunter-gatherer and agriculturalist diets analysed in both studies. Other studies have revealed that hunter-

gatherer diets tend to be far less protein oriented than once thought, and may include considerable amounts of processed plants, either through exchange with agricultural groups (Larsen 1997; Lukacs 1990; Walker and Hewlett 1990), collection of wild plants, or simple agricultural/horticultural practices (Milton 2000). The hunter-gatherer diet is known to be widely variable per region and period in time (Lee 1968), and often includes a (large) proportion of starchy plant foods (e.g., Kubiak-Martens 2002).

The mechanisms causing cupped or non-cupped molar wear are likely to be the same in all humans. Patches of dentine become hollowed out once exposed, since dentine is softer than enamel and wears away more rapidly. The wearing of such patches occurs due to the abrasive properties of pliable foodstuffs or stone particles in them, which when brought into contact with the exposed dentine patches wear them away faster than the surrounding dentine (Chattah and Smith 2006; Kaidonis 2008). These foodstuffs must generally be soft in nature, since tough, abrasive foods would also severely abrade the surrounding enamel, and produce a flatter and rounder occlusal surface shape. Occlusal cupping therefore seems associated with soft, refined foods (generally assumed to be more typical of an agricultural diet) with small abrasive particles, rather than tough fibrous foods (usually thought to characterize a hunter-gather diet).

Evidence from clinical dentistry would suggest a different aetiology for dental cupping altogether. In modern dental practice, the loss of (occlusal surface) enamel, paired with cupping, and often also a polished appearance, is attributed to dental erosion caused by intrinsic or extrinsic acids in the oral environment (Lussi et al. 2004). Erosion that is dietary in origin, i.e., due to the consumption of acidic beverages (carbonated soft drinks, fruit juices, certain alcoholic beverages) or fruits could theoretically be a major factor in prehistoric dental wear patterns, since acidic foods would have been readily available to many human populations in the past. Intrinsic acids, i.e., gastroesophageal reflux, affect all modern human populations, and presumably would have done so in the past too (Scheutzel 1996). This begs the question whether cupped molar surfaces truly reflect the abrasivity of the diet and dominant subsistence and food preparation techniques, or rather a (significant) component of acidic fruits, and perhaps fermented beverages or even gastroesophageal reflux. With regards to the latter, this disorder is generally characterized by a highly typical pattern of erosion throughout the dentition, which affects most smooth surfaces of the teeth too (Scheutzel 1996).

Traditional dental wear evaluation systems (i.e., Brothwell 1981; Murphy 1959) are not equipped to document such characteristics of dental wear (i.e., angle and direction of wear or occlusal surface shape). These dental wear evaluation systems are based on a grading system where numerals represent differing degrees of dentine exposure and loss of crown height. They often either pertain only to the molars or make little or no distinction between the different types of teeth (incisors and canines, premolars, molars). In reaction to these problems, Stephen Molnar developed a more detailed dental wear evaluation system (Molnar 1971a). Mol-

nar's dental wear evaluation method relies on a three-way scoring system where scores are given to the severity of dentine exposure, the direction of the wear, and the shape of the occlusal surface. He increased the accuracy of this scoring system by providing different criteria for degree of wear for each element type. Incisors and canines, for example, are subject to different patterns of wear than premolars or molars. Using this scoring system he was able to prove a positive correlation between tooth wear and cultural factors, since the types and degrees of wear in the different cultural groups he studied showed significant differences. He also found differences between the sexes within each population (Molnar 1971a).

As is the case for dental pathology, previous research has revealed significant differences between male and female patterns of dental wear (e.g., Benfer and Edwards 1991; Molnar 1971a; Powell 1988). These are usually interpreted as the result of differences in non-alimentary activities involving the teeth (see section 2.3.1) or differences in dietary patterns as the result of gender-based differences in labour division. These differences in labour division are thought to lead to differences in food consumption, because women tend to be most heavily involved in foraging and/or plant cultivation and would therefore consume more plant foods (Molnar 1971b). Some have suggested that differences in mean degree of dental wear between the sexes could be attributed to the fact that males are generally larger and more robustly built than females (Chattah and Smith 2006; Chuajedong et al. 2002; Scott and Turner 1988). It is thought that the fact that males require more food intake, and the fact that they are capable of exerting greater force during mastication, may cause higher degrees of dental wear in males (Molnar, McKee, Molnar, and Pryzbeck 1983). However, this does not explain why in some cases females exhibit higher degrees of wear than males (Molnar 1971b; Molnar, McKee, and Molnar 1983; Richards 1984), or why some studies have found no differences between male and female degrees of wear (Kieser et al. 1985; Lovejoy 1985).

Clearly, the interpretation of dental wear patterns is far from straightforward. In order to build a more accurate picture of the relation between patterns of dental wear and diet, each population must be assessed in its own sociocultural and biological context to interpret dental wear and diet.

Hypercementosis

Hypercementosis is the accumulation of excessive cementum on the roots of the teeth, usually affecting the apex of the roots most severely. The result is a swollen, bulbous appearance of the tooth root. The precise cause of hypercementosis remains unclear. Suggested causes include the friction and stress on the periapical ligament associated with heavy dental wear, although the condition also occurs in unerupted teeth (Hillson 1996, 2008b). Alternatively, the condition may be related to Paget's disease, periodontal inflammation, or trauma (particularly in localized hypercementosis). Hypercementosis in prehistoric populations is most frequently observed in older individuals and populations displaying heavy dental wear (Hillson 2008b).

2.3.3 Dental erosion and diet

Erosion is the result of the chemical dissolution of hard tissues due to the presence of acidic chemicals in the mouth. These acids can be categorized as either extrinsic or intrinsic acids, or alternatively as dietary or non-dietary acids. Dietary acids are present in acidic plant foods such as citrus fruits, while non-dietary acids tend to be introduced into the mouth through gastric regurgitation. Extrinsic acids comprise dietary acids but also include for example (industrial) airborne chemicals (Bartlett 2005; Cengiz et al. 2009; Ganss 2006; Lussi 2004). Dietary acids would appear most interesting in this study, but since the origin of the acid cannot be derived from the clinical presentation of erosion, evidence of erosion cannot be used to identify particular acidic components in the diet or environment. Nevertheless, it is extremely important to be aware of possible dental erosion in dental material as it not only erases other forms of dental wear, but it also very closely resembles some patterns of abrasion (Bell et al. 1998).

Certain patterns of dental wear (abrasion) are easily confused with dental erosion, as both can result in characteristic cupping of the dentine on the occlusal surface. Some research has indicated that the depth and orientation of the cupping is a diagnostic criterion for distinguishing abrasion and erosion (Bell et al. 1998). Other studies have shown that occlusal dental cupping appears not to be a reliable characteristic for diagnosis, as it is mostly caused by abrasion or the combination of erosion and abrasion. Instead, the occurrence of concavities on smooth surfaces is suggested to be a diagnostic criterion for identifying dental erosion (e.g., Ganss et al. 2002; Ganss 2008; Kaidonis 2008; Scheutzel 1996).

The effect of dietary acids on archaeological dentitions was assessed in a study by Ganss and colleagues (2002). They compared a group of medieval (A.D. 400–800) dentitions from regions of Griesheim (Hesse) and Sindelsdorf (Bavaria), Germany (group 1), to a modern clinical group consuming an acidic, erosive diet (group 2), and a randomly selected group consuming an average Western diet (group 3). Occlusal cupped patches, where dentine had worn more rapidly than the surrounding enamel, were found in all three groups, but were typical of the group 1. The characteristic dental lesion associated with erosion, which was found very frequently in group 2, is buccal loss of enamel and slightly cupping. This type of lesion was completely absent in group 1 and infrequently observed in group 3. The researchers conclude that although erosion (both intrinsic and extrinsic) must have been a factor in all groups, the typical pattern of cupped occlusal wear is associated not with acidic erosion, but with severe dental wear (attrition and abrasion). The similarity of lesions in the acid erosion clinical group was simply the result of erosion induced severe wear: i.e., heavy wear brought on by compromised enamel strength due to repeated acid attack.

Kaidonis (2008) argues that dental erosion is a modern-day condition, associated with the elevated levels of extrinsic acids available to humans in modern diets (i.e., carbonated soft drinks, certain alcoholic beverages, large quantities of fruit, fruit juices), stating that if erosion was excessive, non-occlusal lesions would be

expected. The latter have to date not been documented in archaeological material. Kaidonis (2008) attributes dentine cupping in archaeological dentitions to abrasion, which in these cases is always characterized by relatively shallow cups, with a depth-breadth ratio that remains the same throughout increasing stages of wear (see also Bell et al. 1998).

2.4 Health and Disease

2.4.1 Developmental defects
Developmental defects of the dentition most frequently consist of defects in the (surface of) the enamel. Enamel defects that are macroscopically observable are divided into hypoplasia, opacities, and discolouration.

Enamel hypoplasia
Hypoplasia are disparities in enamel thickness across the crown, which change the appearance of the crown surface. The most common type of hypoplasia are Linear Enamel Hypoplasia (LEH), also known as furrow-type, so named because of their horizontal linear appearance on the tooth crown. LEH tend to be arranged in a band which extends around the crown surface, representing a disruption event in the layered formation of the matrix of the crown. Essentially, LEH are disruptions in the formation of the perikymata (growth lines that appear on the surface of enamel as a series tiny of grooves), which causes them to become 'exaggerated'. As the development sequence of the perikymata on the tooth crowns is well known, and can be linked to age, the location of the LEH on the tooth crown can indicate the period in life when the disruption took place. As early as the 1940's methods were being developed to estimate the timing of enamel defects, although certain limitations to these techniques still exist (Massler et al. 1941; Hillson 1996).
Other types of hypoplasia are pit-type defects, and plane-type defects. Pit-type defects can affect a part of or the entire crown. The pits may be encountered in clusters and sometimes in bands, which can follow the furrows of LEH. Plane-type defects are larger exposed areas than pit-type defects (Hillson 1996).
Hypoplasia are generally classed as non-specific defects, which means a very large number of factors contribute to their formation. However, it is clear that some factors tend to be more strongly related to the formation of hypoplasia than others. Specifically, physiological stress including particularly metabolic disorders and nutritional deficiency (but also infectious disease, and physical and emotional trauma) during the development of the teeth appears to be an important cause of (linear) enamel hypoplasia. Diets which are extremely specialized or monotonous may be linked to hypoplasia, as a non-varied diet can lead to malnutrition. Furthermore, despite the non-specificity of hypoplasia, research has shown that they are well suited to large scale studies of long term changes in nutritional status, e.g., the transition from hunter-gatherer subsistence to agriculture (Goodman and

Rose 1991; Hillson 1996; King et al. 2005; Smith et al. 1984).

Specific disease related defects
There are developmental defects of the dentition which are specific to a particular disease, and which can be recognized by the characteristic pattern they leave on the teeth. A well-known example is a series of dental defects associated with congenital syphilis. This disease, which affects the dentition only in a very small percentage of cases, leaves characteristic deformations of the crown enamel predominantly in the permanent incisors (Hutchinson's incisors) and the first molars (bud molars and mulberry molars), but also in the canines (Fournier canines) (Anderson 1939; Hillson et al. 1998).

Another example is celiac disease, which can also lead to characteristic deformities in the dentition which occur during development of the teeth. Celiac disease (also gluten-sensitive enteropathy) is an autoimmune disease of the digestive system that damages the small intestine when gluten is ingested. The immune system is activated by the ingested gluten, resulting in inflammation of and damage to small intestine. Symptoms of the disease are diarrhea, weight loss, and the inability to absorb nutrients from foods. The disease can cause (symmetrical) patterns of damage to the enamel of the tooth crowns, with discolouration and hypoplasia as a result of poor mineralization, and crown shape may be affected, with teeth being more pointed or conical than normal (Aine et al. 1990; Greene and Cellier 2007).

Opacities
Opacities, sometimes referred to as hypocalcifications, are defects in the mineralization of enamel during the final or maturation stage. They appear as opaque white to brownish-black patches in the enamel, and can be divided into demarcated opacities and diffuse opacities. The first variety has a clear boundary, although they may vary in size and location, whereas the second variety has no clear boundary (Hillson 1996). Opacities can be the result of a high fluoride consumption during the formation of the teeth; a condition known as dental fluorosis. One of the main components of enamel is hydroxyapatite, which is formed during the early developing stages of the teeth. In the presence of fluoride, fluorapatite is formed and built into the enamel, causing opacities. Consumption of fluoride is known to inhibit the formation of dental caries, as fluoride enhancement of remineralization, combats demineralization and inhibits bacterial enzymes which produce carious lesions. Fluoride may be naturally present in the environment, and may be consumed through drinking water, or certain foodstuffs. Specifically, certain plants (e.g., tea leaves) and marine foods are known to be high in fluoride content (Elvery et al. 1998; Featherstone 1999; Hadjimarkos 1972; Malde et al. 1997; Spencer et al. 1970). Some researchers suggest that marine food consumption has considerable cariostatic effects, meaning that populations who regularly consume large amounts of marine food should be protected from dental decay (Walker and Erlandson 1986).

Discolouration
Discolouration of the enamel may result from pigment deposits due to metabolic disorders (e.g., celiac disease, see above), deficiencies during mineralization (Hillson 1996), or extrinsic staining factors such as smoking. Tobacco and tobacco smoke are well known causes of enamel discolouration, as they contain chemicals, such as nicotine, tar, and other substances, that cause staining of the enamel surface. Tobacco smoke can cause thermal irritation due to the temperature of the smoke which can lead to damage of the enamel surface, leaving it further exposed to staining materials. Chewing tobacco can also cause discolouration, which is particularly severe when parts of the dentine are exposed (Davies 1963).

2.5 Cultural Practices
Apart from 'natural' modifications of the teeth as the result of food mastication or disease, modifications as the result of cultural practices are an important category of study in dental anthropology. These types of modification, sometimes referred to as 'artificial modification' or 'non-alimentary use', can drastically alter the appearance and functioning of the teeth. Artificial modifications can for example be the by-product of an activity which involves the use of the teeth as tools, or the result of intentional alteration of the appearance of the teeth. In the latter case, the teeth are modified by filing, chipping, in-laying with stone or metal, or even extraction, for aesthetic reasons. It is currently thought that the use of the teeth as tools was common in many prehistoric populations.

2.5.1 Teeth as tools
In a review of the field Albert A. Dahlberg suggested "grasping, holding, crushing, cutting, tearing, gnawing, tool-making, leather-treating, and thong, reed and thread fashioning" as just some of the "special uses" the human teeth are put to (Dahlberg 1963:237). Later, Molnar's complete and comprehensive overview of the non-alimentary uses of teeth defined a set of criteria by which to distinguish non-alimentary wear patterns from masticatory wear, and emphasized the value of ethnographic comparisons in linking the clinical presentation of non-alimentary wear to particular (craft) activities (Molnar 1972).

However, research on the non-alimentary uses of the teeth has often been somewhat anecdotal in nature; modifications are relatively rarely encountered in skeletal populations, and are very specific to particular individuals, groups or regions, which initially led to a tendency for an unstructured approach toward their study (Milner and Larsen 1991). Alt and Pichler (1998) have formulated very useful and clear definitions of the non-alimentary uses of the teeth, dividing them into occupational modifications, individual habitual modifications and intentional dental modifications. Occupational modifications can clearly be defined as modifications resulting from the use of the teeth as tools, whereas individual habitual modifications can be the result of other non-masticatory activities, where the teeth are not

used as a tool. An example of the latter may be habitual tooth-picking, which can result in clear interproximal grooves, but does not involve the active engagement of the teeth in a specific task (Alt and Pichler 1998; Lukacs and Pastor 1988; Molnar 2008).

Non-alimentary modifications can often be identified by their 'odd' appearance. Some types of modifications occur relatively frequently in prehistoric dental assemblages, and are therefore more readily identifiable than others. The modifications most often associated with the use of teeth as tools are occlusal surface grooves or notches, and dental chipping.

In some cases, however, the identification of non-alimentary modifications can pose a problem, as malocclusion of the teeth can lead to strange dental wear patterns which may appear to be the result of the use of the teeth as tools. When the jaws are largely intact, such cases are usually easy to spot, however when dealing with loose teeth this can be more challenging. Distinguishing non-alimentary wear patterns from other wear patterns, and occupational from individual habitual modifications, poses the greatest problem in this line of research. In some cases there is no simple way of making distinctions. Research has tended to focus on specific contextual information, and ethnographic parallels. Classificatory systems have been developed for certain types of non-alimentary wear, such as dental notching/grooving (e.g., Bonfiglioli et al. 2004). These classifications are based on the size and shape of the affected area on the tooth crown, and the amount of the tooth crown involved. The development of systems like these is encouraging, as they facilitate comparison between different assemblages, but they have no clear explanatory purpose in determining the exact relation between the activity (if known) and the physical appearance of the wear pattern(s). For example, the length and depth of a dental notch/groove is both indicative of the length of time spent using the teeth as a tool in a particular activity, and the physical characteristics of the material which caused the notch/groove. Again ethnographic parallels may provide valuable comparisons, but with many traditional craft activities dwindling, and the fact that ethnography has rarely focussed on the use of the teeth as a tool, means useful comparisons are scarce (but see Berbesque and Marlowe 2009; Berbesque et al. 2012; Walker et al. 1998).

It seems, therefore, that for the interpretation of non-alimentary dental wear, dental anthropologists need to rely more heavily on what is known of the context in which the skeletal material was found. Any indications in the site context or material culture of activities such as basket manufacture, for example, could be crucial in explaining non-alimentary wear patterns on the teeth. Also, the application of techniques such as Scanning Electron Microscopy (SEM), currently predominantly used for diet reconstruction, may enable more precise identification of the physical characteristics of the materials involved in non-alimentary uses of the teeth (Krueger and Ungar 2010).

Grooves/notches
Occlusal surface and interproximal grooves or notches are formed when an object of generally corresponding size and shape to the groove or notch is repeatedly passed across the occlusal surface, or clamped between occluding teeth. A well-known example of an activity associated with this type of wear is basketry. Some basket makers use their teeth to clamp or strip the flexible materials they use when their hands are occupied. The stripping of sinew is (in order to make it supple) another well-known example of an activity which produces grooves and notches (Alt and Pichler 1998; Brown and Molnar 1990; Larsen 1985; Milner and Larsen 1991; Pedersen 1949; Schulz 1977; Ubelaker et al. 1969; Wallace 1974).

Dental chipping
Dental chipping was first described at length by Turner and Cadien (1969). They analysed 324 prehistoric and protohistoric dentitions belonging to Aleuts, Eskimos and northern Indians, and observed what they called "a little known type of tooth wear […] characterized by severe crushing and/or flaking of the crown surface of one or more teeth", which they named 'pressure-chipping' due to the resemblance to flake scars on chipped stone artefacts (Turner and Cadien 1969:303). They strongly associated this type of dental wear with a diet consisting mainly of meat and with the action of crushing bones with the teeth. The consumption of frozen meat, which was usually the state in which meat was available to Aleuts and other northern Indians, would have caused considerable damage to the teeth. The crushing of bones would have been done mainly as a pastime in order to extract the maximum amount of nutrients – from the bone marrow – from the meaty component of the diet.
More recent research into dental chipping has indicated that it may be the result of increased masticatory function of certain teeth in the dental arch, due to the absence of other teeth (i.e., ante mortem tooth loss or congenital absence of elements). In an epipalaeolithic assemblage from Taforalt, Marocco, the higher frequency of chipping on the posterior teeth was related to the practice of purposeful avulsion of the maxillary central incisors. As a consequence, masticatory and non-alimentary activities shifted to the posterior teeth (Bonfiglioli et al. 2004).
Some researchers have suggested that there is a relation between heavy dental wear and chipping (Bonfiglioli et al. 2004; Budinoff 1991; Molnar 2008). This relation could be the result of the weakening of the tooth by severe wear, which would make the tooth more susceptible to chipping[1], or conversely it is possible that severely chipped teeth wear faster than unchipped teeth. Furthermore, the frequency and severity of dental chipping has been positively correlated with age. The increase in number and severity of dental chips with age is logical, as older individuals have been exposed to the causes of dental chipping for a longer period of time (Molnar 2008).

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1 As the occlusal surface of the tooth becomes worn, the dentine is exposed. The remaining rim of enamel around the occlusal surface becomes less well supported, leaving the tooth prone to chipping.

A number of researchers have suggested masticatory causes for dental chipping, such as the extreme toughness and abrasiveness of some food types which sometimes include parts of snail shells, fruit stones and bones (Bonfiglioli et al. 2004), the adherence of sand and grit to certain foods (Budinoff 1991; Molleson and Jones 1991), and the consumption of dried fish (Budinoff 1991).

Numerous non-alimentary causes for dental chipping have also been suggested, including cracking nuts (Mickleburgh 2007), cracking crab shells (Budinoff 1991), chewing seal hides and preparing sinew (Merbs 1968; Pedersen 1947), cracking bones (de Poncins 1941), retouching chert artefacts (Gould 1968), and holding objects between the teeth (Bonfiglioli et al. 2004; Merbs 1968; de Poncins 1941; Schour and Sarnat 1942).

It seems more likely that dental chipping is the result of any or all of the above mentioned causes. A combination of masticatory and non-alimentary causes most likely gave rise to the numerous dental chips or fractures found in prehistoric dental assemblages, which makes interpreting patterns of dental chipping very complex. There are, however, some indicators which can be used to differentiate between masticatory and non-alimentary causes for dental chipping. Molnar (2008) suggests that next to general morphological appearance, significant differences between the sexes, the increase and decrease of expressions with age, and the link to oral pathology are important indications for distinguishing between masticatory and non-alimentary causes. Significant differences between the sexes may indicate gender-based divisions of labour or craft activities which involve the use of the teeth as a tool, and therefore can be an important indication of a non-alimentary cause. In her study of the relation between dental wear and oral pathology in a Swedish Neolithic assemblage, Molnar found that certain patterns of dental wear were correlated with particular dental and oral lesions. In her analysis of the relation between dental wear and lesions, she classifies dental chipping as a dental lesion. She found that in particular, occlusal excessive load wear[2] was correlated with dental chipping. Furthermore, she found that in general "[t]he patterns of dental wear that were found to correlate with dental and oral lesions are[...] likely to be results of the same actions that also produced chipping, periapical lesions, and tilting" (Molnar 2008:430)

Another important indicator of non-alimentary causes for dental chipping is the location along the dental arch. Broadly speaking, chipping in the anterior teeth could be interpreted as the result of non-alimentary wear, whereas chipping in the posterior teeth (in particular the molars) could be interpreted as the result of the mastication of hard particles and grit in food. Furthermore, any differences between the mandible and the maxilla could be indicative of the cause(s) of the chipping (Belcastro et al. 2007; Bonfiglioli et al. 2004; Scott and Winn 2010).

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2 Occlusal excessive load wear is defined as "Homogenous, excessive wear, i.e., little or no enamel is present on the occlusal surface of molars and on occasion premolars. The excessive wear is in many cases oblique and more severe in the lower jaw than the upper." (Molnar 2008:424).

LSAMAT

Lingual surface attrition of the maxillary anterior teeth (LSAMAT), a pattern of wear found in over 85% of 46 adult individuals excavated at the Itaipu phase (preceramic hunter-gatherer) site of Corondó, Brazil, was first described by Turner and Machado (1983). They define this LSAMAT as "the occurrence of progressive wearing with age of upper anterior lingual tooth surfaces without corresponding lingual or labial surface wear on any lower teeth. It is not the result of any manner of occlusal overbite, overjet, malocclusion, or other normal or abnormal anatomical consideration" (Turner and Machado 1983:126). LSAMAT was found to be correlated with a high rate of caries – in this case 11% – and manifests from the relatively young age of about 10 years onward. The presence of LSAMAT at Corondó was not found to be related to gender. Turner and Machado argue that the most probable cause of LSAMAT is the use of the upper front teeth and the tongue to shred or peel abrasive plant material for either a masticatory (to extract nutrition) or a non-alimentary (teeth as tools) activity. They strongly favour a masticatory cause as they feel that the high degree of lingual attrition paired with the absence for evidence of gender-based differences must be indicative of a dietary practice. They suggest that the use of the maxillary anterior teeth and the tongue to strip the roots of manioc of their outer peel (or perhaps to manipulate tule) was the most likely cause of LSAMAT. The peeling of raw manioc also explains the association of LSAMAT with a high caries rate, which they argue is unexpected for a preceramic hunter-gatherer population. Manioc roots and are extremely nutritious and especially rich in carbohydrates. Regarding the problem of the extreme toxicity of raw manioc tubers, they posit that iodine and protein rich foods, which would have made up a large part of the rest of these hunter-gatherers' diet, would have limited the cyanide uptake in the body (Turner and Machado 1983).

In later studies, Irish and Turner (1987, 1997) found LSAMAT in late prehistoric remains from Venado Beach, Panama and historic skeletal remains from Senegal, and were able to identify the consumption of sweet manioc or sugarcane as the most likely cause. Sucking on manioc roots or sugarcane stems to extract the sugary juices would have caused the patterns of wear on the lingual surfaces of the maxillary teeth, and also explain the associated high caries rate. Furthermore, they suggested that not only the peeling of manioc, but also the sucking of raw (sweet) manioc peel could be the cause of LSAMAT in Amerindian skeletal material (Irish and Turner 1987, 1997).

In reaction to Turner and Machado's work Robb et al. (1991) suggest that erosion due to (gastric) acids is a far more likely cause for the LSAMAT dental wear pattern, sparked a lively discussion. Turner and colleagues strongly refuted the suggestion that LSAMAT could be associated with habitual regurgitation of stomach acids, mainly because they did not believe that very high percentages of populations could take part in such activities – voluntary or involuntary. They also argue that the LSAMAT that they observed did not display the characteristic cupping that erosion does. They reiterate that the pattern of wear they documented was

"flattened at all stages and angled appropriately for some sort of material having been drawn across the lingual tooth surfaces" (Turner et al. 1991:348). Later research focussed on the possibility of a non-alimentary 'teeth as tools' aetiology for LSAMAT, for example for cordage manufacture or basketry (Comuzzie and Steele 1988; Hartnady and Rose 1991; Larsen et al. 2002).

Despite this debate on the cause of LSAMAT the past few decades have seen little further research into the aetiology of LSAMAT, even though this pattern of wear has currently been identified in a large number of different archaeological settings throughout the world (e.g., Liu et al. 2010; Pechenkina et al. 2002).

Microwear

Dental microwear analysis is the study of microscopic patterns of dental wear, in the form of scratches and pits on a tooth's surface. These scratches and pits result from the use of the tooth, and its coming into contact with other materials, principally foodstuffs. Foods (as well as other materials) leave particular patterns of microwear on the teeth, depending on their material properties. Dental microwear research is focussed mainly on the study of the characteristic patterns of microwear in human and animal teeth, in order to understand the relationships between microwear and subsistence patterns. To this end, usually the molar teeth are studied, as these are most heavily involved in the mastication of foods. The majority of research has focussed on humans and non-human primates, often with the aim to reconstruct the diets of our human ancestors (Teaford 1991; Ungar et al. 2008). Dental microwear analysis has also been used to study patterns of wear resulting from the use of the teeth in other activities than food mastication, often referred to as 'teeth as tools' use. As such non-alimentary activities usually involve the anterior dentition, this type of research focuses on microwear patterns in the incisors and canines, and how to distinguish non-alimentary wear patterns from masticatory wear patterns (Krueger and Ungar 2010).

Dental microwear analysis generally uses Scanning Electron Microscopy (SEM), a technique which employs an electron microscope that projects a high-energy beam of electrons in a raster scan pattern onto the surface of the sample. The signal produced by the electrons as they hit the surface of the sample contains information on for example the surface topography and composition of the sample. Using this signal, high-resolution images can be prepared of the sample surface, revealing incredible detail at nanometre scale. This technique has been the basis for dental microwear analysis since the late 1970's and early 1980's, however, over the years researchers have come to realize that this method has a number of drawbacks with regards to interpretation of the patterns of scratches and pits. Foremost among these is the time consuming and subjective practice of identifying individual features of microwear on tooth surfaces, and the effects of observer error on the results. In more recent years, researchers have focussed on solving these issues, introducing among others 'microwear texture analysis', a method for quantifying patterns of dental microwear based on three-dimensional surface data and

scale-sensitive fractal analysis. This method does not require the subjective identification of individual features, countering observer error, while at the same time reducing the amount of man hours involved (Scott et al. 2005; Ungar et al. 2008). Nonetheless, qualitative analyses of dental microwear may still give valuable insights into dietary patterns and the use of the teeth as tools, especially in the light of the vast amount of work done in recent years with which such analyses may now be compared.

2.5.2 Intentional Dental Modification

Alt and Pichler (1998) distinguish two forms of Intentional Dental Modification (IDM): dental mutilations (sometimes known as dental transfiguration) and therapeutic measures on the teeth (dentistry). IDM can be classed as a type of bodily modification for social, cultural, and/or aesthetic reasons. Bodily modifications, or 'bodmods' as they are nowadays popularly known among western practitioners, include a range of artificial modifications of the body, such as tattooing, piercing, scarification, and cranial modification. In contemporary – and in particular in westernized – societies IDM is rare, except for example in the form of gold coating of one or more teeth for social and aesthetic reasons. By contrast, therapeutic treatment of teeth is practiced on a large scale in contemporary societies.

The practice of IDM has been documented in a range of geographical areas, for both living and archaeological populations. It has been extensively reported – although most often in isolated cases or pertaining only to one particular site – for large parts of Africa, North America, Mesoamerica, South America, India, Malaysia, the Philippines, New Guinea, Japan, and Oceania (Milner and Larsen 1991). Less extensively researched is IDM in the Caribbean region, although a small number of cases are known. Our current understanding of these cases is that they represent an African tradition of IDM, introduced into the Caribbean together with enslaved Africans (Crespo Torres and Giusti 1992; Handler 1994; Handler et al. 1982; Jay Haviser personal communication 2010; Rivero de la Calle 1974; Schroeder et al. 2012; Stewart and Groome 1968).

IDM in pre-Columbian Mesoamerica is very well documented, as important work done by Javier Romero (1970) sparked a lasting interest in the subject. Romero distinguished 7 types of modification, based on his study of a collection of 1212 teeth housed at the Instituto Nacional de Antropología e Historia, Mexico City. Each type has 5 or more subtypes, giving a total of 59 types of modification (Milner and Larsen 1991; Romero 1970). Although Romero's work largely pertains to Mesoamerican dental material, his classification system has been widely used by scholars working in other regions.

Based on a broad range of practices from many regions worldwide, some basic types of dental modification can be distinguished. The first, and possibly most common form of IDM, is the filing of the tooth crowns into a different shape. As with all dental modifications, the anterior teeth are more often treated in this way (as they are the most visible to others). The same effect of reshaping the tooth

crown can be achieved by chipping parts of the crown off. This practice is often used together with, or in preparation for, filing. Staining or bleaching of the teeth is another form of dental modification which is practiced in many different regions of the globe. Perhaps the most striking dental modification, however, is the inlaying with ornaments. In this case, the labial surfaces of (usually) the anterior teeth are drilled until there is a hole deep enough to insert a small piece of stone or metal. In Mesoamerica, this form of dental modification has often been documented together with tooth crown filing. Sometimes the complete removal of certain teeth (again usually the anterior teeth), is thought to be aesthetically pleasing. The teeth may be extracted by pulling or knocking them out (Alt and Pichler 1998; Milner and Larsen 1991).

In recent years, researchers have tended to focus on the social role of dental modification rather than on constructing classification systems for the different types which can be identified (e.g., Labajo González et al. 2007; Tiesler 1999; Williams and White 2006). It is now recognized that IDM, like other intentional body modifications, represents an important class of archaeologically available data which can be used to understand social and cultural practices. This demands a more systematic approach to the study of IDM in skeletal populations, in order to understand the complex social dynamics which underlie them.

Therapeutic treatment

Although therapeutic treatment of the teeth, or dentistry, seems to be a relatively modern practice, cases have been documented for the past nine millennia. The oldest known evidence for dentistry comes from the Neolithic site of Mehrgarh in Pakistan. Here, flint-tipped bow drills were used to create holes of 1.3 to 3.2 mm in diameter with a depth of 0.5 to 3.5 mm. The drilling was performed ante mortem, as is evidenced by the smoothing of the edges of the affected area, which must have occurred through food mastication after the holes were drilled. The nine individuals affected were dated to between 9000–7500 B.P. (Coppa et al. 2006).

In prehistoric dentitions worldwide, documented types of dental therapy are tooth extraction, drilling, filling, trepanation (of the jaw bone), splinting, and fabrication of artificial dentures. Obviously, intentional extraction of teeth is (almost always) indistinguishable from exfoliation due to trauma or pathology. The other forms of dental therapy, however, are very clearly the result of human intervention, and therefore represent unambiguous evidence of cultural practices of healing, affording insights into past human attitudes toward health and sickness.

2.5.3 Other non-alimentary modifications

Other non-alimentary practices leading to modification of the teeth are generally the result of wearing facial jewellery or individual habits such as pipe smoking. Classed as 'individual habitual modifications' (Alt and Pichler 1998), these modifications are not the result of a particular task activity involving the teeth as tools. Neither are they associated with occupation, although in some cases there is an

indirect link between the modification and the occupation.

As these types of modification tend to be very individual in nature, there are no clearly distinguishable types of modification, although some modifications have been reported relatively frequently. The first of these is the modification of the teeth caused by pipe smoking. As pipe smokers tend to clamp the stem of the pipe between the occluding teeth, the stem wears away an oval shaped 'hole' over time, often referred to as a 'pipe notch'. Similarly, extensive tooth picking has been shown to leave interproximal grooves (Lukacs and Pastor 1988; Ubelaker 1969; Wallace 1974). Habitual pen biting, causing similar wear patterns to pipe smoking, was found to be common among office workers by Hickel (1989). In this case, although the habit was clearly individual, it was indirectly related to the occupation. Oral and facial jewellery, such as lip studs, lip plugs, lip rings, labrets, and cheek plugs have been shown to crack and chip teeth, or leave smoothly polished wear facets on the (labial) surfaces. Very large ornaments in the lower lip sometimes cause malpositioning of the anterior mandibular teeth, as a result of the pressure exerted on them during long term use of the ornament. Regardless of the type of material the ornament is made of, where it comes into contact with the gingiva, it will invariably damage them and cause them to recede. Gingival recession may in turn eventually lead to exfoliation of the teeth as the alveolar bone resorbs and leaves the teeth unsupported. In modern dentistry the wearing of tongue studs has provided ample examples of the trauma and infection associated with wearing oral jewellery. Next to (localized) recession of the gingiva, alveolar bone resorption, and infection and abscessing, the use of tongue studs has been shown to cause among other things increased salivary flow, nerve damage and paraesthesia, swelling, risk of haemorrhage, risk of inhalation of the studs, allergic reactions to the metal, and interference with speech, chewing, and swallowing (Kieser et al. 2005; Maheu-Robert et al. 2007; O'Dwyer and Holmes 2002; Pires et al. 2010).

Bruxism

Bruxism or bruxing is "the habit of grinding the teeth together (tooth to tooth contact when not eating" (Abrahamsen 2005:269). It is a major cause of abrasion to the human dentition. Estimates from clinical studies of percentages of bruxers, range from 6% to 88% of the population (Ahlberg 2002). Precise reasons for bruxing remain unclear, although researchers have put forward a number of explanations, including stress, temporomandibular joint disorder (TMJD), and reflex chewing during sleep (Abrahamsen 2005; Ahlberg et al. 2002; Watts et al. 1999). Due to the extremely high forces of pressure when the teeth are clenched together or ground, bruxing can cause chipping and fracturing of the enamel and underlying dentine, and (severe) wear of the entire crowns of the teeth (Arnold 1981; Pavone 1985). The latter is usually associated only with severe or prolonged sleep bruxing, or bruxing which goes undiagnosed or untreated by a dentist.

In the increasingly interdisciplinary and interdependent academic world, it has become clear that no discipline is an island – that, in fact, formerly rigid boundaries are displaying a considerable amount of elasticity that encourages interaction (Rose and Burke 2006:323).

As shown above, dental anthropology is a multifaceted discipline which deals with a range of topics, many of which overlap with the disciplines of archaeology, osteoarchaeology, biology, forensics, evolutionary biology, and genetics. In fact, dental anthropology is a well-established sub-discipline of bioarchaeology and human osteology and is recognized by many archaeologists as a valuable contribution to their discipline. The application of dental anthropological research in archaeology can still be further explored, however, as is discussed below.

One of the underlying notions of the research presented here is that the incorporation of numerous lines of evidence from different fields of research will ultimately benefit all disciplines involved. Archaeology has a lot to gain from the routine incorporation of dental anthropological research in the study of past human lifeways. Dental anthropology can be of particular importance in subsistence studies and the study of specific cultural practices, and complements interpretations of dietary patterns derived from stable isotope and faunal and palaeobotanical data. Conversely, of course, closer collaboration with archaeologists allows dental anthropologists (and osteoarchaeologists in general) to interpret their findings within their specific socio-cultural context. Being able to incorporate data on for example, mortuary practices, site environment, faunal and botanical remains, and archaeometric analyses enables a far more informed interpretation of the behavioural patterns which gave rise to the condition of the dental remains. The lack of such an inclusive approach has been an important point of appraisal in recent discussions on the disciplinary divide between archaeology and osteoarchaeology (Larsen 2006). Osteoarchaeologists are said to have contributed to this situation by presenting their research as a highly specialized set of research techniques as opposed to a research paradigm in its own right. Conversely, archaeologists are charged with considering osteoarchaeology simply as a 'service provider', supplying archaeologists with raw data which they then interpret within the correct socio-cultural context (Sofaer 2006). To all intents and purposes, osteoarchaeology needs to shed its reputation for being a largely atheoretical discipline to fulfil its role as a sub-discipline of archaeology. Achieving this is the responsibility of researchers in both fields, as all will ultimately benefit from overcoming this 'disciplinary divide', thus opening up a range of possibilities for archaeologists and osteoarchaeologists or dental anthropologists alike to strengthen and incorporate different lines of evidence into their research.

2.6.1 Dental anthropology and Caribbean archaeology

Dental anthropological studies have rarely been done in the Caribbean region, and the research that has been done on the subject falls within the scope of more general physical anthropological and osteological pursuits. Some researchers have however highlighted the potential of pre-Columbian Caribbean human dentitions to reveal past patterns of biology and behaviour in this region. These studies are summarized here.

Forensic specialist and physical anthropologist Edwin Crespo Torres, being a student of one of the most influential researchers in the field of dental anthropology, Christy Turner, has shown a profound interest in human dental wear, morphology and pathology, incorporating routine and thorough dental analysis into his research (Crespo Torres 1991, 2000, 2005a, 2005b, 2010, 2011). Crespo Torres was the first to identify LSAMAT in pre-Columbian Caribbean dentitions (Crespo Torres 1994; see also Turner and Machado 1983).

In his osteological report on the human skeletal material recovered from the site of Hacienda Grande, Jeffrey Walker included a very extensive analysis of dental wear, linking the patterns and degree of wear to particular subsistence strategies and including an investigation into the use of teeth as tools (Walker 1985).

On Barbados intensive research led by Peter Drewett in the 1980's yielded a larger number of human skeletons, which were subsequently subjected to thorough osteological analyses. The latter included a study of the dentitions by Don Brothwell, revealing excessive tooth wear and tooth loss, and patterns of wear associated with the use of the teeth as tools in cultural activities. Research into the prehistory of Barbados continued throughout the 1990's to the present, always including systematic osteological analysis of human remains by experts in the field (Drewett 1991, 2000).

Also during the late 1980's, Aad Versteeg conducted research on Aruba, where among other things he excavated the Archaic cemetery site of Malmok and together with physical anthropologist Jouke Tacoma studied the osteology and mortuary practices of the approximately 60 individuals buried there. Later, in the mid 1990's, efforts were made to place this Archaic cemetery of Malmok in a Caribbean-wide cultural context for the period, as both Versteeg and Tacoma visited Cuba to compare their results to Archaic burial assemblages there (Versteeg 1991; Versteeg et al. 1990). Tacoma studied a number of skeletal assemblages from Aruba, Curacao, and Suriname. He professed an acute interest in the study of the human dentition, making certain that the teeth were carefully collected during excavation and that the pathological conditions of the dentition were documented. He also documented some of the most conspicuous morphological traits in the dentitions that he studied, paying specific attention to the presence and degree of incisor shovelling (Tacoma 1959, 1990, 1991; Versteeg et al. 1990).

The 42 human skeletal remains excavated at the site of Tutu, St. Thomas, USVI, were the subject of a multi-disciplinary investigation into past biology and behaviour, including osteology and pathology, mortuary practices, and dietary practices

at the site, including trace element and stable isotope analyses and a dental anthropological study (Farnum and Sandford 2002; Larsen et al. 2002; Norr 2002; Righter et al. 1995; Sandford et al. 2002). The latter study recorded pathological conditions of the Tutu teeth, including dental caries, enamel defects, and calculus, as well as macro- and microwear patterns. The researchers conclude that the high degree of dental wear exhibited in the Tutu population was the result of abrasives in the diet, such as sand and grit. They distinguished a small number of cases of non-alimentary wear related to the use of the teeth as tools, including the presence of LSAMAT. Furthermore, they found slight differences in caries prevalence between males and females, which they interpreted to be the result of different food consumption patterns (Larsen et al. 2002).

Characteristics of non-metric dental traits have been used to study the degree of biological affinity between some groups (e.g., Archaic Age vs. Ceramic Age) within the region (Coppa et al. 1995; Crespo Torres 1994). Alfredo Coppa and colleagues document changes in stress incidence over time, evidenced by a decrease in the frequency and timing of enamel hypoplasia (disruptions in the enamel formation) between Archaic Age groups and Ceramic Age groups in the Dominican Republic. They furthermore found evidence for a greater genetic homogeneity in Late Ceramic Age groups from the Dominican Republic when compared to Archaic Age groups, which they relate to different waves of migration to the island (Coppa et al. 1995; Coppa et al. 2008).

Where dental anthropology has grown into a discipline in its own right in other parts of the world, sadly in the Caribbean dental studies are still few and far between. Nonetheless, the precedent for dental anthropological research in the Caribbean has already been set by a number of researchers such as Edwin Crespo Torres, Alfredo Coppa, Jouke Tacoma, and Jeffrey Walker, who demonstrated the value of dental anthropological studies in the region. What has been lacking is a comprehensive overview of what is known of the human dentition in the prehistoric Caribbean, and larger-scale research involving the comparison of numerous skeletal assemblages from different periods in time from throughout the region. The routine incorporation of dental analyses into osteoarchaeological endeavours – already the norm in other regions in the world – will undoubtedly benefit the discipline of osteoarchaeology in the Caribbean, and as argued above will ultimately benefit the discipline of archaeology to an equally great extent (Crespo Torres et al. 2013).