Dental indicators of ancient dietary patterns: dental analysis in archaeology

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IN BRIEF

- Highlights that investigating ancient dentitions can provide information about the dietary habits of our ancestors.
- Describes the wide range of analytical techniques available to investigate ancient teeth.
- Provides examples of how such investigations have aided the archaeologist and historian in reconstructing ancient lifestyle patterns.

What can the study of ancient teeth tell us about the dietary habits of our ancestors? Diet plays a prominent role in the organisation and evolution of human cultures and an increasingly diverse array of analytical techniques are available to help reconstruct diet in ancient populations. Dental palaeopathology is particularly important as it can provide direct evidence of the type of diet an individual consumed during life. Heavy occlusal tooth wear is the most frequent condition recognisable and an examination of both macro and microscopic patterns of wear can establish the differences between the hard fibrous diet typical of a hunter-gatherer, and a diet primarily consisting of softer plant foods consumed by an agriculturist. The distributions of trace elements and stable isotopes in food webs make it possible to use them as natural tracers of foodstuffs. Through a consideration of photosynthetic pathways, the ratios of the different stable isotopes of carbon and nitrogen can determine which specific groups of plants and animals were dominant in the food chains of various populations – a fact that has been used to trace the spread of agriculture in ancient civilisations.

INTRODUCTION

A primary concern for the dental profession is the oral health of our patients, a responsibility that necessitates being aware of an individual's dietary regime and providing appropriate dietary advice. However, what information can teeth and particularly ancient teeth provide about the dietary habits of our distant ancestors? The prominent role of diet in the organisation and evolution of human cultures has long been recognised, and an understanding of ancient dietary patterns can provide information concerning the social, economic and biological status of past populations.

The dentition maintains its integrity in burial contexts while bones may well have suffered some post-mortem decomposition and so teeth may be the only human tissue sufficiently well-preserved for scientific analysis. The range of analytical techniques that are now available to help reconstruct ancient diets is diverse and expanding. These encompass dental palaeopathology, stable isotope analysis, biomonitoring of trace elements, dental microwear analysis and a study of attrition angles in macroscopic tooth wear. Dental palaeopathology is still of paramount importance, as palaeopathological studies of the oral cavity provide direct evidence of the type of diet that an individual consumed during life.

DENTAL PALEOPATHOLOGY

Tooth wear

All human dentitions display evidence of some loss of tooth tissue due to physiological wear but the tooth wear frequently visible in the dentitions of ancient populations is often excessive and frequently considered as pathological.[1,2] Tooth wear, embracing components of both attrition and abrasion, provides direct evidence of masticatory behaviour. Mastication is intimately related to diet and so patterns of tooth wear can be used to make dietary inferences and because of its correlation with aging can be used as a method of determining age at death.

Tooth wear is the cumulative loss of enamel and dentine from both the occlusal and interproximal surfaces of the teeth and is a result of the combined action of attrition and abrasion.[3] The level of attrition may indicate the nature of the food stuff being consumed, as illustrated by the high meat content found in the diet of some of the ancient hunter-gatherer populations, which would have required a greater amount of chewing. However, it is abrasion caused by the introduction of foreign material into foods that results in rapid advanced tooth wear. Inorganic abrasive particles such as silicate phytoliths deposited in plants and grit lodged in shellfish may be present in unprepared foods.[4] In societies such as that of ancient Egypt fine particles were accidentally generated when grain was ground with stone implements, and wind-borne sand would have been a major contaminant in food preparation processes.[5] Australian Aborigines were known to pound up the entire bodies of small animals and then consume the resulting mash, a mixture that would have included the bones and would have resulted in a high degree of tooth wear.[6]

Excessive tooth wear, therefore, is an indication of the type of diet consumed by an individual, and the pattern of this wear can also provide additional dietary information. Historically, the teeth of both the early hunter-gatherers and the later agriculturists are characterised by rapid pronounced tooth wear, but it is the angle of crown wear rather than the absolute degree of wear that can help to distinguish between these groups.[4,7] This variation is related to the major differences in subsistence and food preparation. Hunter-gatherers developed flatter molar wear due to the mastication of tough fibrous food. Agriculturists on the

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Fig. 1 Lateral view of a mandible of a hunter-gatherer demonstrating a flat wear plane. Skull 5436: ancient Egyptian Neolithic. (Courtesy of the Duckworth Collection, the University of Cambridge)

Fig. 2 Lateral view of a mandible of an agriculturist demonstrating an oblique wear plane. Skull 1756: ancient Egyptian, Naqada Period. (Courtesy of the Duckworth Collection, the University of Cambridge)

other hand developed oblique molar wear due to a diet based on ground grains and food cooked in water, which resulted in a reduction in the role of the teeth in breaking down foods (Figs 1 and 2).[7]

The mechanism to account for this difference is explained by dividing mastication into two cycles, each characterised by a different type of tooth wear.[8,9] In the initial cycle termed 'puncture crushing', teeth do not contact, but repeatedly crush the food bolus, producing blunting wear over the tooth surface. This is then followed by a cycle of 'chewing' in which the teeth shear and grind across each other producing characteristic oblique wear facets. For the hunter-gatherer when fibrous foods were prominent in the diet, teeth did not often make contact during mastication and molar wear is more evenly distributed, resulting in a relatively low wear plane angle in advanced tooth wear. However, with the prepared food of the agriculturalist, the molar teeth were in contact for longer periods and display a more restricted pattern of wear and a steeper wear angle.[7]

A number of extraneous factors such as individual differences in the quality of enamel and dentine may obscure the effects of tooth wear. An increase in the level of fluoride in the water would increase the hardness of the enamel and so affect wear patterns between various archaeological populations. Ante-mortem tooth loss would intensify stress on the remaining teeth, thereby increasing tooth wear. Nevertheless in general an assessment of the angle of tooth wear, rather than the absolute degree of wear, can be used to support dietary inferences and highlight changes in mastication and diet in some of our earliest ancestors.

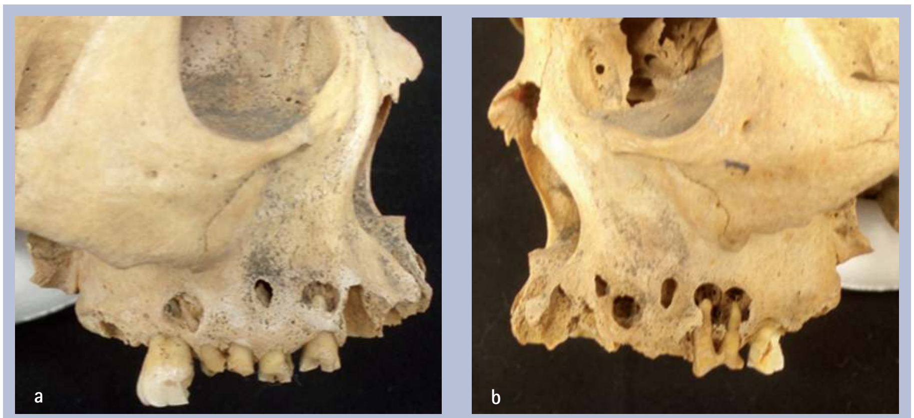

Fig. 3a and b Right and left lateral views demonstrating multiple periapical cavities above the roots of the maxillary teeth. Unprovenanced skull from ancient Nubia. (Courtesy of the Duckworth Collection, the University of Cambridge)

Caries

Dental caries is a particularly useful indicator for addressing dietary differences within and between different population groupings. Although the aetiology of caries involves several interacting variables such as oral bacteria, dietary elements, tooth structure and saliva, the study of earlier populations indicates that diet and specifically refined carbohydrates played a key role in the formation of carious lesions.[4]

The hunter-gatherers usually experienced a low incidence of caries consuming as they did few simple carbohydrates. However, the change to a more sedentary lifestyle brought a greater reliance on plant foods and food preparation techniques. These latter processes broke down the complex carbohydrates into simple sugars, the mono- and disaccharides, with a resultant increase in caries rates.[4] Changes in caries experience over time within population groups can be illustrated by considering the population of ancient Egypt where during much of the Pharaonic period (*c.* 3000-332 BC) caries incidence was low, perhaps in the region of 5%. However, with the arrival of Greeks into Egypt in the fourth century BC figures of as much as 30% are suggested, directly attributable to changing dietary habits.[5] An even more extreme example is provided by the Inuit who inhabit Canada, Greenland and Alaska. The native diets altered from one that consisted primarily of animal products (non-cariogenic protein and fat) into one that included large amounts of carbohydrates, a change that resulted in dramatic rises in caries rates.[4,10,11]

Periapical cavities

Severe tooth wear and gross caries associated with specific dietary components commonly precipitate pulpal necrosis. Oral bacteria and their toxic products would then enter the periapical tissues and induce an acute or chronic inflammatory result. The level of response would depend on the balance between the immunity of the host and the virulence of the infection. A frequent consequence is the formation of a periapical cavity in the alveolar bone and the terms 'abscess' or 'abscess cavity' are commonly used in anthropological literature to describe these cavities. However, abscess formation is only one of a number of possible inflammatory responses to infection of the dentition and its supporting structures.[12] In most cases the cavities would be occupied during life by periapical granulomata or apical periodontal cysts, these varying in size with 5-15 mm being a commonly suggested range.[13]

In examinations of ancient skeletal material the teeth associated with these periapical cavities have often been lost ante-mortem but the presence of such pathological features is a useful dietary indicator. It is not uncommon to observe multiple periapical cavities in a skull and although the infection that caused such cavities would have persisted during life, the individual may not necessarily have been ill (Figs 3a and 3b). Nevertheless any such untreated lesion, as would have been the case in antiquity, has the potential for the involvement of the dental infection in the death of an individual.[12] A virulent strain of bacteria or compromise of the immune system could result in the development of a serious acute abscess with possible systemic consequences.

Historical information indicates that dental infections were a significant cause of deaths in past populations.[13–16]

Calculus

A number of factors affect the rate and extent of calculus formation in individuals, with dietary patterns being one of these. An alkaline environment in the oral cavity increases mineral precipitation from the surrounding oral fluids and diets high in protein facilitate calculus formation by increasing this alkalinity.[17,18] However, individual variation, cultural practices, the degree of mineral content in the drinking water, the presence of silicon and bacterial involvement in the mineralisation process all need to be considered as influences in the formation of calculus.[19] The presence of large amounts of calculus on ancient teeth is by itself not necessarily an indicator of specific dietary components but does supply evidence that may assist in determining dietary patterns.

Dietary reconstructions based on plant microfossils, such as starch grains and phytoliths recovered from calculus, are also useful methods for increasing our understanding of past populations.[4,20,21] The formation of calculus traps food particles and plant microfossils into the matrix of what is primarily calcium phosphate. These calculus deposits are heavily mineralised and survive well in the archaeological context. Plant microfossils are protected in this mineralised matrix and once recovered can provide direct evidence of elements of the diet.[22]

The technique to recover these plant microfossils involves removing areas of the thickest calculus from a tooth. The sample is then treated with sodium hexametaphosphate (calgon), sonicated and centrifuged. Hydrochloric acid is added to the supernatant to dissolve the calculus and the remaining sample is viewed under a light microscope at 40x to identify the microfossils. A study of teeth from a middle Holocene (*c.* 5500-4500 BC) archaeological site in Syria was able to determine that the individuals were consuming a variety of plant foods. Domesticated cereals such as wheat and barley, which the archaeological record had previously hypothesised as supplying the major sources of starches, was found to make up a surprisingly small portion of the diet.[22,23]

As described below, stable isotope analysis of teeth has become a common technique in the reconstruction of ancient dietary patterns. However, it is a destructive technique as teeth have to be sampled and so curatorial concerns may prohibit this analysis from being performed. Recently a new technique has been described in which calculus has been analysed for stable carbon and nitrogen concentrations. Comparison with results from other biomaterials such as bone, collagen, teeth and hair suggest that calculus is a suitable biomaterial for dietary analysis. The advantage of using calculus is that it is not an inherent part of the skeleton, but a secondary material and thus this may overcome curatorial concerns regarding preservation of the specimen.[24]

Periodontal disease and alveolar resorption

Periodontal disease resulting in generalised horizontal loss of crestal bone is not an uncommon finding in general dental practice. However, without the presence of soft tissues periodontal disease in ancient skulls has to be identified with care. An increase in the distance between the cemento-enamel junction and the alveolar crest, inaccurately used as an indicator of periodontal disease in the past, has been shown to be due to continuous eruption as a result of tooth wear. More positive indicators are altered morphological shape and/or the appearance of macroscopic porosity on the alveolar bone caused by resorption of the cortical plate to reveal the underlying porous cancellous structure.[5,25]

Periodontal disease is recognised as an interaction of bacterial plaque with the host. Although bacterial plaque has been implicated as the primary aetiological agent in most forms of periodontal disease, theoretically a deficiency of any essential nutrient might also affect the status of the periodontal tissues. A correlation between the severity of periodontal destruction and deficiency of vitamin B has been established for a modern Sri Lankan population.[26] Severe periodontal destruction has long been associated with scurvy, which is a result of vitamin C deficiency. However, the connection between periodontal disease and scurvy may be more complex with plaque-induced inflammation being needed for gingival changes to take place.[27] In severe nutritional deficiency, usually accompanied by extremely poor oral hygiene, there is rapid destruction of the periodontal tissues and early tooth loss.

However, studies would suggest that the incidence of periodontal disease in ancient populations was not high and vertical bone defects of pulpal aetiology were far more common and severe often resulting in tooth loss.[25,28–30] Clarke[30] suggests that in ancient populations there may have been a higher level of efficiency of the host defence systems that operate in the gingival crevice and gingivae. In modern societies these may be compromised by prolonged or combined environmental factors such as stress, smoking and diet.

Fig. 4 Example of linear enamel hypoplasia. Ancient Egyptian mandible c. 1500 BC. (Courtesy of the Duckworth collection, the University of Cambridge

Ante-mortem tooth loss

The loss of teeth before death is recognisable by the progressive resorptive destruction of the alveolar bone with heavy tooth wear, caries, trauma and periodontal disease being the principal factors responsible for this process. Establishing the primary causal agent that produces alveolar bone loss and ante-mortem tooth loss can yield valuable information about the nature of the masticatory stress in a skeletal population.[31]

Enamel hypoplasia

Enamel hypoplasia is a defect in the structure of tooth enamel that disrupts the normal contour of the crown surface and is macroscopically visible as discrete pitting or horizontal furrows (Fig. 4). The condition is a result of interruptions in the secretion of enamel by the ameloblasts during crown development, resulting in incomplete or defective formation of the organic enamel matrix. These surface defects have been described in terms of defect type, number or demarcation, and location.[32] The distance of the hypoplastic disturbance from the cemento-enamel junction determines the age at which stresses occurred. Simultaneous occurrences of hypoplasias on different teeth of the same adult provide a 'memory' of systemic growth disruption and stress.[33]

The aetiology of the disruption is not always discernable, but enamel hypoplasia appears to be a sensitive reflection of physiological stress. Hereditary factors have been cited but evidence suggests that environmental stressors are more common causes. Dietary deficiencies are one group of stressors that historically were considered as primary causes of enamel defects, but the interaction of two or more factors, particularly diet and disease is now understood to be involved.[34,35]

Starling and Stock[36] conducted a study of five populations who inhabited the Nile valley spanning a period from 13000-1500 BC. Their results indicated that the prevalence of enamel hypoplasia was highest in the 'proto-agricultural' (pastoralist) Badari population (4400-4000 BC). This was a period associated with the emergence of agriculture and known from other archaeological evidence to be linked with poor health and uncertain food supplies. In later periods improved agriculture, increasing urbanisation and enhanced trade links resulted in more guaranteed food supplies, improved health and a reduction in the incidence of hypoplasia.

A study by Goodman *et al.*[33] of 111 adults from an archaeological site at Illinois (AD 950-1300) found that the number of individuals with one or more enamel hypoplasias increased significantly over this time period. The rise is considered to relate to a greater reliance on maize agriculture and an increased population density potentially causing increased spread of infectious diseases compared to the more balanced dietary patterns and lower population levels previously recorded at this site.

DENTAL MICROWEAR ANALYSIS

Many studies have demonstrated the usefulness of dental microwear analysis (DMA) for dietary reconstruction among non-human primates,[37,38] early hominids,[39,40] and prehistoric humans.[41–43] Dental microwear is the name given to the pits and scratches that form on the surface of the enamel during mastication. Pits are caused when hard abrasive particles are driven or compressed into the enamel surface, whereas scratches occur when particles are dragged between opposing enamel surfaces as the jaw moves through the chewing cycle. Among the types of particles causing these features are microscopic phytoliths found in crops, grit from the soil which has not been sieved out, mineral fragments from milling stones and inorganic materials purposely added.[44–47] Variations in the size, morphology, frequency and orientation of these pits and scratches, known as dental microwear patterns, can be related to changes in diet and provide insights into dietary habits.[48,49]

DMA involves a statistical evaluation of the microwear features identified on the wear facets of molar teeth, mainly the cusp tips (used primarily for crushing) and the patterns on the cuspal slopes (used for shearing). Originally this technique involved taking silicone impressions of the occlusal surfaces of the molar teeth with replicas subsequently being cast in epoxy resin. These were then examined with a scanning electron microscope and photomicrographs of the microwear features were then analysed with specialised software. However, this two-dimensional imaging study is time-consuming and prone to subjectivity and observer error. A more recent approach is the use of dental microwear texture analysis (DMTA), based on three-dimensional surface measurements, a technique that uses white-light confocal microscopy and scale-sensitive fractal analysis. From the surface data obtained by DMTA, photosimulations of the features are able to be created (Figs 5 and 6). This improved technique is more sensitive, economical and free from observer measurement error.[50]

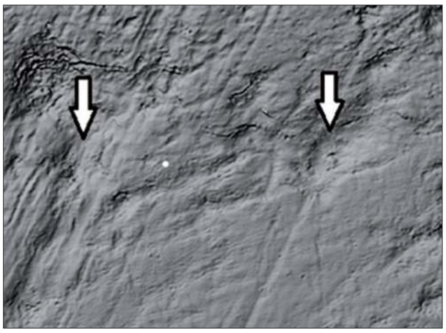

Fig. 5 Photo-simulation of microwear showing pits and scratches. Late Archaic Period individual, Indiana, USA. (Arrows indicate pits. Courtesy of Zolnierz M, University of Arkansas & Schmidt C, University of Indianapolis)

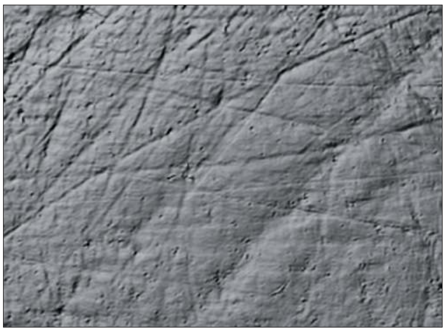

Fig. 6 Photo-simulation of microwear showing scratches. Early Late Archaic period individual, Indiana, USA. (Courtesy of Zolnierz M, University of Arkansas & Schmidt C, University of Indianapolis)

The results of such analyses indicate that individuals who eat harder foods requiring greater masticatory forces tend to have a greater number of and larger pits, while those eating softer foods tend to have mainly scratches. However, these traits are not mutually exclusive and the occlusal surfaces usually have both pits and scratches present. Dietary patterns are determined by which microwear features are dominant in a particular population.[51]

A study by Mahoney[52] comparing hunter-gatherers with later agriculturists revealed an increase in pit size and wider scratches present on the teeth of the agriculturists, indicating that they relied more heavily on stone-ground crops containing as they did various contaminants. Schmidt,[51] in a study based in Indiana, compared semi-sedentary foragers dating to 3000-1000 BC with later primarily agriculturists dating to 500 BC-AD 500. His results indicated that the softer plant foods such as tubers and wild plants of the foragers produced microwear features dominated by scratches from phytoliths and exogenous grit, whereas the later gardeners relied more on a harder diet of nuts and oily seeds, foodstuffs which produced more pitting. Consequently, the analysis of dental microwear is a technique that is not only capable of determining major shifts in subsistence such as from hunter-gatherer to agriculturists, but is also capable of discerning subtle dietary shifts that may not be as readily accessible by other means of dietary reconstruction.

STABLE ISOTOPES AND TRACE ELEMENTS

The distributions of stable isotopes and trace elements in food webs make it possible to use them as natural tracers of foodstuffs. Their measurement in archaeological bones and teeth provides a direct record of diet.[53] Early work in this field was on trace elements but the focus has now shifted to stable isotope measurements, although trace elements are still used in some studies.

Trace elements

Trace elements are present in very low quantities in body tissue, in the order of a few milligrams per kilogram body weight. More than a dozen trace elements are necessary for the maintenance of health and they are involved in almost every biochemical process in body cells, thus playing an important and complex role in human metabolism.[54]

While many investigative techniques are directed at bone samples to detect these elements, the inorganic fraction of tooth enamel is often analysed as its greater density and crystallinity make it better resistant to diagenesis.[55,56] Variations in the content of trace elements in the teeth have been previously demonstrated.[57] Particularly sensitive indicators are the trace elements barium (Ba) and strontium (Sr), which enter skeletal tissues in proportion to their dietary abundance and hence to their local environmental levels. Among those regions that contrast geologically or climatologically, the environmental abundance of these two elements can vary substantially and exceed the variation that is due solely to local dietary differences.

As enamel incorporates Ba and Sr during amelogenesis and retains the original levels of these elements it can provide a chemical signature of the geographic origins of individuals.[58]

The use of Sr and Ba as dietary indicators is based upon trophic levels in the food chain. Plants absorb strontium and calcium from the soil equally, but the mammalian gut absorbs more calcium than strontium. Consequently, a human diet consisting primarily of plants will contain more strontium than one composed of carnivore meat, as the animal from where the meat is sourced will have already preferentially absorbed more calcium. Therefore teeth can give an indication of whether meat or more of a vegetarian diet was consumed during childhood.

By the technique of laser ablution inductively coupled plasma-mass spectrometry (ICP-MS)[59] it is possible to reconstruct a detailed chronological history of an individual's dietary habits in early life by mapping the differences in strontium calcium intensities across thin sections of deciduous teeth. These variations in strontium calcium levels are able to provide insight into the onset and duration of breastfeeding and the introduction of non-maternal sources of food when the child was weaned.[60] Other techniques used in trace element analysis are proton induced X-ray emission (PIXE),[61] atomic absorption spectrometry (AAS)[62] and the more powerful method of inductively coupled plasma-optical emission spectroscopy (ICP-OES).[63]

Zinc, another trace element, is present to some extent in most food items but higher levels are found in meats, seafoods and certain crustaceans and so this element was originally considered to have the potential to be a dietary marker.[64,65] However, different groups of researchers have produced conflicting results in terms of estimating the meat content of ancient diets, and so zinc is no longer considered to be a reliable dietary indicator.[66–68]

It is now well accepted in dentistry that fluoride plays an inhibitory role in the development of dental caries. There have also been some studies suggesting that other environmental trace elements may affect caries experience either singly or in combination. Molybdenum, in particular, has been associated with a reduced incidence of caries.[69–72]

Stable isotopes

Since the early 1990s there has been an expanding interest in the stable isotope composition of skeletal tissues to assist in the reconstruction of ancient dietary patterns. Carbon and nitrogen stable isotopes are the best understood and the most commonly studied in human remains. Collagen extracted from bone or tooth dentine and to a lesser extent carbonates sampled from tooth enamel are the tissues used in these studies. Again teeth are particularly useful for study because of the excellent preservation of biogenic elements in the tooth structure and their resistance to diagenesis. Additionally, different teeth preserve elements ingested at particular stages of life.[73] Isotopes of oxygen and strontium have been used as indicators of geographical origin while other isotopes such as those of hydrogen, sulphur and lead have also been explored but to a lesser extent.

Isotopes are atoms of the same element with the same number of protons, but different numbers of neutrons in the nucleus, resulting in different atomic weights.[74] The technique of stable carbon isotope analysis depends upon the characteristic differences in the natural abundances of stable isotopes caused by isotopic fractionation (fluctuation in the carbon isotope ratios as a result of natural biochemical processes). Heavier and lighter isotopes of the same element undergo reactions at different rates. Stable isotopes of carbon ($^{13}C/^{12}C$) are the most widely used palaeodietary tracer and the abundance of these isotopes within a given sample (known as its isotopic ratio) is compared to the ratio of a known standard. The final calculated ratio, the delta C-13 value (δ13C), is expressed in parts per thousand or per mil (‰) difference from a standard.

Stable isotope analysis utilises the carbon content of carbon dioxide in the atmosphere that occurs primarily in the two isotopically stable forms of ^{13}C and ^{12}C. The level of these isotopes varies between different groups of animals and plants. This variation is because, as carbon diffuses into the pores of plants as carbon dioxide, differing groups of plants obtain carbon from the carbon dioxide in different ways. The C3 photosynthetic pathway, in which the first product of photosynthesis is a 3-carbon compound, is used by trees, shrubs, root crops and temperate grasses including domesticated grasses such as wheat, barley and rice. Tropical and sub-tropical grasses, which include the domestic crops sorghum, millets, maize and sugar-cane, employ what is known as the C4 pathway, in which carbon is fixed initially into a 4-carbon compound.[53]

The carbon isotope ratios of the two plant groups are quite distinctive; the C3 pathway plants have a $\delta^{13}C$ level ranging from 20 to 35‰ and the C4 plants a range from 9 to 14‰. The value of these two groups of plants does not overlap. Consequently, the different plant groups are incorporating differing amounts of the isotopes of carbon into their plant tissue. When these plants are consumed the carbon isotopes they contain are incorporated into the hydroxyapatite of bones and teeth and importantly in differing amounts. By quantifying the relative amount of each isotope within the hydroxyapatite, the main component of the diet is able to be identified.

Typically, the technique used in stable isotope analysis in relation to tooth enamel involves, firstly, pre-treating ground samples of enamel with bleach, such as sodium hypochlorite, to dissolve any organic components, followed by a weak acid, such as acetic acid, to remove non-biogenic carbonates. Samples are then freeze-dried and phosphoric acid added to the powder to release carbon dioxide. Carbon dioxide is then analysed in an isotope ratio mass spectrometer to determine the stable isotope abundance ratios.[75,76]

This technique has been used to demonstrate the increasing importance of rice over millet in a late Neolithic site in Shandong, China.[77] Stable isotope ratios of carbon and oxygen have helped in understanding Neolithic subsistence patterns in northern Borneo, and they have been used to trace the adoption and spread of maize agriculture in the woodlands of North America.[76,78]

As described above the element strontium is used in the technique of trace element analysis to identify geographical origins of an individual. Isotopes of strontium are also widely used in this same identification. The method consists of comparing $^{87}Sr/^{86}Sr$ values from the tooth enamel of ancient skeletal remains with the local strontium isotope signature determined from faunal and environmental samples. By this technique it has been possible to address archaeological questions regarding human residential mobility in areas of the world where strontium ratios are sufficiently varied to show differences between potential places of origin.[79]

MULTIPLE TECHNIQUES

Increasingly teeth are being analysed by more than one technique and an integrated research methodology is being adopted to reconstruct past subsistence activities. Comparing DMA information with the other techniques described above can yield a much more specific view of dietary habits than merely using a single method. Data from DMA and isotope analysis are often considered together to assess dietary changes through time.[80] Lillie and Richards[81] used both stable isotope analysis and dental palaeopathological evidence to help understand the transition from the Mesolithic to the Neolithic periods in the Ukraine.

CONCLUSION

The importance of diet in understanding past lifestyles cannot be underestimated since its effects are so influential upon the human body and an analysis of dietary patterns can provide insights into subsistence strategies and status differentiation. Determining dietary information of our ancestors can be difficult as there is frequently little direct archaeological evidence of the foodstuffs that were consumed. However, teeth are well preserved in archaeological remains often surviving long after their supporting structures have deteriorated.

The physical condition of the dentition can provide valuable information on diet and health status. Studies of macroscopic wear and dental microwear yield evidence of dietary texture. Biomonitoring of trace elements assist in evaluating an individual's nutritional and environmental status. Stable isotope analysis of tooth enamel is a technique that was first applied to the study of human subsistence in the 1970s but since then there has been a dramatic expansion of its applications and this technique now has a major role in the study of dietary patterns. Consequently, a comprehensive visual and scientific analysis of ancient teeth can provide a direct record of past diets, information that might otherwise not be retrievable from the archaeological record and which may help with a better understanding of earlier populations.

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