Hunter-gatherer dental pathology: Do historic accounts of Aboriginal Australians correspond to the archaeological record of dental disease?

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Abstract

Objectives: Studies of hunter-gatherer oral pathology, particularly in Australia, often focus upon dental wear and caries or assume that historic studies of Aboriginal people reflect the pre-contact past. Consequently the range of population variation has been underestimated. In this paper dental pathology from human remains from Roonka are compared to a model of dental pathology derived from historic studies. The aim is to identify aspects of dental pathology indicative of regional or intra population diversity.

Methods: Adult dentitions (n= 115) dating from the mid to late Holocene were recorded for the following conditions: dental wear, caries, periapical voids, calculus, periodontal disease and antemortem tooth loss. Statistical analysis was used to identify patterns of dental pathology and to identify causal relationships between conditions.

Results: Dental wear is marked while dental caries rates are extremely low. Other indications of dental pathology are uncommon (less than 7% of teeth affected). Temporal heterogeneity is apparent: there are three young adults with caries who died in the postcontact period. There is also a small group of middle age to old adults with disproportionate abscessing and pulp exposure who may represent temporal variation or heterogeneity in individual frailty.

Conclusions: The results confirm dental wear as the major cause of dental pathology in this group and that, at a general level, historic accounts do correspond with this archaeological sample. However, intra-sample heterogeneity is apparent while two dental conditions: calculus and periodontal disease along with the pattern of sex differences deviate from expectation demonstrating that to identify regional variation attention needs to be paid to the dentoalveolar complex as a whole.

Keywords:

dental anthropology, dental palaeopathology, hunter-gatherer, Aboriginal Australia, Roonka

Historically Australian Aboriginal people are characterized as experiencing severe and rapid dental wear often seen as characteristic of hunter-gatherer populations more generally (Barrett 1953; Campbell & Barrett 1953). Further work has identified regional differences in the rate and patterning of wear between different groups (Littleton et al. 2013; Molnar et al. 1989; Richards 1984). However, the focus on wear has meant that there has been little analysis of dental pathology either in terms of its relationship to wear or in relation to regional patterning. Yet it is the complexes of dentoalveolar conditions that are informative of patterns of food consumption, environmental exploitation and hygiene practices (Lukacs 2012).

Commonly, it has been assumed that historic studies of Aboriginal people prior to and soon after sustained contact with Europeans are reflective of conditions in prehistory. To what extent is that correct and how much intra- and interpopulation variability has been overlooked as a consequence? Most of the historic observations are from arid or northern regions of Australia. Certainly Europeans were struck by the combination of generally very perfect and beautiful teeth" (Eyre 1845 II:205) and the extensive wear of older people (Angas 1847; Taplin 1879). Systematic observations, however, though do not occur until the 1920s and from then to the 1960s there are a series of observations of dental pathology among remote Aboriginal populations, particularly by dentists associated with the University of Adelaide Dental School (Campbell 1938, 1939; Campbell & Lewis 1926; Cran 1957; Elphinstone 1971; Heithersay 1959; Moody 1949). It has often been explicitly assumed that these studies characterized pre-contact Aboriginal populations which were assumed to be one homogeneous group with little, if any, regional variation. Such a view is represented by Abbie's (1960: 142) comment that, "The normal aboriginal dentition is usually very good. The coarse diet ensures vigorous mastication and even wearing of the teeth. And as the teeth wear (ultimately down right to the level of the gums) secondary dentine is formed to prevent exposure of the pulp. Dental troubles such as malformations and periapical abscesses do occur but caries is practically unknown.” How accurate and generalizable is this view and what was the cause of ‘dental troubles’?

In this paper I use evidence from studies of Aboriginal people around the time of sustained European contact (Table 1) and an understanding of the relationship between dental conditions to clarify the possible linkages between dental wear and oral pathology. These are then assessed for the human remains from the site of Roonka in south-eastern Australia (Figure 1) in order to determine whether similar processes are likely to have produced the pattern of dental pathology seen in this sample. This, in turn, allows consideration of the nature of occupation and food consumption at the site.

INSERT TABLE 1 AND FIGURE 1

The comparison with historic material from known areas has the potential to identify which aspects of dental pathology were not constant among a “continent of hunter-gatherers” (Lourandos 1984) and hence indicative of regional or intra population diversity within Australia. Such diversity has been evidenced in studies of hunter-gatherers outside of Australia (e.g. Griffin 2014; Keenleyside 1998; Lieverse et al. 2007; Luna & Arranda 2014; Walker & Hewlett 1990).

The comparison undertaken in this paper is focussed upon the pattern and causal linkages of oral pathology more than the absolute frequency of conditions given the unavoidable differences in recording between observers. One problem is that archaeological samples are, except in very unusual circumstances, time averaged. It must be remembered, however, that frequently the same process affects historic samples from a period of rapid change; young people growing up in a different political and economic system may be exposed to a completely different set of stressors than the elderly. On the other hand, unless dental pathology is contributing to the cause of death in a sample, historic and archaeological observations are comparable since teeth are not subject to remodelling.

Dental Wear and Dental Pathology

Severe dental wear is certainly the characteristic of Australian Aboriginal teeth that has captured observers' attention. Most early descriptions of dental wear are qualitative but Campbell compiled data from his surveys in central Australia (Campbell 1939) and Barrett (1953) reported on Aboriginal adults at Yuendumu (Barrett 1953). Both used Broca's method for recording dental wear and classified individuals on the basis of the overall degree of wear. A significant proportion of people in both groups have severe wear (Broca stage IV: Excessive wear resulting in marked reduction in the crown portion of the tooth towards the cervical region) but there is little difference between the two groups. Heithersay (1960) also recorded dental wear at Haast's Bluff in the 1950s recording severe dental wear among older adults. His method of recording Broca's scores is different (he averaged the scores for each tooth in the mouth) but all individuals over the age of 50 had either marked or severe dental wear comparable with the observations at Yuendumu. Recent work by Clement et al. (2009) confirms that anterior teeth were more worn relative to posterior teeth at Haast's Bluff and Yuendumu although at Kalumburu (also recorded in the 1950s by the University of Adelaide Dental School) this bias towards the anterior teeth is not so clear. Similarly work by Moody (1949) in communities in Northern Australia in 1948 demonstrates severe wear among adults but primarily on the molars. In each case females are reported as having greater degrees of wear than males. For ease of comparison only data for old adults (50 years plus) has been presented in Table 1 (for locations see Figure 1). The data show relatively little difference between groups but wear among old adults does seem to have decreased as missions and settlements were established.

Understandings of dental wear in relation to dental pathology have focussed on the removal of dental enamel and its potential to expose new sites to oral microbes (Clarke & Hirsch, 1991), creating areas for food impaction, or removing areas of the crown susceptible to decay, particularly the fissure system on the occlusal surface (Newman 1999; Powell 1985). More recent perspectives have pointed out the relationship between the vigorous mastication or abrasion creating dental wear and disturbance of the oral biofilm thereby disturbing microbial communities which are consequential for the development of pathology (Griffin 2014; Selwitz et al. 2007).

Individual Dental Conditions

Caries is the localised demineralisation of the tooth's surface caused by the acidic by-products deriving from the metabolism by bacteria in the dental plaque of fermentable carbohydrates. The process results from frequent consumption of fermentable carbohydrates, host susceptibility including oral hygiene, and disturbance of the balance between commensal and pathogenic oral bacteria (Selwitz et al., 2007). It has been argued that there is competition between caries and the degree of dental wear that serves to remove the sites most likely for carious decay (Maat & Van Velde 1987) or disturb the oral biofilm (Griffin 2014; Selwitz et al. 2007). However, other work has suggested that wear can facilitate carious attack by exposing the dentine to cariogenic bacteria (Miles 1969; Silverstone 1981) or through facilitating root caries (Hillson 2001). Alternatively, it has been argued that the two conditions are independent of each other with caries incidence driven principally by diet (Meikeljohn et al. 1992).

It has sometimes been assumed that caries did not exist in Aboriginal groups prior to the introduction of European foodstuffs because of a lack of fermentable carbohydrates in the diet (Brown 2016). The observations of Aboriginal people prior to sustained European contact (Table 1) confirm the general lack of caries (rates less than 7% of teeth) especially for groups with very limited contact with Europeans (Campbell 1939). However, the low rates per tooth disguise the prevalence of caries in these groups where up to 40% of people had at least one carious lesion. The single contradictory report of caries in early groups is Elphinstone (1971) who noted multiple gross dental caries among a group of people without European contact in the Great Sandy Desert. Comparison of the percentage of people affected, however, shows a low prevalence of caries for this group. There are no data on the percentage of carious teeth for this group which makes Elphinstone’s observations hard to interpret.

The oral biofilm is also implicated in the formation of periodontal disease. Inflammation of the gingival margin is associated with an increase in plaque formation but the shift from gingivitis to periodontitis depends upon the host factors and the nature of the bacteria (Dumitrescu & Kawamura 2010). An immune-inflammatory response develops in the periodontal tissues in the chronic presence of plaque bacteria and results in the destruction of the periodontal structures (Pihlstrom et al. 2005). Gingival recession or the replacement of resorbed bone with gingiva give the tooth less support leading to tooth mobility and potentially tooth loss.

Dental calculus is mineralised plaque accumulating either above (supragingival) or below (subgingival) the gum line. Multiple factors are implicated in the formation of calculus including an alkaline oral environment (which can be the result of a diet high in protein), variation in salivary flow, the mineral content of water, silicon content of food and water, hydration and plaque accumulation (Lieverse 1999; Mandel 1990). While supragingival calculus is not associated directly with periodontal disease, subgingival calculus is associated with loss of the periodontal attachment and pocket formation (Dumitrescu & Kawamura 2010) although it may be that calculus provides a surface for biofilm attachment resulting in gingivitis i.e. periodontal infection preceding subgingival calculus (Jepsen et al. 2011; White

1977). This link, however, is not inevitable as Loe et al.'s study of Sri Lankan labourers shows calculus can be present without associated periodontal destruction (Clarke and Hirsch 1991; Loe et al. 1986).

It has been suggested that dental wear may promote gingivitis and dental calculus by creating larger areas for food impaction around the teeth (Lieverse et al. 2007). Alternatively, it may have a cleaning effect particularly in the presence of abrasives (Cran 1957). The studies of historic Aboriginal groups are contradictory in relation to periodontal disease. Most studies report common marginal gingivitis (Barrett 1953; Cran 1957; Elphinstone 1971; Moody 1949) and food debris but reports of calculus and severe periodontal disease are highly variable (Table 1). Cran (1957: 280) describes at Yuendummu in the early days of the mission 'not even in aged subjects was calculus found in large quantities' while deep periodontal pockets and recession of the gingivae was rare. In contrast, Moody recording dental pathology among Aboriginal people at Arnhem Land settlements noted that calculus was not common but that periodontal destruction was advanced in older people leading to possible exfoliation of teeth (Moody 1949). None of these reports mention any potential oral hygiene mesures such as using sticks or twigs to remove plaque and calculus deposits.

While dental wear has the potential to be protective in conditions associated with dental plaque, the exposure of the tooth pulp due to removal of the enamel (and dentine) or trauma results in periapical inflammation. These lesions of endodontic origin most commonly develop from exposure of the pulp to oral bacteria due to caries or severe wear exceeding the tooth's odontoblastic capacity or from trauma (Graves et al. 2011). The pulp becomes a reservoir of bacteria that cause inflammation in the periapical region and bone resorption. The infection persists and ultimately leads to the formation of granuloma or cysts (Dias et al. 2007). If infection is not contained, drainage occurs through the formation of fistula. In studies of dry bone with radiography it is the fistula that marks the presence of a lesion. Pulp disease can, however, induce periodontal lesions through the communicating channels (lateral and accessory canals) linking the peridontium to the pulp tissues, while apical lesions may extend and drain along the periodontium (Clarke & Hirsch 1991; Meng 1999). Thus periapical abscessing can lead to tooth loss particularly when combined with severe attrition and reduced root support (Clarke & Hirsch 1991).

Periapical lesions were observed among Aboriginal groups; Campbell recorded alveolar abscesses occurring in 19.4% of adult and 74.4% of old adult individuals (Campbell 1939). Moody (1949) also records high rates of abscessing among the older adults. In both instances lesions are associated with pulp exposure.

Antemortem tooth loss can therefore be the result of destruction of the periodontal support for the tooth due to periodontitis or periapical lesions and resultant loss of root support particularly in cases of severe wear. It can, however, also result from deliberate avulsion of the teeth, primarily anterior teeth. Avulsion was widespread but not ubiquitous among Australian Aboriginal men with historic accounts from a range of areas including the Northern Territory (Barrett 1953), Queensland (Elvery et al. 1998), New South Wales (Barker 1975) South Australia and Victoria (Campbell & Prokopec 1984; Durband et al., 2014)

Based on both the historic accounts of Aboriginal dental health and the relationships between dental conditions it should be expected therefore that, as with many other hunter-gatherer groups (Lukacs 1989), the predominant dental complex should be of primarily healthy dentitions with very severe wear (particularly among females) resulting in localised periapical lesions, but low rates of caries and low to moderate rates periodontal disease. Calculus deposition might be facilitated by the impaction of food but this relationship is not clear. In any case, rates of antemortem tooth loss should be low except for cases associated with severe wear or deliberate avulsion. This model provides a basis for assessing the impact of dental wear on dental pathology among pre-contact Aboriginal groups, particularly at the site of Roonka which is sufficiently large for the pattern and development of pathological conditions to be analysed.

Materials and Methods

Material

The remains studied come from the site of Roonka located adjacent to the Murray River, South Australia (Figure 1). The site is bordered by a lagoon and lies on the edge of the semi-arid mallee plain. In all a minimum of 216 individuals have been recovered from the site including 153 burials excavated from the main trench (Littleton et al. 2017; Pretty, 1977). Analysis of stable isotopes by Pate (1998, 2006) and excavations of a nearby rock shelter (Paton 1983) suggest people relied upon local riverine and terrestrial resources. Smith et al. (1988) undertook a description of the metric and non-metric characteristics of the teeth and the pattern of dental pathology in a smaller sample from the excavation. The current analysis is undertaken as part of a wider reanalysis in collaboration with local Aboriginal people.

The original dating of the site suggested that the use of the site for burials extended from 8000 years ago to the early post-contact period (i.e. mid-1800s) (Pretty 1977). More recent direct dating on a small number of burials indicates that burials occurred on site over the last 4000 years, that the site cannot be sequenced by burial style, and that site use may have been intermittent (Littleton et al. 2017). There is unavoidable time averaging as a result although, as shown below, potential temporal variability is at least partly apparent. The model of relationships between dental conditions outlined above provides a basis for assessing intra-population variability and its causes.

Methods

All individuals with eruption of the second molar were included in this analysis. Age was estimated using multiple indicators: pubic symphyseal aging (Brooks & Suchey 1990), sacroauricular aging (Lovejoy et al. 1985), and cranial suture fusion (Meindl & Lovejoy 1985). Tooth wear was not used since this would create circularity within the analysis. For younger individuals, closure of the epiphyseal surfaces (Scheuer & Black 2004) and dental formation and eruption were also used based on Australian Aboriginal data (Brown 1978). Estimated ages were combined into four groups: juveniles (12-16 yrs), young adults (17 – 35 yrs), middle adults (35-50 yrs), and old adults (50+).

Sex assignment was based on pelvic indicators, size of the femoral head, and robusticity of the cranial indicators (Buikstra & Ubelaker 1994) taking into account the greater robusticity of Australian Aboriginal characters (Brown 1981).

The dental conditions recorded were: dental wear, caries, calculus accumulation, periapical inflammation, periodontal disease (based on observation of the interdental septa) and antemortem tooth loss. Dental wear was scored using Littleton and Frohlich's modification of Scott's scoring system with each tooth scored from 1 (least wear) to 10 (tooth root function) (Littleton & Frohlich 1993, Scott 1979). Caries, based upon penetration of the enamel, was recorded by severity of the lesion and location on the crown (Buikstra & Ubelaker 1994). Non-carious pulp exposure was scored separately. Scoring of calculus followed Brothwell (1978) with a distinction made between supra- and subgingival accumulation. Periapical inflammation was recorded using the scale suggested by Dias and Tayles (1997). Scoring was based on macroscopic observation of periapical voids and thus does not include smaller lesions which do not penetrate the outer cortical bone and could only be identified radiographically. Scoring of the condition of the interdental septa followed Kerr (1988): 1. A normal healthy interdental septa; 2. Porosity, argued to be equivalent to gingivitis; and scores of 3 and above suggestive of periodontitis. Antemortem tooth loss (AMTL) was recorded using the guidelines as outlined in Buikstra and Ubelaker (1994). In a population with extensive dental wear it is possible for teeth to be maintained in the jaw even with significant resorption of the socket (Taylor 1991) so AMTL was recorded only on the basis of completely healed sockets.

Statistical analysis was undertaken using both the number of individuals and the number of teeth as well as the proportion of teeth affected per individual. Tests were undertaken using IBM-SPSS v23 statistics package and using non-parametric and parametric tests of significance as applicable. Comparisons of the distributions of pathology by age, sex and by sex controlling for age were undertaken using chi-square tests (including linear by linear association (LLA) for ordered variables or Fishers exact tests for 2 x 2 comparisons). Proportions of teeth affected within individuals were compared using either Mann-Whitney U for two samples or Kruskal-Wallis for multiple samples. Binary logistic regression was used to analyse the contribution of parameters such as age, gender, and wear to the presence or absence of pathology within individuals and on individual teeth while stepwise multiple regression was undertaken to analyse how these predictors and interactions among them account for variance in the percentage of teeth lost antemortem per individual. Odds ratios were also calculated in order to identify potential risk factors and sequelae in each tooth position.

Results

Sample Composition

The age and sex distribution of individuals and of the total number of teeth/sockets is shown in Table 2. The distribution of males and females by age group was not statistically significantly different (χ^2= 4.872, 4 df, p = 0.30) and there was no difference between the sexes in the average number of teeth (t-test =1.094, 85 df, p = 0.28). The average number of teeth per individual is 18.9 (sd = 10.62) and 22.8 sockets per individual (sd = 11.4).

INSERT TABLE 2

Wear

As expected, dental wear proceeded rapidly among the Roonka individuals with marked wear on the incisors as well as the first molar (Table 3). Despite the early eruption of the first molars relative to other teeth, all anterior teeth, including the later erupting canine, are worn nearly as much, if not more, than the first molar (Littleton 2017). By middle adulthood 47% of teeth were severely worn (stage 8 and above) comparable to the extent of wear seen among old adults at Yuendummu 1951-52 (Barrett 1953) suggesting that wear may be marginally more rapid than among the historic remains.

INSERT TABLE 3

Wear on the molars progressed regularly with age but wear on the anterior teeth is marked among young adults and severely worn among middle adults. There is little or no change between the middle and old adults and only moderate increases in wear on the premolars (Table 3, Figure 2).

INSERT FIGURE 2

As shown in Table 3 there is very little difference between the sexes in the degree of wear. When males and females are compared by age group the only statistically significant difference is that male lower canines are more worn than female among middle adults (Mann-Whitney U, $p = 0.008$). The lack of difference between males and females in wear on the premolars and molars is striking particularly given expectations from the historic data of gendered diets and work patterns (Campbell 1939).

Caries

Caries was observed among the Roonka remains but at a low rate: 5.2% of individuals (6/115) were affected and 0.4% of teeth (8/2111) (Table 4). These rates are markedly lower than those recorded for the historic groups. Carious lesions did not vary significantly with either age or sex although all but one affected individuals were young adults at the time of death.

INSERT TABLE 4

There were six people with caries - all in light or moderately worn teeth (i.e. wear with a score of less than five per cusp) except for Burial 85 where the affected UM1 was worn to stage 7 on each cusp (Table 5). Most caries were on the occlusal surface (4/8), three were interproximal and one was on the smooth surface with the molars affected (6/8 teeth) more than the anterior teeth (2/8 teeth). No lesions were at the cemento-enamel junction or root surfaces. The median degree of tooth wear for carious teeth was 4 compared to 6 for non-carious teeth, however, this difference was not statistically significant.

INSERT TABLE 5

The individuals with caries are probably not representative of the whole sample. Two (A20, and DNR 1963) had pipe facets indicative of a post-contact burial and a third individual (A_78) returned a radiocarbon determination which crosses into modern (Littleton et al. 2017). In these three instances it is possible that the caries is affected by the introduction of fermentable carbohydrates with European settlement. In two cases the date is uncertain and in one case (A-4) the radiocarbon date is mid-Holocene so it cannot be assumed that all caries is automatically indicative of a post-contact date (contra Brown 2017) but the probability is that even the low rate observed is inflated by the presence of post/peri-contact individuals.

Pulp exposure

Pulp exposure subsequent to dental wear was relatively common among individuals but with a low tooth prevalence (3%). There was a statistically significant relationship between the degree of wear on a tooth and whether or not pulp exposure was present (Mann-Whitney $U = 12884$, $n = 2093$, $p < 0.001$, Figure 3). Given the extent of wear it is surprising that not more pulp exposure was recorded but in general reparative dentine formation kept pace with removal of the tooth’s surface. Even when the tooth roots were functional (Stage 10) only

28% of teeth had any indication of pulp exposure. This ties with historic descriptions of the effectiveness of reparative dentine formation (Campbell & Barrett 1953).

INSERT FIGURE 3

In total 22.7% of people had pulp exposure with a statistically significant increase in exposure with age (Table 4, LLA = 29.89, 1 df, $p<0.001$). The same trend is seen in the percentage of teeth affected with age but the numbers remain low – only old adults have a median percentage of teeth affected greater than zero (K-W = 33.38, 4 df, $p < 0.001$). There was no statistically significant difference between the number of females and males with pulp exposure (Fishers exact, $p = 0.29$) or the percentage of teeth affected (Mann-Whitney U = 807.0, $p = 0.19$).

The teeth most commonly affected were the lower M1 (7.9%, n= 139), the lower M2 (8.3%, n=144) and the upper M1 (6.2%, n= 146). If only heavily worn teeth (wear scores of 9.1 and above) are considered, the molars and maxillary premolars are disproportionately affected compared to other tooth types ($\chi^2 = 18.6$, 5df, $p = 0.002$) so pulp exposure is not merely following wear but also tooth type.

Most people (83.6% of people with pulp exposure) only had one or two teeth affected (mean 1.45, n= 20). The distribution of the number of teeth, however, is unequal. Seven people (Table 6) had multiple teeth with pulp exposure including one woman (Trench A53) with seven exposed teeth suggesting a concentration of dental trauma or more rapid wear in a small group of individuals (mean 4.85 teeth, n = 7).

INSERT TABLE 6

Periapical voids

Overall 29.5% of individuals had some form of periapical void comprising 4.3% of teeth (Table 4). This condition is strongly associated with pulp exposure: 3.6% of non-carious teeth had voids (59/1642) but 50% of teeth with visible pulp exposure had voids (23/46).

Teeth with voids larger than 3mm had a median wear score of ten compared to a median score of six for teeth without any periapical void. Smaller voids had a lower median wear score (8) but without radiography relatively few of these lesions are visible. These differences in the degree of wear by void state were statistically significant (K-W = 52.172, 3 df, $p<0.001$).

The pattern of periapical voids across the mouth varies by tooth position with the mandibular M1 most commonly affected although the difference is not statistically significant ($\chi^2 = 3.36$, 2df, $p = 0.163$) even when only severely worn teeth are considered.

The probability of periapical inflammation is strongly associated with age with a major increase from young adults to middle adults and then to old adults (Table 4). Differences between the age groups and the presence of periapical voids were statistically significant both in terms of prevalence and the percent of teeth affected (LLA = 29.56, 1 df, $P <0.0005$, K-W = 34.71, 4 df, $p <0.001$). Females have a marginally higher frequency of inflammation but comparison of individuals and proportion of teeth affected by sex indicates this difference is not statistically significant ($p > 0.05$).

The percentage of teeth with periapical voids follows the same pattern as seen among individuals with the frequency of teeth increasing by age group (Table 4). There are no statistically significant differences between the numbers of males and females affected in the younger age groups but more males than females have voids in the oldest age group (Fishers exact, $p = 0.0052$).

Binary logistic regression was undertaken to assess the effect of sex, gender, age group, wear and pulp exposure on the presence or absence of a periapical void at a socket. The resultant model was statistically significant ($\chi^2 = 135.80$, $p < 0.0005$) and accounts for approximately 32.0% of the variance based upon Nagelkerke's R^2. Pulp exposure (B= -2.290, Wald = 31.99, $p < 0.001$) and wear (B = 0.652, Wald = 31.42, $p < 0.001$) were the parameters associated with periapical voids, sex and age group were not statistically significant ($p > 0.05$).

Of the 33 people with voids, 28 had no more than three with most having only one (average 1.57). Five individuals have 34 of the total 78 voids (43.6%) with an average of 6.8 (range 5 to 8) per individual. Two of these individuals are the same as those with extensive pulp exposure (Table 6) but there is not a perfect correlation between pulp exposure and periapical inflammation (13.4% of adults have non-concordant status i.e. either pulp exposure or periapical voids but not both). While most of the inflammation is endodontic in origin (voids located in the periapical region), micro-fracturing may have allowed entry of bacteria rather than the more overt pulp exposure.

Calculus

While 33.9% of individuals had calculus deposits only 6.9% of teeth were affected (Table 7) and most of these deposits are only slight accumulations on the most susceptible teeth – the buccal surface of the maxillary molars and the lingual surface of the mandibular incisors reflecting the position of the salivary ducts which contribute to an alkaline oral environment (Dumitrescu & Kawamura, 2010). Most deposits were supragingival and consisted of a thin band of mineralized plaque.

Comparing the number of individuals affected there were differences by age group (Table 6). The frequency of individuals with calculus increased markedly between middle and old adults but this difference is not statistically significant although the increase in the number of teeth by age group was statistically significant (LLA = 59.91, 1 df, $p < 0.0005$). Among both young and middle adults males have statistically significantly more calculus deposits than females (Fishers exact $p < 0.008$). Calculus accumulates with age so the increase is as expected, but the more frequent accumulation by the younger males suggests that there may be differences in oral ecology predisposing males to calculus at younger ages. None of these deposits are severe and they are on the least accessible teeth suggesting that the difference may be a reflection of dental hygiene or oral ecology rather than a systematic difference in diet (not apparent in the comparison of wear).

INSERT TABLE 7

Binary logistic regression was undertaken to ascertain the effects of age group, sex, attrition, caries, pulp exposure and abscessing on the deposition of calculus. The overall model was statistically significant ($\chi^2 = 78.24$, $p < 0.001$) explaining approximately 10.9% of the variance (Nagelkerke's R^2) in calculus. Old age (B = 1.618, Wald =10.4; p = 0.001) and female sex (B = -.441, Wald = 4.41, p = 0.036) were the only statistically significant parameters associated with calculus. Old adults are 5.04 times more likely to have calculus (and evidence suggests that older females are more affected) but overall females are less likely than males to have calculus (B = 0.643, CI: 0.426 - 0.971).

Periodontal disease

Periodontal disease beyond the level of mild porosity of the interdental septa (gingivitis) was uncommon and primarily concentrated upon the molars. Of the total number of individuals with observable septa 33.9% had evidence of moderate periodontal disease (i.e. Kerr's stages 3 and above) with 12.6% of observable septa (n= 1272) affected (Table 6).

Analysis of both the number of individuals (LLA = 10.49, 1 df, p < 0.001) and of tooth positions (LLA = 47.59, 1 df, p <0.001) demonstrated that moderate periodontal disease increased with age particularly between young to middle adults. Across these age groups the extent of periodontal disease per individual increases (Kruskal-Wallis = 11.09, 3 df, p = 0.011) but no individual had more than 40% of the observable septa with moderate periodontal disease – even among old adults the median percentage of sites affected was only 6.25.

There is a trend for higher rates of periodontal disease among women than men (Table 6) but considering the number of individuals this difference is not statistically significant (χ^2=1.615, df 2, p=0.142) although a higher percentage of females had more than 20% of sites affected. The number of teeth with moderate or severe periodontal disease is significantly different between the sexes (χ^2 = 5.850, df = 2, p=0.016). This difference is affected by age. There are no statistically significant differences between males and females when age is controlled except for older adults where a third of female septa are affected compared to 16 % of male septa (Fishers exact, p = 0.008).

The overall pattern particularly of moderate to severe periodontal disease is of disease concentrated around the molars while gingivitis is more common on the anterior teeth (figure 4).

INSERT FIGURE 4.

Binary logistic regression was used to determine which variables contributed to the presence of moderate to severe periodontal disease at individual septa. The model was statistically significant, (χ^2 = 94.50, p <0.0001). Although it explains only 15.6% (Nagelkerke R^2) of the variance it correctly classified 88.3% of cases. Calculus presence (B = 0.6; Wald = 4.092, p = 0.043), pulp exposure (B = -1.553, Wald = 13.391, p < 0.001), and female sex (B = 0.555, Wald = 7.324, p = 0.007) were all associated with an increased likelihood of periodontal disease. Females were 1.74 times more likely to have moderate to severe periodontal disease in individual septa. The variables of attrition, age, abscessing and caries yielded statistically insignificant results (p > 0.05).

AMTL

Antemortem tooth loss includes those incisors lost prematurely through deliberate tooth avulsion (Durband et al. 2014) and potentially trauma (De França Caldas & Burgos 2001). Apart from these lost teeth, the mandibular molars are the most frequently lost teeth (Figure 5). Overall, however, the frequency of AMTL is low: only 1.9% of teeth were lost prematurely affecting 20.9% of individuals (n=115). Not included in these calculations are the 19 (0.7%)instances of congenital absence (or possible impaction) of the third molars.

INSERT FIGURE 5

Rates of AMTL increased steadily with age (Table 6). The increase is statistically significant ($LLA_{individuals}$ = 15.79, 1 df, $p < 0.0005$; LLA_{teeth} = 29.10, 1 df, $p < 0.005$). Despite some males being subjected to tooth avulsion there is no statistically significant difference between the frequency of males and females with AMTL (Fishers exact test, $p > 0.05$) nor in the percentage of teeth lost per individual (Mann Whitney U = 1016, p=0.447). However, significantly more old adult male sockets had evidence of AMTL than female (Fishers exact test, p = 0.037).

This overall lack of difference in frequency obscures the different patterns of tooth loss: among women the mandibular molars (M1 and M2) are most commonly lost (Fishers exact p = 0.005) while among males the anterior maxillary teeth are most frequently lost (Fishers exact, p = 0.001) presumably reflecting the contribution of tooth avulsion although it is clear tooth avulsion was not universal among all males.

While AMTL is more common among old adults, no individual had lost more than one-third of their visible sockets. Generally only one tooth was lost (14/23 individuals with AMTL). The majority of these (11/14) are cases where the tooth loss is due to avulsion. The remaining cases include individuals with multiple anterior teeth lost possibly due to avulsion (2/23) and those who have lost molars (7/23). AMTL when it did occur in the posterior tooth positions most commonly affected more than the single tooth (5/8 cases). This patterning and the predominance of the mandibular molars corresponds to the pattern of periodontal disease among individuals, however, periapical infection is also most frequent on the first mandibular molar.

In order to evaluate possible relationships between AMTL and age group, gender and other pathological conditions, stepwise multivariate analysis was undertaken. The proportion of teeth abscessed was the only significant predictor (B = 0.663, p = 0.000) explaining 39.3% of the variance (adjusted R square) in the proportion of teeth lost antemortem.

Relationships between dental conditions

In order to identify the relationships between dental conditions on the same tooth, χ^2 tests were undertaken and odds ratios calculated for pairs of the following variables: severe wear (8+), caries, pulp exposure, abscessing, periodontal disease, and calculus deposits (Table 8). Odds ratios require careful interpretation since they could be biased by individuals with multiple and extensive dental conditions– in this case, however, the median number of affected teeth per individual for every pathological condition is low. Caries was not related statistically to any other condition, while severe wear was associated with all conditions though most strongly pulp exposure and abscessing. This relationship is confounded with age – both periodontal disease and calculus are observed to accumulate with age in populations not exposed to dental hygiene practices (White 1997) so it is possible that the association between these two conditions and wear reflects increasing wear with age rather than being a direct effect. As expected pulp exposure and severe wear are related to abscessing. There is, however, also a relationship between abscessing and pulp exposure with moderate to severe periodontal disease. This is in addition to the expected relationship between the presence of calculus on a tooth and periodontal disease. In this population the odds ratios for abscessing and pulp exposure relative to periodontal disease exceed those for calculus.

INSERT TABLE 8

DISCUSSION

Dental wear and Dental pathology

It is difficult in a sample where dental pathology is relatively uncommon to discern the linkages between dental conditions. Figure 6 depicts the relationships between conditions that have been highlighted through binary logistic regression, stepwise multivariate regression and odds ratios. The strength and direction of relationships is shown by the thickness of the arrows. Some relationships remain uncertain (e.g. between wear and caries). Dental pathology accumulates with age, particularly in populations without dental hygiene or treatment and it can be difficult to untangle the impact of dental wear from the effect of age since the two, particularly in a population with heavy and rapid dental wear are strongly correlated.

As the figure demonstrates, these relationships help confirm wear as the primary stressor upon the teeth and precursor or covariate with age to most dental conditions. Gender is implicated in conditions related to periodontitits but primarily through the greater susceptibility of females rather than any difference in wear. What also needs to be remembered, however, is how relatively uncommon dental pathology is in this sample.

INSERT FIGURE 6

Wear proceeds steadily in this population and there is very little difference in the gradient of molar wear between age groups, sexes or even between individuals. Wear on the anterior teeth is frequently greater or equivalent to the first molar reflecting the use of the teeth for non-masticatory purposes. This pattern of wear reflects age graded acquisition of tasks (Littleton 2017) but shows very little difference between males and females.

As predicted, extensive wear places stress upon the dentine potentially creating trauma as well as exposing the pulp - making the tooth susceptible to periapical inflammation. Both pulp exposure and periapical lesions were associated with the development of moderate to severe periodontitits as described by Clarke and Hirsch (1991). This pattern of disease is centered particularly upon the mandibular first molars probably due to series of reasons including the severity of wear on this tooth and its morphology (Barker 1975)

Calculus was not common in this group although deposition did occur more among young males, possibly because of oral ecology. However, this sex difference did not carry into older age groups. Analysis of individual teeth demonstrated that calculus was associated with periodontitis but it should be noted that most calculus deposits observed were supragingival. The same teeth susceptible to abscessing and periodontal disease are susceptible to AMTL but the rate of tooth loss was low and loss of the molars primarily a female pattern. This set of relationships is not accounted for by differences in the degree of dental wear on the molars but potentially may be associated with the morphology of the molars and the phenomenon of pregnancy periodontitis (Dumitrescu & Kawamura 2010) rather than any clear difference between the sexes in terms of food consumption (see also Pate1998), oral hygiene, or the abrasiveness of the diet.

As with many hunter-gatherer populations there were very few caries among the people from Roonka but even that low rate is potentially elevated by the inclusion of a small number of post-contact individuals at the site. From an early stage of European contact in the region rations of flour, sugar and tobacco were handed out (Eyre 1845) or given in exchange for service. Such contact does not, however, account for all cases of caries in the sample but caries is certainly not implicated in the development of other dental pathology. There is a negative relationship between dental wear and caries which might support the idea of caries-attrition competition (Maat & Van der Velde 1987) but the rarity of caries and the temporal heterogeneity at Roonka makes this difficult to evaluate with any certainty.

The relationship with historic samples

In comparison therefore with the potential set of relationships between dental conditions highlighted in studies of Aboriginal populations in the historic period, Roonka matches expectations: extensive dental wear from an abrasive diet as well as non-masticatory wear creating trauma to teeth. This resulted in a relatively low frequency of periapical inflammation which itself is related to low rates of periodontitis mainly accumulating among old adults. Rates of caries are even lower at Roonka than in any of the historic samples. Comparisons of the degree of wear with the historic populations are difficult given the nature of the observations but it seems possible that severe wear was more common among middle and older adults at Roonka suggesting higher abrasiveness of the diet which could be related either to the nature of the food or methods of cooking. This might account for the marginally higher total frequency of abscessing at Roonka although rates among old adults are very similar between Roonka and Yuendumu (Barrett 1953).

In contrast with some of these records, however, there is little evidence for the accumulation of calculus and its role in terms of periodontal disease was probably minor. Calculus is multi-factorial in nature so it is difficult to identify any precise cause for variation in the rate of calculus deposition. However, as with the Lake Baikal samples (Lieverse et al. 2007) calculus rates vary regionally both in recent historic and archaeological samples in Australia. One possible cause here is the contribution of starch to the overall dietary intake. Calculus was ubiquitous among skeletons from further upriver at Euston (Brown 1978). These calculus deposits also included high levels of coarse vegetable matter while the ethnohistoric records emphasise the reliance of local populations upon the processing of typha both for netting and for extracting starch which was then baked (Beveridge 1889). At Roonka the pattern of wear and the ethnohistoric record suggests processing of typha and other grasses for netting and basketry (Eyre 1845) but the lack of calculus may indicate lesser reliance upon starch as a major part of the diet. Hence calculus and periodontal disease (both of which have been relatively understudied) are likely to be significantly reflective of ecological differences between Aboriginal populations while dental wear because of its ubiquity and dental caries because of its rarity are potentially less informative.

The other difference between Roonka and the historic populations is the overall lack of difference in dental wear and pathology between males and females. While females experienced higher rates of periodontal disease and tooth loss at older ages, there were no differences in the amount of tooth wear by sex which contrasts with many of the observations made in the historic period. These observations center around the hard work undertaken by women relative to men (Curr 1883:258; Krefft 1865: 361) and differences in foraging between the sexes as the following quote demonstrates: “The womenfolk would naturally tend to consume a greater proportion of the type of foods they spend their time in collecting. These are, in particular, those vegetable foods which are pulled or dug up from the ground; and in eating such foods considerable sand and grit is chewed as well. Then in the distribution of meat food, the women generally receive as their share the tougher and more sinewy parts of the carcass. Thus a more marked wear of the females’ teeth is rather to be expected. ” (Campbell 1939:147).

There is no evidence of this sex difference at Roonka but there are major ecological differences between arid central Australia and a riverine economy. In particular, it seems likely that women at Roonka would have more access through their own efforts to meat sources including fish, mussels and small marsupials. Carbon and nitrogen stable sotope analysis of collagen by Pate (1998, 2006) does not show evidence of significant sex differences suggesting a similar intake of animal protein sources. Comparably the dental wear analysis (Littleton 2017) suggests a lack of difference in abrasiveness (which was probably high for both males and females). One cannot assume from this, however, that there was an absence of a gender division in food since our indicators are partial and time averaged.

What is clear at Roonka but not evident in the historic accounts is that dental disease was unequally distributed – while most old adults had severely worn teeth relatively few ended up with any periapical lesions or antemortem tooth loss (apart from that caused by avulsion). Yet there is a small group of middle and old adults with extensive periapical abscessing and antemortem tooth loss suggesting that the burden of dental disease was unequally born either within communities or through time. In these individuals, reparative dentine formation, which has managed to protect pulp cavities in most teeth, has not kept pace suggesting that a small group who either experienced more rapid and extensive dental wear or who were, once teeth were worn, more susceptible to breakdown and exposure of the pulp cavity. There is no apparent reason why this group exists but it should be noted that the associated dates for these individuals are earlier in the sequence and not within the last 500 years of the site which may suggest that, like the post-contact group with caries, they reflect temporal variation. This potential intra-sample heterogeneity is also suggested in a recent study of microwear texture analysis which identified a smaller group with higher measures of surface complexity and total fill volume both indicative of abrasiveness (Smith & Littleton 2017).

Conclusion

The Roonka sample corresponds to what we have come to expect in terms of hunter-gatherers and more specifically Australian Aboriginal dental pathology prior to European contact: high rates of wear. In general, however, this wear that keeps pace with reparative dentine formation so that pulp exposure, even though it occurs in middle aged and older adults, often does not result in extensive periapical inflammation or AMTL. The characterisation of traditional Aboriginal dentitions as markedly healthy with limited dental pathology primarily restricted to old adults holds suggesting that historic accounts are, at a broad level of generalisation, true of dental conditions on the continent prior to European contact. However, that generalisation can only be held so far: at Roonka the prevalence of calculus, patterns of periodontal disease and sex differences in the pattern of dental pathology all vary from expectation. Similarly the degree of wear probably does vary but a lack of detail in historic accounts makes this hard to define. Furthermore the identification at Roonka of a small group of middle to old adults with concentrated dental pathology raises the issue of intra-sample heterogeneity which may result from temporal changes or from intrinsic variation in susceptibility between people from the same location. All of which supports Lukacs' (2012) contention that it is the study of the dentoalveolar complex which is revealing of patterns of dietary and regional diversity not simply focus upon one or two features such as caries and wear.

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Literature Cited

Abbie, A. A. (1960). Physical changes in Australian Aborigines consequent upon European contact. Oceania, 31, 140-144.

Angas G. (1847). Savage Life and Scenes. London: Smith, Elder and Co.

Barker, B. C. W. (1975). Periodontal disease and tooth dislocation in aboriginal remains from Lake Nitchie (NSW), West Point (Tasmania) and Limestone Creek (Victoria). Archaeology and Physical Anthropology in Oceania, 10, 185-217.

Barrett, M. J. (1953). Dental observations on Australian Aborigines: Yuendumu, Central Australia, 1951–52. Australian Journal of Dentistry, 57, 127-138.

Beveridge, P. (1889). The Aborigines of Victoria and Riverina. Melbourne: ML Hutchinson.

Brooks, S., & Suchey, J. M. (1990). Skeletal age determination based on the os pubis: a comparison of the Acsádi-Nemeskéri and Suchey-Brooks methods. Human Evolution, 5, 227-238.

Brothwell, D. R. (1981). Digging Up Bones: the Excavation, Treatment, and Study of Human Skeletal Remains. New York: Cornell University Press.

Brown, P. (1978). The Ultrastructure of Dental Abrasion: Its Relationship to Diet. Unpubd. BA Hons Thesis. Canberra: Australian National University.

Brown, P. (1981). Sex determination of Australian Aboriginal crania from the Murray River Valley: a reassessment of the Larnach and Freedman technique. Archaeology in Oceania, 16, 53-63.

Brown, P. (2016) Roonka. Retrieved from: http://www.peterbrown-palaeoanthropology.net/Roonka.html.

Brown, T. (1978). Tooth emergence in Australian Aboriginals. Annals of Human Biology, 5, 41-54.

Buikstra, J. E., & Ubelaker, D. H. (1994). Standards for data collection from human skeletal remains. Fayetteville: Arkansas Archaeological Survey, Research Series No. 44.

Campbell, A. H., & Prokopec, M. (1984). Antiquity of tooth avulsion in Australia. Artefact, 8, 3-9.

Campbell, T. D. (1938). Observations on the teeth of Australian Aborigines, River Diamentina, South Australia. Australian Journal of Dentistry, 42, 121-124.

Campbell, T.D. (1939). Food, food values and food habits of the Australian Aborigines in relation to their dental conditions. Part I. Australian Journal of Dentistry, 43, 2–15.

Campbell, T. D. & Barrett, M. J. (1953). Dental observations on Australian Aborigines: a changing environment and food pattern. Australian Journal of Dentistry, 57, 1-6.

Campbell, T. D. & Lewis, A. J. (1926). The aborigines of South Australia: dental observations recorded at Ooldea. Australian Journal of Dentistry, 30, 371-376.

Clarke, N. G. & Hirsch, R. S. (1991). Physiological, pulpal, and periodontal factors influencing alveolar bone. In M. Kelley and C. Larsen (eds), Advances in Dental Anthropology (pp, 241-266). New York: Wiley-Liss.

Clement, A., Hillson, S., de la Torre, I., & Townsend, G. (2009). Tooth use in Aboriginal Australia. Archaeology International, 2007, 37-41.

Cran, J. A. (1957). Notes on the teeth and gingivae of Central Australian Aborigines. Australian Dental Journal, 2, 277-282.

Curr, E. M. (1883). Recollections of Squatting in Victoria then called the Port Phillip district from 1841 to 1851. Melbourne: George Robertson.

De França Caldas, A. & Burgos, M. E. A. (2001). A retrospective study of traumatic dental injuries in a Brazilian dental trauma clinic. Dental Traumatology, 17: 250–253.

Dias, G. J., Prasad, K. & Santos, A. L. (2007). Pathogenesis of apical periodontal cysts: guidelines for diagnosis in palaeopathology. International Journal of Osteoarchaeology, 17, 619-626.

Dias, G. & Tayles, N. (1997). 'Abscess cavity'—a misnomer. International Journal of Osteoarchaeology, 7, 548-554.

Dumitrescu, A. L. & Kawamura, M. (2010). Etiology of periodontal disease: dental plaque and calculus. In A. Dumitrescu (ed.), Etiology and Pathogenesis of Periodontal Disease (pp.1-38). Berlin, Heidelberg: Springer-Verlag.

Durband, A. C., Littleton, J. & Walshe, K. (2014). Patterns in ritual tooth avulsion at Roonka. American Journal of Physical Anthropology, 154, 479-485.

Elphinstone, J. J. (1971). The health of Australian Aborigines with no previous association with Europeans. The Medical Journal of Australia, 2, 293-301.

Elvery, M. W., Savage, N. W. & Wood, W. B. (1998). Radiographic study of the Broadbeach Aboriginal dentition. American Journal of Physical Anthropology, 107, 211–219.

Eyre. E. J. (1845). The manners and customs of the Aborigines and the state of their relations with Europeans. London: T and W Boone.

Graves, D. T., Oates, T., & Garlet, G. P. (2011). Review of osteoimmunology and the host response in endodontic and periodontal lesions. Journal of Oral Microbiology, 3, 5304 - DOI: 10.3402/jom.v3i0.5304

Griffin, M. (2014) Biocultural implications of oral pathology in an Ancient Central California Population. American Journal of Physical Anthropology, 154, 171-188.

Heithersay, G. (1959). A dental survey of the aborigines at Haast's Bluff, Central Australia. Medical Journal of Australia, 1, 721-729.

Hillson, S. (2001). Recording dental caries in archaeological human remains. International Journal of Osteoarchaeology 11, 249–289.

Jepsen, S., Deschner, J., Braun, A., Schwarz, F. & Eberhard, J. (2011). Calculus removal and the prevention of its formation. Periodontology 55, 167–188.

Keenleyside, A. (1998.) Skeletal evidence of health and disease in Pre-contact Alaskan Eskimos and Aleuts. American Journal of Physical Anthropology, 107: 51–70.

Kerr, N. W. (1998). The prevalence and natural history of periodontal disease in Britain from prehistoric to modern times. British Dental Journal, 185, 527-535.

Krefft, G. (1866). On the manners and customs of the Aborigines of the Lower Murray and Darling. Transactions of the Philosophical Society of NSW 1, 357–74.

Lieverse, A. R., Link, D. W., Bazaliiskiy, V. I., Goriunova, O. I. & Weber, A. W. (2007). Dental health indicators of hunter-gatherer adaptation and cultural change in Siberias Cis-Baikal. American Journal of Physical Anthropology, 134, 323–339.

Lieverse, A. R. (1999). Diet and the aetiology of dental calculus. International Journal of Osteoarchaeology, 9, 219-232.

Littleton, J. (2017). Dental wear and age grading at Roonka, South Australia. American Journal of Physical Anthropology, 00, 1–12. DOI: https://doi-org.ezproxy.auckland.ac.nz:9443/10.1002/ajpa.23226

Littleton, J. & Frohlich, B. (1993). Fish-eaters and farmers: Dental pathology in the Arabian Gulf. American Journal of Physical Anthropology, 92, 427-447.

Littleton, J., Petchey, F., Walshe, K., & Pate, D. (2017) Preliminary redating of the Holocene Roonka burials, southeastern Australia. Archaeology in Oceania. doi:10.1002/arco.5126

Littleton, J., Scott, R., McFarlane, G., & Walshe, K. (2013). Hunter-gatherer variability: Dental wear in South Australia. American Journal of Physical Anthropology, 152, 273-286.

Lovejoy, C. O., Meindl, R. S., Pryzbeck, T. R. & Mensforth, R. P. (1985). Chronological metamorphosis of the auricular surface of the ilium: a new method for the determination of adult skeletal age at death. American Journal of Physical Anthropology, 68, 15-28.

Löe, H., Anerud, A., Boysen, H. & Morrison, E. (1986). Natural history of periodontal disease in man. Journal of Clinical Periodontology, 13, 431-440.

Lourandos, H. (1997). Continent of Hunter-gatherers: New Perspectives in Australian Prehistory. Cambridge: Cambridge University Press.

Lovejoy, C. O., Meindl, R. S., Pryzbeck, T. R. & Mensforth, R. P. (1985). Chronological metamorphosis of the auricular surface of the ilium: a new method for the determination of adult skeletal age at death. American Journal of Physical Anthropology, 68, 15-28.

Lukacs J. (1989). Dental paleopathology: Methods for reconstructing Dietary Patterns. In K. Kennedy & M. Y. Iscan (eds), Reconstruction of Life from the Skeleton (pp. 261–86). New York: AR Liss.

Lukacs, J. R. (2012). Oral health in past populations: context, concepts and controversies. In A Grauer (ed.), A Companion to Paleopathology (pp. 553-581). New York: John Wiley and Sons.

Luna, L. H. & Aranda, C. M. (2014). Trends in oral pathology of hunter-gatherers from Western Pampas, Argentina. Anthropological Science, 122, 55-67.

Maat, G. J. & Van der Velde, E. A. (1987). The caries-attrition competition. International Journal of Anthropology, 2, 281-292.

Mandel, I. D. (1990). Dental calculus (calcified dental plaque). In R. J. Genco, H. M. Goldman & D. W. Cohen (eds), Contemporary Periodontics (pp. 135-146). St Louis: Mosby.

Meiklejohn, C., Wyman, J. M., & Schentag, C. T. (1992). Caries and attrition: Dependent or independent variables? International Journal of Anthropology, 7, 17-22.

Meindl, R. S. & Lovejoy, C. O. (1985). Ectocranial suture closure: A revised method for the determination of skeletal age at death based on the lateral-anterior sutures. American Journal of Physical Anthropology, 68, 57-66.

Meng, H. X. (1999). Periodontal abscess. Annals of Periodontology, 4, 79-82.

Miles, A. E. W. (1969). The Dentition of the Anglo-Saxons [Abridged]. Proceedings of the Royal Society of Medicine 62, 1311–1315.

Molnar, S., Richards, L., McKee, J. & Molnar, I. (1989). Tooth wear in Australian Aboriginal populations from the River Murray Valley. American Journal of Physical Anthropology, 79, 185-196.

Moody, J. (1949). Supplementary data provided to the Nutrition Group of the Arnhem Land Scientific Expedition, 1948. Australian Journal of Dentistry, 53, 145-152.

Newman H. N. (1999). Attrition, eruption, and the periodontium. Journal of Dental Research 78,730–734.

Pate F. D. (1998). Stable carbon and nitrogen isotope evidence for prehistoric hunter-gatherer diet in the lower Murray River basin, South Australia. Archaeology in Oceania 33, 92–99.

Pate, F. D. (2006). Hunter-gatherer social complexity at Roonka Flat, South Australia. In B. David and I. McNiven (eds), The Social Archaeology of Australian Indigenous Societies, (pp.226-242). Canberra: Aboriginal Studies Press.

Paton, R. C. (1983). An Analysis of Aboriginal Subsistence in the Lower Murray District, South. (Unpublished Honours thesis). Australian National University, Canberra.

Pihlstrom, B. L., Michalowicz, B. S. & Johnson, N. W. (2005). Periodontal diseases. The Lancet, 366, 1809-1820.

Powell, M. L. (1985). The analysis of dental wear and caries for dietary reconstruction. In: R. Gilbert & J. Mielke, (eds), The Analysis of Prehistoric Diets (pp 307– 338). Orlando: Academic Press.

Pretty, G. L. (1977). The cultural chronology of the Roonka Flat: a preliminary consideration. In R. Wright (ed.) Stone Tools as Cultural Markers, (pp. 288–331). Canberra: Australian Institute of Aboriginal Studies.

Richards, L. C. (1984). Principal axis analysis of dental attrition data from two Australian Aboriginal populations. American Journal of Physical Anthropology, 65, 5-13.

Scheuer, L. & Black, S. (2004). The juvenile skeleton. Academic Press.

Scott, E. C. (1979). Principal axis analysis of dental attrition data. American Journal of Physical Anthropology, 51, 203-211.

Selwitz, R. H., Ismail, A. I. & Pitts, N. B. (2007). Dental caries. The Lancet, 369, 51-59.

Silverstone, L. M. (1981). Dental Caries: Etiology, Pathology and Prevention. New York: Macmillan.

Smith, P., Prokopec, M. & Pretty, G. (1988). Dentition of a prehistoric population from Roonka Flat, South Australia. Archaeology in Oceania, 23, 31-36.

Smith, C. & Littleton, J. (2017) Dietary variability and age-related behavioural changes among hunter-gatherers from Roonka, South Australia. Poster presented at Annual Meeting of the American Association of Physical Anthropology, 21 April, New Orleans.

Taplin, G. (1879). The Folklore, Manners and Customs of the South Australia Aborigines. Adelaide: E Spiller.

Taylor, R. (1991). Anatomy and biology of tooth dislocation and wear in the Pre-European Maori and Australian Aborigine. Unpubd PhD Thesis Auckland: University of Auckland.

Walker, P. L. & Hewlett, B. S. (1990). Dental health diet and social status among Central African foragers and farmers. American Anthropologist, 92, 383-398.

White, D. J. (1997). Dental calculus: recent insights into occurrence, formation, prevention, removal and oral health effects of supragingival and subgingival deposits. European Journal of Oral Sciences 105, 508–522.