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Caries and Periodontal Disease in Rice-Cultivating Yayoi People of Ancient Japan

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1. Introduction

The people of the Yayoi period were the first wet-rice agriculturalists in Japan, and the people of modern Japan are the direct descendents of the Yayoi people. They dominated the Japanese archipelago from the 5th C B.C. to 3rd C A.D. The remains of the Yayoi people have been excavated from several sites in western Japan. It has been proposed that the Yayoi originated in East Asia, based on the morphologic characteristics of the skull and teeth (Hanihara, 1993), as well as genetic evidence(Omoto & Saitou, 1997) . Agriculture practices during the Yayoi period in Japan closely resembled those in southern China and Korea. Based on these findings, the Yayoi people are believed to have been migrants from the Asian continent who introduced wet-rice agriculture to the Japanese islands (Temple, 2010).

Previous studies of ancient populations have revealed a close relationship between oral disease and subsistence patterns (Eshed *et al.*, 2006). In Japan, the incidence of carious teeth among Yayoi period agriculturalists was found to be higher than that among hunter-gatherers from the preceding Jomon period (Temple & Larsen, 2007). Temple and Larsen (Temple & Larsen, 2007) reported that dietary and behavioral variations among the people of the Yayoi period during the transition to an agriculture-based society precipitated an increase in the frequency of carious teeth, as well as variations in carious tooth frequency, based on geographic location and sex.

Most of the carious lesions in ancient populations occurred at or near the cemento-enamel junction–alveolar crest (CEJ–AC). (Hildebolt *et al.*, 1988, Kerr *et al.*, 1988, Lunt, 1974, Moore & Corbett, 1971, Moore & Corbett, 1975, Varrela, 1991, Vodanovic *et al.*, 2005) These lesions appear to be associated with an exposed root surface caused by alveolar bone recession, although a definitive conclusion has not been reached. Exposure of the root surface is a prerequisite for carious lesions of the root, and alveolar bone loss is a major cause of such exposure. Therefore, root caries may occur as a result of alveolar bone loss.

Using multiple sets of remains from the Yayoi period, we investigated carious disease(Haraga, 2006) and alveolar bone loss(Uekubo, 2006) among the Yayoi people. Moreover, we identify the factors associated with root caries, and examine the relationship between root caries and alveolar bone loss(Otani *et al.*, 2009). Our findings may be useful for investigating the pathology of root caries in relation to the Yayoi diet.

2. Relationship between root caries and alveolar bone loss Yayoi people of ancient Japan

2.1.1 Material

We studied 5,010 teeth and the surrounding alveolar bones in 263 ancient human skeletal remains excavated at 49 archeological sites, and which are preserved at the Kyushu University Faculty of Medicine. The distribution of each site are shown in Figure 1. The remains, which were classified as belonging to the Yayoi period, included 152 males, 100 females, and 11 unknowns. The remains were further categorized by age as follows: young adults (estimated age 20–39 years, n = 126), and elderly (estimated age 40–59 years, n = 137). Gender and age were assigned in accordance with the standard procedures of the Department of Anatomy, Faculty of Medicine, Kyushu University. Only remains with teeth and alveolar bone were selected.

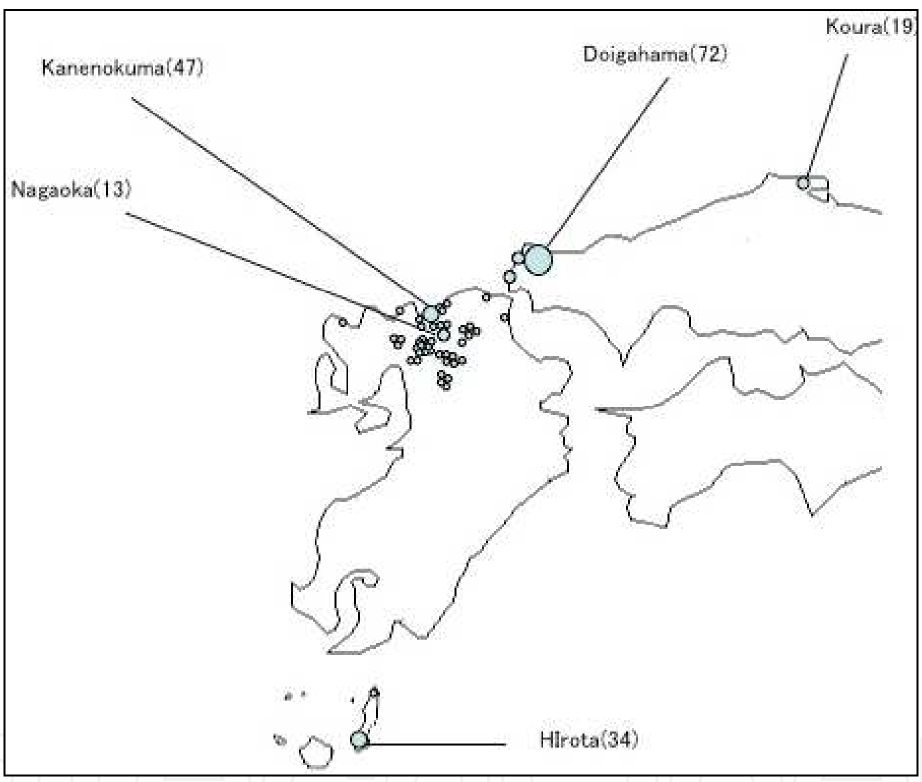

Fig. 1. Location of sites

2.1.2 Methods

Only those teeth with obvious cavities were recorded as being carious (Figure 2). Color changes to the enamel that lacked well-defined cavity edges, possibly as a result of erosion, were not considered to be evidence of caries. Caries was detected on nine different tooth surfaces: the occlusal surface; the distal, buccal, mesial, and lingual (palatal) surfaces of the crown; and the distal, buccal, mesial, and lingual (palatal) surfaces of the root.

Gingivitis leaves no trace in alveolar bone, whereas periodontitis causes alveolar bone loss. Accordingly, periodontitis can be evaluated using bone loss as an index. We measured the CEJ–AC distances only in jawbone specimens with alveolar bone remaining around the teeth using a periodontal probe. Up to four tooth surfaces (distal, buccal, mesial, and lingual/palatal) were examined, and the measurements are expressed in millimeters. For tilted teeth, we measured the vertical distance. Teeth with a fractured alveolar crest or that were missing were excluded from the analysis. Teeth were also excluded if the alveolar bone on the buccal side was lost due to physiologic fenestration or a lesion in the root apex.

Fig. 2. Caries in Yayoi people

2.2 Distribution of dental caries in Yayoi people

The distribution and site characteristics of dental caries previously identified in a Yayoi population using the aforementioned procedure. We examined 5010 teeth, 941 teeth were classified as antemortem teeth, and 998 teeth were classified as postmortal loss (Otani *et al.*, 2009) (Table 1). The number of teeth in each individual ranged from a minimum of 2 to a maximum of 32, with an average of 19.5. The total number of carious teeth was 883, for a cares ratio of 17.6%. The percent of individuals with caries was 79.1%, and the percent of individuals with root caries was 65.8%

Our analyses indicated that among the Yayoi people, most caries occurred in the root area, particularly on the approximal surface of the tooth root (Haraga, 2006). Moreover, Figure 3 shows the distribution of caries by tooth surface. When categorized into 3 groups, namely occlusal, , the occlusal surface percentage was 10.4%, the crown and root were compared, the crown ratio was 37.4% and the root ratio was 52.2%. When Caries location was classified into 9 tooth surfaces as follows: occlusal surface, crown buccal surface, crown lingual surface, crown approximal surface, root buccal surface, root lingual surface, and root approximal surface. The caries frequency was highest in the root approximal surface area, followed in order by the crown approximal surface and root buccal surface, while it was lowest in the buccal and lingual surfaces of both the crown and root.

Number of teeth present	Mean number of teeth present per person(SD)	Number of antemortem teeth	Number of postmortem teeth	Number of teeth lost at unknown timing	Number of carious teeth	Rate of caries (%)[a]	Caries prevalence (%)[b]	Root caries prevalence (%)[c]
5010	19.5(7.1)	941	998	999	883	17.6	79.1	65.8

[a] Rate of caries: Number of carious teeth / Number of teeth present × 100
[b] Caries prevalence (%): Number of individuals with caries/ Number of individuals× 100
[c] Root caries prevalence (%)[c]: Number of individuals with root caries/ Number of individuals× 100

Table 1. Number of teeth present, deciduous teeth, and teeth with caries, and rate and prevalence of caries.

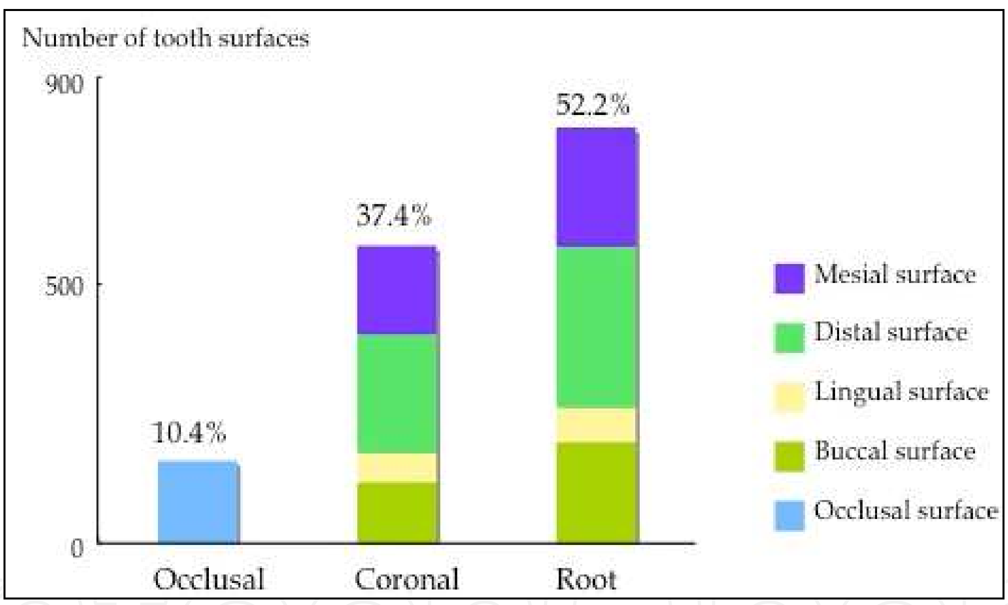

Fig. 3. Distribution of caries by tooth surface

In contrast, we analyzed caries in the Yayoi people and determined the first caries attack site (Haraga, 2006). For determining where caries began in Yayoi people, only caries observed independently on the occlusal surface, crown and root were counted by tooth surface (Figure 4). Large cavities (e.g., spreading in both the tooth crown and root) were excluded from this analysis, and the carious surfaces that were located in only a limited area, such as pits and fissures, crowns, and root surfaces, were determined with certainty as cases. As for the third molar, caries beginning in the occlusal surface accounted for 33.3% in the maxilla and 44.4% in the mandible. Caries beginning in the occlusal surface area were not observed in the upper first premolars and the first molars, the lower first and second premolars, or the first molars. Caries that began in the molars most often originated in the root (70.5% to 86.3%). The percentage of caries beginning in the occlusal surface, crown, and root was

6.9%, 26.9%, and 66.3%, respectively. Thus, most of the molar surfaces affected during the first caries attack were located in the root area. Therefore, these carious lesions may have been initiated in the root area in the Yayoi people. These observations indicate a different pathology from that seen in modern people. Thus, the mechanisms underlying the development of root and coronal caries in the people of the Yayoi period may be different from those in modern people.

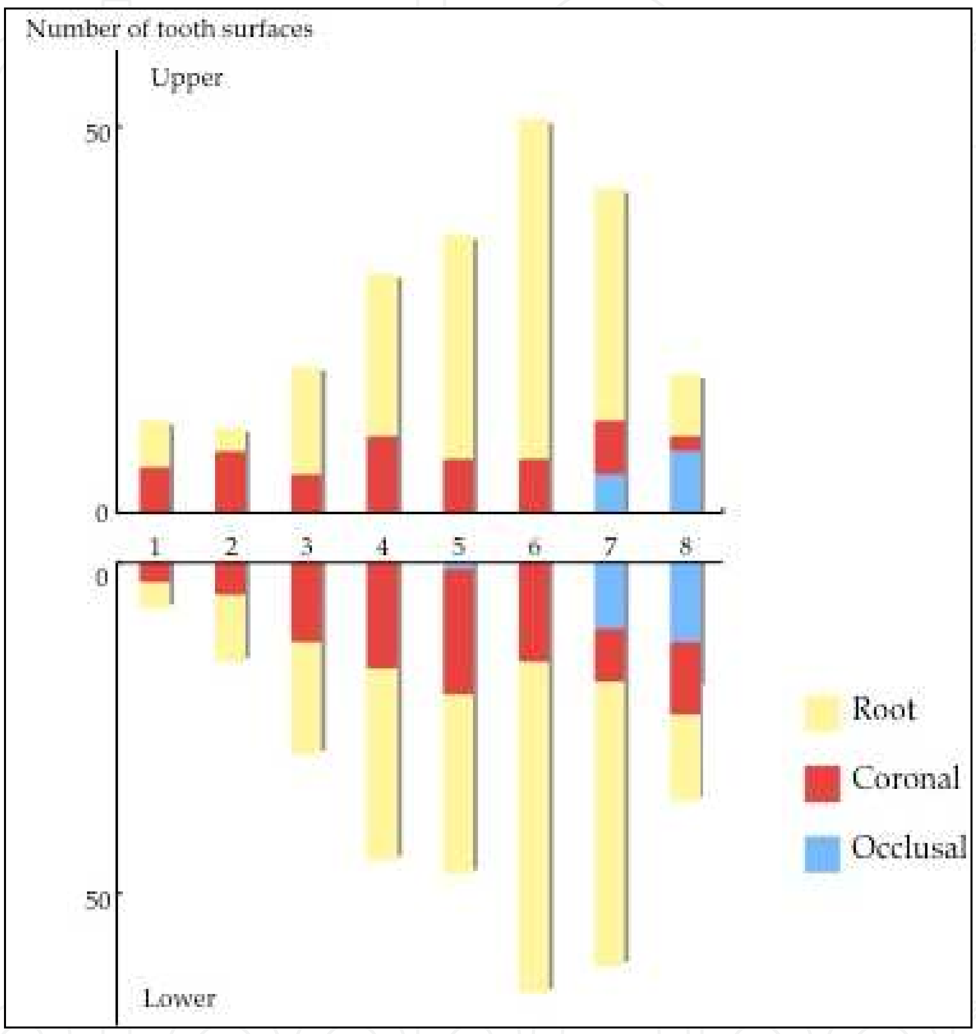

Fig. 4. Distribution of "primary caries" by tooth surfaces in Yayoi people

We have presented here the frequencies of carious lesions in younger and elderly people according to tooth type in Yayoi people (Fig. 5). It is clear that the frequncy of carious lesions was higher in the elderly (Haraga, 2006). In the modern Japanese, the caries ratios in the first molars of younger and elderly people are very similar (Fig 6). These findings also support the suggestion that most of the caries was found in the root area in Yayoi people, likely following the establishment of periodontal disease.

The location of dental caries in the people of the Yayoi period differs from that seen in modern Japanese people. In the skeletal remains of the Yayoi, most carious lesions were located in the root area, while in modern populations, most of these lesions are in the crown. This difference is considered to be associated with dietary variation, particularly the consumption of cariogenic foodstuffs. During the digestion of staple foods, such as rice, acid production causes tooth decalcification (Tayles *et al.*, 2000). Moreover, cooked starch is more easily degraded and fermented by bacteria (Lingstrom *et al.*, 1989). The Yayoi people engaged mainly in agriculture, in contrast to their forebears, the Jomon. Indeed, the Yayoi utilized an advanced system of wet-rice agriculture, which supported an increase in population density in western Japan during the Yayoi period. The increase in whole dental caries was associated to a great extent with the increase in root caries.

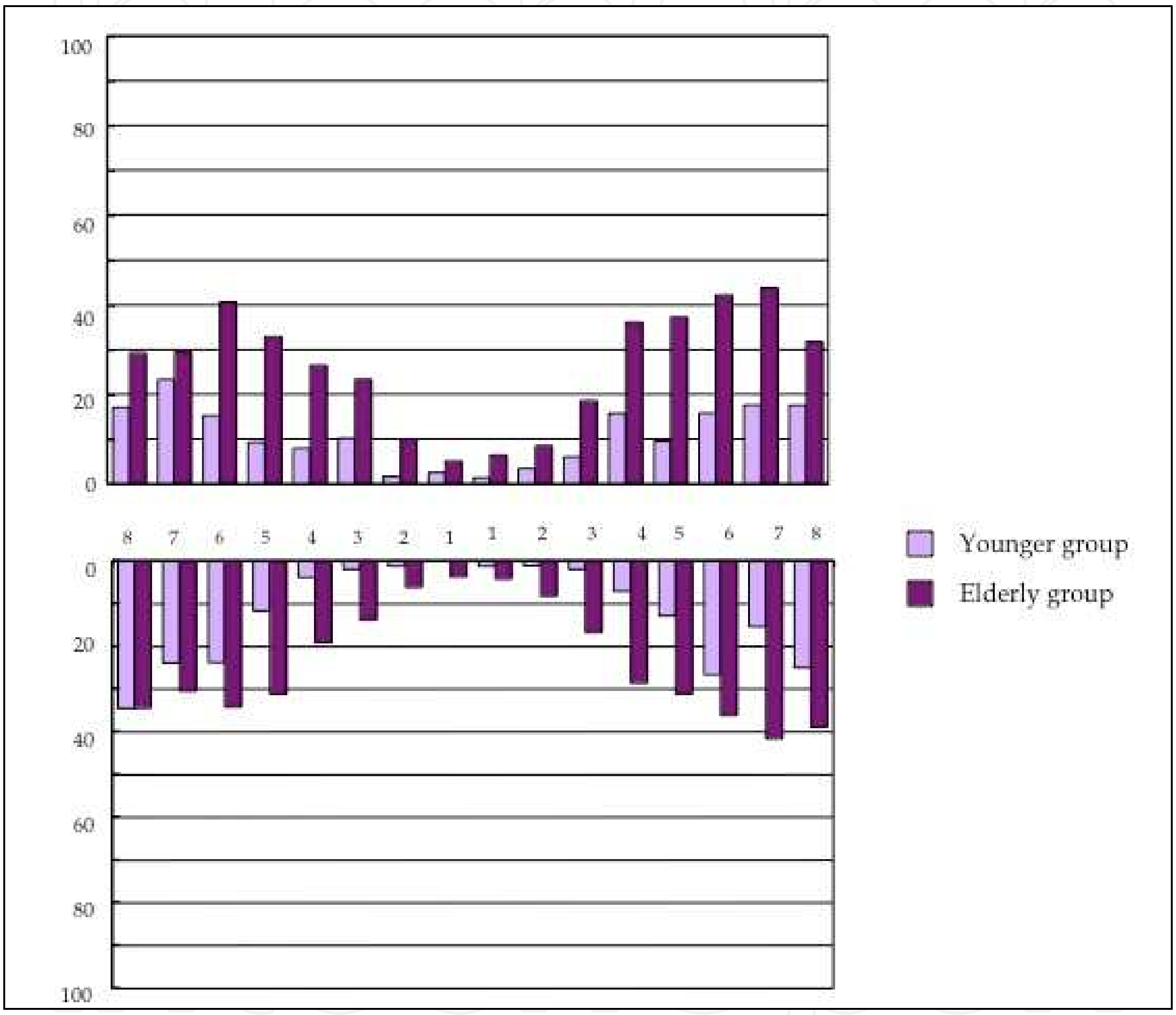

Fig. 5. Number of carious teeth, treated and untreated, by age group and teeth type, in Yayoi people.

However, starch is less cariogenic than sucrose (Lingstrom *et al.*, 1989), and sucrose is a better substrate for *Mutans streptococci* than any other dietary carbohydrate. The high prevalence of root caries yields the most information in this regard. The substrate of the caries in the Yayoi people was most likely a cooked starch, which became a substrate for acid production by oral acid-producing bacteria (not necessarily *Mutans streptococci*), while modern caries are generally induced by *Mutans streptococci* which use sugar as a substrate (Kamp *et al.*, 1983). O'Sullivan (O'Sullivan *et al.*, 1993) compared the skeletal remains of children from an 18th century British population with those of older remains. The results indicated an alteration in pathologic conditions during the 18th century that changed the site of most primary tooth caries from the contact points to the CEJ–AC. In the UK, the average intake of sucrose has consistently increased since the early 1700s (Yudkin, 1972). Yudkin (Yudkin, 1972) reported a positive correlation between the degree of dental caries and the amount of sugar (i.e., sucrose) ingested. Furthermore, the prevalence and distribution of dental decay have changed since the 17th century in Britain (Vodanovic *et al.*, 2005), and these changes may be associated with the importation of sugars.

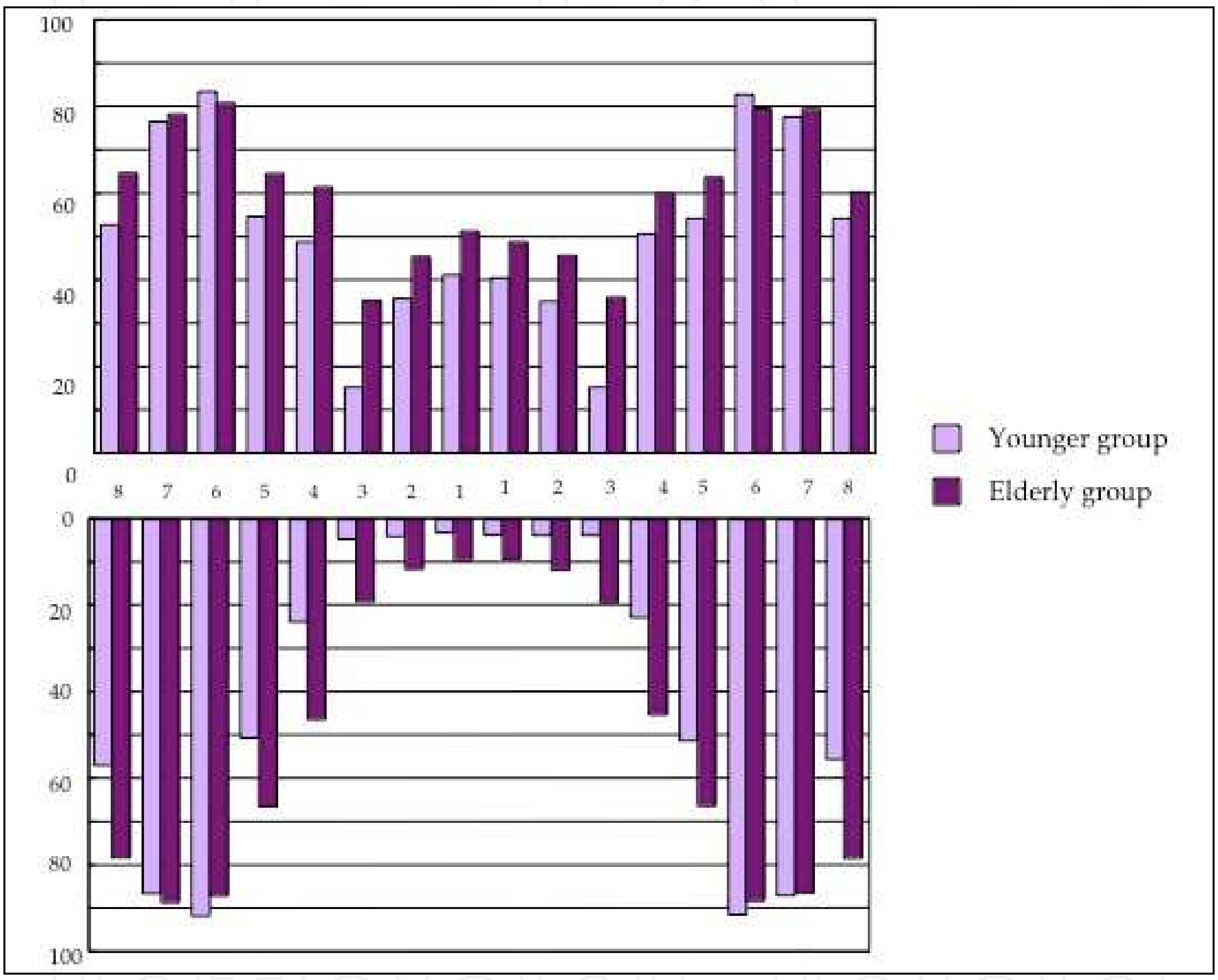

Fig. 6. Number of carious teeth, treated and untreated, by age group and teeth type, in modern Japanese. [From Dental Health Division of Health Policy Bureau, Ministry of Health and Welfare Japan, 1999]

2.3 Alveolar bone loss in Yayoi people

We attempted to clarify the prevalence of periodontal disease in the Yayoi people. Although periodontal disease is characterized by alveolar bone loss, ascertaining the prevalences of periodontal disease in ancient populations is difficult. Although gingivitis does not leave any trace in ancient bones, periodontal disease causes alveolar bone loss, thus periodontal disease can be evaluated by using the degree of alveolar bone loss as a parameter (Stoner, 1972). Therefore, the establishment of an internationally accepted method for quantifying alveolar bone loss would be helpful. There have been few reports regarding periodontal disease in ancient skeletal remains. Notable exceptions include the studies of Clarke et al. (Clarke *et al.*, 1986), Sakashita et al., (Sakashita *et al.*, 1997) and Kerr, (Kerr, 1998) which assessed the prevalence of periodontal disease in ancient populations. Clark et al. (Clarke *et al.*, 1986) investigated ancient human bones stored in 20 museums in 10 countries and reported that the prevalence of periodontal disease was 10% in ancient people. Further, Sakashita et al. (Sakashita *et al.*, 1997) examined bones from the Yin-Shang period in China and reported that periodontal disease prevalence ranged from 20% to 30%. Kerr (Kerr, 1998) reported the prevalence to range from 70% to 100%, however, the investigation method used in that study was detection of lesions while viewing specimens with a stereoscopic microscope. Therefore, it is difficult to compare the results, as they varied depending on the cut-off point employed for alveolar bone loss when evaluating periodontal disease prevalence. A distance of 2 mm in the cementoenamel junction-alveolar crest (CEJ-AC) is generally regarded as normal, while that greater than 2 mm is regarded as a lesion (Lennon & Davies, 1974)., Using that parameter, data can be compared even when not reported by the same researcher. Whittaker et al. (Whittaker *et al.*, 1982) measured the CEJ-AC distance in skulls excavated from human remains of the Roman Empire in England and reported that alveolar bone loss was more remarkable in the elderly group than the adolescent group, as the distance reached 6 mm or more in some of the elderly individuals, which indicated that disease severity was dependent on the CEJ–AC distance.

We investigated alveolar bone loss among the Yayoi people(Uekubo T, 2006). In that study, we measured the CEJ-AC distance in Yayoi specimens to clarify the prevalence of periodontal disease. The minimum CEJ-AC distance was 0 mm and the maximum 17 mm. In most of the site, the elderly group had significantly larger distance values than the adolescent group. As for tooth type, in the adolescent group, the first molar of the maxilla showed the most largest CEJ-AC distance value, followed in order by the first molar of the mandible, canine of the mandible, second molar of the maxilla. In the elderly group, the first molar of the maxilla showed the highest severity, followed in order by the second molar of the maxilla, first molar of the mandible, second molar of the mandible. We reported that alveolar bone loss increased with age among the Yayoi people, with this tendency being most evident in the first molars, and we concluded that alveolar bone loss among the Yayoi was more severe than in other ancient populations.

2.4 Relationship between root caries and alveolar bone loss in Yayoi people

Above mentioned, the people of the Yayoi had carious lesions that were most frequently located on the root surfaces of their teeth. Root surface exposure is a prerequisite for this type of decay, and alveolar bone loss is the main cause of such exposure. Therefore, we identify the factors associated with root caries, and examine the relationship between root caries and alveolar bone loss in the people of the Yayoi period.

As shown in Table 2, the prevalence of root caries was significantly higher (78.7%) among those with a mean CEJ–AC distance ≥3.4 mm than among those with a distance ≤3.3 mm (54.1%). In addition, significant differences in the mean number of teeth with root caries were observed according to age, presence of coronal caries, and the mean CEJ–AC distanceper person. The prevalence of root caries and the mean number of teeth with root caries per person were significantly associated with the mean CEJ–AC distance per person.

		Root caries prevalence (n) (%)	p -value[1]	Mean number of teeth with root caries per person	p-value[2]
Mean CEJ-AC distance per person	<3.3 mm(133)	54.1(72)	< 0.001	1.3±1.7	< 0.001
	>3.4 mm (127)	78.7(100)		2.4±2.6	

[1]χ^2 –test, [2]M-W test

Table 2. Root caries prevalence and mean number of teeth with root caries per person by CEJ-AC distance per person.

Figure 6 shows the percentage of root caries surfaces per tooth surface according to the mean CEJ–AC distance per tooth surface. We calculated the percentage of each root surface (distal, buccal, mesial, and lingual/palatal) affected by caries. Those subjects with a greater mean CEJ–AC distance per tooth surface had a significantly higher percentage of surface root caries for all surfaces compared to those with shorter mean distances.

For the upper and lower molars, the mean CEJ–AC distance per tooth surface was based on the presence of root caries (Table 3). In the upper jaw, root caries on the distal surface of the premolars or on the distal, mesial, and palatal surfaces of the molars, were significantly associated with a greater mean CEJ–AC distance value per tooth surface. In the lower jaw, significantly greater distance values were associated with root caries on the distal, buccal, and mesial surfaces of the molars or on the distal and buccal surfaces of the premolars.

Our results confirm the relationship between root caries and the CEJ–AC distance, which is used as an index of alveolar bone loss, in the bones of the Yayoi people. In ancient agrarian populations, the amount of starchy mass on the tooth surface was probably a key factor in the development of root caries. In addition, alveolar bone loss, which is a major cause of root exposure, tends to precede the development of root caries. Several reports have suggested an association between the occurrence of caries and periodontal disease in ancient populations, although no previous studies have examined this correlation. Thus, the findings of the present study are valuable because they clarify for the first time the relationship between root caries and alveolar bone loss in an ancient population (the Yayoi people). To our knowledge, this is the first study to evaluate the relationship between root caries and CEJ–AC distance using skeletal remains.

Previous reports regarding caries (Haraga, 2006) and alveolar bone loss (Uekubo T, 2006,) among the Yayoi people indicated that carious lesions on the approximal surface were common. The present study, which reveals a CEJ–AC distance-dependent increase in the percentage of surface root caries, confirms these findings (Figure 7). We believe that the close relationship between root caries and alveolar bone loss on the approximal surface is suggestive of the involvement of this bone loss in the manifestation of root caries. Although the mechanism of alveolar bone loss in the Yayoi people has not been elucidated, root caries may be a consequence of alveolar bone loss.

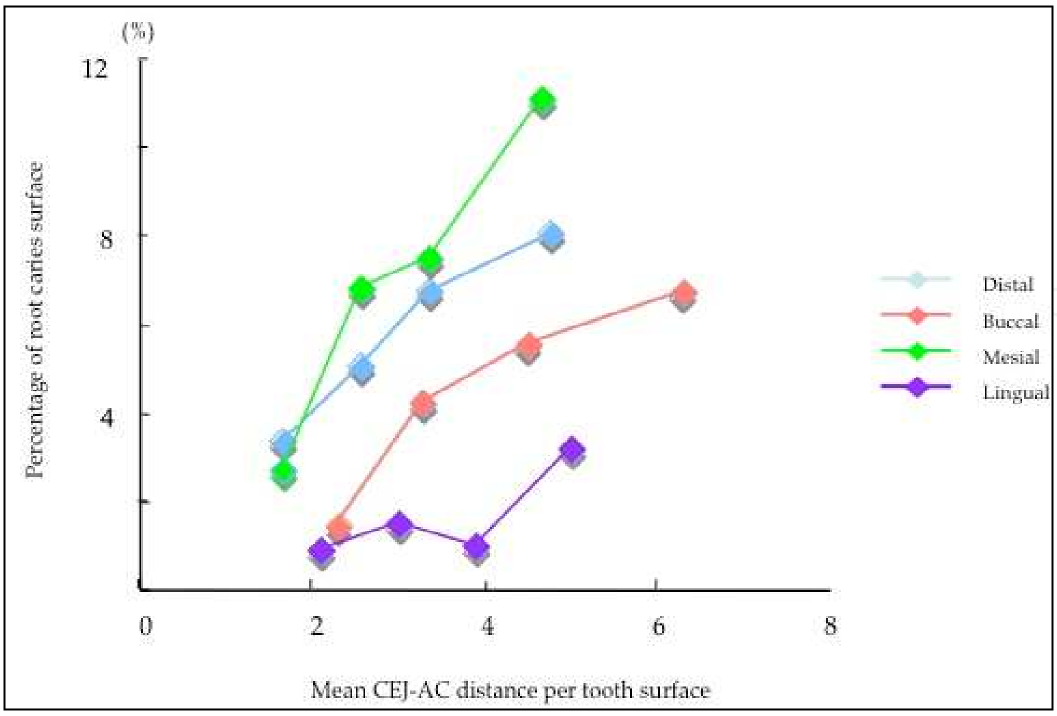

Fig. 7. Relation with percentage of root caries surfaces per tooth surface and mean CEJ-AC distance per tooth surface.

Tooth type	Mean CEJ-AC distance per tooth surface mm±SD (number of tooth surfaces) Without root caries	With root caries	*p*-value [1]
Upper premolar			
Distal	2.9±1.3(423)	3.6±1.9(23)	0.045
Buccal	3.5±2.0(404)	4.3±3.1(3)	0.490
Mesial	3.0±1.3(405)	3.4±1.4(9)	0.224
Palatal	3.6±1.3(477)	4.00(1)	--------
Upper molar			
Distal	3.3±1.7(311)	3.9±1.2(27)	0.010
Buccal	3.8±2.0(359)	4.3±2.1(16)	0.367
Mesial	3.0±1.4(367)	4.3±1.6(24)	< 0.001
Palatal	4.4±2.1(397)	5.4±1.8(17)	0.011
Lower premolar			
Distal	2.7±1.5(617)	3.6±1.5(32)	0.001
Buccal	4.0±2.1(569)	6.0±2.8(10)	0.013
Mesial	2.6±1.4(618)	3.9±2.8(10)	0.126
Lingual	3.0±1.4(511)	-------- (0)	--------
Lower molar			
Distal	3.1±1.8(453)	4.0±2.0(36)	0.002
Buccal	4.1±2.3(453)	5.7±2.4(39)	< 0.001
Mesial	2.9±1.6(471)	4.6±1.9(27)	< 0.001
Lingual	3.7±1.6(504)	4.3±1.1(16)	0.192

[1] Mann-Whitney test

Table 3. Mean CEJ-AC distance per tooth surface by the presence of root caries.

3. Conclusion

We investigated the relationship between caries and periodontal disease in the people of the Yayoi period. The Yayoi, who dominated the Japanese archipelago around the 5th C B.C., are the direct ancestors of the modern Japanese and were the first people to engage in rice cultivation in Japan.

The people in the Yayoi period had a high prevalence of root caries, and the rate of dental caries, is suggested to be due to changes in dietary habits that occurred concomitant with the development of agriculture. On the other hand, tooth wear and compensatory physiologic growth of the abraded tooth are reduced with a rice diet, and alveolar bone loss occurs due to periodontitis. This results in increased exposure of the root surface, which is thought to result in root caries.

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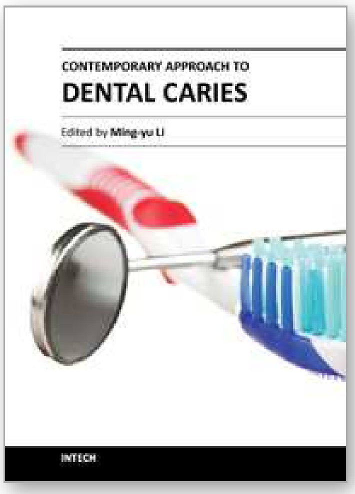

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