Doctoral Dissertation（Consored）
博士論文（要約）

Oral Health Indicators of Prehistoric Jomon: Temporal, Sex and Environmental Differences

（縄文人口腔衛生指標の時期差・性差・環境差）

A Dissertation Submitted for the Degree of Doctor of Philosophy
令和元年５月博士（理学）申請
May　2019

Department of Biological Science, Graduate School of Science,
The University of Tokyo
東京大学大学院理学系研究科生物科学専攻

Saso Aiko
佐宗　亜衣子

Abstract

Oral paleopathologies, including dental caries and periodontal disease, have been thought to increase with the progression and change in economy and social structure of mankind. That is to say, it has been reported that the affected rates increased after the Neolithic in which the agricultural revolution had begun (Aufderheide et al., 1998), and even more so in periods and places after the industrial revolution, which increased consumption of food containing purified flour and sugar (Ismail et al., 2001). In addition, examination of bacterial DNA in the dental calculus of archaeological human remains has revealed that types of oral bacteria changed in the composition from Mesolithic to the present day in Europe, and the composition ratio of *P. gingivitis,* one of the main causative bacteria of periodontitis, has increased since the Neolithic, and that of *S. mutans*, the main bacteria of dental caries has rapidly increased in the modern times (Adler et al. 2013).

Up until now, research on oral health indicators of Jomon people has focused on dental caries (Fujita 1995; Temple 2007; Temple 2011; Temple and Larsen 2007), and has indicated that they have high rates of dental caries as a hunter-gatherers population (average 8.3 %, Fujita 1995). However, comprehensive studies including the other oral health indicators have been rarely conducted, and thus we cannot reach an overview of the oral health status of Jomon people. This study uses six indicators of oral health; dental caries, antemortem tooth loss (AMTL), dental wear, crown defects (chipping), levels of root exposure calculated from the distance between the cement-enamel junction and the alveolar crest (CEJ-AC distance), and morphological assessment of the interdental septum inflammation. Then, it examines temporal changes, gender differences, and geographical differences between site locations in order to dictate oral health status of the Jomon population.

In Chapter I, I first re-examined evaluation methods of periodontal disease in dry bones, since there were almost no objective evaluation of periodontal disease in Jomon archaeological remains since Turner (Turner 1979). For samples from three sites in Late Jomon period (one inland area and two coastal areas), I evaluated two methods, the CEJ-AC distance and morphology of the interdental septum. Results indicated that 31.8 to 66.0% of individuals had more than moderate levels of periodontal disease, the percentage of which matches to those of hunter-gatherer populations in other countries (Costa 1982; Jurmain 1990; Littleton 2017). Compared with result from other indicators, inter-population and inter-sex differences were smaller in the periodontal diseases than those of the other oral health indicators. In a multivariate space, sex differences were almost comparable to the

inter-site differences, and the inter-site differences were greater in females than males. In males, CEJ-AC distance, levels of inflammation of the interdental septum, and chipping scores tended to be high, whereas in females, the rates of dental caries and AMTL tended to be high. In addition, higher levels of inflammation in the interdental septum were often seen in populations with stronger dental wear. A higher correlation was detected between the levels of interdental inflammation and the scores of dental wear than that between the CEJ-AC distance and the dental wear. This indicates that mechanical loads in the dental occlusion may trigger inflammation of the periodontal tissue and advance periodontal disease.

Next in Chapter II, using specimens of 453 individuals from 46 sites, I tested temporal and inter-site differences in oral health indicators. Firstly, I found temporal differences in rates of caries, AMTL, and periodontal disease during the five Jomon time periods (Initial, Early, Middle, Late, and Final). In addition, I found different patterns of change between inland and coastal sites in levels of AMTL, dental caries, and periodontal disease, leading an assumption that the contents and means of wild plant usage were different between the two geographical groups. The features of each period are as follows.

Initial: The characteristics of oral health indicators for both males and females are similar, with low frequencies of dental caries and AMTL, and unusually strong occlusal wear and crown damage. Rates of dental caries are, according to Turner (1979) that of foraging (0 ~ 5.3 %). Inland sites have caries rates of 1.2%, while those in coastal areas are 6.9%, which is already high for hunter-gatherers.

Early: Sex differences increase but not that much, and the characteristics of oral health indicators for both males and females are similar. There is a slight increase in dental caries rates to the mixed foraging/agriculture level (0.4 to 10.3%, Turner 1979). On the other hand, differences between coastal and inland areas can be seen in multiple indicators. Periodontal disease rates increase in the coastal populations, while dental caries and AMTL rates increase in inland areas. Sex differences tend to be different from those after the Middle period, especially in the inland populations of Early Jomon period, where males have high rates of caries and AMTL.

Middle: Rates of dental caries further increase (12.1% in combined sexes), up to the level of agriculture (2.3 ~ 29%, Turner 1979). Sex differences are evident, and males are characterized by large root exposure, heavy crown damage, and strong dental wear, and the rate of dental caries is at 8.0% reaching the level of mixed foraging/agriculture. Females are characterized by AMTL and dental caries, and the dental caries rate (18.9 %) is clearly at the agriculture level. AMTL rates are different in sexes, but the overall average is slightly lower than in the Early period. Periodontal disease rates still differ between the coastal areas and the inland areas, and they are high in the coastal areas.

Late: The overall average rate of dental caries (13.5%) does not differ much from the Middle period. The rates of AMTL increase slightly. Those of periodontal disease are somewhat low and do not exhibit any sex difference. In addition, the rates of dental caries and AMTL are high in the coastal area and low in the inland areas. As a result, the geographical difference between the coastal and the inland areas increases.

Final: Dental caries rates are 27.3% for females and 17.8% for males, and both meet levels of that of agriculture (Turner 1979). In males, the rates of dental caries and AMTL increase and so the differences between males and females reduce. Periodontal disease rates increase slightly in average. In inland areas, sex differences in the rates of AMTL increase, but disappear in the coastal areas.

Because the formation of dental caries is strongly associated with ingestion of carbohydrates, an increase in the dental caries rate has been considered as one of the signals indicating transition to a farming and cultivation society (Turner 1979, Larsen 1983). Temporal changes seen in the frequencies of dental caries and AMTL in the Jomon people imply the subsistence shift and the development of wild plant utilization during the Jomon period.

In addition, it was suggested that in coastal sites the cause of AMTL is mainly from the dental caries, but in the inland areas, AMTL is related to dental wear. On the other hand, changes in the frequency of periodontal disease did not show a stable trend. Therefore, it was assumed that some other factors should affect periodontal disease, which are those not related to dental caries and AMTL. In the time from Initial to Early periods where the geographical difference between coastal and inland sites expanded, and in the time between Middle and Late periods where the geographical difference decreased, we can assume some kinds of change at the onset of wild plant utilization, or in the population movement between the inland and coastal areas.

Finally, in Chapter III, I analyzed the carbon and nitrogen stable isotope ratios based on the Jomon human remains, and detected the temporal changes and the differences in sex and geographical locations. Then I investigated the correlation between the stable isotope ratios and the oral health indicators. The stable isotope ratios increased from the Initial to the Early period, after that both $\delta^{15}N$

and $\delta^{13}C$ values showed a decreasing trend up until the Final period. This implies that as time went on, Jomon people decreased their dependence on marine resources and increased the dependence on terrestrial resources in reverse. In this analysis, however, insufficient sample size and uneven distribution of available sample among locations or sites may distort the results. The observed temporal variation in the stable isotope ratios should be reconsidered in terms of geographical/environmental variation.

As for the correlation between the stable isotope ratios and the oral health indicators, individuals with more dental caries and with stronger dental wear showed lower $\delta^{13}C$ values, and those with high levels of alveolar inflammation exhibited higher $\delta^{15}N$ values. This correlation does not change even when taking sex and temporal differences into account, suggesting a stable relationship maintained throughout the whole Jomon period. That is, carbon and nitrogen stable isotope ratios of collagen from individuals relate with oral health indicators of the same individual, and this relationship may be stable during the time of Jomon period. With regard to the $\delta^{13}C$ values, it was expected that the higher the intake of terrestrial resources (especially C3 plants), and the higher the rates of dental caries. The relation of the $\delta^{13}C$ values with the occlusal wear could be explained in terms of ways of wild plant processing and cooking or as the sampling bias to the coastal area. As for the variation of the $\delta^{15}N$ values, the higher value was assumedly related to the active intake of oceanic fishes or marine mammals of high trophic levels or dietary resources from freshwater ecosystem. However, the causal relationship of the $\delta^{15}N$ values with the degree of alveolar inflammation was obscure.

In conclusion, we see a large gap between the Initial and the post-Early periods during the Jomon times in regard to the oral health indicators. If we consider the Early-Middle period as transitional one, the whole Jomon times can be divided roughly into the three: Initial, Early-Middle, and Late-Final. In the middle term of Early-Middle periods; 1) the rate of dental caries increases remarkably, 2) the sex difference expands, and 3) the geographical difference between the coastal and inland areas becomes evident. The shift from the Early to Final periods was also observed in the stable isotope ratios, being interpretable as a gradual shift in diet to terrestrial resources occurred during the Jomon times.

We may interpret the changes seen in the oral health indicators from the Early to Middle Jomon periods as indicative of the sexual division of labor or that of food sharing and distribution. Otherwise, we can regard them in the process of dietary dependence more on local environments or more on wild plant resources. In this scheme, we may suppose a change in subsistence strategy of highly mobile foragers' to that of more sedentary settlement-based hunter-gatherers. Thereafter, further increase in the dental caries and decrease in the sex difference was observed from the Late to Final periods, for which we may assume the shift towards a full-scaled farming economy.

Acknowledgements

I would like to express my sincere thanks to my supervisor, Dr. Osamu Kondo for his elaborated guidance. During my long doctoral student life which was around ten years, he had always kindly guided me. I was able to recognize this study from invaluable discussion with him deeply.

And I am grateful to Dr. Gen Suwa for a lot of help and advice. I have learned many things from him about the handling of specimens and their data by working as his laboratory staff. These knowledges and techniques are the foundation of my research.

I thank Dr. Yousuke Kaifu of National Museum of Nature and Science, Dr. Katsuji Kumaki of Niigata University, Mr. Yoshitaka Miyauchi of the Education Board of Toride City, Sasebo City Board of Education, Mr. Yoshisuke Takahashi of Iwate Prefecture Archaeological Center, and Tsumoru Tsuchiya of Nagano Prefectural Museum of History for accommodating my request for Jomon skeletal materials used in this study. I also thank Dr. Minoru Yoneda for stable isotope analysis and dating of Jomon populations. A special thank must be given to the members of Kondo lab. and Suwa lab. for their kind support and a lot of advice. Especially, I am very grateful to Ms. Katherine Hampson for helping translate this paper into English.

Finally, I thank for my two daughters, Haruno and Mako. They always supported and encouraged me so far after they were born.

Contents

List of tables

List of figures

INTRODUCTION

Cases of oral paleopathology, including periodontal disease and dental caries, increased after the cultivation of crops began in the Neolithic period (Aufderheide et al. 1998). Furthermore, more cases have been reported since the Industrial Revolution, especially in the periods and areas where the amount of refined wheat and sugar-rich foods increased (Ismail et al. 2001). Recent DNA analysis of dental calculus has successfully recovered intra-oral bacteria from archaeological human remains, revealing a change in the type of oral bacteria in Europe from the Mesolithic to the present day (Adler et al. 2013). According to this analysis, the proportion of *P. gingivitis*, one of causative bacteria of periodontal disease, increased after the Neolithic, and *S. mutans*, which is the major bacterium of dental caries, increased rapidly over the modern period.

Dental caries, periodontal disease, antemortem tooth loss (AMTL), crown damage, and occlusal wear are all indicators for measuring the state of oral hygiene and can be seen in the morphology of the maxilla and mandible in archaeological human remains. Among them, dental caries and periodontal disease are regarded as two major oral diseases in the modern age. After the Neolithic period, the pruning and cultivation of plants, as well as the domestication of animals, began, and the ingestion of more soft carbohydrates possibly led to an increase in periodontal disease. In osteo-archaeological data, many cases of periodontal disease and antemortem tooth loss (AMTL) have been reported in populations with high consumption of vegetable carbohydrates and cooked foods (Larsen 1997; p80). The presence or absence of periodontal disease in dry bone has been evaluated based on the degree of alveolar resorption, and, in practice, the exposure of the tooth root has been measured since the 1970s (Davies et al. 1969, Costa 1982, Lavelle and Moore 1969). In addition, the rate of AMTL has been regarded as an indicator of periodontal disease in archaeological human remains (Lavigne and Molt 1995, Clarke et al. 1986). Larsen (1995, 1997) has argued that there is a strong connection between AMTL and periodontal disease in an archaeological context, although it is difficult to specify the cause of AMTL in many cases. Modern clinical studies, however, have pointed out that the main cause of AMTL is dental caries (Ainomo et al. 1984). Caries has been assumed to be the main cause of AMTL in all age categories of modern populations (China, Kenya, Tanzanian) who often do not have the custom of dental care (Baelum and Fejerskov 1988, Baelum et al. 1986, Manji et al. 1988). In populations with the custom of dental care (England, Finland, France), the main cause of AMTL until middle age (≦40-50 years old) is dental caries, while in the elderly it is periodontal disease (Agerholm and Sidi 1988, Ainomo et al. 1984, Cahen et al. 1985). Lukacs (2007) has suggested the main causes of AMTL to be as follows: variations in dietary consistency, nutritional deficiency diseases, cultural or ritual ablation, and trauma. In his discussion of diet-derived AMTL, he has put forth three scenarios: 1) dental pulp exposure advances with attrition, 2) dental caries progresses due to a soft, processed high carbohydrate diet, and 3) a large amount of dental plaque causes gingivitis, and leads to periodontal disease.

Dental caries confirmedly relates to sugar intake (Takeuchi 1962, Newbrun 1982, Sreebny 1982, Sheiham 1983). Turner (1979) examined ancient human populations around the world, and pointed out that incidence of dental caries increases at the stage of transition from hunting to agriculture, where the average caries rate is 0 to 5.3% for foraging, 0.4 to 10.3% for mixed foraging/agriculture, and 2.3 to 29% for exclusive agriculture people. Studies of North American ancient human populations have reported that the number of dental caries increases after the contact with Western civilization, or after the introduction of agriculture (Larsen and Thomas 1982, Larsen 1983, Lukacs 1992). In contrast, there are reports that indicate no increase in dental caries before and after the commencement of rice farming agriculture, unlike corn and wheat cultivation society (Tayles et al. 2000, Halcrow et al. 2013).

As seen above, these oral hygiene indicators can be used for detecting changes in dietary habits, economy, social structure and the like in various prehistoric groups. Studies of oral hygiene in the Jomon people have mainly focused on cases of dental caries, pointing out that the Jomon people have a high rate of dental caries compared to the other hunter gatherers, interpreting this as a result of the Jomon diet being highly dependent on plant resources (Turner 1979, Fujita 1995). Furthermore, the sex difference in the dental caries rate reportedly increased in the Late and Final Jomon period, and is associated with an increase in the degree of the sexual division of labor in food acquisition and its related behavior (Fujita et al. 2007, Temple 2007, 2011, Temple and Larsen 2007). Inoue et al.

(1981) studied periodical shifts in the dental caries frequency from the Late Jomon period, the Middle Ages (Kamakura period) and modern times. They pointed out that the frequency and severity of dental caries were much higher in the Late Jomon period than in the Middle Ages, but the dento-gnathic discrepancy or malocclusion was less in the Jomon period. This lead to the conclusion that the occurrence of dental caries in Jomon was more affected by global deterioration due to poor oral hygiene than local accumulation of cariogenic residue by dental dislocation (Inoue et al. 1981).

On the other hand, only Turner (1979) collected objective data on periodontal disease for the Jomon people. He investigated the degree of tooth root exposure in 69 Jomon individuals, and pointed out that the frequency of periodontal disease in the Jomon people was as high as that for dental caries and was also higher than that of the average hunter-gatherer group, equivalent to that for the mixed population of agriculture and hunting. However, the details of the studied specimens were described only as “Jomon” people. Except for this study, there only exists a report on the Ohguruwa shell mounds of Aichi prefecture in the Late Jomon period (Inagaki et al. 1990).

Fujita and Suzuki (1995) pointed out that periodontal disease would have been common in the Jomon population on the basis of observations of Jomon individuals with advanced alveolar resorption and those with neck and root caries, whose tooth root was presumably exposed from the gingiva at the time of survival. Fujita (1999) indicated that AMTL in the Jomon population was more frequent in the upper dentition than in the lower and that the frequency of the number of dental caries in the upper and lower dentition was the opposite. He argued that most of the maxillary AMTL was due to periodontal disease. In addition, as the Jomon population exhibited such a high rate of AMTL compared to that found in the Middle Ages, it was thought that their oral health environment was possibly worse (Inoue et al. 1981). Although they attributed the cause of this AMTL to dental caries, periodontitis should be considered among the possible main causes.

However, in order to properly understand the oral hygiene of the Jomon population, it is necessary to examine not only one single indicator, but to perform a comprehensive analysis using multiple indicators. In addition, the Jomon period is as long as about 15,000 years, and it is clear from the previous studies in biological anthropology, archaeology and paleobotany, there are large temporal differences, and also differences in the lifestyles of the people according their surrounding environment. For example, archeological research on lithic assemblages, plant seed impressions or plan opals has suggested intensification of terrestrial plant usage during the Early to Middle Jomon periods in Tohoku and Kanto regions (Habu 2015, Imamura 1989, Kudo and National Museum of Japanese History 2014, Nakayama 2015a, Noshiro and Sasaki 2014, Obata 2011). In addition, paleodemographic approach based on the number of Jomon sites has estimated that the population increased rapidly from Early to Middle, then decreased from Middle to Late Jomon periods (Koyama and Sugito 1984). Oral hygiene indicators are phenotype observable on the human body and assumedly interactive with lifestyles, health and environments. Temporal change of them, therefore, can be considered as traceable tools for complexity in the Jomon society. This study analyzed six oral hygiene indicators, dental caries, periodonal disease (based on root exposure and morphological assessment the interdental septum), occlusal wear, enamel chipping, and AMTL, in order to clarifying temporal, geospatial and gender differences in oral health condition in the Jomon period.

In Chapter I, after reviewing and confirming the method of evaluation for the periodontal disease in archaeological human remains, I studied the frequency of periodontal disease in three local Jomon populations belonging to the Late Jomon period. It provides the objective and quantitative data for the prevalence of periodontal disease in the Jomon population. I analyzed the inter-population and inter-sex variation in the multivariate spaces after adding four oral health indicators of dental caries, occlusal wear, enamel chipping, and AMTL. Then, I discussed relationships among the oral indicators and the regional and sexual variation. In Chapter II, I investigated more Jomon samples in a wider geographical and temporal ranges from Honshu, Kyushu, and Shikoku, and analyzed temporal changes, and sexual and geographical (site location) differences. The results dictate the temporal patterns of oral health status in the Jomon population divided in the following five phases (Initial, Early, Middle, Late and Final Jomon periods). Then, they are interpreted with regards to the introduction of plant resources in the diets of the Jomon people. In the final section, Chapter III, I aim to detect direct relationships of the oral health indicators and the Jomon diet. Thus, I first analyzed temporal changes, sexual and geographical differences in the carbon and nitrogen stable isotope ratios for the Jomon samples, and then investigated relationships between individual data for the oral health indicators and those for the isotopic values.

CHAPTER I

Periodontal Disease in the Neolithic Jomon

Introduction

Periodontal disease is a set of inflammatory conditions affecting the tissues surrounding the teeth (gingiva, periodontal ligament, alveolar bone and cementum) triggered by infection by periodontal bacteria (Holt and Ebersole 2005, Hajishengallis 2014). About 20 species of major causative bacteria of periodontal disease have been identified, and those bacteria are symbiotic to the biofilm formed in the sub-gingival space like the caries (Socransky and Haffajee 2005). The bacterial group that causes periodontal disease is gram-negative bacteria. However, in gingivitis and early periodontitis it has been reported that gram-positive bacteria are more predominant than gram-negative bacteria in dental plaque (Listgarten 1976, Slots 1979). The onset of periodontal disease is thought to be triggered by the accumulation of dental plaque from a predominantly soft carbohydrate diet, poor oral hygiene environment, or impaired body immunity, etc. (Genco 1996, Albandar 2002, 2005). However, the interaction of several factors with each other plays a significant role, and the onset and definitive cause of periodontal disease remains unclear (Albanda 2002, Hold and Ebersole 2005).

Pioneering studies on periodontal disease in archaeological human remains focused on the people living prior to the Industrial Revolution (Costa 1982). Many previous case reports include those of the ancient Pleistocene time such as Neanderthals and *Homo erectus* (Lozona et al. 2013, Martín-Francéset al. 2014, Trinkaus 1985) and those of modern times, and the prevalence rate is variable, ranging from 18% to 100% (Lieverse et al. 2007, Oztunc et al. 2006, Kerr 1994, DeWitte and Bekvalac 2010). There are few studies on periodontitis of the Jomon people. From previous studies, only Turner (1979) reported the periodontal disease frequency of Jomon people based on data investigation. In addition, there is a report on the Oguruwa shell mounds of Aichi prefecture dating to the Late Jomon period (Inagaki et al. 1990). However, it is believed that periodontal disease would have been common in the Jomon population since there have been observations of Jomon individuals with advanced alveolar resorption and/or with neck and root caries (Fujita and Suzuki 1995, Fujita 1999, Inoue et al. 1981).

In order to grasp the state of periodontal disease in the Jomon population, I should observe it on the basis of subjective criteria and integrate those observations into the archaeological context of the Jomon site information. The aim of this chapter is to 1) calculate the prevalence of periodontal disease in the Jomon population on the basis of subjective and quantitative data, 2) investigate the difference in prevalence between the sexes and local groups, and 3) discuss the causes or mechanisms that manifest such differences.

Materials and Methods

I used three Jomon skeletal series, from the Ubayama shell-mound in Chiba prefecture, the Nakazuma shell-mound in Ibaraki prefecture, and the Kitamura site in Nagano prefecture (Figure 1.1). The Ubayama and Nazazuma shell-mounds are in the brackish water system in the Kanto region. Inhabitants from the two sites have reportedly manifested a relatively high rate of dental caries among Jomon populations (Matsumura 1995, Temple 2007). In the latter half of the Jomon period, the Ubayama shell-mound faced the “Old” Tokyo Bay, and the Nakazuma shell-mound was situated at the innermost shore of inland gulf (current Kasumigaura) called “Old” Kido Bay. As for the prevalence of periodontal disease, there was no mention of that for the Ubayama inhabitants, and that for the Nakazuma inhabitants was assumedly high in light of the high rate of AMTL (Matsumura 1995). The Kitamura site is located on a plateau alongside a river in a mountainous region, and its inhabitants were reportedly characteristic in having a very low rate of dental caries but without any report of periodontitis or alveolar resorption (Shigehara 1993, 1994, Temple 2007).

Table 1.1 shows the number of study samples and the sex, age and period breakdowns of individuals. The three Jomon samples belong mainly to the Late Jomon period, although individuals from the Middle Jomon period are included in the Ubayama and Kitamura samples. The associated period, age estimation and sex diagnosis were taken mainly from previous reports or documents (Kondo 1993, Matsumura 1995, Mizushima et al. 2004, Shigehara 1993). Those without records were diagnosed on the basis of bone morphology excluding dentition. Age estimation was done by considering the degree of cranial suture closure and epiphysis closure of limb bones or joint surfaces in total, and then individuals were grouped into the four age categories of "young adult" (approximately 20-30 years old), "early middle-aged" (30-45 years old), "late middle-aged" (45-60 years old), and "elderly old" (over 60 years old). Sex criteria were based on the morphology of the pelvis and cranium (Seta and Yoshida 1990, White et al. 2012). As for the age breakdown, the Nakazuma inhabitants include a proportionately smaller number of young adults but a larger number of early middle-aged adults than those of the other two sites, where the inter-site difference was significant in two of the age categories ($\chi^2(2) = 7.0$, $p < 0.05$ in young adults; $\chi^2(2) = 11.3$, $p < 0.01$ in early-middle adults). However, when I combined the age categories of young and early-middle, and of the late-middle and elderly age groups, I could find no significant difference ($\chi^2(2) = 0.4$, $p = 0.82$). Thus, I finally decided to compare and evaluate the three local samples having similar age breakdowns.

Assessment of periodontal disease

Diagnosis of periodontal disease in clinical cases is based on the presence of periodontal intrabony pockets determined through dental probe or X-ray radiography, or based on the inflammation of gums and hemorrhage frequency (Page and Eke 2007). On dry bone, it has been assessed by the degree of alveolar bone resorption (recession) (Hillson 1996).

In studies of archeological human bones, two indicators have been often used for the assessment of jaw bone resorption. One is the distance from the cement-enamel junction (CEJ) to the alveolar crest (AC), and another is the morphological assessment of the inflammatory reaction on the interdental septum. The CEJ-AC distance measures the exposure of the root, which can be assessed as the degree of alveolar resorption (Clarke et al. 1986). However, it is known that the root exposure advances with age until about 45 years old (physiological eruption) and also relates to the development of dental wear (Kaifu et al 2003, Gonçalves et al. 2015). Because these effects are impossible to separate from those due to periodontal disease, it is necessary to trace the inflammation in the dental gum in addition to the root exposure (Griffin 2014, Wasterlain et al. 2011). In order to assess the presence of inflammation, Kerr (1988) developed criteria to evaluate the inflammatory change in the interdental septum (Table 1.2).

In terms of the target dentition, I focused my interests on the posterior teeth (premolars and molars), because I sometimes encountered damage or intentional tooth extraction in the anterior dentition. The CEJ-AC distance was measured according to the method developed by Lavigine and Molto (1995) with partial modification, which was as follows.

1). The CEJ-AC distance was measured along the longitudinal axis of the dentition at six points around the crown, three points on each (buccal/lingual) side (mesial, middle, and distal points), not on the interproximal surface. A dental probe with a scale of 1 mm interval was set along the dentition and the measurement was recorded to a minimum unit of 0.5mm. Among the six measurable points, the maximum was taken to a representative value for the dentition. In the cases next to the AMTL cases, the nearest point (mesial or distal points) was not measured.

2). In clinical cases, we encounter two cases of the periodontal pocket limiting in the suprabony region and expanding below the alveolar crest (infrabony pocket) where the dental probe reaches into the alveolar socket. However, as these two cases are not distinguishable in the dry bone, I followed the case within the suprabony pocket (Lavigine and Molto 1995), which reduced the final measurement by 1.5 mm from the measurement for each dentition.

3). Thereafter, the measurements were scored from zero (0) to 3; if the measurement was (x) < 1mm, then the score was zero (0); 1mm $\leqq$ x < 2.5mm, then the score = 1; 2.5mm $\leqq$ x < 3.5mm, then the score = 2; 3.5mm $\leqq$ x then the score = 3. The mean score was calculated for each individual and used as a representative value.

Previous studies have judged as pathological when the CEJ-AC distance exceeds 2mm (Clarke et al. 1986, Wasterlain et al. 2011, DeWitte 2012). However, we should consider that a physiological eruption with occlusal wear elongates the distance up to 4mm on average in the modern population

(Tal 1985, Albander 2005), and, as a result, I took a greater threshold of over 4mm (score 2) as pathological in the present study.

Assessment of the interdental septum morphology was based on Kerr (1988, 1991, 1994) (Table 1.2). I observed both mesial and distal sides of interdental septum of the preserved dentition and post-mortem open socket (Figure 1.2). In the case adjacent to the AMTL, the septal surface at the AMTL side was not observed. Among the six categories, those equal to or over "category 3" were counted as "positive" inflammation. The mean of the observed scores was used for each individual.

Assessment of other oral health indicator

I observed dental caries, ante-mortem tooth loss (AMTL), occlusal wear and enamel chipping. Observations of dental caries and AMTL were based on all the preserved dentition. Enamel caries with a destructive concavity were counted as affected but those with only simply colored or ambiguous decalcification were not included. The rate of dental caries (RC) was calculated as the number of caries teeth per the total number of observed teeth. In addition, the average caries frequency per person (ACFP, Sakura 1964), which corrects the variable numbers of postmortem tooth loss, was calculated as follows,

$$\mathrm{ACFP} = 2\left[\mathrm{RC}\{\underline{1}\} + \mathrm{RC}\{\overline{1}\} + \mathrm{RC}\{\underline{2}\} + \mathrm{RC}\{\overline{2}\} + \cdots . + \mathrm{RC}\{\overline{8}\}\right] ,$$

$$\text{where } \mathrm{RC}\{\underline{1}\} = \text{ caries rate of mandibular first incisor.}$$

AMTL was assessed in terms of the degree of dental socket resorption; those with the complete or almost complete closure were counted, but those with ambiguous closure were excluded where the antemortem survival of the dentition was plausible. The rate of tooth loss (RTL) was calculated as the number of teeth loss divided by the number of observed sockets, the latter of which includes those with postmortem tooth loss. In addition, I calculated the average tooth loss frequency per person (ATLFP), applying the above mentioned ACFP calculation for dental caries (Sakura 1969), as follows,

$$\mathrm{ATLFP} = 2\left[\mathrm{RTL}\{\underline{1}\} + \mathrm{RTL}\{\overline{1}\} + \mathrm{RTL}\{\underline{2}\} + \mathrm{RTL}\{\overline{2}\} + \cdots . + \mathrm{RTL}\{\overline{8}\}\right] ,$$

where $RTL\{\underline{1}\} =$ the rate of AMTL in the lower first incisor.

Occlusal dental wear was graded from categories A to E categories based on the degree of dental wear and the estimated ages of the Kitamura Jomon individuals (Shigehara 1993, 1994). Individual scores were determined after grading the wear degree of each side of the teeth in the upper and lower jaws separately due to the fact that some individuals showed a significant right-left difference in their dental wear.

Enamel chipping was graded into a scale from zero (0) to 3, which was modified after Bonfiglioli et al. (2004). I scored only on molars and premolars, and used a mean score (total sum of the scores / number of observed teeth) as an individual chipping score. The grades were:

Grade 0: no chipping,

Grade 1: enamel chipping with 1 to 2mm size,

Grade 2: over 2 mm size or depth, and

Grade 3: a large portion of the cusp was chipped off.

Finally, I counted the frequencies in the division of each local sample and of each sex, and compared those for periodontal disease (CEJ-AC distance and alveolar interdental septum), the rate of dental caries, and the rate of AMTL, separately. In addition, I compared the degree of occlusal wear between the local sites and tested the statistical significance by the Chi-square test.

Correspondence analysis

In order to analyze relationships between the observed characters or any associations of a trait with a local population and/or sex, I performed a correspondence analysis by using the periodontal scores from the CEJ-AC distance and interdental septum morphology, caries rate, AMTL rate, wear score, and chipping score. Statistical analysis was done using SYSTAT ver. 13 after categorizing each variable according to the criteria in Table 1.3.

Results

Frequencies of periodontal disease in Jomon populations

First, I consider the CEJ-AC distance as a measure of periodontal disease. The percentage of individuals whose mean score is equal to or over "2" is 38.6% for Nakazuma, 35.7% for Ubayama, and 31.8% for Kitamura sample (Table 1.4), where there is no significant difference among the three samples ($\chi 2(2) = 0.5$, $p = 0.76$). The percentage of the scores derived by counting alveolar sockets is 53.6% for Nakazuma, 65.7% for Ubayama, and 49.7% for Kitamura, where that of Ubayama is significantly higher than the other two ($\chi 2(2) = 28.0$, $p < 0.01$).

In the assessment of the interdental septum, the individual percentage of those who have a category "3" or more is 38.8% for Nakazuma, 66.0% for Ubayama, and 60.4% for the Kitamura samples (Table 1.5). The percentage by counting interdental septa is 50.5% for Nakazuma, 68.7% for Ubayama, and 64.5% for the Kitamura samples, respectively. In these two cases, the Nakazuma inhabitants exhibit significantly lower rates of positive periodontal disease than the other two samples ($\chi^2(2) = 10.1$, $p < 0.05$ for individual count, $\chi^2(2) = 30.6$, $p < 0.01$ for interdental septum count).

Between sexes, the percentage of affected individuals shows no significant sex difference both in the CEJ-AC distance and in the interdental septum, but that of the males is higher than that of the females, in general. A significantly higher male rate is found in the Kitamura sample in the CEJ-AC distance by counting in the unit of the alveolar socket ($\chi^2(1) = 20.4$, $p < 0.01$). The higher male rate is also found in both the Nakazuma and Kitamura samples in the interdental septum assessment by counting in the unit of the interdental septum ($\chi^2(1) = 4.8$, $p < 0.05$ fo**r** Nakazuma, $\chi^2(2) = 6.7$, $p < 0.05$ for Kitamura).

Frequencies of other oral health indicator

The rate of dental caries is 17.0% for Nakazuma, 11.4% for Ubayama, and 1.9% for Kitamura, where the differences between the three samples are statistically significant ($\chi^2(2) = 92.4$, $p < 0.01$, Table 1.6). Sex difference is significant in the Nakazuma and Ubayama samples where females were more susceptible to having carious teeth ($\chi^2(1) > 68.0$, $p < 0.01$ for Nakazuma, $\chi^2(1) > 68.0$, $p < 0.01$ for Ubayama). The Kitamura samples show no sex difference.

The rate of AMTL is 8.8% for Nakazuma, 10.8% for Ubayama, and 3.7% for Kitamura, respectively, and that for Kitamura is significantly lower than the other two ($\chi^2(2) = 57.4$, $p < 0.01$, Table 1.7). Sex differences are commonly found in the three samples where females show more AMTL than males ($\chi^2(1) = 68.0$, $p < 0.01$ for Nakazuma, $\chi^2(1) = 42.5$, $p < 0.01$ for Ubayama, $\chi^2(1) = 8.2$, $p < 0.05$ for Kitamura).

Periodontal disease and wear

The degree of occlusal wear is considered as an age indicator. In order to check the consistency of the age-wear relationship among groups, the wear degree of each age category is compared among the three sites. In young adults, the grade "A" is abundant in all the three groups and the proportion of the grade "A"/"B-E" individuals is not significantly different ($\chi^2(2) = 2.1$, $p = 0.35$). In the Nakazuma sample, the grade "A" is still abundant in early-middle adults, and the grade "A-B" occupied a relatively large portion in late-middle adults. The Kitamura sample includes comparatively more grade "B" individuals in early-middle adults and also more "C-D" individuals in late-middle adults. Ubayama sample indicates more "D" individuals in early-middle adults and more "E" individuals in late-middle adults. Significant differences are found in the two comparisons of early-middle ($\chi^2(6) = 28.1$, $p < 0.01$) and late-middle adults ($\chi^2(6) = 18.5$, $p < 0.01$). In sum, the rate of occlusal wear is more advanced in the Ubayama sample, slow in the Nakazuma, while that of the Kitamura is intermediate between the two. Sex difference is not significant within each local sample.

The frequency for each CEJ-AC distance score (Figure 1.3) and that for the interdental septum category (Figure 1.4) are presented with divisions made for each age category and sex. These are based on the counts of individual dentitions or septa, respectively. Sex difference within each site is small. The pattern of the age-related shift of the frequencies is also common between the CEJ-AC distance and the interdental septum. However, those between the three sites are different; those for Kitamura and Nakazuma show more high scores with advanced age, indicating more individuals with periodontal disease; in contrast, those for Ubayama exhibit more high-score individuals even in young adults. In the Ubayama females, the frequency of periodontal individuals decreases from early-middle to late middle adults. This is assumedly relevant in terms of the increase in unobservable dentition or dental septum due to AMTL.

The inter-site comparison and age change

Correspondence analysis was conducted in order to visualize the inter-site, sexual, and age-related variations based on the two periodontal observations and the other oral health indicators (occlusal wear, AMTL rate, caries rate, and chipping score) (Figures 1.5 to 1.7). In the plot of the inter-site variation (Figure 1.5), the first axis represents 85.1%, and the second axis represents 14.9 % of the total variation, respectively. Figure 1.6 shows the sex-divided inter-site variation of six groups, where the first axis represents 61.6% and the second axis represents 25.0% of the total variation, respectively. In both plots, the traits of "wear" and "chipping" are plotted on the right, and the "caries" and "AMTL" on the left. The first axis indicates the effect of occlusal functional load in the positive direction and that of infectious alteration in the negative direction.

In Figure 1.5, the second axis helps to visualize the inter-site variation. The Ubayama sample is characterized by the frequencies of "AMTL" and "wear", Nakazuma is of "caries" and "AMTL", and Kitamura is of "chipping" and "wear", respectively. In the sex-divided plot (Figure 1.6), the CEJ-AC distance is plotted in the upper position, and "AMTL", "wear" and "caries" are plotted in the lower position along the second axis. The second axis depicts the sexual difference, where males are directed to the upper right corner and females to the lower left corner with minor differences in each site. Thus, the traits of the "CEJ-AC distance", "septum", and "chipping" are attributable as male-related, and those of "caries" and "AMTL" are considered female-related. Taking the variation of the six subsamples into consideration, the range of inter-sex variation is similar to that of inter-site variation. In addition, the inter-site variation is larger in females than in males. The sex difference is smallest in Kitamura, and becomes larger in Ubayama and Nakazuma.

As for the two traits of periodontal disease, the position of the “CEJ-AC distance” falls near the “caries” and “AMTL” on the left side in the inter-site comparison (Figure 1.5), both of which are assumingly related to the presence of infectious or alien agents. In the sex-divided plot, the item of “CEJ-AC distance” is positioned away from the other five items in the upper area along the second axis. It is the most distant from the “wear” which has been indicated as the most relevant to each other in previous studies (d’Incau et al. 2012, Murphy 1959, Newman and Levers 1979, Whittaker et al. 1985). The trait of “interdental septum” is plotted to the right from the center. Although it cannot be easily distinguished among the six groups, it is assumingly relevant to functional loads, such as “chipping” or “wear”, as compared to the case of the “CEJ-AC distance”. We should note, however, that the two periodontal disease items, both of which fall near the origin of the center, do not clearly exhibit the inter-site variation, and thus the relevance to the other items may be secondary.

Finally, the plot of sex- and age-divided groups (Figure 1.7) seemingly exhibits age change along the first axis and sex difference along the second axis. The shift with age can be commonly detected in both sexes as it goes from the “chipping” abundant stage to the “wear” advanced stage during the period from the adult to the elderly. An insufficient number for the male elderly group (M4) may explain a bias in the scores, which moves it to the left (minus) in the plot. The position of the “wear” on the positive end along the first axis might be due to the high degree of relevance in terms of the amount of “wear” to age. Polychoric correlation coefficients between the “wear” score and age in the present study are 0.67 ($t = 10.2$, $p < 0.01$) in males and 0.81 ($t = 16.1$, $p < 0.01$) in females. The distant position of the “CEJ-AC distance” to the “wear” is consistent with the result seen in the inter-site plot (Figure 1.5). The traits relevant along the second axis are the “CEJ-AC distance”, “caries”, and “AMTL”. Among them, the “CEJ-AC distance” is seemingly attributable as the masculine character, while the “caries” and “AMTL” are associated with the feminine. This consideration is consistent with the sex- and site-divided plot of the six samples (Figure 1.6).

Discussion

Comparison to previous studies and other hunter-gatherer populations

The rate of periodontal disease in Jomon individuals was calculated at 31.8 to 38.6% based on the assessment of the CEJ-AC distance and 38.8 to 66.0% in terms of the evaluation of the interdental septum. Turner (1979) observed 69 Jomon individuals and reported 34.8% (24 individuals) as having moderate or severe periodontal disease. The result in the present study is admittedly similar to that of Turner (1979), considering that the limited observation on the molar teeth in the present study might decrease the periodontal counts. Previous studies for other hunter-gatherers have reported moderate or severe periodontal disease. One such example reported 47.7% for Tigira in Alaskan Eskimos, 44.6% for Ipiutak, 33.9% for Australia aborigines, and 46% for CA-Ala-329 in prehistoric Native Californian (Costa 1982, Jurmain 1990, Littleton 2017). However, for a different site (CA-CCO-548) in prehistoric Native Californian a lower rate of 17.8% has been recorded (Griffin 2014). By comparing these, the periodontal disease rate for the Jomon population can be considered as moderate within the other hunter-gatherer populations.

Difference between two indicators of periodontal disease

The periodontal disease rate in each of the three Jomon populations exhibits a smaller inter-site and sex variation than those of the caries or AMTL rate. The percentage of individuals or teeth with periodontitis judged by the CEJ-AC distance was similar among the three samples. On the other, in the comparison of the interdental septum inflammatory trait, the affected rate was seemingly higher in the group with strong occlusal wear (Ubayama and Kitamura) than in the group with weak occlusal wear (Nakazuma). In addition, the prevalence rate for each age category was higher in the strong wear group of Ubayama, where even the young-aged individuals exhibited periodontitis (Figures 1.3 and 1.4). In the plot of multivariate correspondence analysis, the dental septum tended to associate with “wear” and “chipping”, which can be assumed to correspond to mechanical load, and the CEJ-AC distance associated more closely with “AMTL” and “caries” (Figure 1.6). These results indicate that mechanical loads associated with “wear” and “chipping” possibly resulted in damage to the periodontal tissues and advanced periodontal disease conditions.

A previous study of aboriginal Australians investigated the associations between occlusal wear and the oral health indicators (caries, calculus, pulp exposure, periapical voids, periodontitis) (Littleton 2017). The results indicated that occlusal wear showed the highest associations with pulp exposure and periapical voids, as well as showing a moderate association with periodontitis; only periodontitis showed positive associations with four of the five items (all except caries). Littleton (2017) assumed that the effect of the occlusal wear on periodontal disease was a non-direct, secondary one, between which the aging effect had intervened. Actually, as the degree of occlusal wear relates well with age, it is difficult to judge whether it is occlusal wear or age that has the stronger effect on the prevalence of periodontal disease. In the present study, however, the populations with strong occlusal wear such as Ubayama exhibited more individuals with interdental septum inflammation even in the young adults. Clarke and Hirsch (1991) discussed damage on the periodontal tissue due to the progression of occlusal wear, and linked moderate to severe progression of periodontal disease with the exposure of the dental pulp and presence of periodontal inflammation. In addition, occlusal trauma and excessive occlusal force are reported to promote periodontal disease (Fan and Caton 2018, Harrel 2003, Harrel et al 2006).

In sum, we may hypothesize the following process: a locally limited alveolar recession (periapical voids) due to strong occlusal wear at the onset grows with daily incremental loads, which results in the accumulation of micro damage in the periodontal tissue and the expansion of inflammation into a wider range of periodontal disease.

The observed association of the CEJ-AC distance and caries is plausibly ascribed to a tendency in which the dentition with a greater CEJ-AC distance exposes a larger portion of dentine and thus becomes prone to suffer caries. The association of CEJ-AC distance with AMTL is also plausible, where a greater distance of CEJ-AC distance with the alveolar recession or occlusal wear may eventually contribute to tooth loss.

The two indicators of periodontal disease, CEJ-AC distance and interdental septum, therefore express different etiological characteristics as mentioned above. As pointed out in previous studies, the results of the present study show that assessment of the interdental septum, not of the CEJ-AC distance, seemingly reflects more directly on periodontitis or its associated alteration.

Inter-site or inter-sex comparisons of inland and coastal areas

Next, we discuss the results based on the other oral health indicators. The three local Jomon samples in the present study exhibited different patterns in the rates of dental caries, AMTL, and the degree of occlusal wear, all of which are significantly different among the three samples. The Nakazuma sample showed higher rates of dental caries and AMTL and a lower degree of occlusal wear. The Ubayama sample also showed higher rates of caries and AMTL, but with an advanced degree of occlusal wear, and exhibited higher periodontitis. The Kitamura sample showed lower rates of caries and AMTL but a moderate degree of occlusal wear and periodontitis.

We can assume diet in general as a plausible factor responsible for the different rates of dental caries among the local samples. Recent stable isotope analyses have reported on the dietary patterns of inhabitants for each Jomon site (Yoneda 2008, 2014). The Ubayama and Nakazuma inhabitants had proportionately well-balanced diets ranging from terrestrial flora and fauna to marine products; the Kitamura inhabitants mainly depended on a terrestrial C3 plant-based ecosystem, including terrestrial herbivores. Approximately 54 to 70% of their diet was assumedly occupied by animal protein (Naito et al. 2013). These dietary discrepancies may be the cause of the observed inter-site difference in the dental caries and AMTL rates between Kitamura and the other two Jomon sites. The latter two sites, Ubayama and Nakazuma, however, exhibited several differences in their oral health indicators, although these two sites are both coastal shell-mounds, close in proximity and similar in diet. Ubayama was a little higher in periodontal disease rate and Nakazuma was higher in caries rate. The difference in the periodontal disease rate can be assumed to relate to the effect of the different degree of occlusal wear, as explained above. On the other hand, the reason for the caries rate difference is obscure. In this regard, we noticed in the multivariate correspondence analysis that the degree of inter-sex difference was similar to that of the inter-site difference. In particular, the inter-site difference among the three sites was greater in females than in males. In terms of univariate comparisons, the caries rate and the AMTL rate were conspicuous in terms of the sexual difference. In contrast, the stable isotope proxy for diet has been reported to be similar in terms of sex and age for each Jomon site (Yoneda 2008, 2014).

The reason for the inter-site or inter-sex difference observed in the oral health indicators seems ascribed to other factors, such as dietary resource differences that were undetectable in the stable isotope study, sex hormonal variation due to pregnancy or childbirth, diet frequency and/or different cooking methods, etc. In particular, although Nakazuma and Ubayama are both shell-midden sites, the geographical locations are somewhat different. The Nakazuma site is situated in the innermost shore of Old Kido Bay (inner bay), and the Ubayama site faces Tokyo Bay (outer bay). As a result of the sea recession seen in the Late Jomon period, the opening of Old Kido Bay to the outer sea seemingly narrowed, and brackishment with wide tidal flats occured around the Nakazuma site (Kamei 2018). Faunal identification of the Nakazuma site revealed the abundance of small-sized fish such as eel and goby, which had adapted to the transition from the brackish water to freshwater; and brackish-water shellfish such as Japanese basket clams (*Corbicula japonica*) were dominant (Toizumi 2018). In addition, oceanic large-sized fishes such as red seabream (Sparidae) or globefish (Tetraodontidae) were identified, the presence of which are assumed to be outcomes of the open-ocean fishery or trade with neighboring communities. Wildlife hunting was also thought to have been activity pursued from the Late to Latest Jomon period, and cervids were abundant at the Nakazuma site in particular.

On the other hand, the eastern coast of Tokyo Bay has reportedly yielded many large-scale shell-midden sites, including Ubayama. It has been assumed that the area was densely populated in the Late Jomon period because large shell-mounds were found at about 2 km intervals (Horikoshi 1972). The diet of the people and their relevant behavior were seemingly rich in variety based on the faunal and floral remains, lithic assemblage variation, and increase in the number of storage pits, etc. It has been pointed out that Jomon inhabitants used edible roots and nuts, forest resources such as deer and wild boar, and marine resources such as little fishes, snails (*Umbonium moniliferum*), and clams

(*Meretrix lusoria*) (Nishino 2009, Abe 2014). This information tells us that a possibly different population pressure existed between the two Jomon sites, and thereafter they possessed different levels of food competition and of labor division. These factors may provide reasons behind the sex difference.

In terms of wild plant utilization, evidence has yet to be provided that the Nakazuma inhabitants used edible root vegetables or nuts, although their caries rate was high. In the large area of the Kanto region in the Late Jomon period, however, several kinds of controlled cultivation have been confirmed, such as the management of chestnut and urushi, nuts of Japanese walnut, horse chestnut, or genus *Quercus*, beans as azuki and soybean, and egoma, gourd, and cannabis, etc., all of which were cultivated to a significant degree (Kudo and Sasaki 2010, Sasaki 2007). Jomon inhabitants supposedly selected breeds with large-sized seeds, constructed a kind of equipment for detoxification, and actively used a variety of wild plants (Noshiro and Sasaki 2014). The difference in the dental caries rate between Nakazuma and Ubayama, which remains to be clarified, may be ascribed to yet undetected dietary variations related to the use of wild plants.

Summary

This Chapter assessed periodontal conditions in the three populations of the Late Jomon period from the Kanto and central Honshu regions through an analysis of CEJ-AC distance and interdental septum inflammation. The results indicated that 31.8% to 66.0% of the individuals had a moderate or severe periodontal condition. The inter-site or inter-sex difference among the three Jomon populations were smaller in the periodontal disease rate than in the other oral health indicators such as caries, AMTL, occlusal wear, and chipping. From the interdental septum assessment, the population with stronger occlusal wear was found to exhibit higher rates of periodontal disease. In addition, multivariate correspondence analysis using all the observed traits indicated a stronger relationship of interdental septum inflammation to degree of occlusal wear than to CEJ-AC distance, a newly observed aspect of periodontal disease not recognized in previous studies. This presumably indicates a more direct effect of occlusal wear on inflammation of the periodontal tissue.

CHAPTER II

Temporal changes in oral health indicators of Jomon populations

本章については、５年以内に雑誌等で刊行予定のため、非公開。

CHAPTER III

Oral Health Indicators and Stable Isotopic Signatures of Paleo-diets in Jomon population

本章については、５年以内に雑誌等で刊行予定のため、非公開。

Conclusions

This study investigates oral health status of the Jomon people by using dental and/or osteological indicators in the mouth. More concrete objectives are to clarify the temporal, gender and environmental (geographical) differences of the oral health indicators for the Jomon people. Viewing the results of all chapters, this thesis sheds new lights on the following two points, 1) the expressivity of the periodontal disease and plausible relation among the oral health indicators or other factors in the Jomon people, 2) the temporal changes in the oral health condition of the Jomon people.

Firstly in Chapter I, regarding the expressivity of the periodontal disease, the rate of positive expression in the Jomon people was shown to be the same level as those in hunter-gatherers from outside of Japan. In addition, it was confirmed that groups with stronger occlusal wear exhibited a higher percentage of individuals with periodontal disease even in a young age. Furthermore, multivariate analysis showed that one of the periodontal indicators, inflammation of the interdental septum, was associated with strong dental wear and crown chipping, suggesting that occlusal mechanical load may damage the periodontal tissue and then progress periodontal inflammation. Using large samples from wider geographical regions in Chapter II, two indicators of periodontal disease (morphology of the interdental septum, CEJ-AC distance) and their relationship to dental wear were examined. As a result, as dental wear progresses, more individuals exhibit severe inflammation at the interdental septum, as well as having a longer CEJ-AC distance. On the other hand, if we regard strong dental wear in archaeological remains as indicative of older ages, the result can be interpreted as showing a simple increase of periodontal disease rate with age.

Table 1.1. Number of individuals in three Jomon populations (Ubayama, Nakazuma and Kitamura) by sex and age used for Chapter I.

	sample number				age groups					period		
	All	Male	Female	unknown	Young	Early middle	Late middle	eldery	unknown	Middle Jomon	Late Jomon	unknown
Nakazuma	77	47	20	10	7	34	25	2	9	0	77	0
Ubayama	58	33	25	0	14	15	22	2	5	9	43	6
Kitamura	62	26	35	1	21	15	21	5	0	13	23	26

Table 1.2. The six categories of the Interdental septum morphology by Kerr (1988, 1994).

Category 0.	Unrecordable, tooth on either side the seprum lost ante morem or the septum damaged post morterm.
Category 1.	Septal form characteristic of its region with the cortical surface continuous. Such a situation is considered to represent the 'healthy' situation.
Category 2.	Septal form characteristic of the region. Cortical surface showing a range from many small foramina and/or grooves to large foramina with prominent grooves or ridges. This category is indicative of inflammation in the overlying soft tissue and a clinical diagnosis of gingivitis.
Category 3.	Septal form showing a breakdown of contour, the essential distinguishing feature being a sharp and ragged texture to the bone defect. Such a defect is representative of an acute burst of periodontitis.
Category 4.	Septal form showing breakdown of contour, the distinguishing feature being a porous or smooth honeycomb effect with all defects rounded. This defect considered to be a previously acute periodontitis that has reverted to a quiescent phase.
Category 5.	Presence of a deep intrabony defect with sides sloping at 45" or more and with a depth of 3mm or more. This defect is equivalent to a more aggressive periodontitis in either an acute or quiescent phase.

Table 1.3. The categorizing criteria of each individual variable using for multivariate analysis.

Categorizing score	1	2	3	4	5
Average value of the CEJ-AC distance[1] scores	X = 0	0<X≦1	1<X≦2	2<X≦3	
Average value of the inter dental septum morphological scores	0<X≦1	1<X≦2	2<X≦3	3<X≦4	4<X≦5
Caries rates	X = 0%	0<X≦0.25	0.25<X≦0.5	0.5<X≦0.75	0.75<X≦1
Rates of AMTL[2]	X = 0%	0<X≦0.25	0.25<X≦0.5	0.5<X≦0.75	0.75<X≦1
Wear	A	B	C	D	E
Average value of the chipping scores	X = 0	0<X≦0.5	0.5<X≦1	1<X≦1.5	1.5<X

1）CEJ-AC distance is distance between cement-enamel junctions to alveolar crests.
2) AMTL is ante mortem tooth loss.

Table 1.4. Percentage of periodontal disease evaluated by the distance between Cement-enamel Junctions to Alveolar crest for three Jomon populations.

(Count in Individual)

	Nakazuma			Ubayama			Kitamura		
	N	≧Score2	%	N	≧Score2	%	N	≧Score2	%
ALL	70	27	38.6%	56	20	35.7%	44	14	31.8%
male	45	23	51.1%	32	11	34.4%	21	9	42.9%
female	14	3	21.4%	24	9	37.5%	23	5	21.7%

(Count in alveolar socket)

	Nakazuma			Ubayama				Kitamura			
	N	≧Score2	%	N	≧Score2	%		N	≧Score2	%	
ALL	330	177	53.6%	624	410	65.7%	**	362	180	49.7%	
male	237	148	62.4%	383	258	67.4%		211	129	61.1%	**
female	64	29	45.3%	251	160	63.7%		151	56	37.1%	

** *P<.01*, * *P<.05*

Table 1.5. Percentage of periodontal disease evaluated by the condition of the interdental septa for three Jomon populations.

（Count in Individual）

	Nakazuma			Ubayama			Kitamura		
	N	≧Category3	%	N	≧Category3	%	N	≧Category3	%
ALL	67	26	38.8% *	53	35	66.0%	48	29	60.4%
male	44	17	38.6%	32	20	62.5%	20	11	55.0%
female	15	5	33.3%	21	15	71.4%	27	17	63.0%

（Count in alveolar septum）

	Nakazuma			Ubayama			Kitamura		
	N	≧Category3	%	N	≧Category3	%	N	≧Category3	%
ALL	408	206	50.5% **	575	395	68.7%	259	167	64.5%
male	280	147	52.5%] *	364	242	66.5%	120	87	72.5%] *
female	94	45	47.9%	211	153	72.5%	137	78	56.9%

** *P<.01*, * *P<.05*

Table 1.6. Percentage of caries by site and sex for three Jomon populations.

	Nakazuma					Ubayama					Kitamura				
	N	Carious teeth	%		ACFP[1)]	N	Carious teeth	%		ACFP[1)]	N	Carious teeth	%		ACFP[1)]
ALL	594	101	17.0%	**	1.30	1183	135	11.4%	**	0.90	780	15	1.9%	**	0.11
male	423	49	11.6%	**	0.90	699	30	4.3%	**	0.30	397	6	1.5%		0.09
female	132	46	34.8%		2.70	484	105	21.7%		1.80	379	9	2.4%		0.13

*** P<.01, * P<.05*

1）ACFP is Average of caries freuencey per person by Sakura (1969).

Table 1.7. Percentage of antemortem tooth loss (AMTL) by site and sex for three Jomon populations.

	Nakazuma					Ubayama					Kitamura				
	N	AMTL	%		ATLFP[1)]	N	AMTL	%		ATLFP[1)]	N	AMTL	%		ATLFP[1)]
ALL	1064	94	8.8%		0.70	1571	170	10.8%		0.80	1171	43	3.7%	**	0.22
male	713	50	7.0%	** (male vs female)	0.60	868	54	6.2%	** (male vs female)	0.50	566	5	0.9%	** (male vs female)	0.06
female	273	38	13.9%		1.10	703	116	16.5%		1.40	586	38	6.5%		0.35

*** P<.01, * P<.05*

1）ATLFT is calculated as the average tooth loss frequency per person defined in this study based on Sakura (1969).

Table 2.1 ~ 3.11, Appendix 2.1 ~ 2.1

５年以内に雑誌等で刊行予定のため、非公開。

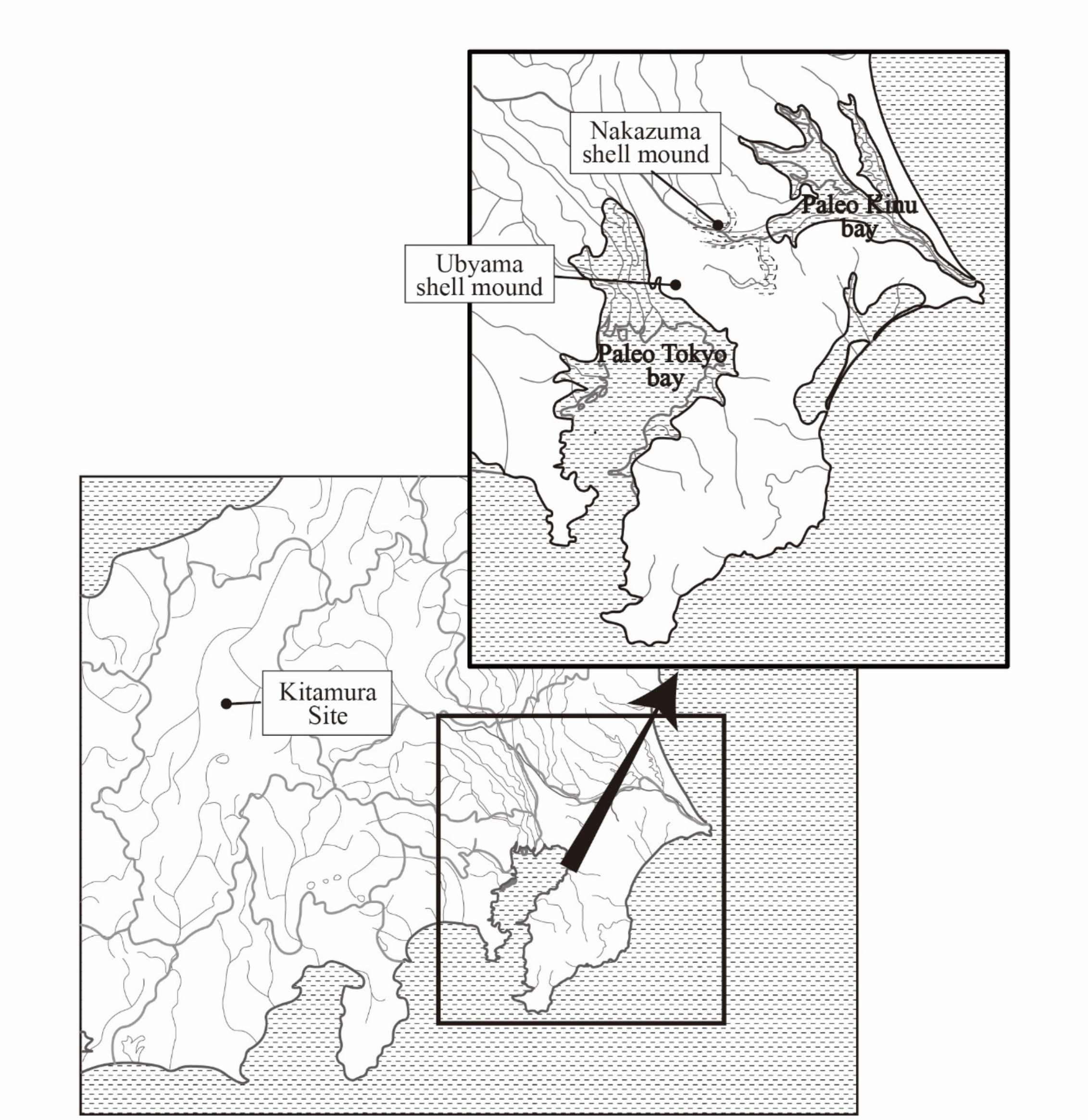

Figure 1.1. Location of three Jomon sites (Ubayama, Nakazuma and Kitamura) mentioned in Chapter I.

In the enlarged view around Tokyo Bay (Upper), the black line shows the coastline around the Tokyo bay and the late Jomon period (about 3,000 years ago), and the gray line is the current coastline. This figure modified from Esaka (1972).

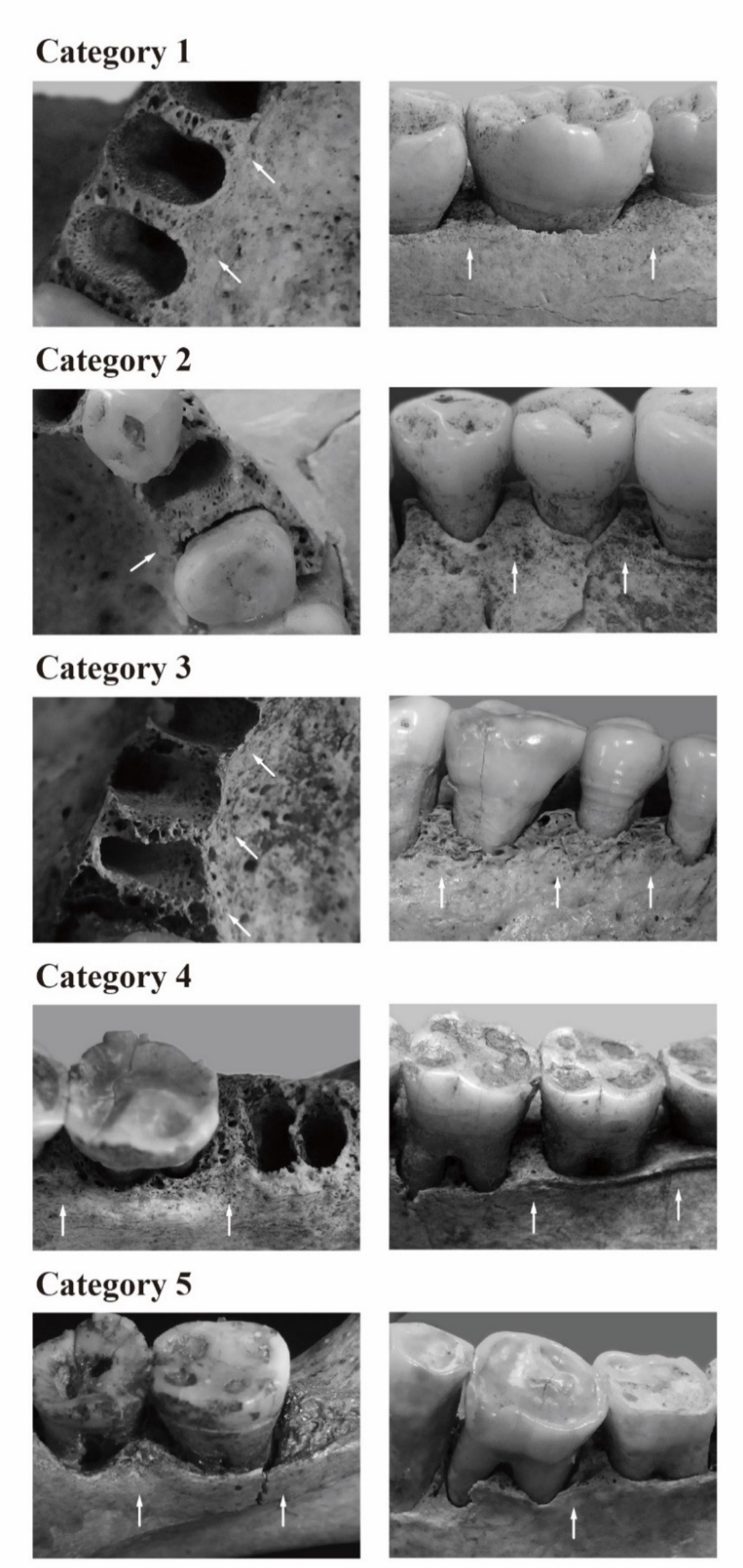

Figure 1.2. Five categories of Interdental septum morphology.

All specimens are selected from the samples in this study.

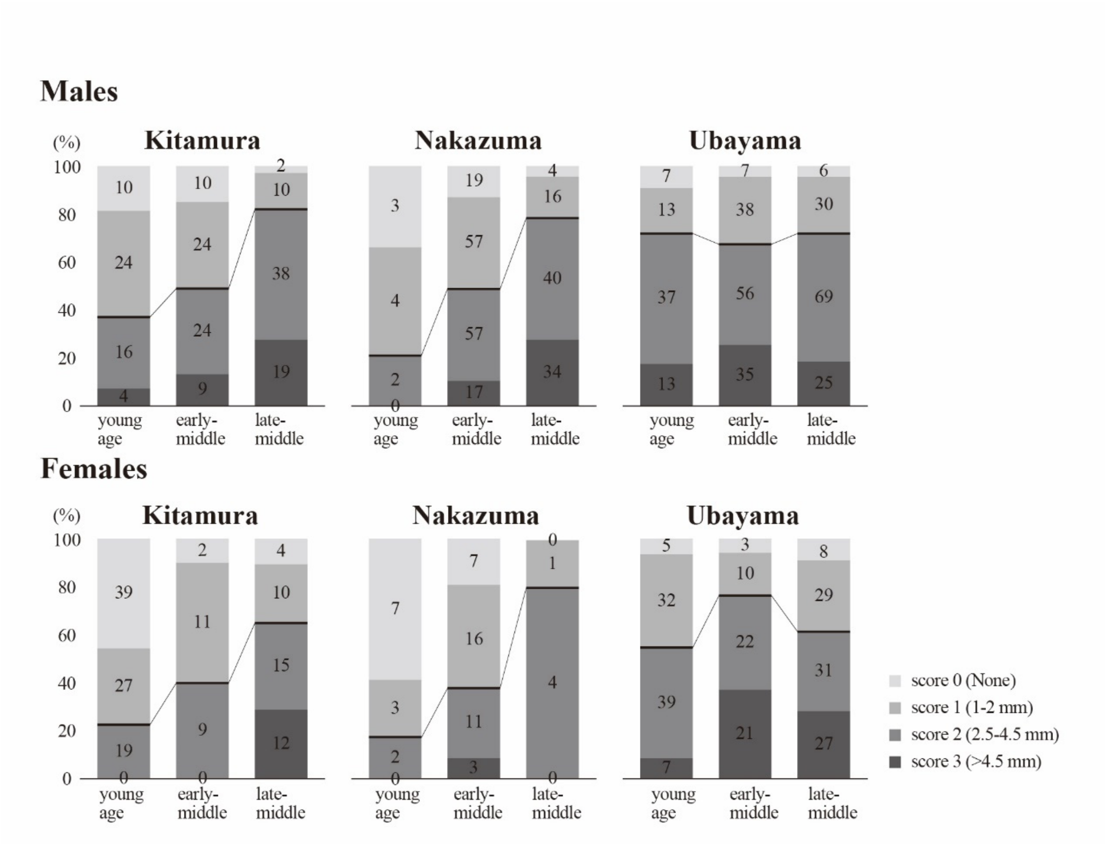

Figure 1.3. Frequency of the CEJ-AC distance score in age groups of three Jomon populations.

Thick black lines indicate the proportion of Score 2 or more (rates of over moderate periodontal disease). The elderly groups were excluded because of the small member of samples.

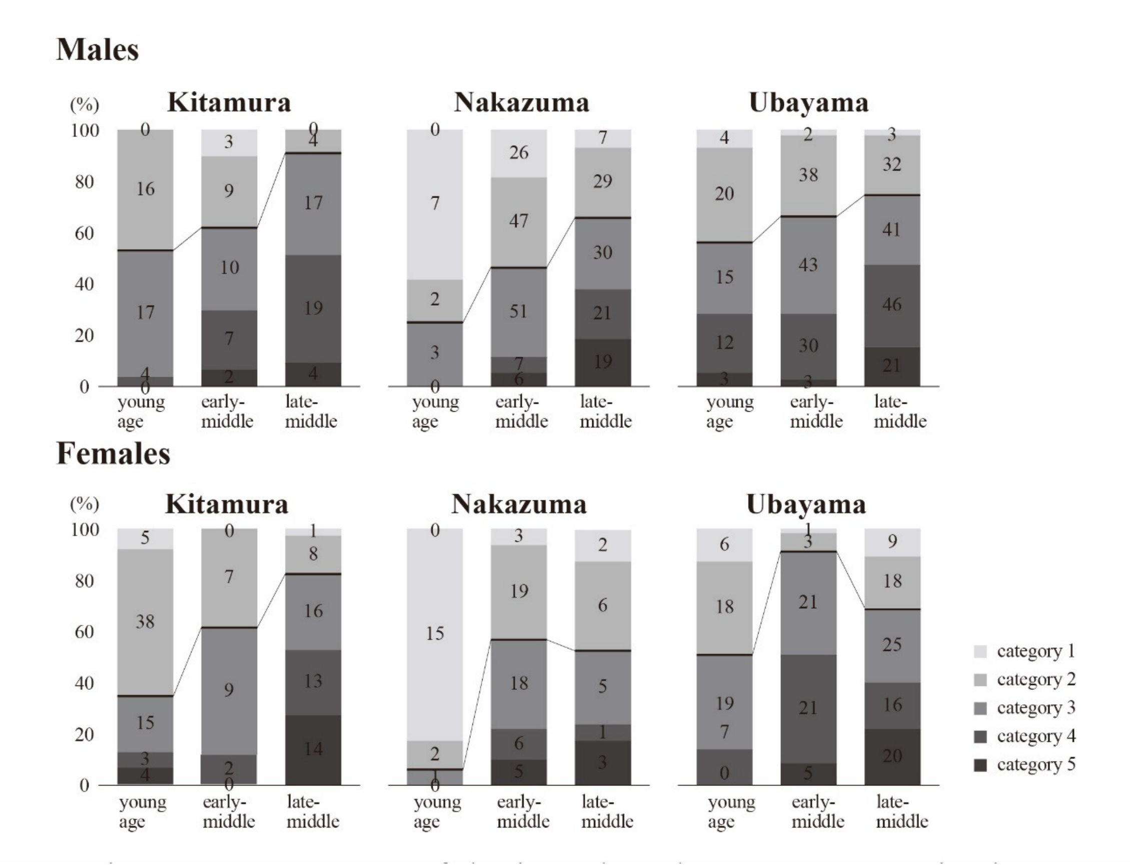

Figure 1.4. Frequency of the interdental septum categories in age groups of three Jomon populations.

Thick black lines indicate the proportion of Category 3 or more (rates of over moderate periodontal disease). The elderly groups were excluded because of the small member of samples.

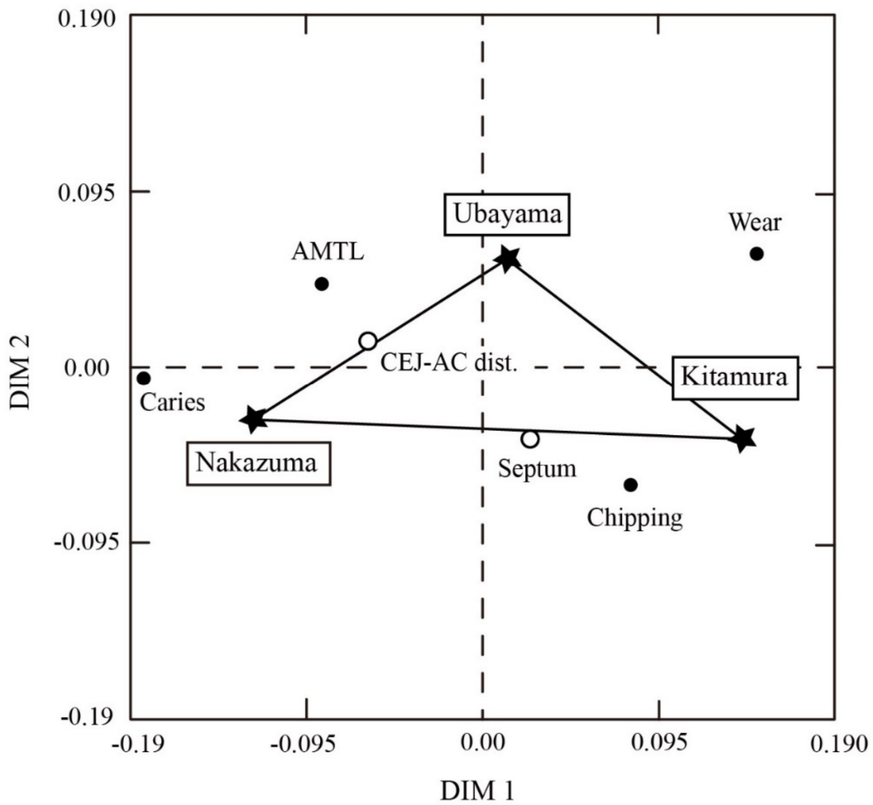

Figure 1.5. Correspondence analysis of the three populations using six oral health indicators.

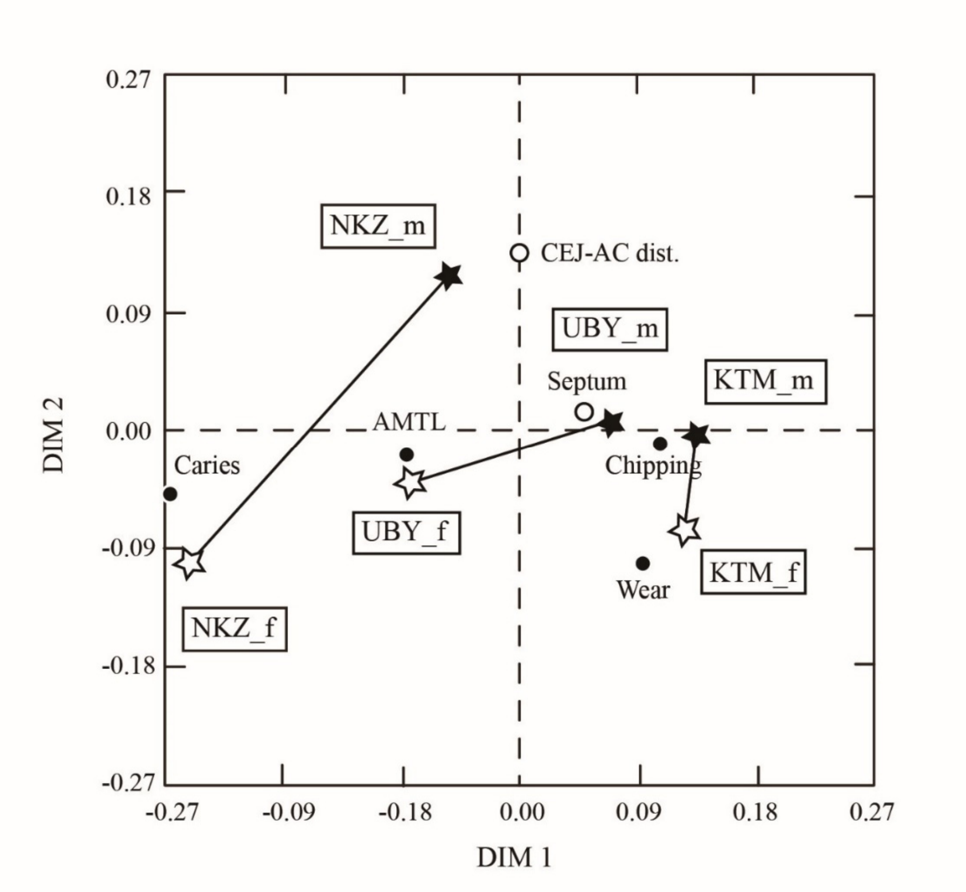

Figure 1.6. Correspondence analysis of the three populations divided by sex.

KTM_m = male of Kitamura site, NKZ_m = male of Nakazuma shell mound, UBY_m = male of Ubayama shell mound, KTM_f = female of Kitamura site, NKZ_f = female of Nakazuma shell mound, UBY_f = female of Ubayama shell mound.

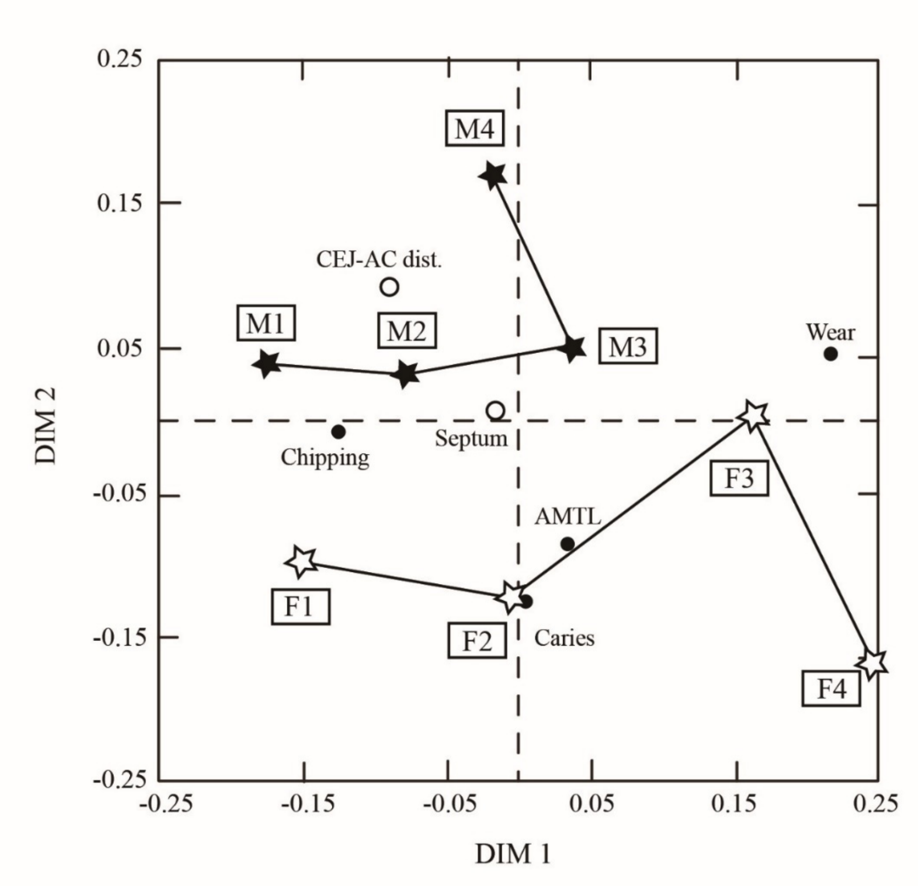

Figure 1.7. Correspondence analysis of ageing changes of the three populations divided by sex.

M1 = young adult male, M2 =early-middle aged male, M3 = late-middle aged male, M4 = earldery male, F1 = young adult female, F2= early-middle aged female, F3 = late-middle aged female, F4 = earldery female.

Figure 2.1 ~ 4.1

５年以内に雑誌等で刊行予定のため、非公開。

References

Abe Y. (2014) Nakazato kaizuka no keisei wo meguru seigyou katsudou to chiiki sei: fukugou teki seigyou kouzou to iseki gun no keisei. In: Abe Y. (eds.), Hama kaizuka to Jomon syakai: kuni shiseki Nakazato kaizuka no jitsuzou wo saguru. Yuzankaku, Inc, Tokyo, pp. 209–226 (in Japanese).

Adler C.J., Dobney K., Weyrich L.S., Kaidonis J., and Walker A.W. et al. (2013) Sequencing ancient calcified dental plaque shows changes in oral microbiota with dietary shifts of the Neolithic and Industrial revolutions. Nature Genetics, 45: 450–455.

Agerholm D.M. and Sidi A.D. (1988) Reasons given for extraction of permanent teeth by general dental practitioners in England and Wales. British Dental Journal, 164: 345–348.

Ainamo J., Sarkki L., Kuhalampi M.L., Palolampi L., and Piirto O. (1984) The frequency of periodontal extractions in Finland. Community dental health, 1: 165–172.

Albandar J.M. (2002) Global risk factors and risk indicators for periodontal diseases. Periodontology 2000, 29: 177–206.

Albandar J.M. (2005) Epidemiology and risk factors of periodontal diseases. Dental Clinics, 49: 517–532.

Ambrose S.H. and DeNiro M.J. (1986) Reconstruction of African human diet using bone collagen carbon and nitrogen isotope ratios. Nature, 319: 321–324.

Aufderheide A.C., Rodriguez-Martin C., and Langsjoen O. (1998) The Cambridge Encyclopedia of Human Paleopathology, Cambridge University Press, Cambridge.

Baelum V. and Fejerskov O. (1986) Tooth loss as related to dental caries and periodontal breakdown in adult Tanzanians. Community Dentistry and Oral Epidemiology, 14: 353–357.

Baelum V., Wen–Min L.U.A.N., Fejerskov O., and Xia C. (1988) Tooth mortality and periodontal conditions in 60–80-year-old Chinese. European Journal of Oral Sciences, 96: 99–107.

Beckett S. and Lovell N.C. (1994) Dental disease evidence for agricultural intensification in the Nubian C-Group. International Journal of Osteoarchaeology, 4: 223-239.

Binford L.R. (1980) Willow smoke and dogs' tails: hunter-gatherer settlement systems and archaeological site formation. American antiquity, 45: 4-20.

Bonfiglioli B., Mariotti V., Facchini F., Belcastro M.G., and Condemi S. (2004) Masticatory and non-masticatory dental modifications in the epipalaeolithic necropolis of Taforalt (Morocco). International Journal of Osteoarchaeology, 14: 448–456.

Cahen P.M., Frank R.M., and Turlot J.C. (1985) A survey of the reasons for dental extractions in France. Journal of Dental Research, 64: 1087–1093.

Chisholm B. (2004) Paleodiet studies in Japan using stable isotope analysis. Bulletin of the International Jomon Culture Conference, 1: 25–33.

Chisholm B. and Koike H. (1999) Reconstructing Prehistoric Japanese Using Stable Isotopic Analysis. In K. Omoto (ed.) Interdisciplinary Perspectives on the Origins of the Japanese, pp. 199–222. International Center for Japanese Studies, Kyoto.

Chisholm B., Koike H., and Nakai N. (1992) Carbon isotopic determination of paleodiet in Japan: marine versus terrestrial sources. In: Aikens C.M. and Rhee S.N. (eds.) Pacific northeast Asia in prehistory: research into the emergence of hunter-fisher-gatherers, farmers, and socio-political elites, pp. 69–73. Washington State University Press, Washington.

Clarke N.G., Carey S.E., Srikandi W., Hirsch R.S., and Leppard P.I. (1986) Periodontal disease in ancient populations. American Journal of Physical Anthropology, 71: 173–183.

Clarke N.G. and Hirsch R.S. (1991) Tooth dislocation: the relationship with tooth wear and dental abscesses. American Journal of Physical Anthropology, 85: 293–298.

Costa R.L. (1982) Periodontal disease in the prehistoric Ipiutak and Tigara skeletal remains from Point Hope, Alaska. American Journal of Physical Anthropology, 59: 97–110.

Craig O.E., Biazzo M., Colonese A.C., Di Giuseppe Z., Martinez-Labarga C., Vetro D.L., LellicR., Martini F., and Rickards, O. (2010) Stable isotope analysis of Late Upper Palaeolithic human and faunal remains from Grotta del Romito (Cosenza), Italy. Journal of Archaeological Science, 37: 2504–2512.

Crowe F., Sperduti A., O'Connell T.C., Craig O.E., Kirsanow K., Germoni P., Macchiarelli R., Garnsey P., and Bondioli L. (2010) Water-related occupations and diet in two Roman coastal communities (Italy, first to third century AD): Correlation between stable carbon and nitrogen isotope values and auricular exostosis prevalence. American Journal of Physical Anthropology, 142: 355–366.

Davies D.M., Picton D.C.A., and Alexander A.G. (1969) An objective method of assessing the periodontal condition in human skulls. Journal of Periodontal Research, 4: 74–77.

DeWitte S.N. (2012) Sex differences in periodontal disease in catastrophic and attritional assemblages from medieval London. American Journal of Physical Anthropology, 149: 405–416.

DeWitte S.N. and Bekvalac J. (2010) Oral health and frailty in the medieval English cemetery of St Mary Graces. American Journal of Physical Anthropology, 142: 341–354.

d'Incau, E., Couture, C., and Maureille, B. (2012) Human tooth wear in the past and the present: tribological mechanisms, scoring systems, dental and skeletal compensations. Archives of Oral Biology, 57: 214–229.

Esaka T. (1959) Jomon bunka no jidai ni okeru shokubutsu saibai kigen no mondai ni taisuru ichi kousatsu. Journal of Archaeological Society of Nippon, 44: 10–6 (in Japanese).

Esaka T. (1972) Change of Natural Environment during the Jomon Cultural Age. The Quaternary Research (Daiyonki-Kenkyu), 11: 135–141 (in Japanese with English abstract).

Fan J. and Caton J.G. (2018) Occlusal trauma and excessive occlusal forces: Narrative review, case definitions, and diagnostic considerations. Journal of periodontology, 89: S214–S222.

Fujimori E. (1970) *Jomon noukou*. Gakuseisha, Tokyo (in Japanese).

Fujio S. (1993) Seigyou kara mita Jomon kara Yayoi. Kokuritsu rekishi minzoku hakubutsukan kenkyuu houkoku, 48: 1–66 (In Japanese).

Fujita H. (1995) Geographical and chronological differences in dental caries in the Neolithic Jomon period of Japan. Anthropological Science, 103: 23–37.

Fujita H. (1999) Jomon jin no shisyuu shikkan: ha no seizen soushitsu suu to ushi suu no kankei no kentou wo chuushin ni. Kodai, 107: 65–76 (in Japanese).

Fujita H., Asakura K., and Ogura M. (2007) Age-and sex-related dental caries prevalence in Japanese from the Jomon period. Journal of Oral Biosciences, 49: 198–204.

Fujita H. and Suzuki T. (1995) Jomon jin no ushi ni tuite. Journal of the Archaeological Society of Nippon, 80: 373–385 (in Japanese).

Genco R.J. (1996) Current view of risk factors for periodontal diseases. Journal of Periodontology, 67: 1041–1049.

Gonçalves P.C.G., Griffiths G., and Rawlinson A. (2015) A study of the periodontal state of a late Medieval United Kingdom population. Archives of Oral Biology, 60: 1797–1801.

Griffin M.C. (2014) Biocultural implications of oral pathology in an ancient Central California population. American Journal of Physical Anthropology, 154: 171–188.

Haberman S.J. (1973) The analysis of residuals in cross-classified tables. Biometrics, 29: 205–220.

Habu J. (2004) Ancient Jomon of Japan. Cambridge University Press, Cambridge.

Habu J. (2015) Mechanisms of long-term culture change and human impacts on the environment: A perspective from historical ecology, with special reference to the Early and Middle Jomon periods of prehistoric. The Quaternary Research 54:299-310.

Hajishengallis G. (2014) Immunomicrobial pathogenesis of periodontitis: keystones, pathobionts, and host response. Trends in Immunology, 35: 3–11.

Halcrow S.E., Harris N.J., Tayles N., Ikehara–Quebral R., and Pietrusewsky M. (2013) From the mouths of babes: dental caries in infants and children and the intensification of agriculture in mainland Southeast Asia. American Journal of Physical Anthropology, 150: 409–420.

Harrel S.K. (2003) Occlusal forces as a risk factor for periodontal disease. Periodontology 2000, 32: 111–117.

Harrel S.K., Nunn M.E., and Hallmon W.W. (2006) Is there an association between occlusion and periodontal destruction?: Yes" occlusal forces can contribute to periodontal destruction. The Journal of the American Dental Association, 137: 1380–1392.

Hillson S. (1996) Dental anthropology. Cambridge University Press, Cambridge.

Holt S.C. and Ebersole J.L. (2005) Porphyromonas gingivalis, Treponema denticola, and Tannerella forsythia: the 'red complex', a prototype polybacterial pathogenic consortium in periodontitis. Periodontology 2000, 38: 72–122.

Horikoshi M. (1972) Jomon jidai no syuuraku to kyoudou soshiki: Tokyo wan engan chiiki wo rei toshite. Sundaishigaku 31: 1–29 (in Japanese).

Imamura K. (1989) Chipped stone axes and storage pit concentrations. In: Watanabe Hitoshi Kyoju Koki Kinen Ronbunshu Kankokai (eds.), *Archaeology and Ethnology (Kokogaku to Minzokushi)*. Rokko, Tokyo, pp. 61–94 (in Japanese).

Imamura K. (1996) *Prehistoric Japan: new perspectives on insular East Asia.* UCL Press, London.

Imamura K. (2000) Hunter-Gatherer Societies from the Viewpoint of Gender. The Nagoya Gakuin Daigaku ronshu. Social sciences, 37: 43–52.

Inagaki K., Suzuki M., Nozaki K., Noguchi T., and Miyajima K. Sakai M., Miyao T., Tsurumi K., and Jinnno T. (1990) A human skeleton from the Ohguruwa remains. Aichi–Gakuin Dental Science, 4: 53–64.

Inoue N., Kuo C.H., Ito G., and Kamegai T. (1981) Dental Diseases in Japanese Skeletal Remains: II. Later Jomon Period. Journal of Anthropological Society of Nippon, 89: 363–378.

Ismail A.I., Hasson H., and Sohn W. (2001) Dental caries in the second millennium. Journal of Dental Education, 65: 953–959.

Jurmain R. (1990) Paleoepidemiology of a central California prehistoric population from CA–Ala–329: Dental disease. American Journal of Physical Anthropology, 81: 333–342.

Kagawa M. (1966) Jomon jidai no noukou. The Archaeological Jouranl, 2: 2–5 (in Japanese).

Kagawa M. (1972) *Noukou no kigen: nihon bunka no genryuu wo saguru*. Koudansha, Tokyo (in Japanese).

Kaifu Y., Kasai K., Townsend G.C., and Richards L.C. (2003) Tooth wear and the "design" of the human dentition: a perspective from evolutionary medicine. Yearbook of Physical Anthropology, 46: 47–61.

Kamei T. (2018) Kogan no chikei hattatsu to iseki keisei. In: Abe Y. (eds.), *Kasumigaura no kaizuka to syakai*. Yuzankaku, Inc, Tokyo, pp. 121–133 (in Japanese).

Kelly R.L. (1995) *The foraging spectrum: Diversity in hunter-gatherer lifeways*. Smithsonian Inst Press.

Kerr N.W. (1988) A method of assessing periodontal status in archaeologically derived skeletal material. Journal of Paleopathology, 2: 67–78.

Kerr N.W. (1991) Prevalence and natural history of periodontal disease in Scotland–the mediaeval period (900–600 AD). Journal of Periodontal Research, 26: 346–354.

Kerr N.W. (1994) PrevaThlence and natural history of periodontal disease in a London, Spitalfields, population (1645–1852 AD). Archives of Oral Biology, 39: 581–588.

Kondo O. (1993) Morphometric data on the skulls of Ubayama shell-mounds. Anthropological science, 101: 333–360.

Kondo O., Yoneda M., and Taniguchi Y. (2018) A female human skeleton from the Initial Jomon period found in the Iyai rock shelter in mountainous Kanto, Japan. Anthropological Science, 126: 151-164.

Kudo Y. and National Museum of Japanese History ed. (2014) *New Perspectives on the plant use of Jomon People*. Shinseisha, Tokyo (in Japanese).

Kudo Y. and Sasaki Y. (2010) Characterization of plant remains on Jomon potteries excavated from the Shimo-yakebe Site, Tokyo, Japan. Bulletin of the National Museum of Japanese History, 158: 1–26 (in Japanese with English abstract).

Koyama S. and Sogito (1984) A study of Jomon population -Computer Simulation Analaysis. Bulletin of the National Museum of Ethnology:1-39.

Kusaka S. (2018) *The stable Isotope Anthorology of Human skeletal remains (Kojinkotsu wo hakaru: douitai jinruigaku jyosetsu)*. Kyoto University Press, Kyoto (in Japanese).

Kusaka S., Ando A., Nakano T., Yumoto T., Ishimaru E., Yoneda M., Fujio H., and Katayama K. (2009) A strontium isotope analysis on the relationship between ritual tooth ablation and migration among the Jomon people in Japan. Journal of Archaeological Science, 36: 2289–2297.

Kusaka S., Hyodo F., Yumoto T., and Nakatsukasa M. (2010) Carbon and nitrogen stable isotope analysis on the diet of Jomon populations from two coastal regions of Japan. Journal of Archaeological Science, 37: 1968–1977.

Kusaka S., Saso A., and Yoneda M (2015a) Radiocarbon dating and carbon and nitrogen isotope analysis on human skeletal remains from Koh and Ikawazu sites of the Jomon period Anthropological Science (Japanese Series), 123: 31–40 (in Japanese with English abstract).

Kusaka S., Uno K.T., Nakano T., Nakatsukasa M., and Cerling T.E. (2015b) Carbon isotope ratios of human tooth enamel record the evidence of terrestrial resource consumption during the Jomon period, Japan. American journal of physical anthropology, 158: 300–311.

Larsen C.S. (1983) Behavioural implications of temporal change in cariogenesis. Journal of Archaeological Science, 10: 1–8.

Larsen C.S. (1995) Biological changes in human populations with agriculture. Annual Review of Anthropology, 24: 185–213.

Larsen C.S. (1997) *Bioarchaeology: interpreting human behavior from the skeleton*. Cambridge University Press, Cambridge.

Larsen C.S. (2006) The agricultural revolution as environmental catastrophe: Implications for health and lifestyle in the Holocene. Quaternary International, 150: 12–20.

Larsen C.S. and Thomas D.H. (1982) The anthropology of St. Catherines Island. 3. Prehistoric human biological adaptation. Anthropological papers of the American Museum of Natural History; 57: 157–276.

Lavigne S.E. and Molto J.E. (1995) System of measurement of the severity of periodontal disease in past populations. International Journal of Osteoarchaeology, 5: 265–273.

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

Lillie M.C. and Richards M. (2000) Stable isotope analysis and dental evidence of diet at the Mesolithic–Neolithic transition in Ukraine. Journal of Archaeological Science, 27: 965–972.

Listgarten M.A. (1976) Structure of the microbial flora associated with periodontal health and disease in man: a light and electron microscopic study. Journal of periodontology, 47: 1–18.

Littleton J. (2017) Hunter–gatherer dental pathology: Do historic accounts of Aboriginal Australians correspond to the archeological record of dental disease? American Journal of Human Biology, 30: e23076.

Lozano M., Subirà M.E., Aparicio J., Lorenzo C., and Gómez-Merino G. (2013) Toothpicking and periodontal disease in a Neanderthal specimen from Cova Foradà site (Valencia, Spain). PloS one, 8: e76852.

Lubell D., Jackes M., Schwarcz H., Knyf M., and Meiklejohn C. (1994) The Mesolithic-Neolithic transition in Portugal: isotopic and dental evidence of diet. Journal of Archaeological Science, 21: 201–201.

Lukacs J.R. (1992) Dental paleopathology and agricultural intensification in South Asia: new evidence from Bronze Age Harappa. American Journal of Physical Anthropology, 87: 133–150.

Lukacs J.R. (2007) Dental trauma and antemortem tooth loss in prehistoric Canary Islanders: prevalence and contributing factors. International Journal of Osteoarchaeology, 17: 157–173.

Macchiarelli R. (1989) Prehistoric "fish eaters" along the eastern Arabian coasts: dental variation, morphology, and oral health in the Ra's al Hamra community (Qurum, Sultanate of Oman, 5th–4th millennia BC). American Journal of Physical Anthropology, 78:575–594.

Manji F., Baelum V., and Fejerskov O. (1988) Tooth mortality in an adult rural population in Kenya. Journal of Dental Research, 67: 496–500.

Martín-Francés L., Martinón-Torres M., Lacasa-Marquina E., Fernández-Colón P., Gracia-Téllez A., and Bermúdez de Castro J.M. (2014) Palaeopathology of the Pleistocene Specimen D2600 from Dmanisi (Republic of Georgia). Comptes Rendus Palevol, 13: 189–203.

Matsumura H. (1995) Jinkotsu shoken, In: Miyauchi, Y. and Nishimori T. (eds.), *Nakazuma kaizuka*. Toride shi kouiku iinkai, Toride, pp. 130–202 (In Japanese).

Minagawa M.（1990）Aisoto-pu shokusei bunseki kara miru senshi mongoroido no shokuseitai, Kakusan shuudan no shokuseitai to jikyu bunpu (douitai ni yoru ko eiyou-gaku, AMS-hou ni yoru nendai sokutei), Report of the Grant-in-Aid for Scientific Research on Priority Areas by Ministry of Education (no.02225105), Science, Sports and Culture, pp 1–15 (In Japanese).

Minagawa M. (2001) Dietary Pattern of Prehistoric Japanese Populations Inferred from Stable Carbone and Nitrogen Isotopes in Bone protein. Bulletin of the National Museum of Japanese History, 86: 333–357 (in Japanese with English abstract).

Minagawa M. and Akazawa T. (1993) Dietary patterns of Japanese Jomon hunter-fisher-gatherers: stable nitrogen and carbon isotope analyses of human bone. In: Aikens C.M. and Rhee S.N. (eds.), *Pacific Northwest Asia in Prehistory: Recent Research into the Emergence of Hunter-Fisher-Gatherers, Farmers, and Sociopolitical Elites*. Washington State University Press, Pullman, pp. 59–67.

Mizushima S., Kuwamura K., and Suwa G. (2004) *Jomon jidai jinkotsu database, 2) Ubayama*. The University of Museum, The University of Tokyo, Material Report No. 54 (In Japanese).

Molleson T. and Jones K. (1991) Dental evidence for dietary change at Abu Hureyra. Journal of Archaeological Science, 18: 525–539.

Murphy T.R. (1959). Compensatory mechanisms in facial height adjustment to functional tooth attrition. Australian Dental Journal, 4: 312–323.

Naito Y.I., Chikaraishi Y., Ohkouchi N., and Yoneda M. (2013) Evaluation of carnivory in inland Jomon hunter–gatherers based on nitrogen isotopic compositions of individual amino acids in bone collagen. Journal of Archaeological Science, 40: 2913–2923.

Nakayama S. (2010) *Syokubutsu koukogaku to nihon no noukou no kigen.* Douseisha,Tokyo (in Japanese).

Nakayama S (2015a) Utilization of domesticated plants secondary vegetation in the central highlands of the Japanese archipelago in the Jomon period. The Quaternary Research, 54: 258–298 (in Japanese with English abstract).

Nakayama S. (2015b) Domestication of the soybean (Glycine max) and morphological differentiation of seeds in the Jomon period. Japanese Journal of Historical Botany, 23: 33–42 (in Japanese with English abstract)

Newbrun E. (1982) Sugar and dental caries: a review of human studies. Science, 217: 418–423.

Newman H.N. and Levers B.G.H. (1979) Tooth eruption and function in an early Anglo-Saxon population. Journal of the Royal Society of Medicine, 72: 341–350.

Nishino M. (2009) Oogata kaizuka keisei no haikei wo saguru. In: Abe Y. (eds.), *Tokyo wan kyodai kaizuka no jidai to syakai*. Yuzankaku, Inc, Tokyo, pp. 143–161 (in Japanese).

Noshiro S. and Sasaki Y. (2014) Management of forest resources during the Jomon period in Japan deduced from excavated plant remains. Bulletin of the National Museum of Japanese History, 187: 15–47 (in Japanese with English abstract).

Obata H. (2011) *Tohoku ajia kominzoku shokubutsu gaku to Jomon noukou.* Touseisha,Tokyo (in Japanese).

Obata H., Sasaki Y., and Senba Y. (2007) Impressions on pottery revealed cultivation of Glycine max subsp. max (soybean) in the late to latest Jomon periods in Kyushu Island. Japanese Journal of Historical Botany, 15: 97–114 (in Japanese with English abstract)

Ooyama K. (1927) Kanawaga kenka araiso mura aza katsusaka ibutsu houganchi chousa houkok. Shizen kenkyukai syouhou, 1: 1–71 (in Japanese).

Otero J.G. and Novellino P. (2011) Diet, nutritional status and oral health in hunter-gatherers from the central-northern coast of Patagonia and the Chubut river lower valley, Argentina. International Journal of Osteoarchaeology, 21: 643–659.

Oztunc H., Yoldas O., and Nalbantoglu E. (2006) The periodontal disease status of the historical population of Assos. International Journal of Osteoarchaeology, 16: 76–81.

Page R.C. and Eke P.I. (2007) Case definitions for use in population-based surveillance of periodontitis. Journal of Periodontology, 78: 1387–1399.

Pate F.D. (1994). Bone chemistry and paleodiet. Journal of Archaeological Method and Theory, 1: 161–209.

Prowse T. L., Saunders S.R., Schwarcz H.P., Garnsey P., Macchiarelli R., and Bondioli L. (2008) Isotopic and dental evidence for infant and young child feeding practices in an imperial Roman skeletal sample. American Journal of Physical Anthropology, 137: 294–308.

Sakazuma N. (1956) Nihon genshi noukou shiron. Journal of Archaeological Society of Nippon,42:

1–12 (in Japanese).

Sakura H. (1964) Historical Changes in the Frequency of Dental Caries among the Japanese People. Journal of the Anthropological Society of Nippon, 71: 153–177.

Sasaki Y. (2007) Mizuba ikou. In: Kosugi Y., Taniguchi Y., Nishida Y., Mizunoe K., and Yano. K (eds.), *Jomon jidai no kouko gaku. 5. Nariwai: syokuryou seisan no gijyutsu*. Dousei–sha, Tokyo, pp. 51–63 (in Japanese).

Schulting R.J., Blockley S.M., Bocherens H., Drucker D., and Richards, M. (2008) Stable carbon and nitrogen isotope analysis on human remains from the Early Mesolithic site of La Vergne (Charente-Maritime, France). Journal of Archaeological Science, 35: 763–772.

Seta S. and Yoshino M. (1990) *Hakkotsu shitai no kantei*. Reibun–sha, Tokyo.

Sheiham A. (1983) Sugars and dental decay. The Lancet, 321: 282–284.

Shigehara N. (1993) Jinkotsu no keishitsu. In Hirabayashi A., Seki M., Machida K., and Hara A. (eds.), *Kitamura Site*. Archaeological research center of Nagano prefecture, Nagano, pp. 259–402 (In Japanese)

Shigehara N. (1994) Human skeletal remains of the middle to late Jomon period excavated from the inland Kitamura site, Nagano Prefecture. Anthropological Science, 102: 321–344.

Shimizu H. (2016) An introduction to the statistical free software HAD: Suggestions to improve teaching, learning and practice data analysis. Journal of Media, Information and Communication, 1: 59–73 (In Japanese).

Shizukuishi S., Tanaka M., and Nagata H. (2011) Current Evidence Regarding Association between Periodontal Disease and Nutrition, Journal of Dental Health, 61: 2-12 (in Japanese with English abstract).

Sillen A. and Kavanagh M. (1982) Strontium and paleodietary research: a review. Yearbook of Physical Anthropology, 25: 67–90.

Slots J. (1979) Subgingival microflora and periodontal disease. Journal of clinical periodontology, 6: 351–382.

Smith P. (1972) Diet and attrition in the Natufians. American Journal of Physical Anthropology, 37: 233–238.

Socransky S.S. and Haffajee A.D. (2005) Periodontal microbial ecology. Periodontology 2000, 38: 135–187.

Sreebny L.M. (1982) Sugar availability, sugar consumption and dental caries. Community Dentistry and Oral Epidemiology, 10: 1–7.

Standen V. and Muños Ovalle I. (2013) Tooth Wear Related to Marine Foraging, Agro-Postorilismand the Formative Transition on the Nothern Chilean Coast. International Journal of Osteoarchaeology, 23: 287–302.r

Takeuchi M. (1962) On the epidemiological principles in dental caries attack. Bulletin of Tokyo Dental College, 3: 96–111.

Tal H. (1985) Periodontal bone loss in dry mandibles of South African blacks: a biometric study. Journal of Dental Research, 64: 925–929.

Tayles N., Domett K., and Nelsen K. (2000) Agriculture and dental caries? The case of rice in prehistoric Southeast Asia. World Archaeology, 32: 68–83.

Temple D.H. (2007) Dietary variation and stress among prehistoric Jomon foragers from Japan. American Journal of Physical Anthropology, 133: 1035–1046.

Temple D.H. (2011) Variability in dental caries prevalence between male and female foragers from the Late/Final Jomon period: implications for dietary behavior and reproductive ecology.

American Journal of Human Biology, 23: 107–117.

Temple D.H. and Larsen C.S. (2007) Dental caries prevalence as evidence for agriculture and subsistence variation during the Yayoi period in prehistoric Japan: biocultural interpretations of an economy in transition. American Journal of Physical Anthropology, 134: 501–512.

Toizumi T. (2018) Doubutsu itai kara mita Kasumigaura no kaizuka no tokucyo: Okadaira kaizuka no cyousa seika wo cyushin ni. In: Abe Y. (eds.), *Kasumigaura no kaizuka to syakai*. Yuzankaku, Inc, Tokyo, pp. 136–158 (in Japanese).

Trinkaus E. (1985) Pathology and the posture of the La Chapelle–au–Saints Neandertal. American Journal of Physical Anthropology, 67: 19–41.

Turner C.G. (1979) Dental anthropological indications of agriculture among the Jomon people of central Japan. American Journal of Physical Anthropology, 51: 619–635.

Walker P.L. and DeNiro M.J. (1986) Stable nitrogen and carbon isotope ratios in bone collagen as indices of prehistoric dietary dependence on marine and terrestrial resources in southern California. American Journal of Physical Anthropology, 71: 51–61.

Wasterlain S.N., Cunha E., and Hillson, S. (2011) Periodontal disease in a Portuguese identified skeletal sample from the late nineteenth and early twentieth centuries. American Journal of Physical Anthropology, 145: 30–42.

Watanabe M. (1974) Various Patterns of Man's Adaptation to the Natural Environments in the Jomon Age. The Quaternary Research, 13: 160–167 (in Japanese with English abstract).

Watanabe M (1975) *Jomon jidai no syokbutsu syoku*. Yuzankaku, Inc., Tokyo (in Japanese).

Watanabe M (1981) Tochi no kozawashi. Busshitsu Bunka, 36: 27-41 (in Japanese).

Watanabe M (1983) Tochi no jitsu syokuyou-ka no jyougen nitsuite. *Studies in paleology,* the Heian Museum of Ancient History, Kyoto, pp. 25–40 (in Japanese).

Watanabe M (1984) Zouho, *Jomon jidai no syokbutsu syoku*. Yuzankaku, Inc., Tokyo (in Japanese).

Weisdorf J.L. (2005) From foraging to farming: explaining the Neolithic Revolution. Journal of Economic surveys, 19: 561–586.

White T.D., Black M.T., and Folkens P.A. (2012) *Human Osteology*, Third Edition. Academic Press, San Diego.

Whittaker D.K., Molleson T., Daniel A.T., Williams J.T., Rose P., and Resteghini R. (1985) Quantitative assessment of tooth wear, alveolar crest height and continuing eruption in a Romano-British population. Archives of Oral Biology, 30: 493–501.

Willis A. and Oxenham M.F. (2013) The neolithic demographic transition and oral health: The Southeast Asian experience. American journal of physical anthropology, 152: 197–208.

Yamamoto N. (2002) *Jomon jidai no syokubutsu saisyuu katsudou: yasei konkeirui syokuryouka no minzoku koukogakuteki kenkyu*. Keisuisha, Hiroshima.

Yoneda M. (2008) Douitai bunseki de mita Ichikawa no Jomon jin no syoku seikatsu. In: Horiuchi M. and Ryozuka M. (eds.), *Ichikawa Jomon kaizuka databook*. Ichikawa kouko Hakubutsukan, Ichikawa, pp. 144–150 (in Japanese).

Yoneda M. (2013) Douitaiseitaigaku de mita Jomon jidaijin ti gendaijin (douitai no kagaku), kagaku to sodatsu, 61: 358–361.

Yoneda M. (2014) Douitai kara mita Nakazuma kaizuka niokeru Jomon jin no syoku seikatsu, In: Toride–shi maizou bunkazai center (eds.), *Nakazuma kaizuka to 101 tai jinkotsu no nazo*, Toride–shi maizou bunkazai center, Toride, pp. 3–4 (in Japanese).

Yoneda M. (2017）Iyai iwakage iseki shutsudo jinkotsu no tanso nendai sokutei tanso chisso antei douitai hisokutei. Jomon jidai souki no maisou jinkotsu-gun to ko shokusei no kenkyuu: Gunma

Iyai Iwakageiseki ni okeru senshi jinruigakuteki kenkyuu (daihyou Taniguchi Yasuhiro), Heisei 28-nendo Kokugakuin daigaku tokubetsu suishin kenkyuu josei-kin kenkyuu seika houkoku-sho, pp. 75–79.

Yoneda M., Hirota M., Uchida M., Tanaka A., Shibata Y., Morita M., and Akazawa T. (2002) Radiocarbon and stable isotope analyses on the Earliest Jomon skeletons from the Tochibara rockshelter, Nagano, Japan. RADIOCARBON, 44: 549–557.

Yoneda M., Omori T., Ozaki H. and Yanagita Y. (2017a) Carbon and nitrogen isotope analysis and radiocarbon dating on the Initial Jomon human skeletons from Iwashita Cave, Sasebo City, Nagasaki, Japan. Anthropological Science (Japanese Series), 125: 39-47 (in Japanese with English abstract).

Yoneda M., Suzuki R., Shibata Y., Morita M., Sukegawa T., Shigehara N., and Akazawa T. (2004) Isotopic evidence of inland-water fishing by a Jomon population excavated from the Boji site, Nagano, Japan. Journal of Archaeological Science, 31: 97–107.

Yoneda M. and Yamazaki T. (2017b) Doui-tai bunseki kara saguru Yayoi jidai no shoku seitai. Kikan koukogaku, 138: 43-46.

Yoneda M., Yoshida K., Yoshinaga J., Morita M., and Akazawa T. (1996) Reconstruction of Palaeodiet in Nagano Prefecture Based on the Carbon and Nitrogen Isotope Analysis and the Trace Elemental Analysis. The Qugano Prefeaternary Research (Daiyonki-kenkyu), 35: 293–303 (in Japanese with English abstract).

Yoshikawa J. (2011) Change in the size of Castanea crenata fruits during the Jomon period. Japanese Journal of Historical Botany, 18: 57–63 (in Japanese with English abstract).

Yoshikawa M. (2006) Identification of Rhus verniciflua Stokes pollen and its occurrence around the Early Jomon Period in Aomori Prefecture Japanese. Journal of Historical Botany. 14: 15–27 (in Japanese with English abstract).

Yoshikawa M. (2011) Dispersal of Castanea crenata pollen and distribution of C. crenata forest around the Sannai-maruyama site during the Jomon period. Japanese Journal of Historical Botany, 18: 65–76. (in Japanese with English abstract).