The bioarchaeology of a Japanese population from the Nozoji-ato site in Kamakura City, Japan

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Abstract The Japanese medieval period encompassed almost 400 years, between 1185 and 1573 AD. Previous research of human skeletal remains from medieval Kamakura City has shown that medieval people had a poor level of health and general living conditions because of malnutrition and interpersonal violence. The aims of this study are to apply bioarchaeological analyses to a new series of human skeletal remains from the Nozoji-ato site in Kamakura City and to test the hypothesis that the bioarchaeological features that characterize medieval Japanese people are commonly seen in the new skeletal series. The Nozoji-ato site has been dated to a chronological age of between 1500 and 1700 AD based on the known sequence of coins and vessels, but most of these artefacts belonged to the medieval period. A sample size of 45 individuals was used in this study from individual graves. The results of this study indicate that the sample from Nozoji-ato is characterized by an old age-at-death distribution and high number of caries-lesion and ante-mortem tooth loss frequencies. Individuals from the Nozoji-ato site also tend to lack evidence for lethal trauma, a phenomenon that is frequently observed in other comparative medieval populations. The results presented in this study led to the conclusion that the Nozoji-ato exhibit different bioarchaeological features compared to the populations from the first half of the medieval period and that living conditions at this site were less severe than expected.

Key words: bioarchaeology, Japan, medieval, secular trends, variation

Introduction

The Japanese medieval period encompassed nearly 400 years, between 1185 and 1573 AD. This time period was characterized by the rise of the warrior class to political power and the establishment of a series of military governments or shogunates. In early work, Suzuki et al. (1956) were the first to conduct a systematic study of medieval Japanese human skeletons from the Zaimokuza burial site within Kamakura City, the center of a medieval period military government (Figure 1). The majority of the injuries in Zaimokuza skulls were scratches (82.3%), while only 2.7% were gashes (Suzuki et al., 1956). Many skull measurements from these individuals also evidenced dolichocephaly, chameprosopy, and prognathism, thought likely to be the result of environmental factors, including dietary conditions and the effects of medical care (Suzuki et al., 1956). These characteristics are noteworthy because the medieval Kamakura people are thought to be the most likely ancestors of modern Japanese (e.g. Dodo and Ishida, 1990, 1992; Hanihara, 1991).

Subsequent excavations at the Seiyokan, Yuigahama Chusei Shudan Bochi, and Yuigahama-minami sites, adjacent to Zaimokuza, have revealed that the medieval people in this region possessed a number of specific morphological features commonly found excavated burial sites, including dolichocephaly, chameprosopy, and prognathism (Nagaoka et al., 2006b). Nakahashi and Nagai (1985) showed that these specific morphological features were generally observed in the medieval human skeletal remains from the Yoshimohama site in the northern Kyushu-Yamaguchi District. It can be assumed that the medieval populations in Kamakura City represented medieval Japanese, because the specific features of the medieval Japanese were commonly observed in all over Japan (Nakahashi and Nagai, 1985) and the number of skeletal remains from the areas other than Kamakura City is small.

The first author of this study (T.N.) and colleagues have further elucidated a number of the characteristics of medieval Japanese urban inhabitants, including short life expectancy (Nagaoka et al., 2006a, 2008, 2013) and short stature (Nagaoka et al., 2008), alongside a low prevalence of dental caries (Nagaoka et al., 2013), and the ubiquitous presence of violence (Hirata et al., 2004; Nagaoka et al., 2009, 2010, 2013). These lines of evidence have all been used to
suggest that the medieval people who inhabited this region were in a poor state of health and had difficult lives because of malnutrition and interpersonal violence. However, little is known about the variability of the bioarchaeological features in this time period. The aims of this study are to apply bioarchaeological analyses to a new series of human skeletal remains from the Nozoji-ato site dating to the latter half of the medieval period and the beginning of the Edo period within Kamakura City in order to confirm the reproducibility of results relating to age-at-death structure, stature, dental caries, ante-mortem tooth loss (AMTL), and violence. This research also tests the hypothesis that the bioarchaeological features that characterize medieval Japanese people are commonly seen at the new skeletal series.

This study focused on the bioarchaeology of Kamakura City from the medieval to the early modern Edo periods, because the region was the center of politics, economics, religion, and culture at that time and the human skeletal remains from there provide information on the influence of urban environments on health.

Materials and Methods

The Nozoji-ato site is located within Kamakura City, Japan. The excavation of human remains from this site was initially undertaken in 2006 by the Kamakura Board of Education and we undertook to perform diagnoses in 2017. The Nozoji-ato was an old temple site of Nozoji, which was established in 1194, dedicated to the soul of a warrior, Yoshiaki Miura, and was destroyed by fire in 1872. Miura and his descendants were buried in the temple, but there is no information on the relationship of the excavated human skeletons to the Miura family. Most of the human skeletons excavated from this site were found articulated, but dried clay adhering to bones unfortunately led to the post-excavation cracking of fragile regions because of the 10-year time interval between excavation and research. The Nozoji-ato site is located in the eastern region to the archaeological sites at Zaimokuza, Seiyokan, Yuigahama Chusei Shudan Bochi (i.e. locations No. 372 and Seika-ichiba), and Yuigahama-minami (Figure 1). The Nozoji-ato site has been dated to the chronological age between 1500 and 1700 AD based on the known sequence of coins and vessels: two individuals were buried with Kanei-tsuho coins definitely dated to the Edo period (between 1600 and 1700 AD), while most of the human remains (associated with Eiraku-tsuho coins and vessels) belonged to the medieval period (between 1500 and 1600 AD) (Tamagawa-bunkazai-kenkyusho, unpublished data). This site is therefore later than other adjacent sites within Kamakura City that have been dated to the period between 1200 and 1500 AD. The difference in chronological age allows us to use the site to detect secular trends in bioarchaeological traits within the medieval period.

The comparative data used in this study were extracted from literature that addresses age-at-death and sex compositions (Nagaoka and Hirata, 2008; Nagaoka et al., 2013), stature (Hiramoto, 1972; Wada and Motomura, 2000; Nagaoka et al., 2008, 2013), dental caries (Sakura, 1964; Fujita, 1995; Todaka et al., 2003), enamel hypoplasia (Sawada, 2010; Nagaoka et al., 2013), cribra orbitalia...
Stature was estimated in this study using the equations outlined by Fuji i’s (1960) and Sasou and Hanihara (1998) that utilize the maximum lengths of the humerus, radius, femur, and tibia. These equations are useful because they lead to only small discrepancies in estimated stature based on each of these four different long bones from medieval Japanese specimens (Nagaoka et al., 2008). Maximum length measurements of these bones were taken following the method proposed by Martin and Knussmann (1988). The estimated stature based on Fuji i’s equations was used for inter-population comparison, because Fuji i’s equations were used to calculate the estimated stature in the comparative samples (Hiramoto, 1972; Wada and Motomura, 2000).

Caries lesion observations were made by eye and with dental instruments. All teeth were grouped as either anterior, premolar, or molar following the method outlined by Oyamada et al. (2007). Enamel color changes lacking depressions were excluded, however, because these are difficult to identify as caries lesions, and frequencies were calculated for tooth units (i.e. the number of affected teeth was divided by the total number of teeth observed) (Lukacs, 1995).

Counts of AMTL were performed by eye on the basis of complete dental socket absorption; AMTL percentages were calculated by dividing the number of AMTLs by the sum of the number of teeth and AMTLs.

Enamel hypoplasia frequencies were examined to clarify physical condition during both infancy and childhood; thus, following the method of Hillson (1996), deficiencies in enamel thickness (e.g. horizontal furrows and pits on surfaces) were identified as examples of this condition. The presence, or absence, of hypoplasia in the upper central incisors and lower canines that retained more than half the crown were recorded, with each tooth observed macroscopically using a LED light (Panasonic BF-425).

The existence of cribra orbitalia in individuals was diagnosed via observations of the exposure of trabecular bone within expanded cancellous bone (Hirata, 1990; Aufderheide and Rodriguez-Martin, 1998).

The location, type, and mechanism of traumas, as well as their healing processes, were considered in this study (Waldron, 2009).

Fisher’s exact test and the Student’s t-test were used for analyses in the software package R 3.1.2 (R Core Team, 2014).

The presence of caries lesions and AMTL were identified by T.N. and the second author of this study (K.H.), while limb bone maximum length measurements were performed by K.H. All other observations and analyses were performed by T.N.

Results

Age-at-death and sex compositions

As discussed above, 45 individuals were included in this analysis, of whom 8 were non-adult, and 37 were adult skeletons (Figure 2). The sample sex ratio of 4 males and 31 females indicates a sexually biased skeletal population (Figure 2); 17.8% of the sample from Nozoi-ato had died before 15 years of age and the ratio of 8 non-adults to 37 adults was 0.21 (Table 1). The proportion of non-adult deaths at Nozoi-ato (i.e. 17.8%; 8/45) is significantly less than that recorded at Hitotsubashi (i.e. 52.2%; 108/207) (P < 0.01), and is not significantly different from data for Yuigahama Chusei Shudan Bochi (i.e. 23.3%, 7/30) (P > 0.05).

The percentages classified into young and elderly groups are 27.6% (8/29) and 72.4% (21/29), respectively, in Nozoi-ato (Table 1). Although data from the Nozoi-ato and Hitotsubashi sites showed 12.4–14.7% higher proportions of elderly individuals than Yuigahama Chusei Shudan Bochi.
there is no significant difference in proportions between present-day and comparative samples ($P > 0.05$) (Figure 3; Table 1).

**Stature**

The data in Table 2 shows the maximum length of limb bones and estimates for stature based on the equations presented by Fujii and Sasou-Hanihara. Due to the small sample size, the inter-population comparison was conducted on females alone. The estimated stature of skeletons from Nozoji-ato was 148.5 cm (females) using Fujii's equations for the maximum length of the right femur (Table 3). The stature of female skeletons from Nozoji-ato is not significantly different from that reported at Yuigahama Chusei Shudan Bochi, Yuigahama-minami, Muromachi, Yayoi, and Kofun ($P > 0.05$), but are significantly higher than those from Zaimokuza ($P < 0.05$) and Edo ($P < 0.05$) (Figure 4; Table 3).

**Dental caries and AMTL**

The data presented in Table 4 illustrates recorded frequencies of caries and AMTL at Nozoji-ato. Results reveal caries frequencies of 16.4% (29/177) in the upper jaw, 9.4% (16/171) in the lower jaw, and 12.9% (45/348) in both jaws. Elderly females also exhibited significantly higher caries lesion frequencies in the upper anterior teeth ($P < 0.05$), lower total teeth ($P < 0.05$), and upper and lower total teeth ($P < 0.01$) than younger females (Figure 5a; Table 4).

The AMTL frequencies recorded in this study were 16.5% (35/212) in the upper jaw, 19.0% (40/211) in the lower jaw, and 17.7% (75/423) in both jaws. Data show that these frequencies were significantly higher in elderly females compared to their younger counterparts in the upper anterior, premolar, and total dental samples ($P < 0.01$), as well as in the lower anterior ($P < 0.01$) and total ($P < 0.05$), and upper and lower total dental ($P < 0.01$) samples (Figure 5b; Table 4).

Data also reveal that individuals at the Nozoji-ato site exhibited a significantly higher frequency of caries lesions (i.e. 12.9%; 45/348) than the medieval period populations from Zaimokuza (i.e. 5.5%; 147/2669) ($P < 0.01$), Yuigahama Chusei Shudan Bochi (i.e. 5.1%; 24/475) ($P < 0.01$), and Yuigahama-minami (i.e. 9.5%; 261/2755) ($P < 0.05$), as well as samples from the Jomon Period (i.e. 8.2%;...
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Recorded frequencies from Nozoji-ato are, however, lower than those seen in the Yayoi (i.e. 19.4%; 354/1823) ($P < 0.01$), Joshinji (i.e. 20.4%; 108/530) ($P < 0.01$), and Unkoin (i.e. 19.3%; 123/638) ($P < 0.05$) samples (Figure 6a; Table 5). Similarly, the AMTL frequency at Nozoji-ato (i.e. 17.7%; 75/423) is significantly higher than values recorded at either Yuigahama Chusei Shudan Bochi (i.e. 6.5%; 36/550) ($P < 0.01$) or Yuigahama-minami (i.e. 3.8%; 134/3531) ($P < 0.01$), also dated to within the medieval period (Figure 6b; Table 5).

Enamel hypoplasia and cribra orbitalia

The recorded frequencies of enamel hypoplasia at the Nozoji-ato site were 58.5% (24/41) in the upper central incisor and 85.7% (24/28) in the lower canine (Table 6). Data show that the frequency of hypoplasia in the upper central incisor at Nozoji-ato was significantly lower than that seen during the Jomon period (i.e. 77.6%; 114/147) ($P < 0.05$), and that 271/3295). Recorded frequencies from Nozoji-ato are, however, lower than those seen in the Yayoi (i.e. 19.4%; 354/1823) ($P < 0.01$), Joshinji (i.e. 20.4%; 108/530) ($P < 0.01$), and Unkoin (i.e. 19.3%; 123/638) ($P < 0.05$) samples (Figure 6a; Table 5). Similarly, the AMTL frequency at Nozoji-ato (i.e. 17.7%; 75/423) is significantly higher than values recorded at either Yuigahama Chusei Shudan Bochi (i.e. 6.5%; 36/550) ($P < 0.01$) or Yuigahama-minami (i.e. 3.8%; 134/3531) ($P < 0.01$), also dated to within the medieval period (Figure 6b; Table 5).

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Table 2. Estimated stature from maximum length of limb bones

|          | Humerus | Humerus | Radius | Radius | Femur | Femur | Tibia | Tibia |
|----------|---------|---------|--------|--------|--------|--------|--------|--------|
|          | Maximum | Maximum | Maximum | Maximum | Maximum | Maximum | Maximum | Maximum |
|          | length  | length  | length  | length  | length  | length  | length  | length  |
| Male     | Right   | Left    | Right   | Left    | Right   | Left    | Right   | Left    |
| Number of individuals | 2 | 2 | 1 | 1 | 2 | 2 | 1 | 1 |
| Mean (cm) | 289.5 | 284.0 | 231.0 | 227.8 | 406.0 | 406.5 | 323.0 | 318.4 |
| Female   | Number of individuals | 10 | 9 | 10 | 8 | 13 | 11 | 10 | 12 |
| Mean (cm) | 276.8 | 275.3 | 211.4 | 208.4 | 390.6 | 392.5 | 316.7 | 311.1 |
| Standard deviation (cm) | 12.5 | 12.7 | 10.2 | 7.8 | 11.6 | 11.1 | 13.3 | 15.5 |
| Estimation using Fujii’s equations |
| Male     | Number of individuals | 2 | 2 | 1 | 1 | 2 | 2 | 1 | 1 |
| Mean (cm) | 154.0 | 153.3 | 158.9 | 158.6 | 155.2 | 155.2 | 153.8 | 152.7 |
| Female   | Number of individuals | 11 | 9 | 10 | 8 | 13 | 11 | 10 | 12 |
| Mean (cm) | 147.7 | 147.3 | 149.1 | 148.8 | 148.5 | 149.3 | 147.5 | 146.6 |
| Standard deviation (cm) | 3.4 | 3.2 | 3.2 | 2.5 | 2.6 | 2.6 | 2.9 | 3.6 |
| Estimation using Sasou and Hanihara’s equations |
| Female   | Number of individuals | 11 | 9 | 10 | 8 | 13 | 11 | 10 | 12 |
| Mean (cm) | 145.9 | 145.3 | 148.0 | 147.3 | 146.3 | 146.7 | 146.3 | 145.2 |
| Standard deviation (cm) | 3.1 | 3.6 | 3.3 | 2.7 | 2.5 | 2.3 | 3.2 | 3.9 |

Table 3. Comparison of estimated stature between the Nozoji-ato site and samples from other sites

| Population            | Period                | Locality                  | Male        | Female       |
|-----------------------|-----------------------|---------------------------|-------------|--------------|
|                       | Number of individuals | Mean (cm)                | Standard deviation (cm) | Student’s $t$-test |
| Nozoji-ato Medieval to Edo | 2 | 155.2 | 13 | 148.5 | 2.6 |
| Zaimokuza Medieval Kamakura | 17 | 159.0 | 4.3 | 5 | 144.9 | 3.3 | $P = 0.026^*$ |
| Yuigahama Chusei Shudan Bochi Medieval Kamakura | 5 | 158.7 | 6.8 | 4 | 146.3 | 3.6 | $P = 0.195$ |
| Yuigahama-minami Medieval Kamakura | 36 | 157.8 | 4.6 | 31 | 147.3 | 4.3 | $P = 0.356$ |
| Muromachi Medieval Tokyo | 26 | 156.8 | 4.7 | 17 | 146.6 | 3.8 | $P = 0.134$ |
| Jomon Medieval Kanto | 11 | 159.1 | 4.2 | 9 | 148.1 | 3.0 | $P = 0.742$ |
| Yayoi Yayoi Northern Kyushu and Yamaguchi | 77 | 161.4 | 4.5 | 66 | 150.8 | 4.0 | $P = 0.051$ |
| Kofun Kofun Kanto | 22 | 163.1 | 5.5 | 9 | 151.5 | 4.8 | $P = 0.072$ |
| Edo Edo Tokyo | 95 | 157.1 | 4.5 | 45 | 145.6 | 3.9 | $P = 0.015^*$ |

Stature is estimated from Fujii’s (1960) equations using the maximum length of femur.

1 Hiramoto (1972); 2 Nagaoka et al. (2013); 3 Nagaoka et al. (2008); 4 Wada and Motomura (2000).

* $P < 0.05$.

Figure 4. Comparison of estimated stature between the Nozoji-ato population and samples from other sites. * $P < 0.05$.
while no significant differences were seen in the lower canine between the data from this site and comparative samples ($P > 0.05$) (Table 6).

The presence of cribra orbitalia was detected in 6 out of 21 orbits (28.6%) when both sexes were combined and there was no significant difference in lesions between Nozoji-ato and comparative samples ($P > 0.05$) (Table 6).

**Depressed fractures**

The sample from the Nozoji-ato site studied in this paper includes the presence of two depressed fractures in a female aged between 15 and 34 years (specimen no. 47). Observations show that the fracture on the anterior of the right parietal comprises a depression that is 30 mm long, while its counterpart on the posterior right parietal is circular and 20 mm in length (Figure 7). These fractures are both shallow, limited to the outer table, and poorly aligned. The fact that these depressions have smooth edges and contain newly formed vascular foramina linked with new bone formation implies that they were formed ante-mortem and that this individual likely subsequently survived. In both cases, these features were identified as blunt-force fractures produced by the direct application of force onto the cranial vault. The frequency of the trauma is 2.2% (1/45).

**Discussion**

**Sample age-at-death and sex composition**

The sex ratio composition reconstruction presented here reveals the presence of 4 males and 31 females within the sample. It is noteworthy, however, that as this determination was carried out based on the macroscopic assessment of pelvic bones with high reliability, misclassification cannot explain such a biased ratio. Yoshiaki Miura and his descendants were buried in the Nozoji temple and it cannot be ruled out that the high-status warriors and their family were included in the materials and the biased sexual ratio is related to unusual situations of death and mortuary practice. However, the reasons underlying this bias remain unclear.

Age-at-death comparisons among the populations studied in this research demonstrate that, in spite of the absence of significant differences, the Nozoji-ato sample appeared to be older at death on average than the individuals from Yuigahama Chusei Shudan Bochi. Indeed, the distribution of the

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### Table 4. Frequency of dental caries and antemortem tooth loss (AMTL)

| Sex              | Age      | Number of teeth | Number of carious teeth | Number of AMTL | Caries frequency | AMTL frequency |
|------------------|----------|-----------------|-------------------------|----------------|------------------|----------------|
| **Male Total adults** |          |                 |                         |                |                  |                |
| Number of teeth  |          | 13              |                         |                |                  |                |
| Number of carious teeth |          | 0               |                         |                |                  |                |
| Number of AMTL  |          | 0               |                         |                |                  |                |
| Caries frequency|          | 0.000           |                         | 0.000          | 0.000            | 0.000          |
| AMTL frequency  |          | 0.000           |                         | 0.000          | 0.000            | 0.000          |
| **Female Young adults** |        |                 |                         |                |                  |                |
| Number of teeth  |          | 107             |                         |                |                  |                |
| Number of carious teeth |        | 29              |                         |                |                  |                |
| Number of AMTL  |          | 7               |                         |                |                  |                |
| Caries frequency|          | 0.045           |                         | 0.143          | 0.179            | 0.112          |
| AMTL frequency  |          | 0.000           |                         | 0.014          | 0.000            | 0.045          |
| **Female Elderly adults** |       |                 |                         |                |                  |                |
| Number of teeth  |          | 48              |                         |                |                  |                |
| Number of carious teeth |        | 13              |                         |                |                  |                |
| Number of AMTL  |          | 22              |                         |                |                  |                |
| Caries frequency|          | 0.263           |                         | 0.267          | 0.143            | 0.229          |
| AMTL frequency  |          | 0.321           |                         | 0.348          | 0.263            | 0.314          |
| **Female Unknown adults** |      |                 |                         |                |                  |                |
| Number of teeth  |          | 9               |                         |                |                  |                |
| Number of carious teeth |        | 3               |                         |                |                  |                |
| Number of AMTL  |          | 8               |                         |                |                  |                |
| Caries frequency|          | 0.000           |                         | 0.500          | 0.500            | 0.667          |
| AMTL frequency  |          | 0.571           |                         | 0.200          | 0.600            | 0.471          |
| **Male + Female Total adults** |      |                 |                         |                |                  |                |
| Number of teeth  |          | 177             |                         |                |                  |                |
| Number of carious teeth |        | 53              |                         |                |                  |                |
| Number of AMTL  |          | 29              |                         |                |                  |                |
| Caries frequency|          | 0.152           |                         | 0.204          | 0.182            | 0.177          |
| AMTL frequency  |          | 0.165           |                         | 0.143          | 0.228            | 0.176          |
| **Fisher’s exact test between young and elderly females** |          |                 |                         |                |                  |                |
| Caries          |          | $P = 0.022$     |                         | $P = 0.247$    | $P = 0.668$      | $P = 0.085$    |
| AMTL            |          | $P = 0.000$**   |                         | $P = 0.000$**  | $P = 0.467$      | $P = 0.000$**  |

* $P < 0.05$; ** $P < 0.01$. 

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Nozoji-ato sample more closely resembles that of the Edo period rather than the medieval period. In earlier work, Nagaoka et al. (2006a) demonstrated that life expectancy improved over the few hundred years between the medieval and Edo periods; the dated age of the Nozoji-ato site is thought to fall between the latter half of the medieval period and the beginning of the Edo period, later than other adjacent sites within Kamakura City. This means that differences in demographic profiles between populations within the area of medieval Kamakura City can be attributed to variations in chronological age within this period as life expectancy also increased over this time span.

Comparing the level of urban sanitation experienced by both medieval and Edo populations has also led to the suggestion that population concentration within Kamakura City at this time impacted negatively on the lives of inhabitants (Nagaoka et al., 2006a). Analyses of archaeological remains suggest that population densities within cities during the medieval period were higher than they are at present, and the bodies of horses and people were often abandoned in side ditches or on streets within Kamakura City (Kawano, 1989, 1995). In contrast, customs related to hygiene, food, and drink, and the more general absence of domestic animals that characterize the Edo period, suggest that living conditions at this time were actually more sanitary than in contemporary European cities (Hanley, 1997). It is generally the case that the period between the medieval and Edo periods corresponded to a time of improvements in urban living conditions; historical demographers have noted that dietary conditions as well as the nature of clothes, houses, bathing facilities, and urban sanitation all improved drastically within the Edo period and led to concomitant increases in life expectancy (Kito, 2000). The level of urban sanitation within Kamakura City during the latter half of the medieval period remains unknown, but it is reasonable to consider that the increasing life spans seen at this time were likely due to improvements in health.

Stature

The results of this study show that the average estimated stature of females living at the Nozoji-ato site was significantly larger than observed for Zaimokuza and Edo. This result is not consistent with previous studies, which have demonstrated that average estimated stature gradually decreased from the Yayoi period into the medieval period and on into the Edo period (Hiramoto, 1972; Nagaoka et al., 2008). Height differences between people at Nozoji-ato and Zaimokuza may also reflect improvements in their living circumstances even though results from the former are not significantly different from data from other medieval sites.

Dental caries and AMTL

The data presented in this study show that the individuals living at Nozoji-ato had a significantly higher frequency of caries-lesions than the medieval populations at Zaimokuza, Yuigahama Chusei Shudan Bochi, and Yuigahama-minami,
as well as Jomon period individuals. At the same time, however, the frequency of these lesions was significantly lower at this site than is seen during the Yayoi and Edo periods, while individuals from Nozoji-ato are also characterized by a significantly higher frequency of AMTL than seen at either Yugihama Chusei Shudan Bochi or Yuigahama-minami. It has generally been accepted that variations in dental caries and the prevalence of AMTL can likely be explained by the changes in subsistence and diet. The development of agriculture around this time is known to have reduced oral health levels and increased the prevalence of dental caries (e.g. Lukacs, 1992; Larsen, 1997); it is also the case that the rate of caries prevalence was higher within Japanese Yayoi period agriculturists than in Jomon period hunter-gatherers (e.g. Oyamada et al., 1996; Todaka et al., 2003). Medieval period dietary habits seem unlikely to explain the prevalence of caries lesion at the Nozoji-ato site, however; archaeological remains from medieval Kamakura City indicate that people at this time utilized rice, nuts, millet, soybeans, fruit, meat, and fish, for example, and cooked these foods using kitchen knives, kettles, pans, and mortars (Kawano, 1995). Studies on the history of Japanese food also imply that the ingredi-

### Table 5. Comparison of frequency of dental caries and antemortem tooth loss (AMTL) between the Nozoji-ato site and samples from other sites

| Population     | Period       | Locality       | Number of teeth | Number of carious teeth | Frequency | Fisher’s exact test |
|----------------|--------------|----------------|-----------------|-------------------------|-----------|---------------------|
| Nozoji-ato     | Medieval to Edo | Kamakura       | 348             | 45                      | 0.129     |                     |
| Zaimokuza      | Medieval     | Kamakura       | 2669            | 147                     | 0.055     | P = 0.000**         |
| Yuigahama Chusei Shudan Bochi | Medieval | Kamakura       | 475             | 24                      | 0.051     | P = 0.000**         |
| Yuigahama-minami | Medieval | Kamakura       | 2755            | 261                     | 0.095     | P = 0.045*          |
| Marunouchi     | Medieval     | Tokyo          | 548             | 80                      | 0.146     | P = 0.553           |
| Jomon         | Jomon        | All Japan      | 3295            | 271                     | 0.082     | P = 0.005**         |
| Yayoi         | Yayoi        | Northern Kyushu-Yamaguchi | 1823   | 354                     | 0.194     | P = 0.004**         |
| Joshiinji     | Edo          | Tokyo          | 530             | 108                     | 0.204     | P = 0.005**         |
| Unkoin        | Edo          | Tokyo          | 638             | 123                     | 0.193     | P = 0.013*          |

1Sakura (1964); 2Nagaoka et al. (2013); 3Oyamada et al. (2007); 4Fujita (1995); 5Todaka et al. (2003).

* P < 0.05; ** P < 0.01.

### Table 6. Comparison of frequency of linear enamel hypoplasia and cribra orbitalia between the Nozoji-ato site and samples from other sites

#### Linear enamel hypoplasia

| Population           | Period       | Locality       | Sex | Number of teeth | Number of teeth affected | Hypoplasia frequency | Fisher’s exact test |
|----------------------|--------------|----------------|-----|-----------------|-------------------------|----------------------|---------------------|
| Nozoji-ato           | Medieval to Edo | Kamakura       | Male | 3               | 3                       | 1.000                |                     |
|                      |              |                | Female | 38             | 21                      | 0.553                |                     |
|                      |              |                | Total   | 41             | 24                      | 0.585                |                     |
| Yuigahama Chusei Shudan Bochi | Medieval | Kamakura       | Male | 147             | 114                     | 0.776                | P = 0.027*  |
|                      |              |                | Female | 157             | 106                     | 0.675                | P = 0.275  |
|                      |              |                | Total   | 157             | 106                     | 0.770                | P = 0.338  |
| Hitotsubashi         | Edo          | Tokyo          | Male | 3               | 0                       | 0.000                |                     |
|                      |              |                | Female | 20             | 6                       | 0.300                |                     |
|                      |              |                | Total   | 21             | 6                       | 0.286                |                     |

#### Cribra orbitalia

| Population           | Period       | Locality       | Sex | Number of orbits | Number of affected orbits | Cribra orbitalia frequency | Fisher’s exact test |
|----------------------|--------------|----------------|-----|------------------|---------------------------|---------------------------|---------------------|
| Nozoji-ato           | Medieval to Edo | Kamakura       | Male | 1               | 0                        | 0.000                    |                     |
|                      |              |                | Female | 20             | 6                        | 0.300                    |                     |
|                      |              |                | Total   | 21             | 6                        | 0.286                    |                     |
| Seiyokan            | Medieval     | Kamakura       | Male | 57             | 14                       | 0.246                    | P = 0.773            |
|                      |              |                | Female | 44             | 4                        | 0.091                    | P = 0.065            |
|                      |              |                | Total   | 102            | 37                       | 0.363                    | P = 0.619            |

1Nagaoka et al. (2013); 2Sawada (2010); 3Hirata (1990).

* P < 0.05.
ents utilized by common people during the medieval period were almost the same as those seen in historic Japan (see Sakura, 1964).

One possible alternative explanation for the recorded caries and AMTL prevalence is the old age-at-death distribution and female-biased sex ratio at the Nozoji-ato site. Increases in both caries and AMTL rates from younger to older age categories might be explained by the elderly age composition at Nozoji-ato compared to Yuigahama Chusei Shudan Bochi. In addition, the female-biased sex ratio at this site may also influence the recorded caries prevalence; higher rates of this condition in females have been reported in both modern and ancient populations and have usually been explained by easier access to food during preparation, the earlier eruption of permanent teeth, and pregnancy (Lukacs and Largaespada, 2006). In bioarchaeological settings, females also tend to exhibit higher rates of AMTL than males due to a higher intake of cariogenic foods and sexual division of labor (Larsen, 1997). The frequency of caries in both upper and lower teeth was also significantly higher in females (8.3%; 14/169) than in males (3.3%; 10/306) at the Yuigahama Chusei Shudan Bochi site, while there was no significant difference in the AMTL rate (males: 4.8%; 16/334; females: 9.7%; 20/216) in spite of a slightly higher rate in females (Nagaoka et al., 2013). Females from Nozoji-ato further exhibited a significantly higher AMTL frequency (17.9%; 70/391) than their Yuigahama Chusei Shudan Bochi counterparts (9.7%; 20/216) \( P < 0.01 \), while there was no significant difference in caries frequency between the individuals from these two sites (Nozoji-ato: 14.0%; 45/321; Yuigahama Chusei Shudan Bochi: 8.3%; 14/169) \( P > 0.05 \) in spite of a slightly higher rate in Nozoji-ato. Thus, an older age-at-death composition and female-biased sex ratio provides a plausible explanation for the high caries and AMTL prevalence at Nozoji-ato.

**Enamel hypoplasia and cribra orbitalia**

Enamel hypoplasia is defined as the presence of developmental defects in dental enamel induced by metabolic stress that result from nutritional disorders or diseases during the formation period of this material (e.g. Goodman and Rose, 1990; Hillson, 1996). In contrast, cribra orbitalia is a pathological change characterized by aggregations of small foramina in the orbital roof in response to marrow hyperplasia in spongy bone. It is generally accepted that the presence of cribra orbitalia indicates bone deformation caused by anemia due to iron deficiency (Hirata, 1990).

The frequencies of enamel hypoplasia and cribra orbitalia recorded in the Nozoji-ato population are almost equal to those seen in Edo period series. Sawada (2010) showed higher frequencies of enamel hypoplasia in the Jomon period than in the Edo period. On the other hand, previous studies in this area have suggested that Edo period people had the highest frequencies of enamel hypoplasia and cribra orbitalia among Japanese populations; this result has been used to provide evidence for the fact that these people lived under stressful conditions, including high population concentrations and the presence of infectious diseases (Yamamoto, 1988; Hirata, 1990). It is therefore safe to conclude, based on current data, that there was no difference in living conditions between the Nozoji-ato site and those seen during the Edo period.

**Depressed fractures**

The presence of a trauma on one female cranium from Nozoji-ato has also been demonstrated in this study. In this case, fractures were identified as likely due to a blunt force produced by direct application, a level of violence that is generally observed at all archaeological sites around Kamakura City, coincident with continuous conflicts and turbulence throughout this period (Suzuki et al., 1956; Morimoto, 1987; Morimoto and Hirata, 1992; Hirata et al., 1993).
Variation in bioarchaeological traits within Kamakura City

The results of this study demonstrate that the individuals who lived at the Nozoji-ato site were different from the populations within medieval Kamakura City. A few specific conclusions can be drawn, including that the Nozoji-ato sample is characterized by an older age-at-death distribution than specimens from Yuigahama Chusei Shudan Bochi (although this difference is not significant). The population at Nozoji-ato is characterized by a significantly higher rate of caries-lesion and AMTL frequencies than are seen at the Zaimokuza, Yuigahama Chusei Shudan Bochi, and Yuigahama-minami sites. Evidence for lethal trauma appears to be absent from the individuals at Nozoji-ato even though this has been frequently observed at the medieval sites within Kamakura City.

The results of this study suggest that the people living within Kamakura City from the medieval period to the beginning of the Edo period showed wider intra-population variations in health conditions than previously anticipated. These results, contrast with earlier findings that medieval populations are homogeneous in short life spans (Nagaoka et al., 2006a, 2013), and low rates of dental caries and AMTL (Sakura, 1964; Nagaoka et al., 2013). One important outstanding question is whether or not the findings reported here are consistent with the accepted theory that medieval people generally experienced poor health conditions and had relatively shorter life expectancy. Over the last ten years, one of the present authors (T.N.) and colleagues have conducted bioarchaeological studies on thousands of medieval human skeletons from known sites within Kamakura City, including Seiyokan, Yuigahama Chusei Shudan Bochi, and Yuigahama-minami. The presence of cut marks on crania from these sites strongly implies that violence was prevalent in Medieval Japan (Hirata et al., 2004; Nagaoka et al., 2009, 2010, 2013), while a paleopathological study of Yuigahama-minami individuals revealed the first evidence for leprosy and tuberculosis in this region at the time (Hirata et al., 2011), alongside less frequent degenerative spinal changes than seen in Okhotsk and Kumejima skeletal series (Shimoda et al., 2012). Paleodemographic studies have also demonstrated a higher proportion of young individual deaths at this time than is seen in the subsequent Edo period of Japan; this also implies that living conditions in medieval Kamakura City were harsh because of malnutrition and warfare (Nagaoka et al., 2006a, 2013; Nagaoka and Hirata, 2008). New data from the Nozoji-ato series dated to the chronological age between the latter half of the medieval period and the beginning of the Edo period has demonstrated secular trends within a few hundreds of years and it is therefore reasonable to conclude that the people at this time did not exhibit homogeneous pathological features and that living conditions at this site were less severe than during the first half of this time period.

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