Paleodemography of a Medieval Population in Japan: Analysis of Human Skeletal Remains from the Yuigahama-minami Site

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ABSTRACT. The purpose of this study is to obtain demographic data regarding the medieval population buried at the Yuigahama-minami site in Kamakura, Japan, and to detect a secular trend in the life expectancy of Japanese population over the last several thousand years. The Yuigahama-minami skeletal sample consists of 260 individuals, including 98 subadults (under 20 years old) and 162 adults. A Yuigahama-minami abridged life-table analysis yielded a life expectancy at birth (e0) of 24.0 years for both sexes, a life expectancy at age 15 years (e15) of 15.8 years for males, and an e15 of 18.0 years for females. The reliability of the estimated e0 was confirmed by analysis of the juvenility index. Demographic profiles comparing the Yuigahama-minami series with other skeletal series indicated that both the survivorship curve and life expectancy of the Yuigahama-minami sample are similar to those of the Mesolithic-Neolithic Jomon population, but are far lower than those of the early modern Edo population. These comparisons strongly suggest that life expectancy changed little over the thousands of years between the Mesolithic-Neolithic Jomon and medieval periods, but then improved remarkably during the few hundred years between the medieval period and early modern Edo period. The short-lived tendency of the Yuigahama-minami sample does not contradict the archaeological hypothesis of unsanitary living conditions in medieval Kamakura. This is the first investigation to address the demographic features of a medieval population in Japan, and will help refine our understanding of long-term trends in the demographic features of inhabitants of Japan. Am J Phys Anthropol 131:1–14, 2006. ©2006 Wiley-Liss, Inc.

Paleodemographic studies provide important information regarding the life-history patterns of ancient populations, and are of great value for understanding population dynamics in historic and prehistoric times. The demographic reconstruction of ancient populations, which has been conducted partially in the field of physical anthropology, has received attention since the early papers of Angel (1947, 1954). Following these, studies of paleodemography became standard practice in physical anthropology, and continue to flourish (e.g., Kobayashi, 1967; Lovejoy, 1971; Lovejoy et al., 1977, Weiss, 1973; Bocquet-Appel and Masset, 1982, 1985, 1986; Mensforth and Lovejoy, 1985; Nakahashi and Nagai, 1985, 1989; Gage and Dyke, 1986; Gage, 1988, 1989, 1990; Walker et al., 1998; Mensforth, 1990; Wood et al., 1992, 2002; Gage and Mode, 1993; Konigsberg and Frankensberg, 1994; Alesan et al., 1998, Drusini et al., 2001). We are concerned in our research with the paleodemographic reconstruction of the ancient skeletal population in Japan. We analyzed the demographic structure of medieval skeletons from the Yuigahama-minami site (Kamakura, Japan), and discuss their life-history patterns. This study distinguishes itself from previous studies by focusing on the paleodemography of the medieval Japanese.

Paleodemography has not yet been settled and has not flourished in Japan. Indeed, we have only a few examples of paleodemographic analyses of Japanese skeletal samples (Kobayashi, 1967; Nakahashi and Nagai, 1985, 1989). Kobayashi (1967) reconstructed demographic profiles of ancient populations in Japan, based on human skeletal samples. Although Kobayashi (1967) investigated the long-term life-span trends of inhabitants of Japan from the prehistoric to modern periods, little is known about the demographic features of populations other than the Mesolithic-Neolithic Jomon (12,000–300 BC) and early modern Edo populations (1600–1850 AD). Additional demographic data were also reported for a medieval population (1300–1600 AD) (Nakahashi and Nagai, 1985), as well as for an Aeneolithic population (300 BC–300 AD) (Nakahashi and Nagai, 1989). However, these reports have not enabled us to determine the long-term trends in life span of the inhabitants of Japan.

The medieval demographic data collected by Nakahashi and Nagai (1985) were insufficient for the elucidation of a secular trend in the demographic features of inhabitants of Japan. Nakahashi and Nagai (1985) reported the

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life expectancy at birth of a medieval skeletal population from the Yoshimohama site. This report was an important first description of the demographic aspects of a medieval Japanese population; however, the report lacked some of the requirements for detailed demographic discussion. First, the report did not provide a profile of the population structure of the Yoshimohama skeletal series due to a lack of statistics. Second, Nakahashi and Nagai (1985) did not present a life table of the Yoshimohama population; thus, it was difficult to compare these data with the data of Kobayashi (1967). Finally, the sample size of the Yoshimohama population (57 subadult individuals and 50 adult individuals) was too small for demographic investigations.

Given the nature of previous studies, no satisfactory discussion has taken place concerning the secular trend in life span of inhabitants of Japan. The medieval population is a missing link in trying to trace long-term trends in life span in Japan over the last several thousand years. To study this population, more medieval skeletal samples need to be collected and investigated.

During the past several decades, many medieval skeletons were excavated from archaeological sites in the Yuigahama area of Kamakura City (Kanto District, Japan). These excavations yielded approximately 5,000 individuals in varying states of preservation from the Zaimokuza (556 individuals; Suzuki et al., 1956), Seiyokan (91 individuals; Morimoto et al., 1984), Yuigahama-minami (3,861 individuals; Hirata et al., 2002; Matsushita, 2002), and Chusei Shudan Bochi (592 individuals; Hirata and Nagaoka, no date) sites. Medieval Kamakura was an ancient capital where a military government, the Kamakura Shogunate, was established. Archaeological data indicate that the high population density in the city caused increased competition and a prevalence of diseases related to bad hygienic conditions (Kawano, 1989, 1995). Most studies of skeletons excavated from these sites focused on craniometry, odontometry, and paleopathology (Suzuki et al., 1956; Morimoto et al., 1984; Hirata et al., 2002, 2004; Matsushita, 2002; Hirata and Nagaoka, no date; Nagaoka and Hirata, 2006). Paleodemographic studies of these skeletons will provide important information about the mortality patterns and life conditions of this medieval Japanese population.

The purpose of this study was to test the hypothesis that health declined with increased aggregation and generally poor living conditions in the medieval period. We do so by evaluation of changes in demographic structure in this, in earlier, and in later settings in Japan. The evaluation also enabled us to detect a secular trend in the life expectancy of the inhabitants of Japan over the past several thousand years.

**MATERIALS**

The materials utilized in this study consist of human remains from the Yuigahama-minami site. The Yuigahama-minami site is located along the seashore of the southern end of Kamakura City, and is adjacent to several other medieval sites: Zaimokuza, Seiyokan, and Chusei Shudan Bochi (Fig. 1). The excavation of the Yuigahama-minami site was undertaken between 1995–1997, and yielded 3,861 skeletons from the late 14th century layer (Hirata et al., 2002; Matsushita, 2002).

The skeletal samples used here were selected according to the following criteria. First, we selected samples from individually buried graves. Individually buried skeletons were found in articulated positions, and were not mixed with the remains of other individuals. These samples can be easily identified as single individuals. Therefore, the age and sex of each sample can be determined synthetically from any available remains of the individual involved.

**METHODS**

**Age determination**

Skeletons were classified into 11 age categories: five subadult groups (under 1 year, 1–4 years, 5–9 years, 10–14 years, and 15–19 years) and six adult groups (20–24 years, 25–34 years, 35–44 years, 45–54 years, 55–64 years, and 65 years and over).

In this study, age at death was estimated on the basis of the macroscopic observation of crania, teeth, ribs, pelvis, and limb bones (Krogman, 1962; Brothwell, 1981; White and Folkens, 2000). Age criteria for human skeletons are usually constructed using a series of modern skeletons of known age and sex. Thus, the assumption that age-related changes in ancient skeletons are similar to those in modern skeletons is required for age estimation.
Subadult age determination

In the case of subadult skeletons, all aspects of dental development, including the completeness of all crowns and roots and the place of each tooth relative to the alveolar margin, were used for age determination (Fig. 71 in Ubelaker, 1989). The degree of development and closure of the occipital synchondrosis (Wakebe, 1990), and degree of ossification and epiphyseal union of the pelvis and long bones (Flecker, 1942; Webb and Suchey, 1985), were used as secondary criteria.

Adult age determination

Estimation of age at time of death for each adult skeleton was carried out using multiple criteria: stage of suture closure of the skull (Okada, 1961; Meindl and Lovejoy, 1985; Suzuki, 1998), stage of tooth attrition (Miles, 1962; Lovejoy, 1985), chronological metamorphosis of the head, tubercle, and costal face of the first rib (Charles, 1999), chronological metamorphosis of the pubic symphysis (Hanihara, 1952), chronological metamorphosis of the auricular surface of the ilium (Lovejoy et al., 1985), and the presence of osteophytes and arthritic lesions in the vertebrae (Erickson, 1978; Nathan, 1962; Stewart, 1958).

Sex determination

No attempt was made to determine the sex of subadult individuals aged 14 years and under. Sex determination of individuals aged 15 years and greater was carried out based on macroscopic assessment of pelvic features. Dimorphic criteria of the pelvis included the greater sciatic notch (Genovés, 1959; Ferembach et al., 1980; Bruzek, 2002), preauricular sulcus (Houghton, 1974; Ferembach et al., 1980; Bruzek, 2002), ventral arc (Phenice, 1969), subpubic concavity (Phenice, 1969), and medial aspect of the ishiopubic ramus (Phenice, 1969).

Demographic methodology

According to Alesan et al. (1999), the following assumptions should be made in undertaking a demographic study of a population. First, only one population, community, or group utilized the cemetery from which the remains were excavated, and this group did not concurrently use other cemeteries. Second, all individuals from that community were buried in the necropolis. Third, the archaeological excavation was complete, and anthropological recovery was meticulous and not differential. Finally, entrances by birth balanced exits by death, and there were no differences between these events in terms of age or sex. We assumed that our skeletal population was representative of the living population who died in this community. Without these assumptions, paleodemographic reconstructions are not possible (Alesan et al., 1999). In this study, we also assumed that skeletal preservation conditions did not differ based on age or sex.

A life table allows us to determine a statistical description of mortality parameters. The use of a life table implies two assumptions (Alesan et al., 1999): 1) that the obtained age-at-death structure is real, and 2) that the population is stationary. In this case, we believe that these assumptions are appropriate, because ancient populations are thought to have had growth rates of virtually zero, and to have been more stable as far as mortality is concerned. This study compares our demographic data from the Yuigahama-minami site with the model life tables of Weiss (1973), so that we may determine an age pattern of mortality that we would not be able to describe from the original data. Although model life tables are powerful tools for paleodemographic analyses, they are subject to potential biases resulting from the use of inappropriate model populations (Gage, 1988).

An alternative to model life tables is mathematical hazard models (Gage, 1988, 1989, 1990; Gage and Dyke, 1986; Gage and Mode, 1993; Wood et al., 1992, 2002). The use of hazard models of mortality for paleodemographic analysis allows us to determine reliable estimates for mortality at all ages, even at those ages for which precise age estimates are impossible (Milner et al., 2000). One of the most parsimonious parametric models of mortality across the entire life span is the Siler competing hazards model, developed for animal populations by Siler (1979, 1983) and extensively tested by Gage and Dyke (1986) and Gage and Mode (1993). This model fits as well as, or better than, most of the other models for human mortality data (Gage and Dyke, 1986; Gage and Mode, 1993). As shown (Gage, 1988, 1989, 1990; Gage and Dyke, 1986; Gage and Mode, 1993), the mortality function of the model is

$$m_x = a_1 \exp(-b_1 x) + a_2 + a_3 \exp(b_3 x)$$

where $m_x$ is the hazard function for paleodemographic reconstruction, or the force of mortality resulting from all three competing hazards at exact age $x$, and where each of the three additive terms on the right-hand side represents a different component of mortality. The first additive component of the equation is a negative Gompertz equation, and represents the rapid decline in mortality during the first few years of life. This is referred to as the immature component of mortality. The parameter $a_1$ is the force of mortality resulting from immaturity at the moment of birth, and $b_1$ is the rate at which immature mortality decreases with respect to age. The second component, $a_2$, represents a force of mortality that is constant with respect to age. This component was
first proposed by Makeham (1860) as an addition to the Gompertz mortality model. A baseline hazard parameter ($a_3$) was excluded from this study, as this parameter is rarely estimated from paleodemographic data (Herrmann and Konigsberg, 2002). The third additive component, the Gompertz mortality model, which has been used extensively to smooth and improve mortality estimates over adult age groups, is referred to here as the senescent component of mortality. The parameter $a_3$ is the force of mortality resulting from senescence at the moment of birth, and $b_3$ is the rate at which this force of mortality increases with age.

The Siler competing hazards model is ideally suited to smooth and improve demographic data, including age-specific survivorship rates from paleodemographic populations, because it smoothes the data without imposing a particular age pattern of mortality (Gage, 1988). The Siler parameters are estimated in mle version 2.1 (Holman, 2003).

To estimate certain demographic parameters ($e_0$, life expectancy at birth; $q_0$, probability of dying between birth and age 1 year; and $q_0$, probability of dying between birth and age 5 years), the juvenility index (Bocquet-Appel and Masset, 1996) was calculated as the ratio between the number of deaths between ages 5–14 years and the number of deaths after age 20 ($D_{5–14}/D_{20–w}$). This index allows us to estimate demographic parameters without the bias due to infant underrepresentation in osteological collections, and also to control for systematic bias in the calculation of adult age distribution.

### RESULTS

#### Age and sex composition of Yuigahama-minami sample

The composition by age and sex of the studied skeletal series is summarized in Table 1. The series comprises 260 individuals, including 98 subadults (under 20 years old) and 162 adults. More specifically, 8 individuals were younger than 1 year, 37 individuals were aged 1–4 years, 17 individuals were aged 5–9 years, 15 individuals were aged 10–14 years, 21 individuals were aged 15–19 years, 38 individuals were aged 20–24 years, 65 individuals were aged 25–34 years, 36 individuals were aged 35–44 years, 18 individuals were aged 45–54 years, 5 individuals were aged 55–64 years, and 0 individuals were classified as over 65. The number of individuals trended lower from the 25–34-year group onward. The mean age of the population was estimated at 24.0 years.

Sex-specific age distributions in the age range of 15 years and over for the Yuigahama-minami population are listed in Table 2. The overall sex ratio was 106 males to 100 females. The sex ratios computed by age group were 163:100 in the 15–19-year group, 111:100 in the 20–24-year group, 124:100 in the 25–34-year group, 80:100 in the 35–44-year group, 100:100 in the 45–54-year group, and 25:100 in the 55–64-year group. There was a higher proportion of males in the 15–19-year to 25–34-year age groups, and a higher proportion of females in the 35–44–year to 55–64-year age groups. The mean age of the population of individuals older than 15 years was 30.6 years for males, 33.0 years for females, and 31.8 years for all individuals.

#### Demographic parameters of Yuigahama-minami population, based on life tables

Table 3 shows the life table computed for the entire population. Figures 2–5 show curves representing the number of surviving individuals ($l_x$), number of dead individuals ($d_x$), mortality rate ($q_x$), and life expectancy ($e_x$), respectively, based on the data shown in Table 3.
Examination of the life table for the entire population (Table 3) demonstrates the following points. First, the number of survivors decreased gradually: the number of survivors aged 25–34 was half the number at birth, and the number of survivors aged 35–44 was a quarter of the number at birth. Second, the number of dead peaked slightly at ages 1–4 and, remarkably, peaked again at ages 25–34. Third, the mortality rate peaked slightly at ages 1–4, subsequently decreased, and then increased gradually after ages 15–19. Finally, life-table analysis of the Yuigahama-minami population showed that life expectancy decreased with age. Specifically, the estimated life expectancy was 24.0 years at birth, 16.8 years at ages 15–19, 9.7 years at ages 35–44, and 5.0 years at ages 55–64.

Table 4 shows the sex-specific life table for the age range of 15 years and over. Figures 6–9 show curves representing the number of surviving individuals (lx), number of dead individuals (dx), mortality rate (qx), and life expectancy (ex), respectively.

Examination of the sex-specific life table demonstrates the following points. First, the number of survivors with age decreased more rapidly among males than females. Second, the number of deaths peaked at the 25–34-year age group for both sexes, but the peak was higher for males than females. The number of death was larger for males than females before age 34, but was smaller for males than females after age 35. Third, while the mortality rate increased gradually with age for both sexes, the mortality rate for males was higher than that for females beginning at age 15 and continuing throughout all of the older age groups. Finally, life expectancy decreased with age, but females had a longer life expectancy than males by several years at all age groups.

Comparison of Yuigahama-minami population and models of Weiss (1973)

Comparison of the demographic data from the Yuigahama-minami population with the model life tables of Weiss (1973) provides an age pattern of mortality that could not be ascertained by analysis of the original data alone. The models were chosen based on two entrance parameters, e15 and l15. The models of e15 = 15 and l15 = 70, on the one hand, and e15 = 20 and l15 = 70, on the other, were chosen based on the entrance parameter values obtained from Table 3. In the comparison of life-table parameters, lx, from the Yuigahama-minami population with the model life table, two main biases were identified: a deficit of individuals under age 1 year and a defi-
The first bias observed was the underrepresentation of infants. The data from the life table suggest that only 3.1% of individuals would have died during the first year of life, while the models by Weiss (1973) of both MT (Model Table) 15–70 and MT 20–70 yielded an expected value of 13.3%. This indicates a deficit of 35 individuals under age 1 year.

The second bias identified was a deficit of elderly remains relative to the prediction of the models. The loss of individuals over age 55 was 6 individuals in the case of MT 15–70, and 26 individuals in the case of MT 20–70.

### TABLE 4. Yuigahama-minami sex-specific abridged life table

<table>
<thead>
<tr>
<th>x (age)</th>
<th>$D_x$</th>
<th>$l_0$</th>
<th>$l_x$</th>
<th>$d_x$</th>
<th>$q_x$</th>
<th>$L_x$</th>
<th>$T_x$</th>
<th>$e_x$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>15–19</td>
<td>13</td>
<td>95</td>
<td>1,000.0</td>
<td>136.8</td>
<td>0.137</td>
<td>4,657.9</td>
<td>15,605.3</td>
<td>15.6</td>
</tr>
<tr>
<td>20–24</td>
<td>20</td>
<td>82</td>
<td>863.2</td>
<td>210.5</td>
<td>0.244</td>
<td>3,789.5</td>
<td>10,947.4</td>
<td>12.7</td>
</tr>
<tr>
<td>25–34</td>
<td>36</td>
<td>62</td>
<td>652.6</td>
<td>378.9</td>
<td>0.581</td>
<td>4,631.6</td>
<td>7,157.9</td>
<td>11.0</td>
</tr>
<tr>
<td>35–44</td>
<td>16</td>
<td>26</td>
<td>273.7</td>
<td>168.4</td>
<td>0.615</td>
<td>1,884.7</td>
<td>2,526.3</td>
<td>9.2</td>
</tr>
<tr>
<td>45–54</td>
<td>9</td>
<td>10</td>
<td>105.3</td>
<td>94.7</td>
<td>0.900</td>
<td>578.9</td>
<td>631.6</td>
<td>6.0</td>
</tr>
<tr>
<td>55–64</td>
<td>1</td>
<td>1</td>
<td>10.5</td>
<td>10.5</td>
<td>1.000</td>
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<td>Female</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>15–19</td>
<td>8</td>
<td>88</td>
<td>1,000.0</td>
<td>90.9</td>
<td>0.091</td>
<td>4,772.7</td>
<td>18,011.4</td>
<td>18.0</td>
</tr>
<tr>
<td>20–24</td>
<td>18</td>
<td>80</td>
<td>909.1</td>
<td>204.5</td>
<td>0.225</td>
<td>4,034.1</td>
<td>13,238.6</td>
<td>14.6</td>
</tr>
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<td>25–34</td>
<td>29</td>
<td>62</td>
<td>704.5</td>
<td>329.5</td>
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<td>5,397.7</td>
<td>9,204.5</td>
<td>13.1</td>
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<tr>
<td>35–44</td>
<td>20</td>
<td>33</td>
<td>375.0</td>
<td>227.3</td>
<td>0.606</td>
<td>2,613.6</td>
<td>3,806.8</td>
<td>10.2</td>
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<tr>
<td>45–54</td>
<td>9</td>
<td>13</td>
<td>147.7</td>
<td>102.3</td>
<td>0.692</td>
<td>965.9</td>
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<td>55–64</td>
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<td>4</td>
<td>45.5</td>
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<td>1.000</td>
<td>227.3</td>
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<td>Total</td>
<td>88</td>
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</tr>
</tbody>
</table>

1 See Table 3 for explanation of symbols.

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**Fig. 6.** Sex-specific curves of number of survivors for Yuigahama-minami site.

**Fig. 7.** Sex-specific curves of number of dead for Yuigahama-minami site.

**Fig. 8.** Sex-specific curves of probability of dying for Yuigahama-minami site.

**Fig. 9.** Sex-specific curves of life expectancy for Yuigahama-minami site.
Siler competing hazards model for Yuigahama-minami population

The Siler competing hazards model contained all parameters except the $a_2$ parameter. The following parameter estimates were calculated: $a_1 = 0.054$, $b_1 = 0.366$, $a_3 = 0.011$, and $b_3 = 0.058$. Figures 11 and 12 show the Siler hazard function and the fitted and original age-specific survivorship curves, respectively. The Siler hazard function for paleodemographic reconstruction of the Yuigahama-minami series provided a plausible age pattern of mortality, due to the observation that the instantaneous death rate declined swiftly and continuously during the first few years of life, reached a minimum around ages 10–15, and then increased at an increasing rate.

In Figure 12, similar trends are seen in both the fitted and original survivorship curves. However, the graduated curve declined a bit more rapidly than the original curve. The number of survivors at age 24 was half the number at birth, and the number of survivors at age 36 was a quarter of the number at birth (Fig. 12). The fitted survivorship curve seemed to provide a more plausible age pattern of mortality than the original curve, as the fitted curve conformed to the general characteristics of human mortality patterns, due to a slightly higher probability of dying at birth.

Demographic parameters of Yuigahama-minami population, based on juvenility index

Bocquet-Appel and Masset (1996) derived a new set of paleodemographic estimators using the juvenility index at death ($D_{5–14}/D_{20–w}$). These estimators yield the life expectancy at birth ($e_0$) and the probability of death at 1 and 5 years ($q_1$ and $q_5$).

Table 5 shows the paleodemographic estimators calculated for the Yuigahama-minami sample. The data from the life table suggest that only 3.1% of individuals would have died within the first year of life, and 17.6% of individuals would have died in their first 5 years of life. However, when estimated using the juvenility index, the values obtained for $q_0$ and $q_5$ were $27.6 \pm 1.5\%$ and $44.1 \pm 1.5\%$, respectively. Therefore, the life table underestimates the rate of infant mortality.

The life-table analysis yielded a life expectancy at birth of 24.0 years. The life expectancy at birth estimated from the juvenility index was $24.8 \pm 1.5$ years (Table 5). This estimation is in good agreement with the value calculated from the life table. No significant discrepancy was found between the two approaches for estimating life expectancy. Therefore, the juvenility-index analysis confirmed the reliability of the estimated life expectancy from the life table.

DISCUSSION

Census errors in Yuigahama-minami sample

Age-at-death structure. Skeletal series unearthed frequently display age-at-death patterns that differ from those of typical living populations. In our comparison of the life-table parameters of the Yuigahama-minami site with the models of Weiss (1973), the Siler hazard model, and the parameters estimated using the juvenility index, we observed that children younger than 5 years are underrepresented in our population. We do not actually know the infant mortality rate of an ancient population, but according to observed patterns in preindustrial populations (e.g., Howell, 1979), we should expect high infant mortality. A higher probability of death during the early years is expected for endogenous and exogenous reasons, and due to a lack of medical and hygienic practices in such a population.
TABLE 5. Demographic parameters computed from life table and juvenility index

<table>
<thead>
<tr>
<th>Series</th>
<th>Chronology</th>
<th>Juvenility index</th>
<th>$D_{0-14}$</th>
<th>$D_{20-60}$</th>
<th>$e_0^1$</th>
<th>$e_0^2$</th>
<th>$q_0^1$</th>
<th>$q_0^2$</th>
<th>$q_0^1_s$</th>
<th>$q_0^2_s$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yuigahama-minami</td>
<td>14th century AD</td>
<td>0.198</td>
<td>32</td>
<td>162</td>
<td>24.010</td>
<td>24.767</td>
<td>0.031</td>
<td>0.276</td>
<td>0.173</td>
<td>0.441</td>
</tr>
</tbody>
</table>

1 Computed from life table.
2 Computed from juvenility index.

TABLE 6. Basic statistics of MCH for Yuigahama-minami samples

<table>
<thead>
<tr>
<th>Measurement item</th>
<th>Male</th>
<th></th>
<th></th>
<th>Female</th>
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<tbody>
<tr>
<td></td>
<td>$N$</td>
<td>Mean (mm)</td>
<td>SD</td>
<td>$N$</td>
<td>Mean (mm)</td>
<td>SD</td>
<td>$t$-value</td>
<td>Probability</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MCH</td>
<td>75</td>
<td>61.7</td>
<td>4.13</td>
<td>65</td>
<td>54.4</td>
<td>3.87</td>
<td>7.87</td>
<td>$P &lt; 0.001$</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Fig. 13. Percent distribution of male and female MCH measurements, with respect to cutpoint determined by discriminant function based on MCH alone. Individuals to right of cutpoint would be classified as males, and individuals at left would be classified as females.

Infant underrepresentation is often cited as a major source of census errors in age distributions that are reconstructed from both extant and extinct human groups (Angel, 1969; Weiss, 1973; Bocquet-Appel and Masset, 1982, 1985; Mensforth, 1990; Alesan et al., 1999). As Mensforth (1990) pointed out, selective cultural biases and mortuary practices at time of death, differential postmortem preservation, selective recovery, and variation in the degree to which age and sex can accurately be inferred from fragmentary skeletal remains all increase the vulnerability of skeletal series to sampling errors. Cultural behaviors that promote this bias include preferential mortuary practices, in which the very young are buried separately from adults, and the practice of infanticide. Furthermore, skeletal populations are at greater risk of infant underrepresentation due to the fact that infant skeletal remains are smaller and less well-mineralized, and thus are more susceptible to postmortem physical and chemical deterioration (Gordon and Buikstra, 1981; Mensforth, 1990; Mays, 1998).

Another possible bias identified in the life table of the Yuigahama-minami population is a deficit of elderly remains relative to predictions from model life tables. The life-table approach is open to criticism on several grounds, including poorly defined age-at-death distribution and age estimation errors (Wood et al., 2002). We cannot exclude the possibility that methodological factors related to difficulties in determining age could be an underlying cause of this bias (Bocquet-Appel and Masset, 1982, 1985, 1996; Walker et al., 1988; Mensforth, 1990; Konigsberg and Frankenberg, 1994). However, despite these criticisms and in contrast with what happens with infants, the deficit of elderly individuals could reflect the actual state of the population. Paleopathological data support the hypothesis that this population existed under difficult living conditions. Cases of cribra orbitalia, cribra cranii, tuberculosis, leprosy, osteoarthritis, fracture, and injury by weapon (Hirata et al., 2000), were examples of the supporting paleopathological evidence on this issue. The deficit of elderly individuals may reflect a population with a low probability of reaching old age. According to the overall small number of individuals in old age groups in archaeological samples, the effect of underestimation of elderly remains might be less than expected, as suggested by Nagar and Hershkovitz (2004).

If this deficit of elderly individuals reflects the actual situation, comparing our calculated life-table parameters with the parameters of other skeletal series would be beneficial in attempting to detect a secular trend in the demographic features of inhabitants of Japan. The use of both original life-table estimations and the Siler competing hazards model will facilitate the empirical comparison of age patterns of survivorship among several popu-
and a number of statistics. The discriminant function shows a Wilk’s $\lambda$ of 0.543, an eigenvalue of 0.843, a canonical correlation of 0.676, and percentages of correct classification of 82.2% for males, 89.2% for females, and 85.5% for both sexes. The number of misclassified individuals was 20. Except for one male in the 55–64-year age group, these individuals were all younger than age 45 (Table 8). The frequency of misclassification was not significantly different between males and females ($\chi^2 = 2.42, P > 0.05$). The individuals identified as misclassified by the discriminant function were classified into the opposite sex group by the macroscopic observation of pelvic bones. The result of this analysis does not contradict the longer life expectancy of females, as the elderly females in the 45–54-year and 55–64-year age groups are likely to be correctly classified.

Comparison of demographic profiles of Yuigahama-minami and other skeletal series

As presented above, this study determined the demographic profile of the Yuigahama-minami sample. Below, we compared our data with data obtained from other skeletal series (Kobayashi, 1967) (Table 9). Kobayashi (1967) computed sex-specific life tables based solely on data from skeletons of individuals estimated at age 15 and older. The exclusion of skeletons of individuals estimated at younger than age 15 circumvents the unavoidable problem of underrepresentation of infants in paleodemographic populations. For the purpose of comparison, we should make the assumption that errors in age and sex estimation are negligible between different observers. Indeed, the methodology of age and sex estimation used in this work is in part common to that of Kobayashi (1967), who used the traditional age and sex estimation indicators described in classic anthropology textbooks (e.g., Krogmann, 1962).

Figure 14 shows the curves representing the number of survivors ($l_x$) in the age range of 15 and over for Yuigahama-minami medieval males (this study), Mesolithic-Neolithic Jomon males (Kobayashi, 1967), and early modern Edo males (Kobayashi, 1967). Comparison of the survival curves of these groups shows that the number of survivors aged 35–44 is 27.4% of the number of survivors aged 15–19 in the medieval population, 28.6% in the Jomon population, and 65.8% in the Edo population. The number of survivors aged 55–64 is 1.5% in the medieval population, 1.2% in the Jomon population, and 32.5% in the Edo population. The medieval and Jomon populations have far lower numbers of male survivors relative to the Edo population at all age stages after age 15. The survivorship curve of Yuigahama-minami medieval males is virtually identical to that of Jomon males, but very different from that of Edo males. Indeed, this tendency was detected not only in males but also in females (Fig. 15).

The sex-combined survivorship curve fitted by the Siler competing hazards model (Fig. 12), which facilitated the empirical comparison of age patterns among several populations, also strongly confirms this trend. At all age stages after age 15, the fitted Yuigahama-minami data show virtually identical numbers of survivors when compared to the Jomon data; in contrast, the number of survivors is much higher in the Edo population (Fig. 16). Figures 17 and 18 show the respective life-expectancy curves for males and females in three populations. Our analysis estimated a life expectancy of 15.6 years for males and 18.0 years for females at ages 15–19 in the Yuigahama-minami population. According to Kobayashi (1967), the estimated life expectancy at ages 15–19 in the Jomon samples was 16.2 years for males and 16.3 years for females, while that in the Edo samples was 30.3 years for males and 25.6 years for females. The life expectancy in the Yuigahama-minami series for both sexes is almost similar to that in the Jomon samples, but is half that in the Edo samples, both in males and females. This difference persists from age 15 throughout all greater age groups, as shown in Figures 17 and 18.

Comparison of these demographic profiles demonstrated similarities between the Jomon and Yuigahama-minami medieval populations, and dissimilarities between the Yuigahama-minami and Edo populations. We note that life expectancy did not change significantly during the thousands of years between the Mesolithic-Neolithic Jomon and medieval periods, but then doubled during the few hundred years between the medieval and early modern Edo periods.
Life history reconstructed from Yuigahama-minami sample

A comparison of life-history data of the Yuigahama-minami sample with those of other skeletal series showed two clear contrasts. First, the Yuigahama-minami sample differed from other skeletal samples in that higher mortality was found in males than in females. Second, the Yuigahama-minami sample demonstrated a relatively short life expectancy when compared to the early modern Edo sample.

Sexual difference in life expectancy in the Yuigahama-minami sample. In the Yuigahama-minami sample, males had a life expectancy that was several years shorter than for females. Interestingly, shorter life expectancy for males was not observed in either the Mesolithic-Neolithic Jomon and early modern Edo sample (Kobayashi, 1967). The data for the Jomon and Edo periods compiled by Kobayashi (1967) showed no sexual differences in life expectancy. In contrast, according to a study of historical documents (shumon-aratamecho) by Kito (2000), females had a shorter life expectancy than males in the early modern Edo period. The higher mortality rate for females was centered between ages 20–40, an age span that corresponds to the reproductive period, gestation, childbirth, and nursing (Kito, 2000). The sexual difference in mortality patterns in the Yuigahama-minami sample raises the question, “What accelerated the death of males in the medieval period?”

A pioneering study on the medieval population of Japan by Suzuki et al. (1956) provides a possible explanation. Suzuki et al. (1956) excavated 556 skeletons from multiple burials at the Zaimokuza medieval site. Most of the dead were male adults, and they frequently had cut marks that may have been caused by sharp weapons, such as Japanese samurai swords. Based on these observations, Suzuki et al. (1956) assumed that the excavated...
skeletons were victims of a war. This assumption may also explain the higher mortality of Yuigahama-minami males, as the excavated skeletons from the Yuigahama-minami site also occasionally showed evidence of injuries in the cranial and postcranial bones (Hirata et al., 2002, 2004).

However, the assumption by Suzuki et al. (1956) is difficult to apply directly to the Yuigahama-minami skeletons. Many more individually buried skeletons were found at the Yuigahama-minami site than at the Zaimokuza site. Among these skeletons, the male-to-female sexual ratio was approximately equal, and injured skeletons were found much less frequently. The possibility that the males were involved directly or indirectly in a war cannot be entirely ruled out, but with the limited data in hand, the causes of death remain unresolved. We believe that it is difficult to attribute the higher mortality rate of males specifically to war. Further analysis is necessary regarding the causes of death of the Yuigahama-minami population.

### Life expectancy in Yuigahama-minami sample and their lives.

The life expectancies of the Yuigahama-minami and Jomon samples were almost similar, and were about half of the life expectancy of the Edo population. The short-lived tendency in the Yuigahama-minami sample is likely to be connected to the living conditions in medieval Kamakura, as described below.

The Yuigahama-minami individuals were inhabitants of medieval Kamakura, an ancient capital where a military government, the Kamakura Shogunate, was established. Kamakura was also a center of politics, economics, and culture during the medieval period of Japan. According to Kawano (1989), medieval Kamakura had a population of between 70,000–100,000, and the population density in the medieval period was higher than in the present day. The overpopulated conditions may have impacted negatively on the lives of the inhabitants. Analysis of archaeological remains showed that the bodies of horses and humans were often abandoned in side ditches or on streets in Kamakura (Kawano, 1995). Scenes of dogs devouring abandoned human remains and people excreting in the streets are portrayed on the medieval picture scroll Gakizoshi. In fact, we found markings consistent with carnivore-gnawing on some of the Yuigahama-minami sample (Hirata et al., 2002). We can assume that sanitary facilities were not well-equipped, and that waste and cadavers were left on streets. Additionally, cases of cribra orbitalia, cribra cranii, tuberculosis, leprosy, osteoarthritis, fracture, and injury by weapon were reported in the Yuigahama-minami sample by Hirata et al. (2002). The observation of injured skeletons implies the possibility that some of the Yuigahama-minami individuals were drawn into direct or indirect involvement in violence or war. However, diseases that leave no diagnostic evidence in bones, including typhus, cholera, and dysentery, cannot be identified by paleopathological investigation.

Comparison of the living conditions described above with living conditions in the early modern Edo period produces a marked contrast. The early modern Edo sample studied by Kobayashi (1967) was of urban inhabitants of the city of Edo (the old name of Tokyo) in the latter half of early modern times. The period between medieval and early modern times corresponds to dramatic changes in urban environments in Japan. Edo became a major city around the beginning of the 17th century under the Tokugawa Shogunate. As previously reported (Hanley, 1987), the level of Japan’s metropolitan sanitation from the mid-17th century to mid-19th century surpassed that of the West, both in terms of water supply and waste disposal. Clean drinking water was constantly supplied from aqueducts, and excrement was often recycled into manure for agricultural use. Customs concerning hygiene, and food and drink, combined with a lack of domestic animals, suggest that living conditions in Edo were more sanitary than in Western cities. Furthermore, there is evidence that standards in medicine began to improve during the early modern Edo period. Vaccination was introduced in Japan during the early modern Edo period (Sakai, 1982). Japanese medicine was modernized following the epoch-making publication by Genpaku Sugita and other doctors of Kaitai Shinsho, the first translation of a Western anatomy book (Sakai, 1982).

Comparison of the lives and living conditions of the medieval Kamakura population and the early modern Edo population suggests that the time between the medieval and early modern periods corresponded not only to a span of remarkable extension of life expectancy, but also to a span of improvement of living conditions, including sanitary facilities and medical care. With the limited data in hand, the main causes of death remain obscure, but at least the unsanitary living conditions during the medieval period certainly do not contradict the short-lived tendency of the Yuigahama-minami samples.

### Japanese life expectancy: past and present

In this study, we investigated past Japanese life expectancy on the basis of ancient skeletons. Our data can be used to refine ideas about a secular trend in life expectancy.
of the inhabitants of Japan. These paleoanthropological data cannot be easily compared with data obtained by national census. However, in spite of differences in demographic methodology, a comparison is useful for the purpose of examining the secular trend in life expectancy in Japan.

A Japanese national census was first undertaken in the late 19th century. According to the 1891–1898 national survey, the life expectancy at birth was 35.3 years for males and 35.8 years for females (Mizushima, 1961). Until the end of World War II, people in Japan lived to around 50. High rates of infant mortality contributed to a lower life expectancy (Fukawa, 2002). However, just a half century after World War II, the Japanese have become one of the longest-lived people in the world. The life expectancy at birth in 2003 was 78.4 years for males and 85.3 years for females (Ministry of Health, Labor and Welfare, 2004). The fact that Japan has not been involved in any wars during this period is one reason for the increased life expectancy. Other factors include higher standards of nutrition and hygiene, advances in medical technology, and easy access to medical services, which have saved the lives of many newborns and people of older ages (Fukawa, 2002). These census data indicate that Japanese life expectancy has increased since the late 19th century.

When does the beginning of the increasing trend in Japanese life expectancy date to? Interestingly, consideration of previous studies and the present analysis suggests that the beginning of improvement of life expectancy dated to before the 19th century. Our data show that the life expectancy doubled for all age groups after age 2 was improved by several years within the early modern Edo period between the 17th and mid-19th centuries. In conclusion, Japanese life expectancy has improved from the medieval to the early modern and modern periods, and even within the early modern period. Therefore, we infer that Japanese life expectancy began to increase following the medieval period, and that this increasing trend in Japanese life expectancy has continued to the present.

CONCLUSIONS

The analysis of demographic data for the Yuigahama-minami population has refined our understanding of the population dynamics of the inhabitants of medieval Japan. Comparison of the demographic data of the Yuigahama-minami sample with those of other periods strongly suggests that the life span of the Yuigahama-minami population was similar to that of the Mesolithic-Neolithic Jomon population, but was half that of the early modern Edo period. This finding helped us detect a secular trend in the life expectancy of inhabitants of Japan over the past several thousands of years.

However, this study encountered problems in terms of demographic methodology. As previously pointed out (Bocquet-Appel and Masset, 1982, 1985, 1996; Walker et al., 1998; Mensforth, 1999; Konigsberg and Frankenberg, 1994), infant underrepresentation and systematic underestimation of age in adults are unavoidable in paleodemography. In spite of the difficulties in demographic methodology, the analyses of the Siler hazard model and of the juvenility index (Bocquet-Appel and Masset, 1996) allow us to estimate demographic parameters without the bias due to infant underrepresentation in osteological collections, and also to control for systematic bias in the calculation of adult age distributions.

More importantly, the purpose of this study was to compare newly obtained medieval data with the data compiled by Kobayashi (1967), and to discuss the secular trend in Japanese life expectancy. The methodological limitations of infant underrepresentation and systematic underestimation of age in adults is common to both our data and to the data of Kobayashi (1967). If the assumptions of demographic methodology proposed above (e.g., the assumptions of burial, excavation, and skeletal preservation conditions) can be applied to the cases studied by Kobayashi (1967), a comparison of data from different periods provides us with a great deal of information regarding chronological differences in Japanese population structures and life span. This study was an investigation to address the demographic features of the medieval population in Japan, and to refine ideas of a long-term trend in demographic profiles of the inhabitants of Japan. The results of this study will afford new perspectives on paleodemography in Japan.

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