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Degenerative changes in the appendicular joints of ancient human populations from the Japan Islands

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Abstract

Degenerative changes in six major limb joints were investigated to compare their prevalence among five ancient skeletal populations from the Japan Islands. The populations assessed in this study consisted of the farmers in the northern Kyushu/ Yamaguchi area and the foragers from the northwestern Kyushu area from the Yayoi period (5th century BC to 3rd century AD); the Okhotsk (5th to 12th centuries AD) foragers from Hokkaido and Sakhalin; the common people from medieval Kamakura (12th to 14th centuries AD) in Kanto, central Japan; and the early-modern farmers (17th to 19th centuries AD) from Kumejima, in the southernmost island chain (Ryukyu Islands). Crude prevalence comparisons showed that the shoulder and hip joints were principally affected in early-modern Kumejima and medieval Kamakura, which contrasted with the high prevalence of elbow and knee joint changes in the Okhotsk people. The heavy dependence on marine mammals and fish for dietary protein intake probably required flexion and extension movements of the most severely degenerated joints in the Okhotsk people. The northern Kyushu/Yamaguchi and northwestern Kyushu Yayoi peoples were more affected by degeneration in the wrist joints than others, possibly due to their use of innovative tools such as stone or shell knives and harpoons. A multivariate logistic regression analysis, adjusted for age, region, and sex as the predictor variables for degenerative changes in joints, was applied to only to the two samples from Kumejima and Kamakura (including previously reported spine data) because of their better preservation. This revealed differences in the prevalence of changes in some joints; for example, age-related changes were recognized. The Kumejima people were more commonly affected by hip and knee joint changes, whereas the Kamakura people were more commonly affected by changes to apophyseal joints. Because a stable isotope analysis indicated that the trophic levels of the two populations were almost the same, the pattern of degenerative changes would have reflected differences in their specific workloads, such as wet rice cultivation using a peculiar hoe by the Kumejima people. This study, combining multivariate logistic regression analysis of degenerative joint changes and stable isotope analyses, uses large skeletal populations to add clarity to the actual rigors of ancient life.

Keywords: Degenerative joint change, Japan Islands, Stable isotope, Okhotsk Culture, Kamakura, Kumejima

1. Introduction

Degenerative joint disease is common among contemporary human populations, with the incidence increasing due to an aging population structure and the recent prevalence of obesity. For example, knee osteoarthritis is prevalent (≥15%) in East Asia (Muraki et al., 2012 and Xing et al., 2013), as well as in Western countries (Felson et al., 1987, Resnick, 2002 and Blagojevic et al., 2010). The association of advanced age with an increase in the incidence of degenerative joint disease is exemplified by the observation that more than half of the women over 80 years old have radiographic changes of the knee (Bijlsma et al., 2011).

Degenerative joint disease is the most frequent chronic alteration of joint articulation. In addition to cartilage driven and synovial inflammatory changes, changes in the subchondral bone, including osteophyte formation, subchondral sclerosis, and attrition, are characteristic of degenerative joint disease (Bijlsma et al., 2011). This condition commonly affects the hands, hips, and knees of individuals belonging to an industrial society (Felson et al., 2000). Systemic and local factors appear to affect the incidence of degenerative joint changes (Resnick, 2002). Systemic factors include age, genetics, obesity, sex, and nutritional status, as well as occupational stress and activity; among these, age has the largest effect (Felson et al., 2000, Dieppe and Lohmander, 2005 and Blagojevic et al., 2010). In addition to the classic family studies, recent genome-wide association studies have also revealed several susceptibility loci for degenerative joint diseases (arcOGEN Consortium and arcOGEN Collaborators, 2012, Gonzalez, 2013 and Rodriguez-Fontenla et al., 2014).

Occupational stress and overload can also lead to degenerative changes in specific joints (Resnick, 2002). For instance, farmers appear to have a higher incidence of hip osteoarthritis, whereas miners tend to develop degenerative changes in their elbows and knees (Coggon et al., 1998 and Felson et al., 2000). In Japan, the Research on Osteoarthritis Against Disability (ROAD) study has revealed several associations between occupational activity and degenerative changes; for example, knee degeneration was statistically correlated with standing, walking, climbing, and heavy lifting, as well as with kneeling and squatting (Muraki et al., 2009 and Muraki et al., 2011).

Because the above risk factors for degenerative joint diseases enable us to reconstruct prehistoric life activities, many bioarchaeologists have investigated the degenerative changes of joints from ancient human populations (Jurmain, 1980, Merbs, 1983, Fukushima, 1988, Bridges, 1991, Lovell, 1994, Lieverse et al., 2007, Schrader, 2012, Woo and Sciulli, 2013, Plomp et al., 2013, Palmer et al., 2014 and many others). As the aforementioned studies show, many systematic factors, especially age, can affect the incidence of degenerative joint changes. Therefore, we cannot assume a simple workload-based, activity-induced pathology (Jurmain, 1999 and Jurmain et al., 2012). In Japan, degenerative changes of the elbow, knee, and spine have mainly been investigated using populations from the prehistoric Jomon and Ainu populations to the present, using the prevalence of different joint disease patterns (Suzuki, 1978, Suzuki, 1998, Yamaguchi, 1984 and Zukeran et al., 2002). Several of the co-authors in this paper recently investigated the degenerative changes of the spine in large skeletal populations from the Japan Islands, including the Ryukyu and Hokkaido Islands (Moromizato et al., 2007 and Shimoda et al., 2012). Although those studies revealed age-, sex-, and population-based patterns of degenerative joint changes, established epidemiological studies in clinical medicine, using very large samples adjusted for age, sex, and region, predominate over bioarchaeological studies based on crude prevalence determinations (Muraki et al., 2009 and Muraki et al., 2010). Baker and Pearson (2006) applied age-adjustment and logistic regression methods to skeletal populations, but, unfortunately, the sample size was too small to generate clear results.

In our previous studies (Moromizato et al., 2007 and Shimoda et al., 2012), different patterns of spinal degenerative changes were demonstrated based on crude prevalence. In this study, we present basic data on the degenerative changes occurring in six major limb joints, among five populations from various locations within the Japan Islands; the prevalence of the degenerative changes was also compared among the populations. Additionally, because several factors, including ages, influenced the incidence, we performed partial correlation and multiple logistic regression analyses, after adjusting for age, sex, and region, using the two well-preserved Kumejima and Kamakura skeletal populations in which individuality could be identified. Based on these analyses, the causes of the different patterns of degenerative changes are also discussed in conjunction with the local cultures, occupations, subsistence patterns, and nutrition of the ancient peoples.

2. Materials and Methods

2.1 Subjects

In this study, we chose five ancient, well-preserved, relatively large adult human skeletal collections (more than 90 individuals) from the Japan Islands to conduct our epidemiological comparisons (Table 1 and Figure 1). The age-at-death estimation of aged ≥15 years was judged as an adult.

Two samples consisted of skeletal remains from the northern Kyushu and Yamaguchi areas and those from the northwestern Kyushu area during the Yayoi period (5th century BC to 3rd century AD) (Crawford, 2011). In the Japan Islands, the Jomon (prehistoric hunter-gatherers) lived during the period 13,000 BC to 5th century BC (Habu et al., 2011), and lacked craniofacial modernization or gracilization, even in the Neolithic age (Suzuki, 1981, Yamaguchi, 1982 and Kamminga, 1992). Because rice-farming people initially migrated to the northern Kyushu and Yamaguchi areas from the East Asia continent, possibly via the Korean peninsula around 5th century BC, the human remains (northern Kyushu/Yamaguchi Yayoi) showed clearly modern East Asian features, including high, flat faces, round orbits, large teeth, and tall stature. These migrants are believed to have established the genetic and physical traits of the modern, main-island Japanese people (Brace and Nagai, 1982, Dodo and Ishida, 1990, Nakahashi, 1993, Oota et al., 1995 and Ishida et al., 2009). The sites divided the plains and the river; thus, paddy field rice farming had already begun at the beginning of the Yayoi period (Mizoguchi, 2013). Because of rice cultivation, the Yayoi people conducted a considerable proportion of their labor activities in these fixed areas.

However, another Yayoi people, from northwestern Kyushu (northwestern Kyushu Yayoi), retained the Jomon physical characteristics (Naito, 1971, Oyamada, 1992 and Saiki et al., 2000). As the archeological sites were distributed along coastal regions, the northwestern Kyushu Yayoi are believed to have engaged mainly in fishing (Mizoguchi, 2013). Only a small number of plains and rivers were distributed in the area; hence, paddy field rice farming had not been developed (Nagasaki Prefecture Board of Education, 1998).

The other three samples in this study included the same populations investigated by Shimoda et al. (2012) for spinal degenerative changes. The third group is formed of the skeletal remains of the prehistoric Okhotsk culture, originating from Hokkaido and

Sakhalin during the 5th and 12th centuries AD. At Wakkanai City, the northernmost city on Hokkaido, the average temperature is currently about 7°C, with temperatures of − 5°C recorded in January. Sea drift ice occupies the coast of the Okhotsk Sea from February to March. Many human skeletal remains were excavated from the area between 1924 and the present day, and classical morphological studies, based on cranial and postcranial morphologies, suggest their similarity to current Amur basin or northern Sakhalin peoples (Kiyono, 1925, Kodama, 1947, Yamaguchi, 1981, Ishida, 1988, Ishida, 1996, Kozintsev, 1990, Kozintsev, 1992, Shigematsu et al., 2004 and Komesu et al., 2008). This relationship is also supported by the results from recent mitochondrial DNA analyses (Sato et al., 2007 and Sato et al., 2009). The Okhotsk culture developed a significant maritime infrastructure and the cultural remains are different from those of the native Hokkaido peoples, or the Ainu ancestors, as verified by zooarchaeological, isotopic, and bioarchaeological studies (Kikuchi, 1999, Hudson, 2004, Naito et al., 2010, Shimoda et al., 2012 and Tsutaya et al., 2014). To obtained food, these people concentrated primarily on fishing and hunting for sea mammals such as fur seals, whales, and sea lions. Severe degenerative changes and compression fractures were found in the spines of these remains, probably due to the heavy loads associated with marine mammal hunting and fishing (Ishida et al., 1994 and Shimoda et al., 2012).

The fourth group of skeletal remains studied here was from the medieval Kamakura City, Kanto District, Japan, which was the capital of the medieval Kamakura Shogunate during the 12th to 14th centuries AD (Figure 1). More than 5000 human skeletal remains were recovered along the coast of Kamakura in the 1950s (Suzuki et al., 1956 and Hirata et al., 2004). The human skeletons from this area are not considered those of the samurai (military soldiers), but those of common people living during the Kamakura Shogunate period (1192 AD to 1333 AD), based on ^{14}C analyses (Minami et al., 2007). Intensive bioarchaeological research has elucidated their relatively short life expectancy and the presence of many weapon-related injuries (Suzuki et al., 1956, Hirata et al., 2004, Nagaoka et al., 2006, Nagaoka and Hirata, 2008, Nagaoka et al., 2009 and Nagaoka et al., 2010). In this study, we used the skeletal remains from the Yuigahama-minami site, located along the seashore at the southern end of Kamakura City (Nagaoka et al., 2006). The excavation yielded 3,861 human remains between 1995 and 1997. We selected samples from individually buried graves to ensure they came from a single individual, and individuals with weapon-related trauma were not included in the study.

The fifth group studied included early-modern skeletal remains from the Kumejima region of the Ryukyu Islands, the southernmost island chain in the Japan Islands (Figure 1). The Kumejima, or Kume, Island, is situated westward about 100 km from Okinawa Island. At Naha City, the capital city of Okinawa Prefecture, the mean temperature is about 23°C, with January temperatures of 17°C. Over 1000 human remains from the 17th to 19th centuries AD were excavated from the Yatchi-no-gama stalactite cave and Kanjinbaru sites on Kumejima Island between 1998 and 2000 (Fukumine et al., 2006, Moromizato et al., 2007, Irei et al., 2008 and Shimoda et al., 2012). Rice cultivation might have begun on Kumejima during the medieval period (12th to 16th centuries AD), leading to the name of the island; kume translates as "rice"inJapanese.Thepriorexistence of rice paddies around the caves indicates that the skeletal population represents farmers (Moromizato et al., 2007). Because much of the rice produced was collected from the farmers as tributes, the farmers themselves probably consumed sweet potatoes and taro as their principal food, supplemented by wild grass, nuts, seaweed, and seafood (Miyazato, 1976 and Nakachi, 2002). Stable isotopic analyses also indicate that the former inhabitants of the area consumed both C3 plants and fish (Yoneda et al., 2004 and Yoneda, 2011), corroborating the information available from historic records and dental data (Uezu, 2007 and Irei et al., 2008).

Because the latter two samples, i.e., the Kumejima and Kamakura groups, were more well preserved than the other three samples, in >50% of the individuals (75.8% and 57.1%, respectively), the six major limb joints were observable. Therefore, further advanced analyses were applied to the Kumejima and Kamakura samples but not to the others (see Methods section).

2.2 Methods

We estimated the sex of the adult individuals using standard methods, including assessment of pelvic and cranial morphologies (White et al., 2011). The ages of the Kumejima and Kamakura individuals at their time of death were estimated using analyses of the auricular surfaces of the iliums (Nagaoka et al., 2006, Nagaoka et al., 2012 and Nagaoka et al., 2014). However, the ages at time of death and adulthood of the other three samples were judged based on tooth eruption, epiphyseal closure, and/or the auricular surface of the ilium (White et al, 2011, Nagaoka et al., 2012).

To diagnose the degenerative changes on the articular surface, the osteophytes (bony outgrowths) were examined because they are the most characteristic abnormality (Resnick, 2002). Although eburnation is also a good indicator (Weiss and Jurmain, 2007 and Waldron, 2009), we did not use it here because it develops only at the end stage of degenerative changes (Kellgren and Lawrence, 1957 and Sulzbacher, 2013). Osteophytes develop in the marginal areas of the joints, although additional locations (central or periosteal area) may also be involved.

Six major joints (shoulder, elbow, wrist, hip, knee, and ankle) were graded and recorded. We scored the severity of the degenerative changes in the glenoid cavity, acromion, acromial end of the clavicle, and humeral head for the shoulder joint; the distal end of the humerus, the head of the radius, and the trochlear and radial notches of the ulna for the elbow joint; the carpal articular surface of the radius for the wrist joint; the femoral head and acetabulum margin for the hip joint; the condyles of the femur and tibia for the knee joint; and the distal ends of the tibia and fibula, as well as the trochlea of the talus, for the ankle joint.

We examined the progressive stages of marginal osteophytes to evaluate their severity, according to macroscopic criteria (Merbs, 1983, Bridges, 1991, Tsurumoto, 1986 and Tsurumoto et al., 2013), with some modifications (Figure 2). Osteophyte severity was graded as follows: Grade 0, no changes; Grade 1, obscure osteophytes; Grade 2, articular margins with distinct borders; Grade 3, moderate osteophyte growth around the periarticular margin; Grade 4, severe osteophyte proliferation at the articular border and surface. Three authors used the same criteria to independently evaluate the degenerative changes in the Kumejima series in order to minimize interobserver errors. Interobserver errors among the three authors were evaluated statistically as an intraclass correlation coefficient (ICC) using the osteophyte Grades for the humeral head. The ICC was high (0.942), which indicated that interobserver errors could be discounted. Subsequently, the authors examined the marginal osteophytes of the remaining skeletal populations. Therefore, we consider all of the data to be comparable.

The most progressive changes in each joint were judged as the overall joint Grade. Finally, we determinedtheindividual’sgradeasthemost severe Grade observed for the right and left joint osteophytes. When only one joint could be assessed, the Grade of this joint was used for the individual. This was deemed acceptable because Grade differences were not found between the right and left sides of six joints per sample in this study, with the exception of the wrist joints for the Okhotsk female series (P = 0.042; but this was not significant after multiple comparison tests, see Appendix). A Grade 3 or 4 joint was classified as exhibiting degenerative change; a Grade 4 change was classified as a severe degenerative change, as described by Bridges (1991).

2.3 Statistical analyses

The prevalence of degenerative changes was calculated based on individual counts. Fisher's exact probability tests or the Fisher-Freeman-Halton test (Freeman and Halton, 1951) was used to evaluate the differences in the prevalence of degenerative joint changes, according to sex, age, and population; $P < 0.05$ was considered significant.

The relationship between the Grades of the respective joint changes, including spine data (Shimoda et al., 2012), was assessed using a partial correlation analysis to adjust for age in the Kamakura and Kumejima series. In addition, the relationship among the Grades was also assessed according to the maximum length and head diameter of the femur (Kudaka et al., 2013), using a partial correlation analysis to adjust for age in the Kumejima series, because these two femur parameters are effective for estimating stature and weight, respectively (Ruff et al., 2012).

Multivariate logistic regression analysis was conducted using age, sex, and region as predictor variables for the presence or absence of degenerative change in each joint, including the spine data already published by Shimoda et al. (2012). Data analyses were performed using Excel for Mac 2011 (Microsoft, Redmond, WA, USA) and SPSS statistics 19 (IBM, Armonk, NY, USA).

3. Results

3.1 Demographics

Table 1 summarizes the numbers of skeletons examined in this study, where they were discovered, and the institution(s) in which they are located. The number of samples, per series, ranged from 90 to 163, with the sex ratio not being significantly biased (P = 0.441).

The three age-classes of the Kumejima and Kamakura individuals at their time of death are shown in Table 2 (Nagaoka et al., 2014). Significant age-class differences were found between these two samples (P = 7.44E-4 for females, P = 1.06E-4 for males), confirming the short life expectancy in the Kamakura series. Because of these differences, partial correlation and multivariate logistic regression analyses must be conducted to adjust for age (see Materials and Methods).

3.2 Crude prevalence of degenerative changes

Table 3 and Figure 3 summarize the crude prevalence, per individual, of degenerative joint changes from the five populations. Sex-based differences were not found in the six joints examined, except for severe degenerative changes in the shoulder joints of the northern Kyushu/Yamaguchi Yayoi ($P = 0.016$).

Inter-articular differences were found for degenerative changes (Grade 3 and 4) in all series ($P = 2.58E\text{-}9$–0.002), except for the northwestern Kyushu Yayoi female series. The northern Kyushu/Yamaguchi and northwestern Kyushu Yayoi showed a high prevalence of degenerative changes in their wrist and shoulder joints; the former also showed a high prevalence of changes in their hip joints (Figure 3). The shoulder and hip joints were more affected in the Kumejima and Kamakura samples, which contrasted with high frequencies of elbow and knee joint changes in the Okhotsk people.

Inter-population comparisons also confirmed the above results, thus showing the significantly different patterns of degenerative changes in the shoulder, wrist, hip, and knee joints of these populations. Higher frequencies of shoulder joint degenerative change were observed in the northern Kyushu/Yamaguchi, northwestern Kyushu Yayoi, and Kumejima series, with the former two populations also showing a high prevalence of degenerative changes in their wrist joints. The highest frequency of hip joint degenerative changes was recognized in the Kumejima series. The knee joint was more affected in the Okhotsk and Kumejima series than in other populations.

Considered together with the prevalence of severe degenerative changes, the patterns of degenerative change in each population become more obvious (Table 3). The rates of severe degenerative change in the elbow and knee joints were particularly high in the Okhotsk people whereas high frequencies of severe shoulder and hip joint changes remained associated with the Kumejima and northern Kyushu/Yamaguchi Yayoi series.

Age-related changes in the prevalence of degenerative changes in the Kumejima and Kamakura samples were almost recognized, but older age was significantly correlated with degenerative change in at least a few joints. The small sample size probably contributed to the absence of statistical significance for more of the joints, as shown in Table 4.

3.3 Partial correlation analysis

After adjusting for age, there were significant correlations between several joints in the Kamakura series following Bonferroni correction (Table 5). Conversely, only higher shoulder joint Grades were significantly correlated with higher hip joint Grades in the Kumejima series after Bonferroni correction ($r = 0.521$, $P < 0.001$), as described in Table 6. Although the two measurements of the femur, representing stature and weight, were highly correlated with each other ($r = 0.830$), these variables were not correlated with Grades of degenerative change in joints. The numbers of affected joints, per individual with all six major limb joints for observation, or crude frequencies were counted to enable correlations to elucidate differences between the two populations (Table 7). The Kumejima people had more joints affected by degenerative change than did the Kamakura ($P = 4.88E\text{-}04$), suggesting that the absence of degenerative change (or higher than Grade 0) in the younger generations of the Kamakura people might result in more correlations of degenerative change grades between joints.

3.4 Multivariate logistic regression analysis

Table 8 summarizes the odds ratios (ORs) and confidence intervals (CIs) of joint degenerative change prevalence, after adjusting for age, region, and sex, in the multivariate logistic regression analysis. The age reference sample was middle age (35–54) for individuals in the Kumejima sample for region, with males used for the sex adjustment. With the exception of the knee joint, significant positive effects of aging on prevalence rates were clearly recognized (OR = 0.10–0.37 for younger age) compared with the crude prevalence comparisons (Table 4); however, the ORs for the wrist and ankle joints could not be calculated because of the zero rate among the younger individuals. Hip and knee joint degenerative changes were less prevalent among the Kamakura people than among the Kumejima sample (OR = 0.44 and 0.20, respectively), whereas apophyseal joint degeneration was more prevalent (OR = 3.50). No significant differences were found between the sexes.

4. Discussion

In this study, we confirmed that appendicular joint degenerative changes among ancient skeletal populations were generally more pronounced in the older population segments, based on crude prevalence and multivariate logistic regression analyses, similar to observations from contemporary samples (Bijlsma et al., 2011 and Muraki et al., 2012). However, sex-based differences were not observed in this study.

4.1 Inter-population differences and stable isotope analyses

We found significant population-based differences in the crude prevalence rates of degenerative changes in six major appendicular joints, reflecting what was previously reported in the spines of similar populations (Shimoda et al., 2012).

In addition to archaeological and zooarchaeological findings, stable isotope analyses can reveal the nutritional status of ancient human populations, which assist with making inferences regarding their subsistence patterns (Naito et al., 2010, Yoneda, 2011, 2014, and Tsutaya et al., 2014). Figure 4 shows carbon and nitrogen isotope ratios in human collagen compared with nutritional resources with an enrichment correction of 3.5 for nitrogen and 4.5 for carbon, using adult human bones of both sexes from the five series used in this study (Minami et al., 2007, Yoneda, 2011, 2014 and Tsutaya et al., 2015).

As previously mentioned, the Okhotsk people had a specific pattern of severe elbow and knee joint degenerative changes, as well as degeneration of the lumbar spine (Shimoda et al., 2012). The stable isotope ratios of the Okhotsk samples ranged from −16.0% to −12.7% for carbon and from 16.0% to 20.8% for nitrogen, indicating a heavy dependence on marine mammals and fishes for dietary protein intake, as shown in Figure 4 (Naito et al., 2010 and Tsutaya et al., 2014). Bone-derived tools, including hooks and harpoons for hunting and fishing, were found in the Okhotsk cultural sites (Hudson, 2004), thereby supporting this observation. In addition, the Okhotsk people traveled in boats and probably fished using nets, given that stone net weights have also been discovered (Amano, 2003). Thus, both the isotopic and archaeological findings are concordant regarding the nature of Okhotsk culture subsistence. Such labor, especially net fishing, probably required flexion and extension movements of the elbows, knees, and lumbar spine, resulting in the high frequencies of degenerative joint changes observed in the present study. Moreover, females tended to be affected more by degenerative joint changes in the knees (although this was not significant), suggesting sexual diversity in the allocation of labor.

A high prevalence of degenerative changes in the elbow and knee joints was also recognized in the coastal Neolithic Jomon people, recent Ainu peoples, and the inland

Neolithic Baikal population of Northeastern Asia, whose subsistence was also mainly reliant on hunting-gathering-fishing (Yamaguchi, 1984, Suzuki, 1998, and Lieverse et al., 2007). Because a contemporary population analysis in Japan also confirmed this tendency (Muraki et al, 2009), the elbow and knee joint changes are considered to be common among foragers of east and northeast Asia, as well as in other areas (Lieverse et al., 2007).

From the beginning of the Yayoi period, wet rice production became established in the northern Kyushu/Yamaguchi area of Japan (Crawford, 2011). However, the northwestern Yayoi people also continued fishing and gathering, while also starting to cultivate rice (Kanaseki, 1997). These facts are reflected by the clear difference in the stable isotope ratios between the two Yayoi peoples, especially for the δ^{13}C values (Figure 4). Because agricultural pursuits tend to affect hip joint degenerative disease (Felson et al., 2000), a higher prevalence of degenerative disease in these joints of the northern Kyushu/Yamaguchi Yayoi was expected. The higher rates of degenerative disease in the wrist joints were possibly the result of their also using innovative new tools such as stone or shell knives and harpoons (Makabe, 1997 and Yamaura, 1999), similar to the modern agricultural populations that have been affected in the wrist joints because of hand-wrist bending (Dillon et al., 2002). In this study, the prevalence of degenerative change among the northwestern Kyushu Yayoi did not tend to be related to a particular joint, probably because of their reliance on fishing and gathering, as well as cultivation, for their subsistence; this was also reflected in the wide variation in carbon and nitrogen isotope ratios that were observed (Figure 4).

4.2 Early-modern Kumejima and medieval Kamakura series

Both simple comparisons, based on the crude prevalence, and partial regression and multivariate logistic regression analyses were applied to the Kumejima and Kamakura populations. As shown in Figure 4, the carbon and nitrogen isotope ratios in the Kumejima and Kamakura samples overlapped and could not be discriminated from each other. However, the Kumejima people had a higher prevalence of hip and knee degenerative changes and a lower rate of apophyseal joint changes than did the Kamakura, even after adjusting for age, region, and sex (Table 8).

Moromizato et al. (2007) already reported that the spinal degenerative changes in the Kumejima series were generally milder than those of the early-modern Edo and Jomon peoples in the Kanto region of central Japan, based on crude rates, comparable to the present results. As described above, the longer life expectancy and the lower rate of apophyseal joint changes for the early-modern Kumejima population compared with the medieval Kamakura, Edo, and Jomon series may reflect a better quality of life in Kumejima (Nagaoka et al., 2014).

Because the medieval Kamakura series is considered a mixed population, comprising merchants, civil servants, workmen, and housekeepers (Hirata et al., 2004 and Nagaoka et al., 2006), specific labor patterns were not observed. However, the higher frequencies of hip and knee degenerative changes from the early-modern Kumejima samples may have resulted from specific agricultural workloads. In particular, because age-related changes were not detected in the knee joint (Table 8), we can infer the nature of the labor of the Kumejima people from youth. For example, a specific hoe with a short handle was used for rice farming in the wetlands of Kumejima Island during the early-Modern period (Uezu, 2007); thus, flexion and extension movements of the hip and knee joints were required. This movement would have overloaded in the lower limbs, as with general agricultural work (Dillon et al., 2002), although this seems to be inconsistent with their long life expectancy.

Similar to methods in clinical medicine (Muraki et al., 2012), we used multivariate logistic regression analysis to compare the prevalence of degenerative joint changes among ancient skeletal populations, after adjusting for age, region, and sex. However, there are some limitations to this study. First, individuals were only categorized into three age classes (young, middle-aged, and elderly), based on a sophisticated method (Nagaoka et al., 2012 and Nagaoka et al., submitted), whereas established epidemiological studies use age-specific data, based on census registrations (Muraki et al., 2009 and Muraki et al., 2010). In addition, because age at death was estimated based on changes to the auricular surface of the ilium (Nagaoka et al., 2012), the demographic data might be influenced by the degenerative changes (Tsurumoto et al., 2013). Second, the multivariate logistic regression analysis could not be applied to three skeletal populations because of their relatively poor preservation. Regardless, this study remains at the frontier of attempts to elucidate the actual conditions of ancient human populations.

5. Conclusion

The crude prevalence of degenerative changes in the six major limb joint bones showed distinctive patterns among five ancient human populations in the Japan Islands. The early-Modern Kumejima and medieval Kamakura peoples were mainly affected by these changes in their shoulder and hip joints, which contrasted with the high frequencies of elbow and knee joint changes in the Okhotsk people. Based on the isotope analysis, the Okhotskpeople'sheavy dependence on marine mammals and fishes for dietary protein intake required work involving joint flexion and extension. The northern Kyushu/Yamaguchi and northwestern Kyushu Yayoi peoples were more affected in their wrist joints than were the other populations, possibly due to their use of innovative tools, such as stone or shell knives and harpoons. A multivariate logistic regression analysis of the Kumejima and Kamakura samples, adjusted for age, region, and sex, revealed the prevalence of degeneration in several joints, with age-related changes being generally apparent. The Kumejima people were mostly affected by degeneration of the hip and knee joints, whereas the apophyseal joints of the Kamakura were most affected. Because the carbon and nitrogen isotope analyses revealed that the trophic levels of the two populations were almost the same, the pattern of degenerative changes would have differed based on their life expectancies and/or specific workloads, such as the agricultural use of a peculiar hoe in Kumejima. This study used relatively large skeletal samples, multivariate logistic regression analysis, and stable isotope analysis to infer the living status of ancient populations.

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Figure legends

Figure 1. Original location of the five series of the northern Kyushu/Yamaguchi Yayoi (a), northwestern Kyushu Yayoi (b), Okhotsk (c), medieval Kamakura (d), and early-modern Kumejima (e) skeletal remains.

a: 1-Doigahama, 2-Tateiwaryuoji, 3-Kanenukuma, 4-Okuma-toge, 5-Hara, 6-Ichimonden, 7-Mami, 8-Nishihiratsuka, 9-Nagaoka, 10-Kuma-No.5, 11-Dojoyama, 12-Yasunagata, 13-Kuriyama, 14-Hasakonomiya, 15-Shobaru, 16-Onobaru, 17-Nishijin-cho, 18-Futatsukayama, 19-Shiwayaropponmatsu, 20-Asahikita.

b: 1-Otomo, 2-Neshiko, 3-Ukumatsubara, 4-Miyanomoto, 5-Hamago, 6-Fukahori.

c: 1-Susuya, 2-Koitoi, 3-Tomiiso, 4-Souya-Pirikatai, 5-Funadomari-Hamanaka, 6-Jubeizawa, 7-Hamanaka 2, 8-Utoro, 9-Moyoro.

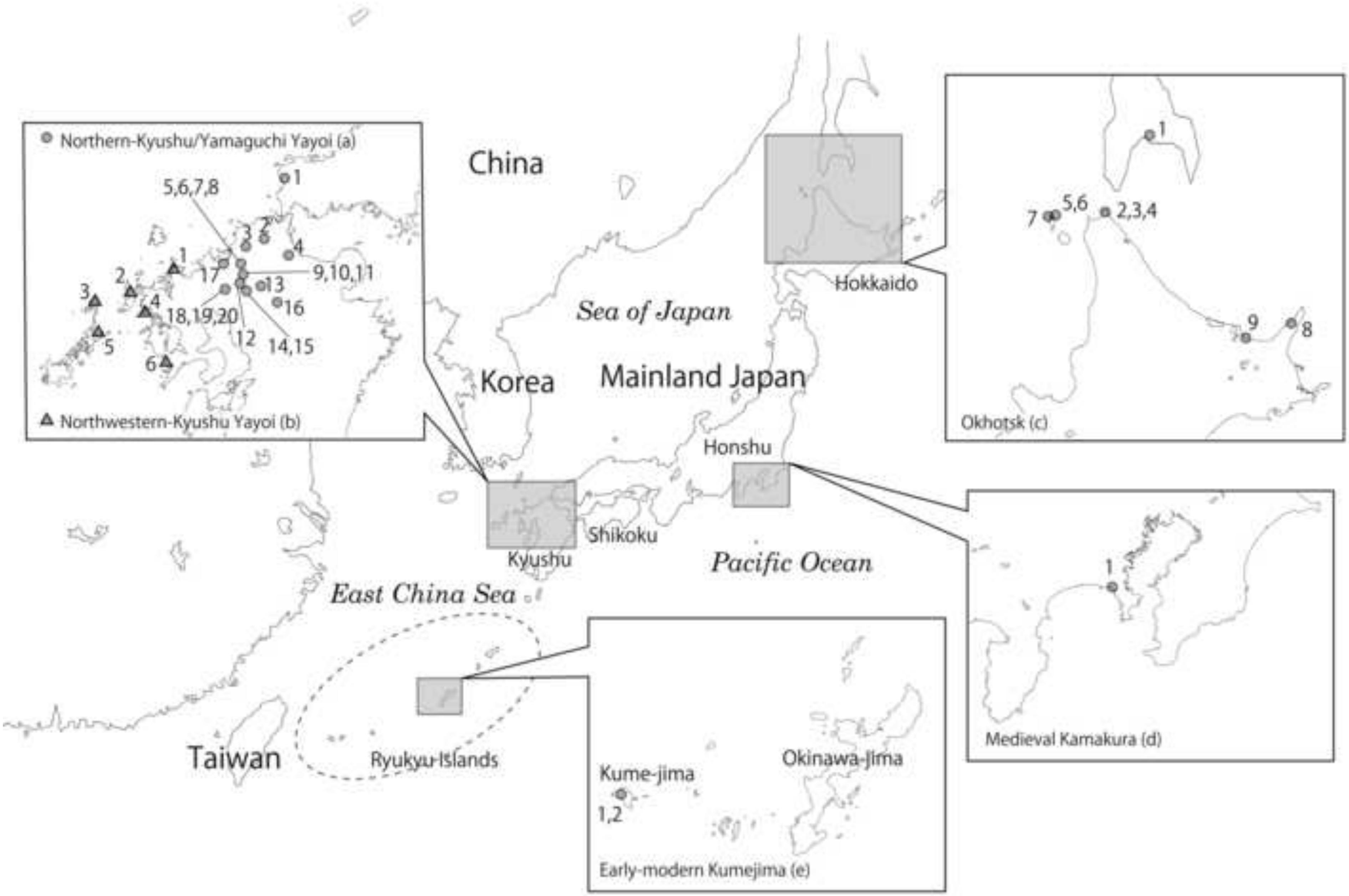
d: 1-Yuigahama-Minami.

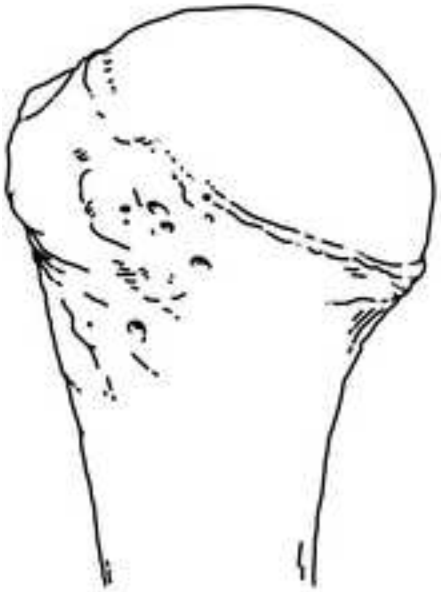
e: 1-Yacchinogama, 2-Kanjinbaru.

Figure 2. Schema of periarticular marginal osteophytes at the head of the humerus in Grades 1, 2, 3, and 4. [Redrawn from Tsurumoto (1986)]

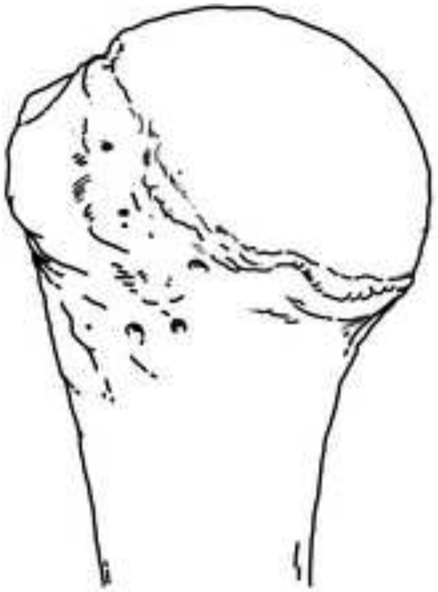
Figure 3. Crude prevalence of the degenerative changes in six appendicular joints in the early-modern Kumejima, northwestern Kyushu Yayoi, northern Kyushu/Yamaguchi Yayoi, medieval Kamakura, and Okhotsk series. *: Significant difference between sex (*P* = 0.016).

Figure 4. Carbon and nitrogen isotope ratios in human collagen compared with nutritional resources with an enrichment correction of 3.5 for nitrogen and 4.5 for carbon. Isotope ratios are shown as delta values compared with international standards (V-PDB and AIR for carbon and nitrogen, respectively).

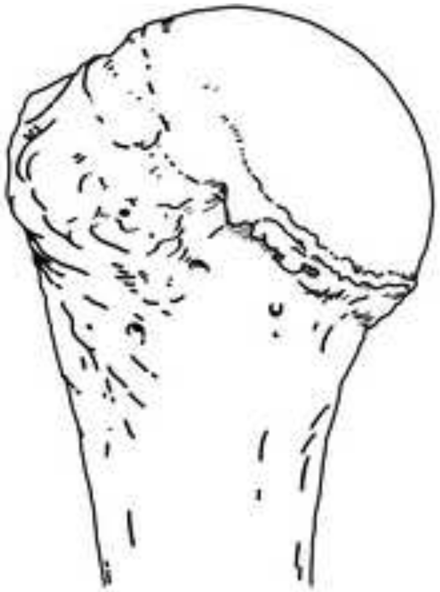

● Northern-Kyushu/Yamaguchi Yayoi (a)
1
5,6,7,8
3
2
6
4
1
17
9,10,11
2
3
13
4
16
18,19,20
5
12
14,15
6
▲ Northwestern-Kyushu Yayoi (b)
China
Sea of Japan
Korea
Mainland Japan
Hokkaido
1
7
5,6
2,3,4
9
8
Okhotsk (c)
Honshu
Shikoku
Kyushu
Pacific Ocean
East China Sea
1
Medieval Kamakura (d)
Taiwan
Ryukyu Islands
Kume-jima
Okinawa-Jima
1,2
Early-modern Kumejima (e)



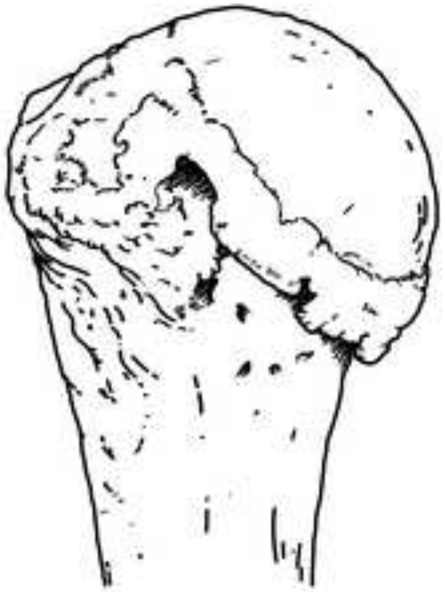
Grade 1



Grade 2



Grade 3



Grade 4

Figure

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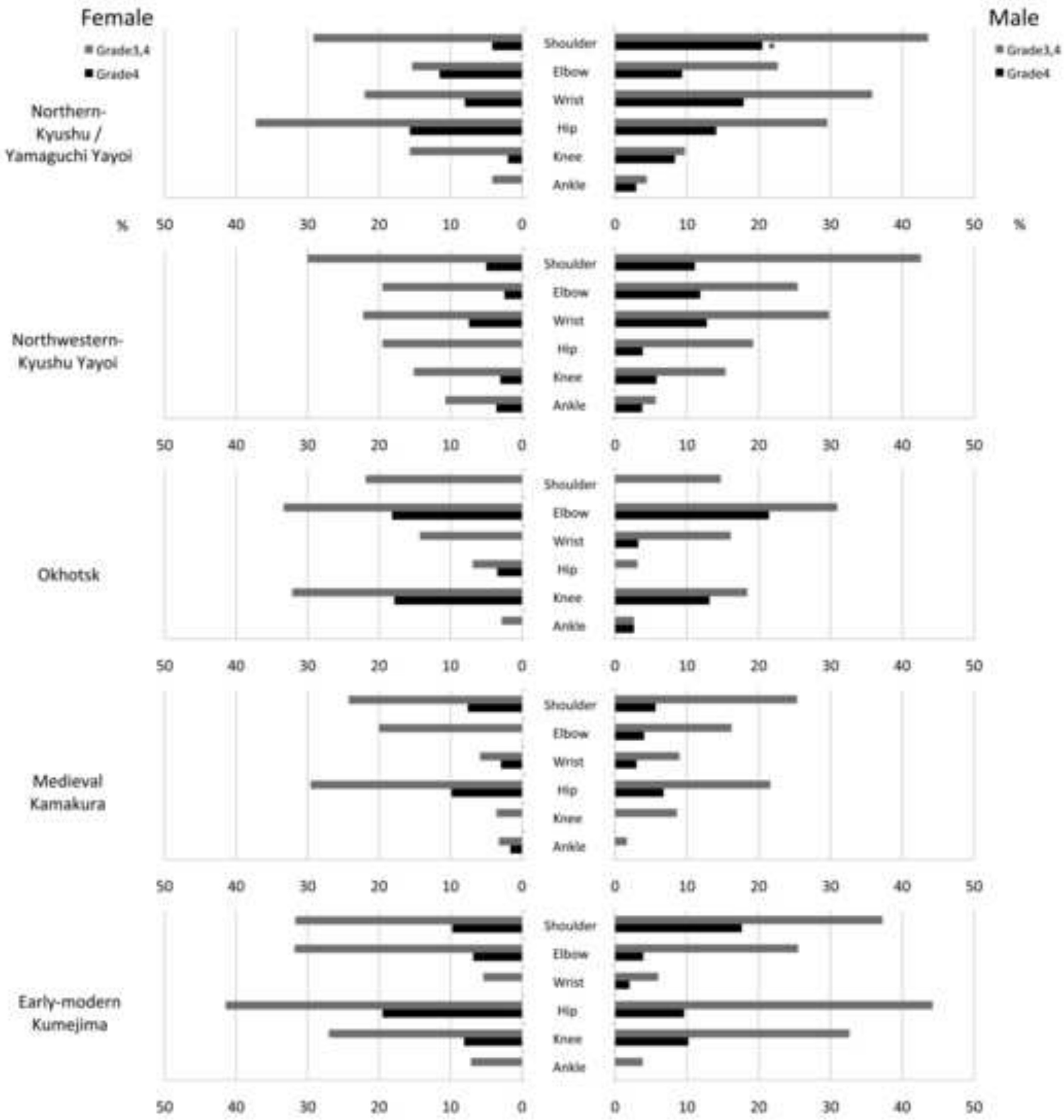

Figure

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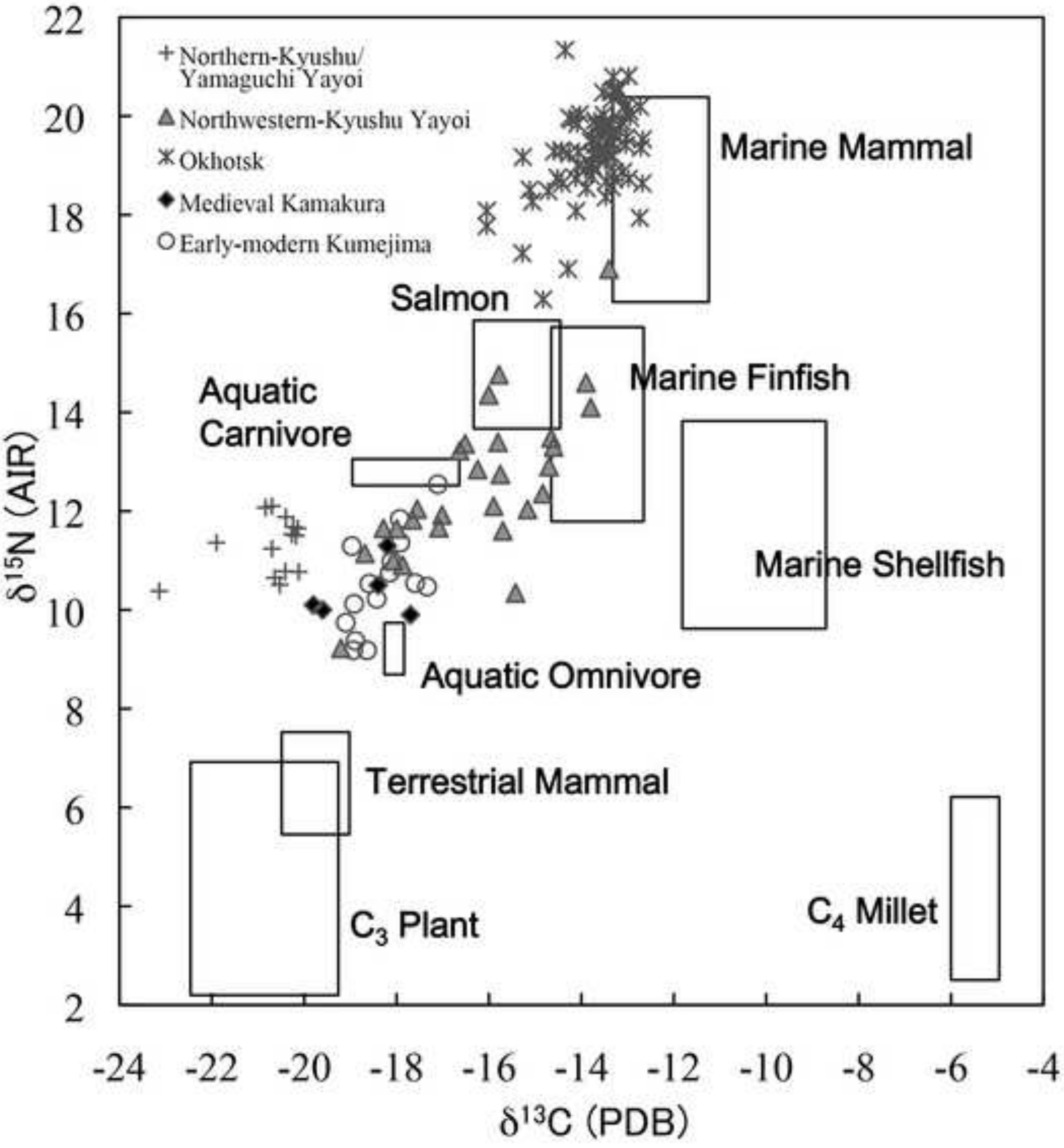

Table

Table 1. Skeletal populations used in this study.

Sample	Site	Date	Location	Female	Male	Total	Institution
Northern Kyushu/Yamaguchi Yayoi (Fig. 1	Doigahama; Kanenokuma; Futatsukayama; Shiwayaropponmatsu; Yasunagata; Asahikita; Ichinotani; Nagaoka; Kuriyama; Monden; Nshijin–cho; Nishihiratsuka; Hasakonomiya; Shobaru; Onobaru; Tateiwaryuoji; Kuma–No.5; Dojoyama;	5th C BC–3rd C AD	Kyushu, Honshu	61	91	152	KU, NU
Northwestern Kyushu Yayoi (Fig. 1b)	Otomo; Hamago; Fukahori; Miyanomoto; Neshiko; Ukumatsubara	5th C BC–3rd C AI	Kyushu	59	73	132	NU
Okhotsk (Fig. 1c)	Moyoro; Funadomari–Hamanaka; Hamanaka–No.2; Utoro; Susuya; Jubeizawa; Koitoi; Tomiiso; Souya–Pirikatai	5th–12th C AD	Hokkaido, Sakhalin	40	50	90	HU, SMU
Medieval Kamakura (Fig. 1d)	Yuigahama–Minami	12th–14th C AD	Kanto	83	80	163	STMU
Early–modern Kumejima (Fig. 1e)	Yacchinogama; Kanjinbaru	17th–19th C AD	Ryukyu	45	54	99	OPAC

KU, Kyushu University, Fukuoka, Japan.
NU, Nagasaki University, Nagasaki, Japan.
HU, Hokkaido University, Sapporo, Japan.
SMU, Sapporo Medical University, Sapporo, Japan.
STMU, St. Marianna University, Kawasaki, Japan.
OPAC, Okinawa Prefectural Archaeological Center, Okinawa, Japan.

Table

Table 2. Age distribution in the Early−modern Kumejima and Medieval Kamakura series.

Sample	Females				Males				Total	Source
	Young (15−34 years)	Middle (35−54 years)	Elderly (55+ years)	Unknown	Young (15−34 years)	Middle (35−54 years)	Elderly (55+ years)	Unknown		
Kamakura	15	49	4	15	14	54	1	11	163	Nagaoka et al., 2014
Kumejima	7	20	14	4	14	26	12	2	99	Nagaoka et al., 2014

A significant difference in age distribution was found between Early−modern Kumejima and Medieval Kamakura series, using the Fisher−Freeman−Halton test (Female: P = 7.44E−04; Male: P = 1.06E−04).

Table 3. Crude prevalence rates for the degenerative changes in the appendicular joints of the Northern Kyushu/Yamaguchi Yayoi, Northwestern Kyushu Yayoi, Okhotsk, Medieval Kamakura, and Early-modern Kumejima series.

Degenerative changes (Grade 3 + Grade 4)

		Northern Kyushu/Yamaguchi Yayoi		Northwestern Kyushu Yayoi		Okhotsk		Medieval Kamakura		Early-modern Kumejima		
Joint	Sex	A/O	Freq	A/O	Freq	A/O	Freq	A/O	Freq	A/O	Freq	*P*
Shoulder	Female	14/48	29.2	12/40	30.0	7/32	21.9	16/66	24.2	13/41	31.7	0.846
	Male	34/78	43.6	23/54	42.6	5/34	14.7	18/71	25.4	19/51	37.3	0.009 **
	Total	48/126	38.1	35/94	37.2	12/66	18.2	34/137	24.8	32/92	34.8	0.011 *
Elbow	Female	8/52	15.4	8/41	19.5	11/33	33.3	14/70	20.0	14/44	31.8	0.186
	Male	17/75	22.7	15/59	25.4	13/42	31.0	12/74	16.2	13/51	25.5	0.418
	Total	25/127	19.7	23/100	23.0	24/75	32.0	26/144	18.1	27/95	28.4	0.104
Wrist	Female	11/50	22.0	6/27	22.2	4/28	14.3	4/68	5.9	2/37	5.4	0.025 *
	Male	24/67	35.8	14/47	29.8	5/31	16.1	6/67	9.0	3/50	6.0	3.84E-05 ***
	Total	35/117	29.9	20/74	27.0	9/59	15.3	10/135	7.4	5/87	5.7	1.64E-07 ***
Hip	Female	19/51	37.3	8/41	19.5	2/29	6.9	21/71	29.6	17/41	41.5	0.006 **
	Male	21/71	29.6	10/52	19.2	1/32	3.1	16/74	21.6	23/52	44.2	2.26E-04 ***
	Total	40/122	32.8	18/93	19.4	3/61	4.9	37/145	25.5	40/93	43.0	3.59E-07 ***
Knee	Female	8/51	15.7	5/33	15.2	9/28	32.1	2/56	3.6	10/37	27.0	0.003 **
	Male	7/72	9.7	8/52	15.4	7/38	18.4	5/58	8.6	16/49	32.7	0.009 **
	Total	15/123	12.2	13/85	15.3	16/66	24.2	7/114	6.1	26/86	30.2	3.77E-05 ***
Ankle	Female	2/48	4.2	3/28	10.7	1/35	2.9	2/62	3.2	3/42	7.1	0.569
	Male	3/68	4.4	3/53	5.7	1/38	2.6	1/61	1.6	2/52	3.8	0.841
	Total	5/116	4.3	6/81	7.4	2/73	2.7	3/123	2.4	5/94	5.3	0.474
P	Female	6.52E-04 ***		0.501		0.002 **		6.34E-07 ***		1.03E-04 ***		
	Male	2.58E-09 ***		1.31E-04 ***		0.003 **		2.55E-04 ***		3.20E-08 ***		
	Total	1.56E-12 ***		4.91E-05 ***		1.39E-06 ***		3.30E-11 ***		2.35E-13 ***		

Severe degenerative changes (Grade 4)

Joint	Sex	A/O	Freq	A/O	Freq	A/O	Freq	A/O	Freq	A/O	Freq	*P*
Shoulder	Female	2/48	4.2	2/40	5.0	0/32	0.0	5/66	7.6	4/41	9.8	0.460
	Male	16/78	20.5	6/54	11.1	0/34	0.0	4/71	5.6	9/51	17.6	0.004 **
	Total	18/126	14.3	8/94	8.5	0/66	0.0	9/137	6.6	13/92	14.1	0.002 **
Elbow	Female	6/52	11.5	1/41	2.4	6/33	18.2	0/70	0.0	3/44	6.8	0.001 **
	Male	7/75	9.3	7/59	11.9	9/42	21.4	3/74	4.1	2/51	3.9	0.025 *
	Total	13/127	10.2	8/100	8.0	15/75	20.0	3/144	2.1	5/95	5.3	1.67E-04 ***
Wrist	Female	4/50	8.0	2/27	7.4	0/28	0.0	2/68	2.9	0/37	0.0	0.198
	Male	12/67	17.9	6/47	12.8	1/31	3.2	2/67	3.0	1/50	2.0	0.005 **
	Total	16/117	13.7	8/74	10.8	1/59	1.7	4/135	3.0	1/87	1.1	2.22E-04 ***
Hip	Female	8/51	15.7	0/41	0.0	1/29	3.4	7/71	9.9	8/41	19.5	0.011 *
	Male	10/71	14.1	2/52	3.8	0/32	0.0	5/74	6.8	5/52	9.6	0.096
	Total	18/122	14.8	2/93	2.2	1/61	1.6	12/145	8.3	13/93	14.0	8.35E-04 ***
Knee	Female	1/51	2.0	1/33	3.0	5/28	17.9	0/56	0.0	3/37	8.1	0.003 **
	Male	6/72	8.3	3/52	5.8	5/38	13.2	0/58	0.0	5/49	10.2	0.045 *
	Total	7/123	5.7	4/85	4.7	10/66	15.2	0/114	0.0	8/86	9.3	2.12E-04 ***
Ankle	Female	0/48	0.0	1/28	3.6	0/35	0.0	1/62	1.6	0/42	0.0	0.493
	Male	2/68	2.9	2/53	3.8	1/38	2.6	0/61	0.0	0/52	0.0	0.371
	Total	2/116	1.7	3/81	3.7	1/73	1.4	1/123	0.8	0/94	0.0	0.325
P	Female	0.011 *		0.609		3.66E-04 ***		0.005 **		0.005 **		
	Male	0.010 *		0.301		6.30E-04 ***		0.130		0.004 **		
	Total	5.57E-04 ***		0.153		8.11E-08 ***		6.54E-04 ***		1.01E-05 ***		

A, the number of affected joints; O, the total number of joints observed; Freq, frequency (%); *P*, *P*-values obtained using the Fisher-Freeman-Halton test for differences among the 5 regional series and among the appendicular joints: $^{*}P < 0.05$, $^{**}P < 0.01$, $^{***}P < 0.001$.

Table

Table 4. Age-related differences in the crude prevalence of degenerative joint change between the Medieval Kamakura series and Early-modern Kumejima.

Degenerative changes (Grade 3 + Grade 4)

		Female							Male						
		Young age (15–34)		Middle age (35–54)		Old age (55+)			Young age (15–34)		Middle age (35–54)		Old age (55+)		
Joint	Region	A/O	Freq	A/O	Freq	A/O	Freq	*P*	A/O	Freq	A/O	Freq	A/O	Freq	*P*
Shoulder	Kamakura	1/12	8.3	13/41	31.7	1/4	25.0	0.215	2/13	15.4	12/48	25.0	1/1	100.0	0.223
	Kumejima	2/6	33.3	5/17	29.4	6/14	42.9	0.814	1/13	7.7	10/25	40.0	8/12	66.7	0.009 **
Elbow	Kamakura	0/13	0.0	11/42	26.2	1/4	25.0	0.079	1/13	7.7	9/51	17.6	0/1	0.0	0.723
	Kumejima	0/7	0.0	5/19	26.3	9/14	64.3	0.008 **	1/12	8.3	5/26	19.2	7/12	58.3	0.018 *
Wrist	Kamakura	0/13	0.0	2/40	5.0	1/4	25.0	0.316	0/13	0.0	6/46	13.0	0/1	0.0	0.390
	Kumejima	0/5	0.0	1/17	5.9	1/14	7.1	1.000	0/13	0.0	2/23	8.7	1/12	8.3	0.602
Hip	Kamakura	0/13	0.0	16/45	35.6	2/4	50.0	0.012 *	1/14	7.1	12/50	24.0	0/1	0.0	0.413
	Kumejima	1/6	16.7	8/19	42.1	7/13	53.8	0.340	4/14	28.6	11/25	44.0	8/12	66.7	0.163
Knee	Kamakura	0/11	0.0	2/36	5.6	0/4	0.0	1.000	1/10	10.0	4/42	9.5	0/1	0.0	1.000
	Kumejima	0/5	0.0	5/17	29.4	4/13	30.8	0.452	2/12	16.7	7/25	28.0	7/10	70.0	0.033 *
Ankle	Kamakura	0/10	0.0	2/40	5.0	0/4	0.0	1.000	0/11	0.0	1/43	2.3	0/1	0.0	1.000
	Kumejima	0/6	0.0	1/20	5.0	2/14	14.3	0.731	0/13	0.0	2/25	8.0	0/12	0.0	0.735
Apophyseal joint	Kamakura	2/13	15.4	14/43	32.6	2/3	66.7	0.151	4/14	28.6	19/48	39.6	1/1	100.0	0.338
	Kumejima	0/4	0.0	0/12	0.0	6/14	42.9	0.016 *	0/11	0.0	6/19	31.6	4/10	40.0	0.054
Vertebral body	Kamakura	2/13	15.4	14/35	40.0	2/3	66.7	0.123	1/14	7.1	22/46	47.8	1/1	100.0	0.005 **
	Kumejima	0/4	0.0	6/12	50.0	10/14	71.4	0.052	1/11	9.1	12/19	63.2	7/10	70.0	0.006 **

Severe degenerative changes (Grade 4)

		Female							Male						
		Young age (15–34)		Middle age (35–54)		Old age (55+)			Young age (15–34)		Middle age (35–54)		Old age (55+)		
Joint	Region	A/O	Freq	A/O	Freq	A/O	Freq	*P*	A/O	Freq	A/O	Freq	A/O	Freq	*P*
Shoulder	Kamakura	0/12	0.0	5/41	12.2	0/4	0.0	0.71	0/13	0.0	3/48	6.3	0/1	0.0	1
	Kumejima	1/6	16.7	1/17	5.9	2/14	14.3	0.495	0/13	0.0	4/25	16.0	5/12	41.7	0.023 *
Elbow	Kamakura	0/13	0.0	0/42	0.0	0/4	0.0	1.000	0/13	0.0	3/51	5.9	0/1	0.0	1.000
	Kumejima	0/7	0.0	0/19	0.0	3/14	21.4	0.070	0/12	0.0	0/26	0.0	2/12	16.7	0.108
Wrist	Kamakura	0/13	0.0	1/40	2.5	1/4	25.0	0.185	0/13	0.0	2/46	4.3	0/1	0.0	1.000
	Kumejima	0/5	0.0	0/17	0.0	0/14	0.0	1.000	0/13	0.0	1/23	4.3	0/12	0.0	1.000
Hip	Kamakura	0/13	0.0	5/45	11.1	1/4	25.0	0.294	0/14	0.0	4/50	8.0	0/1	0.0	0.595
	Kumejima	1/6	16.7	4/19	21.1	2/13	15.4	1.000	1/14	7.1	3/25	12.0	1/12	8.3	1.000
Knee	Kamakura	0/11	0.0	0/36	0.0	0/4	0.0	1.000	0/10	0.0	0/42	0.0	0/1	0.0	1.000
	Kumejima	0/5	0.0	2/17	11.8	1/13	7.7	1.000	0/12	0.0	3/25	12.0	2/10	20.0	0.305
Ankle	Kamakura	0/10	0.0	1/40	2.5	0/4	0.0	1.000	0/11	0.0	0/43	0.0	0/1	0.0	1.000
	Kumejima	0/6	0.0	0/20	0.0	0/14	0.0	1.000	0/13	0.0	0/25	0.0	0/12	0.0	1.000
Apophyseal joint	Kamakura	2/13	15.4	12/43	27.9	1/3	33.3	0.560	0/14	0.0	9/48	18.8	0/1	0.0	0.233
	Kumejima	0/4	0.0	0/12	0.0	2/14	14.3	0.614	0/11	0.0	3/19	15.8	3/10	30.0	0.137
Vertebral body	Kamakura	0/13	0.0	12/35	34.3	2/3	66.7	0.012 *	0/14	0.0	5/46	10.9	0/1	0.0	0.384
	Kumejima	0/4	0.0	0/12	0.0	1/14	7.1	1.000	0/11	0.0	1/19	5.3	2/10	20.0	0.221

A, the number of affected joints; O, the total number of joints observed; Freq: frequency (%); *P*, *P*-value obtained using the Fisher–Freeman–Halton test for differences among the 3 age groups: * $P < 0.05$, ** $P <$

Table

Table 5. Partial correlation among grades for degenerative changes of joints in the Medieval Kamakura series. Correlation coefficients

	Shoulder	Elbow	Wrist	Hip	Knee	Ankle	Apophyseal joint	Vertebral body
Shoulder		0.377 *	0.520 *	0.336 *	0.142	0.181	0.247	0.393 *
Elbow	2.54E−05		0.467 *	0.432 *	0.510 *	0.494 *	0.309 *	0.322 *
Wrist	2.24E−09	1.24E−07		0.381 *	0.360 *	0.332 *	0.252	0.316 *
Hip	2.00E−04	5.93E−07	2.39E−05		0.460 *	0.280	0.279	0.372 *
Knee	0.153	3.79E−08	1.87E−04	9.98E−07		0.375 *	0.203	0.338 *
Ankle	0.061	5.58E−08	4.42E−04	0.003	9.64E−05		0.214	0.210
Apophyseal joint	0.007	5.56E−04	0.006	0.002	0.040	0.026		0.376 *
Vertebral body	1.04E−05	3.51E−04	5.42E−04	3.10E−05	4.83E−04	0.029	2.53E−05	

Both sexes are combined. The control variable is the age group. * Significant after Bonferroni correction.

Table

Table 6. Partial correlation among joint degeneration grade changes, the MLF, and VDHF in the Early-modern Kumejima series. Correlation coefficients (right upper half) and *P*-values (left lower half) are listed.

	Shoulder	Elbow	Wrist	Hip	Knee	Ankle	Apophyseal	Vertebral body	MLF	VDHF
Shoulder		0.314	0.257	0.521 *	0.222	0.159	0.094	0.206	0.158	0.000
Elbow	0.003		0.117	0.180	0.054	−0.059	0.079	0.099	−0.068	−0.008
Wrist	0.019	0.293		0.310	0.160	0.037	0.370	0.279	0.141	0.077
Hip	2.78E−07	0.093	0.004		0.190	0.050	0.012	0.227	−0.084	−0.100
Knee	0.047	0.631	0.161	0.090		0.094	−0.027	0.231	−0.135	−0.153
Ankle	0.142	0.581	0.742	0.643	0.404		−0.134	0.049	−0.094	−0.136
Apophyseal	0.442	0.521	0.002	0.924	0.832	0.279		0.358	0.231	0.417
Vertebral body	0.089	0.419	0.022	0.065	0.066	0.695	0.003		−0.002	0.235
MLF	0.273	0.642	0.328	0.564	0.352	0.516	0.122	0.988		0.830 *
VDHF	0.999	0.953	0.595	0.484	0.285	0.343	0.003	0.107	3.11E−12	

Both sexes are combined. The control variable is age group. * Significant after Bonferroni correction.

MLF, maximum length of femur; VDHF, vertical diameter of head of femur.

Table 7. Numbers of affected limb joints (Grade 3 + 4) per individual (%).

	0	1	2	3	4+
Kamakura	42 (45.2)	30 (32.3)	14 (15.1)	6 (6.5)	1 (1.1)
Kumejima	25 (33.3)	12 (16.0)	15 (20.0)	15 (20.0)	8 (10.7)

According to a Fisher–Freeman–Halton test, the numbers of affected limb joints were statistically different between the regions (P = 4.88E−04).

Table

Table 8. Odds ratios for degenerative changes for each factor obtained using multivariate logistic regression analysis, after adjusting for age, region, and sex.

		Age (Reference: Middle Age)		Region	Sex
Joint		Elderly	Young	(Reference: Kumejima)	(Reference: Male)
Shoulder	OR (95% CI)	2.06 (0.86–4.92)	0.34* (0.13–0.88)	0.70 (0.36–1.36)	0.89 (0.48–1.67)
	P	0.105	0.026	0.292	0.715
Elbow	OR (95% CI)	3.60** (1.47–8.81)	0.16* (0.04–0.71)	0.72 (0.34–1.52)	1.30 (0.65–2.59)
	P	0.005	0.016	0.386	0.453
Hip	OR (95% CI)	1.71 (0.71–4.08)	0.25** (0.10–0.65)	0.44* (0.23–0.85)	1.10 (0.60–2.01)
	P	0.230	0.004	0.014	0.768
Knee	OR (95% CI)	2.33 (0.84–6.48)	0.37 (0.10–1.40)	0.20** (0.08–0.52)	0.47 (0.19–1.13)
	P	0.106	0.143	0.001	0.091
Apophyseal joint	OR (95% CI)	4.58** (1.55–13.54)	0.37* (0.14–0.98)	3.50** (1.43–8.58)	0.59 (0.30–1.14)
	P	0.006	0.045	0.006	0.117
Vertebral body	OR (95% CI)	2.08 (0.77–5.68)	0.10*** (0.03–0.29)	0.82 (0.40–1.71)	1.00 (0.53–1.88)
	P	0.151	2.84E–05	0.603	0.996

OR, odds ratio; CI, confidence interval. $^{*}P < 0.05$, $^{**}P < 0.01$, $^{***}P < 0.001$.

Appendix. Crude prevalence rates for the degenerative changes in the appendicular joints on right and left sides of individuals from the Northern Kyushu/Yamaguchi Yayoi, Northwestern Kyushu Yayoi, Okhotsk, Medieval Kamakura, and Early-modern Kumejima series.

Degenerative changes (Grade 3 + Grade 4)

			Northern Kyushu/ Yamaguchi Yayoi			Northwestern Kyushu Yayoi			Okhotsk			Medieval Kamakura			Early-modern Kumejima		
Joint	Sex	Side	A/O	Freq	*P*	A/O	Freq	*P*	A/O	Freq	*P*	A/O	Freq	*P*	A/O	Freq	*P*
Shoulder	Female	Right	7/44	15.9	0.590	7/23	30.4	0.747	6/29	20.7	0.730	7/58	12.1	0.774	10/40	25.0	1.000
		Left	9/43	20.9		6/26	23.1		4/29	13.8		6/61	9.8		9/39	23.1	
	Male	Right	18/68	26.5	0.268	18/39	46.2	0.058	5/32	15.6	0.223	8/65	12.3	0.783	16/49	32.7	1.000
		Left	24/67	35.8		9/37	24.3		1/24	4.2		6/58	10.3		14/45	31.1	
Elbow	Female	Right	4/46	8.7	0.506	3/27	11.1	1.000	11/32	34.4	1.000	10/63	15.9	1.000	8/41	19.5	0.605
		Left	6/41	14.6		4/27	14.8		11/32	34.4		10/66	15.2		11/43	25.6	
	Male	Right	12/66	18.2	0.455	14/41	34.1	0.333	13/42	31.0	0.433	12/65	18.5	0.203	5/49	10.2	0.264
		Left	7/59	11.9		9/38	23.7		7/34	20.6		6/64	9.4		10/51	19.6	
Wrist	Female	Right	4/41	9.8	0.519	3/15	20.0	0.598	4/23	17.4	0.042 *	3/57	5.3	1.000	1/35	2.9	1.000
		Left	7/41	17.1		1/14	7.1		0/26	0.0		3/59	5.1		1/35	2.9	
	Male	Right	15/56	26.8	1.000	7/34	20.6	0.403	5/30	16.7	0.687	3/57	5.3	1.000	2/45	4.4	1.000
		Left	14/52	26.9		10/32	31.3		2/20	10.0		3/59	5.1		2/48	4.2	
Hip	Female	Right	15/46	32.6	0.825	4/28	14.3	0.714	2/26	7.7	0.227	6/65	9.2	0.771	14/39	35.9	0.814
		Left	16/44	36.4		5/23	21.7		0/28	0.0		7/59	11.9		13/41	31.7	
	Male	Right	12/62	19.4	0.396	7/37	18.9	1.000	1/30	3.3	1.000	7/66	10.6	0.763	18/51	35.3	1.000
		Left	17/62	27.4		6/35	17.1		1/31	3.2		5/66	7.6		19/51	37.3	
Knee	Female	Right	5/45	11.1	0.714	2/21	9.5	0.269	7/28	25.0	1.000	2/44	4.5	0.612	6/34	17.6	1.000
		Left	3/45	6.7		6/26	23.1		8/28	28.6		1/46	2.2		7/35	20.0	
	Male	Right	4/67	6.0	0.242	7/46	15.2	0.422	7/37	18.9	0.311	4/48	8.3	0.677	12/48	25.0	1.000
		Left	9/67	13.4		10/43	23.3		3/34	8.8		2/48	4.2		11/46	23.9	
Ankle	Female	Right	1/38	2.6	1.000	2/16	12.5	0.484	1/31	3.2	1.000	1/56	1.8	1.000	1/42	2.4	0.606
		Left	1/41	2.4		0/15	0.0		1/28	3.6		1/61	1.6		2/39	5.1	
	Male	Right	2/58	3.4	1.000	2/36	5.6	1.000	1/33	3.0	1.000	0/55	0.0	1.000	1/52	1.9	0.618
		Left	1/54	1.9		1/34	2.9		0/32	0.0		1/55	1.8		2/51	3.9	

A, the number of affected joints; O, the total number of joints observed; Freq, frequency (%); *P*, *P*-values obtained using Fisher's exact test for differences between both sides: * $P < 0.05$.