The Relationship between Immigration and the Prevalence of Dental Caries in the Yayoi People

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Abstract Skeletal remains of the Yayoi people, who had been excavated from Northern Kyushu and Yamaguchi Prefecture in Japan, are thought to be largely the descendants of continental immigrants. Carious ratios of the Yayoi people are higher than those of the Jomon people and their descendants. Results of the present study showed that, in frequency of carious lesions and in state of dental attrition, the Yayoi people of the Northern Kyushu and Yamaguchi regions were different. Caries ratios of the Yamaguchi Yayoi people were high in both adolescent and elderly groups. But, although caries ratio of the elderly Yayoi people of the Northern Kyushu region was high, that of the adolescent group of Northern Kyushu was low and close to that of the Jomon people. Dietary custom is thought to be the cause of this difference. The location of site is also different between the two Yayoi period samples. Moreover, there are some differences in skeletal shape between them. Therefore, the main subsistence of the Northern Kyushu Yayoi people might have been different from that of the Yamaguchi Yayoi people. Chinese skeletal remains whose carious teeth ratio was as high as that of the Yayoi people of the Northern Kyushu region and Yamaguchi Prefecture have not yet been found in any population examined by the present or other studies. Taking these findings into consideration, we assume that it is highly possible that the carious teeth ratio increased after the ancestors of the Yayoi people immigrated to Japan.

Keywords: Yayoi, caries, dental attrition, immigrant, subsistence

Introduction

Dental caries is one of the relatively few diseases that can be studied using human skeletal remains. Such studies are important because dental health conditions strongly reflect both the life habits and environmental conditions experienced by the subject population. However, in spite of their potential importance, there have been few studies of dental caries of human skeletal remains of the Yayoi period (300 B.C.–300 A.D.), and most of these refer to dental caries only in the context of human skeletal remains

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excavated from a particular site (Ono, 1957; Sanui, 1960; Yamada et al., 1970). Although such findings were compared with similar studies of other populations, no attempts were made to establish factors underlying the differences between populations.

Inoue et al. (1986) studied the extent of dental caries in excavated human skeletal remains ranging from the Jomon period (10000–300 B.C.) to the Meiji era (1868–1912 A.D.), and revealed that the prevalence of dental caries was high from the late-final Jomon to the Kofun (300–700 A.D.) periods, reaching a peak during the Yayoi period. In general, it is thought that the Jomon people subsisted mainly in fishing, hunting and gathering, and rice cultivation was brought from the Asian continent during the Yayoi period (Sahara, 1987). The introduction of rice cultivation thus marks the transition from a hunter-gatherer lifestyle, dependent on foraging success, to one based on agriculture, which allowed a more reliable, abundant staple diet. Inoue et al. (1986) inferred that the transitional period in which both hunter-gatherer and agricultural lifestyles were combined would have resulted in poorer oral hygiene and hence an increased prevalence of dental caries.

Oyamada et al. (1996) made a comparative study of dental caries between the excavated skeletal remains of the Yayoi people from Northern Kyushu and those from the Okinawa Islands dating from the final Jomon to the early Yayoi periods. Materials were divided into adolescent (consisting of adolescent and young adult age classes) and elderly groups (consisting of middle-aged and senior age classes), and the extent and condition of dental caries within the two groups were compared. The results indicated that the prevalence of root caries and tooth loss increased sharply in the elderly group of the Northern Kyushu Yayoi people. The authors inferred that this might have been caused by periodontal diseases.

Morphological studies of skeletal remains have revealed differences in traits not only between the Jomon and the Yayoi peoples but also among populations of the Yayoi people occupying different sites. Based on these findings, several important theories have been proposed regarding the formation of Yayoi populations. Kanaseki (1976) made a comparative study of skeletal remains between the Jomon and Yayoi peoples in the Northern Kyushu-Yamaguchi region. He proposed that the Yayoi populations in these districts were genetically affiliated to immigrants from the Asian Continent. Subsequently, Naito (1984) divided the Yayoi skeletal series excavated from Kyushu and the Yamaguchi Prefecture into three groups: the Northern Kyushu-Yamaguchi Yayoi were characterized by tall stature and narrow faces, the North-western Kyushu Yayoi were characterized by short stature and broad faces, and the Southern Kyushu Yayoi and its outlier populations were characterized by short heads, in addition to their broad faces and short stature. He inferred that the Northern Kyushu-Yamaguchi Yayoi were genetically affiliated to immigrants from the Asian continent, whereas the remaining two groups inherited traits from the Jomon people

who had existed in each respective district.

Although small in number, several comparative studies of human skeletal remains excavated in continental China, from the region suggested to be the general area of origin of the immigrants, have been carried out. Similarities between these skeletal remains of continental China and those of the Northern Kyushu-Yamaguchi Yayoi strongly suggest a genetic affiliation between the two (Ogata et al., 1997; Han, 2000; Zhang, 2000; Matsushita, 2000; Manabe and Rokutanda, 2000; Oyamada and Rokutanda, 2000).

However, even among the Yayoi populations thought to have descended from continental immigrants, regional differences have been established. Between the Yayoi people of the Yamaguchi Prefecture and the Northern Kyushu region, there are definite differences in skeletal morphology of the neurocranium, face, and upper and lower limbs as well as in the prevalence of ritual tooth extraction (Kanaseki, 1976; Matsushita, 1994; Nakahashi and Nagai, 1997). The reason for these differences is currently unresolved, with both genetic (Matsushita, 1994, 2001) and biogeographical (Nakahashi and Nagai, 1997) theories being proposed.

No previous studies have compared or discussed regional differences in dental caries among the Yayoi people. Here we present a comparative investigation of dental caries prevalence among the Jomon people, the Yayoi people of the Northern Kyushu-Yamaguchi region (who are assumed to be descended from continental immigrants) and the Yayoi people of the Southern Kyushu region and its outlier populations, including the inhabitants of Tanegashima Island, who are assumed to be descendants of the Jomon people. As before (Oyamada et al., 1996), each population was divided into an adolescent (consisting of the adolescent and young adult age classes) and an elderly group (consisting of the middle-aged and senior age classes). Dental caries conditions were compared between the age groups as well as among the populations, allowing us to infer related differences in dietary and life habits. Next, we compared the results of the present study with the prevalence of dental caries in skeletal remains excavated in China, to obtain a comparative basis in the evaluation of the Yayoi populations. Finally we investigated the possible genetic relationship between the skeletal remains excavated in Japan and China by measuring the size of the crowns of the teeth, and discussing them in relation to the frequency of dental caries.

Materials and Methods

Table 1 shows the periods and excavated sites of the nine populations used in the present study for comparison of caries prevalence and those of the 13 populations used for comparison of tooth crown sizes. Fig. 1 shows the map of the Yayoi sites and Chinese Provinces relevant to the present study in comparisons of caries prevalence. The sample sizes of the materials used for comparison of dental caries preva-

Table 1. Period and sites of the skeletal series in the present study
Caries

Group	Period	Site
Japanese		
Jomon	Jomon (10000–300 B.C.)	Yoshiko, Tsukumo
Tanegashima Yayoi	Yayoi (300 B.C.–300 A.D.)	Hirota, Torinomine
Northern Kyushu Yayoi*	Yayoi (300 B.C.–300 A.D.)	Asahikita, Shiwaya-ropponmatsu, Kanenokuma
Doigahama Yayoi*	Yayoi (300 B.C.–300 A.D.)	Doigahama
Ancient Chinese		
Shandong Neolithic	4300–2500 B.C.	Fujia
Jiangsu Neolithic	4300–3500 B.C.	Longquizhuang
Henan Shang	1400–1100 B.C.	Anyan
Qinghai Bronze	1000 B.C.	Shangsunjia, Ahatelashan, Lijiashan
Shandong Han	206 B.C.–220 A.D.	Yixi
Tooth Size		
Group	Period	Site
Japanese		
Jomon	Jomon (10000–300 B.C.)	Yoshiko, Tsukumo
Mashiki	Latest Jomon-Yayoi	Mashikiazamabaru
Tanegashima Yayoi	Yayoi (300 B.C.–300 A.D.)	Hirota, Torinomine
Northern Kyushu Yayoi*	Yayoi (300 B.C.–300 A.D.)	Futatsukayama, Yokokumakitsunozuka
Doigahama Yayoi*	Yayoi (300 B.C.–300 A.D.)	Doigahama
Northwestern Kyushu Yayoi	Yayoi (300 B.C.–300 A.D.)	Hanago, Neshiko, Fukahori, Miyanomoto
Otomo Yayoi	Yayoi (300 B.C.–300 A.D.)	Otomo
Southern Kyushu Kofun**	Kofun (300–700 A.D.)	Hirohata, Higashimihara, Tachikiri
Ancient Chinese		
Shandong Neolithic	4300–2500 B.C.	Fujia
Jiangsu Neolithic	4300–3500 B.C.	Longquizhuang
Henan Shang	1400–1100 B.C.	Anyan
Qinghai Bronze	1000 B.C.	Shangsunjia, Ahatelashan, Lijiashan
Shandong Han	206 B.C.–220 A.D.	Yixi

*: They are generally thought to be immigrants based on bone and dental morphology

**: They are thought to be immigrants based on dental morphology (Oyamada et al., 1995)

Figure 1. Yayoi sites and Chinese Provinces relevant to the present caries study.

Table 2. Sample sizes of the present materials regarding caries

	Male			Female			TOTAL
	Adolescent group	Elderly group (Senior)	Total	Adolescent group	Elderly group (Senior)	Total	
Jomon	12	46 (5)	58	15	42 (17)	57	115
Tanegashima Yayoi	16	14 (0)	30	16	10 (0)	26	56
Northern Kyushu Yayoi	21	30 (0)	51	13	36 (4)	49	100
Doigahama Yayoi	14	55 (16)	69	24	35 (2)	59	128
Shandong Neolithic	13	5 (0)	18	15	3 (0)	18	36
Jiangsu Neolithic	13	20 (0)	33	14	11 (0)	25	58
Henan Shang	120	63 (16)	183	56	15 (3)	71	254
Qinghai Bronze	56	40 (2)	96	66	27 (2)	93	189
Shandong Han	20	21 (0)	41	17	10 (1)	27	68

Adolescent group: Adolescent and young adult age classes

Elderly group: Middle-aged and senior age classes

Adolescent class: 16–19 years old

Young adult age class: 20–39 years old

Middle-aged class: 40–59 years old

Senior age class: over 60 years old

lence with respect to the gender and age group of each population are shown in Table 2. Sex and age of the ancient Chinese was determined by Matsushita (2000) from morphological criteria. Those of the ancient Japanese had been determined by Kiyono (1969), Matsushita et al. (1991, 1992) and the Department of Anatomy, Faculty of Medicine, Kyushu University (1988).

Unaided visual examinations, using dental tools, were used to assess the severity and location of dental caries. The degree of closure of the dental socket was used to judge whether the tooth had been lost during the individual's lifetime (i.e. antemortem), or whether the loss was postmortem. Dental attrition was classified into eight grades according to Molnar's (1968) wear coding system, partly modified by Hinton (1981). The buccolingual and mesiodistal diameters of tooth crowns were measured according to Fujita's method for measurement of teeth (Fujita 1949).

Results

In Table 3 the numbers of observable teeth (Observable), carious teeth (Carious), and the ratios of carious teeth (Carious R) of the nine populations are shown with respect to the adolescent and elderly groups as well as for the total population. In Table 4 the numbers of examined molars and dental sockets of molars (Examined), antemortem molar tooth loss (AMTL), and the ratios of molar AMTL (AMTL R) are shown. Although sex-biased differences in dental caries conditions have been reported for hunter-gatherers, resulting from the different roles played by males and females in such societies (Larsen, 1983, 1984; Lukacs, 1992), the present materials

Table 3 (continued)

Doigahama Yayoi Adolescent group	Shandong Neolithic						Jiangsu Neolithic														
	Upper			Lower			Upper			Lower											
	Ant.	Pre.	Mol.	Ant.	Pre.	Mol.	TOTAL	Ant.	Pre.	Mol.	Ant.	Pre.	Mol.	TOTAL							
Observable	108	102	112	135	104	104	665	48	65	87	58	58	80	396	81	64	83	44	43	62	377
Carious	11	20	32	10	24	49	146	0	0	3	0	0	12	15	1	7	13	0	2	9	32
Carious R (%)	10.2	19.6	28.6	7.4	23.1	47.1	22.0	0.0	0.0	3.4	0.0	0.0	15.0	3.8	1.2	10.9	15.7	0.0	4.7	14.5	8.5
Elderly group																					
	Upper			Lower			TOTAL	Upper			Lower			TOTAL	Upper			Lower			TOTAL
	Ant.	Pre.	Mol.	Ant.	Pre.	Mol.		Ant.	Pre.	Mol.	Ant.	Pre.	Mol.		Ant.	Pre.	Mol.	Ant.	Pre.	Mol.	
	Ant.	Pre.	Mol.	Ant.	Pre.	Mol.		Ant.	Pre.	Mol.	Ant.	Pre.	Mol.		Ant.	Pre.	Mol.	Ant.	Pre.	Mol.	
Observable	167	133	126	182	150	146	904	17	16	26	15	19	27	120	71	59	82	75	71	101	459
Carious	28	33	38	26	39	65	229	0	0	5	0	0	8	13	0	3	15	0	0	15	33
Carious R (%)	16.8	24.8	30.2	14.3	26.0	44.5	25.3	0.0	0.0	19.2	0.0	0.0	29.6	10.8	0.0	5.1	18.3	0.0	0.0	14.9	7.2
All																					
	Upper			Lower			TOTAL	Upper			Lower			TOTAL	Upper			Lower			TOTAL
	Ant.	Pre.	Mol.	Ant.	Pre.	Mol.		Ant.	Pre.	Mol.	Ant.	Pre.	Mol.		Ant.	Pre.	Mol.	Ant.	Pre.	Mol.	
	Ant.	Pre.	Mol.	Ant.	Pre.	Mol.		Ant.	Pre.	Mol.	Ant.	Pre.	Mol.		Ant.	Pre.	Mol.	Ant.	Pre.	Mol.	
Observable	275	235	238	317	254	250	1569	65	81	113	73	77	107	516	152	123	165	119	114	163	836
Carious	39	53	70	36	63	114	375	0	0	8	0	0	20	28	1	10	28	0	2	24	65
Carious R (%)	14.2	22.6	29.4	11.4	24.8	45.6	23.9	0.0	0.0	7.1	0.0	0.0	18.7	5.4	0.7	8.1	17.0	0.0	1.8	14.7	7.8

Table 4. Molar AMTL condition of the present materials

	Adolescent group			Elderly group			All		
	Examined	AMTL	AMTL R (%)	Examined	AMTL	AMTL R (%)	Examined	AMTL	AMTL R (%)
Jomon	269	9	3.3	751	222	29.6	1020	231	22.6
Tanegashima Yayoi	327	16	4.9	230	52	22.6	557	68	12.2
Northern Kyushu Yayoi	326	23	7.1	540	219	40.6	866	242	27.9
Doigahama Yayoi	342	86	25.1	721	384	53.3	1063	470	44.2
Shandong Neolithic	206	9	4.4	66	4	6.1	272	13	4.8
Jiangsu Neolithic	212	27	12.7	270	34	12.6	482	61	12.7
Henan Shang	1398	15	1.1	636	39	6.1	2034	54	2.7
Qinghai Bronze	1061	134	12.6	610	202	33.1	1671	336	20.1
Shandong Han	333	3	0.9	278	50	18.0	611	53	8.7

were pooled for sex because of small sample sizes. Because the preservation conditions of the skeletal remains differed markedly among populations and many of the materials were as a consequence incomplete, the carious teeth ratio is shown as the ratio of the number of carious teeth to the number of observable residual teeth. Ritual tooth extraction is frequently seen in the Jomon people and the Yayoi people of Tanegashima and Doigahama (Yamaguchi Prefecture), with regard to the incisors, canines and premolars. Because tooth extraction would influence both AMTL counts and dental attrition, we used only the molar data in our populational comparisons. Results of the chi-square test regarding carious teeth and molar AMTL ratios between Northern Kyushu or Doigahama Yayoi and other groups are shown in Table 5.

Carious teeth ratio

Fig. 2 illustrates the carious teeth ratio of the adolescent, elderly and total groups of the nine populations. Among the Japanese populations, the carious teeth ratio of the Jomon people and the Tanegashima Yayoi people (the Yayoi people in the Southern Kyushu district and its surroundings) were similar. In the Northern Kyushu Yayoi people the carious teeth ratio of the adolescent group was almost the same as those of the Jomon and Tanegashima Yayoi peoples, whereas the ratio increased sharply in the elderly group and was significantly different from those of the Jomon and Tanegashima Yayoi peoples. On the other hand, the carious teeth ratio of the Doigahama Yayoi people exceeded 20% even in the adolescent group, which was extremely high compared with the other populations. The carious teeth ratio was higher in the elder-

Table 5. Results of the chi-square test regarding carious teeth and molar AMTL ratios between the immigrant Yayoi and other groups

Northern Kyushu Yayoi VS	Adolescent group		Elderly group		All	
	Carious R	AMTL R	Carious R	AMTL R	Carious R	AMTL R
Jomon	—	>	>>	>>	>>	>>
Tanegashima Yayoi	—	—	>>	>>	>>	>>
Doigahama Yayoi	<<	<<	—	<<	<<	<<
Shandong Neolithic	>	—	>>	>>	>>	>>
Jiangsu Neolithic	—	<	>>	>>	>>	>>
Henan Shang	>>	>>	>>	>>	>>	>>
Qinghai Bronze	—	<<	>>	>>	>>	>>
Shandong Han	—	>>	>>	>>	>>	>>

>>, >: Ratio of Northern Kyushu Yayoi is significantly larger at the 1% and 5% levels, respectively.

<, <<: Ratio of compared group is significantly larger at the 1% and 5% levels, respectively.

Doigahama Yayoi VS	Adolescent group		Elderly group		All	
	Carious R	AMTL R	Carious R	AMTL R	Carious R	AMTL R
Jomon	>>	>>	>>	>>	>>	>>
Tanegashima Yayoi	>>	>>	>>	>>	>>	>>
Shandong Neolithic	>>	>>	>>	>>	>>	>>
Jiangsu Neolithic	>>	>>	>>	>>	>>	>>
Henan Shang	>>	>>	>>	>>	>>	>>
Qinghai Bronze	>>	>>	>>	>>	>>	>>
Shandong Han	>>	>>	>>	>>	>>	>>

>>: Ratio of Doigahama Yayoi is significantly larger at the 1% level.

ly group of the Doigahama Yayoi people, but the difference between the age groups was not as great as that seen in the Northern Kyushu Yayoi people. The carious teeth ratio of the Chinese skeletal remains seems to increase with the sample era. But even the ratio of the most recent Han period materials, excavated in the Shandong Province, was almost the same as that of the Jomon and Tanegashima Yayoi peoples, and was significantly lower than that of the Northern Kyushu and Doigahama Yayoi people. No Chinese population showed a difference between the age groups comparable with the condition seen in the Northern Kyushu Yayoi people.

Location of dental caries

To determine whether the differences in the carious teeth ratio in the Northern Kyushu Yayoi, Doigahama Yayoi, Jomon and Tanegashima Yayoi peoples are reflected in the location of dental caries, the locations were compiled with respect to each age group of each population (Table 6). For brevity, the locations were classified into

Figure 2. Caries ratios of the present materials.

tooth crown caries, tooth root caries and cases in which only the residual tooth root remained as a result of carious decay. The caries encompassing both tooth crown and root were classified into the tooth crown caries category just for simplicity.

Fig. 3 shows the dental caries ratio at each respective location of the tooth, obtained by multiplying the carious teeth ratio by the relative frequency of caries at each location [For example, the caries ratio of the tooth crown of the adolescent group of the Jomon people is obtained as follows: The carious teeth ratio: $43 / 453 = 9.5\%$ (Table 3), the number of crown caries teeth: 29 (Table 6), the number of root caries teeth: 16 (Table 6), the total number of carious lesions: $29 + 16 = 45$, the tooth crown caries ratio: $9.5\% \times 29 / 45 = 6.1\%$]. Large differences in the caries ratio at different locations of the crown were not found between the Jomon and Tanegashima Yayoi peoples. The adolescent group of the Northern Kyushu Yayoi people showed a tendency similar to the Tanegashima Yayoi people, but the root caries and residual root prevalence increased sharply in the elderly group of the Northern Kyushu Yayoi people. In the Doigahama Yayoi people, the adolescent group showed a high prevalence for all three forms of caries, while in the elderly group the prevalence of root caries showed a high proportion.

Table 6. Location of carious lesions

Adolescent group Number of Carious lesions		Crown Caries						Root Caries						C4		ALL	
		Upper			Lower			Upper			Lower						
		Ant.	Pre.	Mol.	Ant.	Pre.	Mol.	TOTAL	Ant.	Pre.	Mol.	Ant.	Pre.	Mol.	TOTAL		
Jomon	0	1	8	0	0	0	20	29	0	1	1	0	6	8	16	0	45
Tanegashima Yayoi	1	3	9	0	3	11	27	5	8	5	0	1	8	27	9	63	
Northern Kyushu Yayoi	3	6	11	0	3	15	38	0	0	4	1	1	6	12	7	57	
Doigahama Yayoi	4	11	19	6	16	34	90	3	3	13	2	6	16	43	28	161	
Rate of Carious lesions																	
		Crown Caries						Root Caries						C4		ALL	
		Upper			Lower			Upper			Lower						
		Ant.	Pre.	Mol.	Ant.	Pre.	Mol.	TOTAL	Ant.	Pre.	Mol.	Ant.	Pre.	Mol.	TOTAL		
Jomon	0.0	0.2	1.7	0.0	0.0	0.0	4.2	6.1	0.0	0.2	0.2	0.0	1.3	1.7	3.4	0.0	9.5
Tanegashima Yayoi	0.1	0.3	1.0	0.0	0.3	1.3	3.1	3.1	0.6	0.9	0.6	0.0	0.1	0.9	3.1	1.0	7.2
Northern Kyushu Yayoi	0.4	0.8	1.4	0.0	0.4	1.9	4.8	4.8	0.0	0.0	0.5	0.1	0.1	0.8	1.5	0.9	7.2
Doigahama Yayoi	0.5	1.5	2.6	0.8	2.2	4.6	12.3	12.3	0.4	0.4	1.8	0.3	0.8	2.2	5.9	3.8	22.0
Elderly group																	
Number of Carious lesions		Crown Caries						Root Caries						C4		ALL	
		Upper			Lower			Upper			Lower						
		Ant.	Pre.	Mol.	Ant.	Pre.	Mol.	TOTAL	Ant.	Pre.	Mol.	Ant.	Pre.	Mol.	TOTAL		
Jomon	1	2	10	0	6	39	58	1	7	20	2	7	30	67	8	133	
Tanegashima Yayoi	1	0	5	0	3	14	23	1	5	14	1	6	12	39	10	72	
Northern Kyushu Yayoi	21	13	24	7	24	21	110	8	15	28	20	19	34	124	86	320	
Doigahama Yayoi	15	15	15	11	16	30	102	6	9	21	12	22	39	109	33	244	
Rate of Carious lesions																	
		Crown Caries						Root Caries						C4		ALL	
		Upper			Lower			Upper			Lower						
		Ant.	Pre.	Mol.	Ant.	Pre.	Mol.	TOTAL	Ant.	Pre.	Mol.	Ant.	Pre.	Mol.	TOTAL		
Jomon	0.1	0.2	0.9	0.0	0.6	3.7	5.5	5.5	0.1	0.7	1.9	0.2	0.7	2.8	6.3	0.8	12.5
Tanegashima Yayoi	0.2	0.0	0.9	0.0	0.6	2.6	4.3	4.3	0.2	0.9	2.6	0.2	1.1	2.2	7.3	1.9	13.4
Northern Kyushu Yayoi	1.9	1.2	2.2	0.6	2.2	1.9	9.9	9.9	0.7	1.3	2.5	1.8	1.7	3.0	11.1	7.7	28.7
Doigahama Yayoi	1.6	1.6	1.6	1.1	1.7	3.1	10.6	10.6	0.6	0.9	2.2	1.2	2.3	4.0	11.3	3.4	25.3
Ant.: Anterior teeth (incisors and canine) C4: Only root remaining because of carious decay																	
Pre.: Premolars																	
Mol.: Molars																	

Ant.: Anterior teeth (incisors and canine) C4: Only root remaining because of carious decay

Pre.: Premolars

Mol.: Molars

Figure 3. Frequencies of crown and root carious lesions, C4 refers to advanced carious lesions with only the root remaining. For abbreviations, see Fig. 2.

Molar antemortem tooth loss (AMTL)

Fig. 4 illustrates the molar AMTL ratio of the adolescent, elderly and total groups of the nine populations. The AMTL ratio of the adolescent group of the Northern Kyushu Yayoi people was low, as in the Jomon and the Tanegashima Yayoi peoples, and that of the elderly group was remarkably high. In the Doigahama Yayoi people, the AMTL ratio exceeded 20% even in the adolescent group and was over 50% in the elderly group, a strikingly higher ratio than in the other groups. The AMTL ratio in the Chinese skeletal remains was generally lower than that of either the Jomon or the Northern Kyushu Yayoi peoples, but the Bronze Age skeletons excavated from the Qinghai Province showed higher ratios than seen in the Jomon people.

Attrition

Table 7 shows the mean dental attrition rates in the adolescent and elderly groups of the four Japanese populations. Fig. 5 provides a graphical representation of the results of the principal component analysis applied to the molar attrition scores of Table 7. Attrition in both the adolescent and elderly groups was least severe in the Northern Kyushu Yayoi people. Although the four adolescent groups did not differ

Figure 4. Molar AMTL ratios of the present materials. For abbreviations, see Fig. 2.

Figure 5. Result of principal component analysis applied to molar attrition scores. For abbreviation, see Fig. 2.

by much, attrition was most severe in the Doigahama Yayoi people. In the elderly groups, attrition of the Doigahama Yayoi people was almost as severe as that of the Tanegashima Yayoi people.

Size of tooth crown

The results of the measurements of the buccolingual and mesiodistal diameters of the tooth crown are summarized in Tables 8 (males) and 9 (females). The results of Penrose's distance analysis of 28 measurements, that is, the buccolingual and me-

Table 7. Dental attrition in the four Japanese populations

	Upper							Lower						
	11	12	C	P1	P2	M1	M2	11	12	C	P1	P2	M1	M2
Jomon-A	2.9	3.1	2.5	3.1	3.3	3.5	3.0	3.7	3.1	3.4	3.0	3.3	3.5	3.0
Tanegashima Yayoi-A	3.5	3.1	3.2	2.9	3.0	3.4	3.0	3.4	3.0	3.1	2.8	2.8	3.2	3.1
Northern Kyushu Yayoi-A	2.6	2.3	2.8	2.8	2.8	3.6	3.0	2.7	2.5	2.6	2.5	2.6	3.4	2.7
Doigahama Yayoi-A	3.7	3.3	3.5	3.2	3.0	3.4	3.0	3.8	3.3	3.4	3.1	3.1	3.6	3.3
Jomon-E	4.4	4.4	4.7	4.6	4.5	4.7	4.3	5.4	4.6	5.0	4.5	4.7	4.9	4.4
Tanegashima Yayoi-E	4.4	4.0	4.3	4.2	3.8	4.8	4.1	4.5	4.2	4.3	4.2	4.0	4.4	4.3
Northern Kyushu Yayoi-E	4.1	3.5	4.1	4.1	3.9	4.5	3.5	3.9	3.7	4.2	4.0	3.6	4.4	4.0
Doigahama Yayoi-E	4.7	4.8	4.5	4.3	4.1	4.3	4.1	5.3	4.8	4.5	4.2	4.2	4.7	4.2

A: Adolescent group, E: Elderly group

siodistal diameters of the tooth crowns from the central incisor to the second molar of the upper and lower jaws, are shown in Tables 10 (males) and 11 (females). In addition, the results obtained by a principal coordinate analysis of the distance matrices are shown graphically in Figs. 6 (males) and 7 (females).

The Jomon and the Tanegashima Yayoi peoples are relatively close to each other with respect to both overall size and proportion of the tooth crown sizes, whereas the Northern Kyushu Yayoi and the Doigahama Yayoi peoples are distant from the Jomon and Tanegashima Yayoi peoples, and are closer to the Chinese samples.

Discussion

Condition of dental caries and attrition rates

The Yayoi people from Northern Kyushu and Doigahama (the Yayoi site of Yamaguchi Prefecture)

Studies of dental caries of human skeletal remains from the Yayoi period have so far revealed that the carious teeth ratio of the Yayoi people of the Northern Kyushu-Yamaguchi region is higher than that of both the Jomon people and the Yayoi people of the Southern Kyushu and its surrounding areas (Ono, 1957; Sanui, 1960; Yamada et al., 1970; Inoue et al., 1986). The present study confirmed this and also showed that the carious teeth ratio of the Yayoi people in an outlying group of the Southern Kyushu region (Tanegashima) was almost the same as that of the Jomon people, and significantly lower than that of the Yayoi people of the Northern Kyushu-Yamaguchi region. Inoue et al. (1986) provided an explanation for the high carious ratio of the Yayoi people by pointing out that this period coincided with the introduction of rice cultivation, and that the combination of hunting-gathering and agriculture would have caused poor oral health, leading to an increase in dental caries. But, they had not mentioned the regional difference of carious conditions during the Yayoi period.

Results of the present study showed that, in frequency of carious lesions and in

Table 8. Buccolingual and mesiodistal crown diameters: Male

	Jomon			T Yayoi			N Yayoi			D Yayoi			NW Yayoi			O Yayoi			Mashiki		
	N	Mean	SD	N	Mean	SD	N	Mean	SD	N	Mean	SD	N	Mean	SD	N	Mean	SD	N	Mean	SD
BLU11	15	7.33	0.36	20	7.59	0.36	18	7.53	0.44	29	7.61	0.43	18	7.37	0.30	32	7.44	0.39	6	7.24	0.19
BLU12	15	6.71	0.41	20	6.83	0.47	22	6.85	0.44	18	6.77	0.61	16	6.71	0.30	33	6.64	0.34	6	6.65	0.42
BLUC	6	7.94	0.34	22	8.19	0.49	28	8.72	0.50	18	8.53	0.43	13	8.26	0.41	23	8.14	0.37	5	7.70	0.21
BLUP1	16	9.15	0.60	24	9.21	0.46	27	9.68	0.62	31	9.59	0.60	20	9.43	0.52	30	9.31	0.51	7	9.06	0.31
BLUP2	17	9.02	0.52	25	9.07	0.51	30	9.57	0.69	30	9.46	0.53	20	9.13	0.61	28	9.23	0.52	9	8.75	0.30
BLUM1	13	11.63	0.45	22	11.74	0.50	17	11.72	0.58	29	11.86	0.62	19	11.82	0.66	26	11.56	0.43	4	11.72	0.34
BLUM2	16	11.41	0.50	22	11.65	0.61	25	11.74	0.57	26	11.60	0.64	14	11.49	0.80	25	11.30	0.53	6	11.08	0.28
BLUM3	14	10.86	0.50	18	10.84	0.86	11	11.02	0.65	14	10.68	0.77	15	11.13	0.92	19	10.64	0.77	6	11.07	0.38
BL111	8	5.83	0.25	15	5.76	0.27	23	5.94	0.30	11	6.08	0.27	11	5.88	0.19	27	5.95	0.32	5	5.89	0.15
BL112	12	6.29	0.34	27	6.15	0.36	32	6.39	0.30	23	6.31	0.30	18	6.22	0.22	29	6.23	0.32	7	6.09	0.21
BL1C	10	7.43	0.38	29	7.59	0.37	33	7.97	0.58	30	7.96	0.52	25	7.63	0.38	34	7.64	0.43	4	6.92	0.35
BL1P1	20	7.48	0.40	26	7.52	0.31	35	8.07	0.55	33	8.00	0.54	28	7.64	0.49	32	7.76	0.52	4	7.62	0.40
BL1P2	19	8.07	0.38	29	8.28	0.35	37	8.61	0.67	32	8.34	0.52	23	8.24	0.42	32	8.38	0.45	7	8.06	0.44
BL1M1	18	11.06	0.42	20	10.76	0.33	27	11.04	0.53	27	11.06	0.43	15	11.39	0.51	27	10.81	0.43	1	11.15	—
BL1M2	19	10.35	0.45	24	10.32	0.65	24	10.64	0.57	30	10.48	0.52	17	10.74	0.46	29	10.34	0.53	4	10.27	0.33
BL1M3	19	10.02	0.65	17	9.82	0.52	15	10.27	0.42	21	10.11	0.65	15	10.28	0.65	23	9.81	0.76	5	10.24	1.15
MDU11	15	8.42	0.34	20	8.37	0.50	18	8.62	0.50	28	8.58	0.38	18	8.21	0.36	32	8.44	0.57	6	8.24	0.26
MDU12	13	7.24	0.46	21	6.90	0.56	21	7.34	0.54	18	7.19	0.69	16	6.93	0.39	33	6.95	0.56	6	6.86	0.32
MDUC	7	7.49	0.61	22	7.49	0.36	27	8.20	0.44	18	8.03	0.66	13	7.59	0.24	23	7.64	0.39	5	7.29	0.31
MDUP1	15	6.92	0.40	24	6.82	0.39	28	7.49	0.50	29	7.40	0.48	20	6.89	0.39	30	6.98	0.38	6	6.65	0.21
MDUP2	14	6.56	0.34	25	6.42	0.37	30	6.96	0.48	26	6.91	0.39	18	6.57	0.46	28	6.72	0.40	9	6.22	0.36
MDUM1	12	10.35	0.39	22	9.95	0.51	15	10.80	0.59	29	10.54	0.52	18	10.55	0.51	26	10.76	0.48	4	10.53	0.46
MDUM2	15	9.22	0.71	22	9.23	0.63	26	10.06	0.56	24	9.81	0.74	15	9.63	0.60	25	9.87	0.55	6	9.25	0.58
MDUM3	14	8.73	0.77	16	8.18	0.66	11	9.28	1.03	14	8.54	0.73	16	8.99	0.85	19	8.77	0.73	6	8.86	0.78
MDL11	8	5.11	0.36	15	5.13	0.41	23	5.28	0.37	11	5.48	0.29	11	5.03	0.40	25	5.08	0.49	5	5.04	0.32
MDL12	12	5.73	0.40	27	5.59	0.38	32	6.09	0.39	22	5.97	0.39	18	5.39	0.50	28	5.71	0.46	7	5.54	0.23
MDLC	10	6.83	0.39	29	6.59	0.31	33	7.11	0.46	30	7.07	0.48	25	6.65	0.33	33	6.70	0.43	4	6.25	0.20
MDLP1	20	6.87	0.41	26	6.68	0.37	34	7.27	0.43	33	7.19	0.49	27	6.72	0.32	32	6.91	0.39	4	6.70	0.20
MDLP2	19	6.87	0.37	28	6.97	0.36	36	7.44	0.49	30	7.31	0.46	24	6.95	0.44	31	7.16	0.43	7	6.71	0.39
MDLM1	18	11.47	0.46	18	11.14	0.45	28	11.73	0.46	27	11.51	0.46	14	11.72	0.49	26	11.36	0.44	1	11.37	—
MDLM2	18	10.82	0.45	22	10.82	0.53	23	11.44	0.54	28	11.10	0.64	17	11.18	0.62	27	10.86	0.49	4	10.77	0.49
MDLM3	18	10.55	0.59	17	10.35	0.72	15	10.86	0.53	21	10.58	0.62	14	10.81	0.75	22	10.53	0.74	5	10.36	0.54

T Yayoi: Tanegashima Yayoi, N Yayoi: Northern Kyushu Yayoi, D Yayoi: Doigahama Yayoi, NW Yayoi: Northwestern Kyushu Yayoi, O Yayoi: Otomo Yayoi

Table 8 (continued)

	S Kofun			S Neolithic			J Neolithic			H Shang			Q Bronze			S Han		
	N	Mean	SD	N	Mean	SD	N	Mean	SD	N	Mean	SD	N	Mean	SD	N	Mean	SD
BLUH	27	7.10	0.42	6	7.00	0.64	16	7.69	0.54	62	7.25	0.52	4	7.23	0.39	18	7.22	0.49
BLU2	31	6.56	0.36	9	6.19	0.56	19	6.77	0.48	79	6.66	0.53	8	6.62	0.49	24	6.58	0.47
BLUC	32	8.36	0.43	13	7.96	0.62	22	8.56	0.47	87	8.33	0.50	16	8.64	0.50	22	8.47	0.51
BLUP1	35	9.42	0.52	16	9.28	0.57	22	9.57	0.57	99	9.52	0.46	32	9.16	0.54	30	9.48	0.54
BLUP2	33	9.23	0.58	13	9.05	0.63	23	9.29	0.49	107	9.35	0.58	38	9.28	0.69	30	9.39	0.66
BLUM1	25	11.82	0.45	13	11.46	0.56	21	11.86	0.44	89	11.63	0.56	45	11.74	0.65	25	11.63	0.50
BLUM2	29	11.76	0.42	17	11.32	0.64	24	11.77	0.58	105	11.66	0.63	54	11.87	0.69	33	11.82	0.64
BLUM3	19	11.24	0.84	9	10.55	0.55	18	11.04	0.68	82	10.96	0.80	19	10.69	0.82	17	10.73	0.64
BLH1	25	5.84	0.33	6	5.58	0.44	11	6.13	0.29	33	5.74	0.34	10	5.86	0.30	17	5.78	0.43
BLH2	30	6.22	0.33	12	6.06	0.30	15	6.42	0.39	46	6.13	0.35	16	6.31	0.31	27	6.31	0.38
BLLC	38	7.76	0.39	14	7.37	0.47	23	7.99	0.48	49	7.68	0.69	24	7.98	0.53	23	7.80	0.61
BLLP1	38	7.98	0.44	17	7.69	0.56	26	8.03	0.42	55	7.83	0.53	27	8.08	0.63	27	7.96	0.50
BLLP2	35	8.34	0.47	17	7.85	0.47	27	8.34	0.44	60	8.18	0.49	35	8.34	0.57	26	8.29	0.57
BLLM1	29	10.92	0.47	17	10.72	0.55	27	10.85	0.37	57	10.68	0.57	38	10.93	0.60	27	10.88	0.49
BLLM2	33	10.63	0.53	18	10.16	0.57	26	10.53	0.60	64	10.37	0.52	44	10.54	0.52	26	10.53	0.56
BLLM3	21	10.17	0.57	9	10.30	0.98	19	10.45	0.84	56	10.30	0.83	28	10.03	0.71	28	9.95	0.87
MDUH	28	8.33	0.39	6	8.52	0.73	16	8.65	0.38	61	8.54	0.59	4	8.57	0.71	18	8.49	0.64
MDU2	31	7.12	0.46	9	7.00	0.56	19	7.04	0.50	79	7.13	0.47	9	6.95	0.56	23	7.18	0.63
MDUC	32	7.79	0.36	13	7.78	0.49	22	8.06	0.37	87	7.86	0.42	14	7.94	0.53	22	7.95	0.51
MDUP1	35	7.31	0.45	16	7.06	0.52	22	7.03	0.42	100	7.30	0.37	31	7.11	0.47	31	7.31	0.42
MDUP2	34	6.75	0.39	13	6.50	0.42	23	6.72	0.40	98	6.73	0.40	34	6.76	0.49	30	6.86	0.57
MDUM1	25	10.57	0.45	13	10.04	0.74	21	10.21	0.58	91	10.43	0.47	40	10.41	0.58	25	10.36	0.54
MDUM2	29	9.82	0.47	18	9.34	0.56	23	9.80	0.60	105	9.75	0.65	54	9.63	0.63	33	9.75	0.58
MDUM3	19	9.14	0.79	9	8.52	0.59	18	8.90	0.65	83	8.98	0.85	19	8.86	0.74	17	8.71	0.67
MDL1	25	5.40	0.34	6	5.26	0.44	11	5.52	0.56	33	5.29	0.37	9	5.28	0.44	17	5.37	0.38
MDL2	31	5.89	0.33	12	5.92	0.43	14	5.87	0.39	46	5.95	0.47	15	5.90	0.56	27	6.01	0.43
MDLC	39	6.81	0.33	14	6.72	0.49	23	7.04	0.52	50	6.95	0.38	22	7.05	0.56	22	7.02	0.54
MDLP1	38	7.09	0.36	17	6.84	0.71	25	6.98	0.46	53	7.13	0.40	27	7.19	0.45	27	7.08	0.41
MDLP2	36	7.24	0.42	17	6.97	0.62	27	7.06	0.63	58	6.98	0.51	33	7.04	0.51	26	7.26	0.55
MDLM1	29	11.50	0.53	17	11.18	0.50	28	11.20	0.49	54	11.31	0.59	35	11.30	0.68	27	11.42	0.55
MDLM2	34	11.17	0.59	18	10.67	0.53	26	10.65	0.64	63	10.99	0.66	43	10.91	0.70	26	10.97	0.67
MDLM3	21	10.82	0.70	9	10.63	1.17	18	11.01	0.69	55	10.77	0.94	27	10.59	0.73	29	10.44	0.89

S Kofun: Southern Kyushu Kofun, S Neolithic: Shandong Neolithic, J Neolithic: Jiangsu Neolithic, H Shang: Henan Shang, Q Bronze: Qinghai Bronze, S Han: Shandong Han

Table 9. Buccolingual and mesiodistal crown diameters: Female

	Jomon			T Yayoi			N Yayoi			D Yayoi			NW Yayoi			O Yayoi			Mashiki		
	N	Mean	SD	N	Mean	SD	N	Mean	SD	N	Mean	SD	N	Mean	SD	N	Mean	SD	N	Mean	SD
BLUI1	12	7.01	0.34	18	7.37	0.41	14	7.44	0.33	18	7.40	0.40	13	6.92	0.49	20	7.22	0.43	6	6.87	0.20
BLUI2	11	6.40	0.45	18	6.57	0.41	17	6.58	0.35	15	6.61	0.41	15	6.48	0.56	16	6.70	0.41	6	6.04	0.36
BLUC	2	7.25	0.57	21	7.71	0.37	22	8.32	0.45	15	8.08	0.38	6	7.85	0.49	12	8.04	0.32	7	7.15	0.35
BLUP1	10	9.05	0.58	25	9.12	0.52	20	9.65	0.62	28	9.28	0.44	17	8.99	0.56	17	9.13	0.47	6	8.40	0.31
BLUP2	10	8.66	0.44	25	8.88	0.57	19	9.27	0.58	31	9.09	0.47	23	8.76	0.61	17	9.05	0.47	8	8.30	0.44
BLUM1	12	11.12	0.52	22	11.44	0.41	19	11.61	0.61	34	11.54	0.49	21	11.10	0.54	15	11.43	0.40	4	11.29	0.44
BLUM2	14	10.79	0.62	24	11.26	0.73	22	11.43	0.44	28	11.36	0.56	20	10.91	0.60	15	10.98	0.56	7	10.71	0.29
BLUM3	12	10.22	0.73	16	10.40	1.00	10	10.83	0.53	11	10.56	0.72	13	10.28	0.56	11	10.22	0.90	6	10.16	0.28
BLLI1	3	5.61	0.50	15	5.69	0.33	8	5.85	0.29	19	5.77	0.36	9	5.74	0.38	8	5.93	0.17	4	5.39	0.46
BLLI2	6	5.86	0.37	22	5.97	0.32	15	6.28	0.27	31	6.20	0.32	15	5.90	0.34	11	6.23	0.17	6	5.71	0.40
BLLC	9	6.77	0.53	26	7.08	0.44	18	7.49	0.39	31	7.45	0.34	23	6.96	0.42	15	7.48	0.31	7	6.81	0.40
BLLP1	16	7.34	0.44	25	7.55	0.36	21	8.00	0.42	36	7.76	0.51	27	7.46	0.52	18	7.59	0.34	9	7.21	0.49
BLLP2	19	7.87	0.46	23	8.24	0.41	26	8.30	0.59	31	8.20	0.46	25	8.20	0.40	22	8.44	0.29	8	7.66	0.46
BLLM1	17	10.67	0.47	19	10.63	0.44	20	10.89	0.46	29	10.82	0.54	19	10.81	0.34	12	10.83	0.41	5	10.34	0.26
BLLM2	15	9.91	0.52	23	10.03	0.46	18	10.11	0.52	20	10.26	0.60	15	10.21	0.56	11	10.14	0.57	6	9.58	0.37
BLLM3	13	9.55	0.62	16	9.53	0.48	12	9.88	0.47	12	10.01	0.60	15	9.87	0.53	10	9.61	0.38	8	9.60	0.69
MDUI1	11	8.13	0.37	18	8.14	0.34	14	8.52	0.33	18	8.43	0.52	12	8.00	0.63	20	8.38	0.54	6	8.05	0.40
MDUI2	11	6.68	0.46	17	6.70	0.50	19	7.21	0.53	15	7.13	0.35	16	6.78	0.57	16	7.12	0.43	6	6.61	0.29
MDUC	2	7.26	0.58	21	7.06	0.31	22	7.83	0.56	15	7.75	0.27	6	7.40	0.42	11	7.49	0.37	7	7.01	0.52
MDUP1	10	6.63	0.33	25	6.80	0.38	19	7.46	0.32	29	7.22	0.40	17	6.86	0.39	16	6.94	0.43	6	6.30	0.32
MDUP2	10	6.25	0.39	24	6.47	0.43	19	6.98	0.32	31	6.79	0.42	23	6.50	0.48	17	6.77	0.44	8	6.10	0.41
MDUM1	12	9.84	0.27	19	9.73	0.49	18	10.66	0.50	33	10.30	0.46	20	10.21	0.50	15	10.49	0.57	4	10.17	0.18
MDUM2	14	8.98	0.63	24	9.08	0.54	22	9.75	0.53	24	9.67	0.49	20	9.42	0.56	15	9.92	0.47	7	9.02	0.39
MDUM3	12	8.26	0.59	15	8.16	0.84	10	8.68	0.74	11	8.79	0.48	13	8.58	0.42	11	8.99	0.72	6	8.68	0.80
MDLI1	3	4.70	0.34	15	5.01	0.35	8	5.39	0.23	18	5.33	0.36	9	5.13	0.37	8	5.40	0.37	4	4.86	0.34
MDLI2	6	5.55	0.58	22	5.39	0.25	15	6.04	0.25	27	6.05	0.32	15	5.50	0.38	11	5.81	0.42	6	5.39	0.37
MDLC	9	6.36	0.33	26	6.29	0.35	19	6.80	0.24	30	6.76	0.32	23	6.35	0.32	14	6.61	0.41	7	6.19	0.39
MDLP1	16	6.63	0.31	25	6.80	0.34	23	7.16	0.40	32	7.11	0.38	26	6.69	0.41	16	6.86	0.43	8	6.53	0.38
MDLP2	18	6.72	0.31	23	7.00	0.28	26	7.26	0.43	31	7.24	0.38	24	6.94	0.47	21	7.15	0.40	9	6.68	0.24
MDLM1	16	11.01	0.46	18	10.99	0.56	20	11.39	0.42	28	11.32	0.63	18	11.19	0.51	12	11.15	0.57	5	10.81	0.33
MDLM2	16	10.50	0.67	23	10.69	0.54	18	10.81	0.60	18	11.01	0.69	15	10.85	0.59	10	10.91	0.38	6	10.10	0.30
MDLM3	13	10.11	0.63	16	10.10	0.77	12	10.02	0.65	10	10.58	1.03	15	10.80	0.72	10	10.51	0.31	8	10.15	0.66

For abbreviations, see Table 8.

Table 9 (continued)

	S Kofun			S Neolithic			J Neolithic			H Shang			Q Bronze			S Han		
	N	Mean	SD	N	Mean	SD	N	Mean	SD	N	Mean	SD	N	Mean	SD	N	Mean	SD
BLUI1	20	7.00	0.48	2	7.00	0.75	8	7.42	0.59	26	7.37	0.52	5	7.60	0.52	13	7.30	0.46
BLUI2	22	6.38	0.46	5	6.05	0.37	8	6.67	0.39	36	6.50	0.51	10	6.56	0.53	15	6.68	0.37
BLUC	24	7.92	0.43	7	7.51	0.28	13	8.15	0.58	46	8.27	0.56	24	8.23	0.51	18	8.24	0.53
BLUP1	25	9.40	0.67	7	8.75	0.59	13	9.35	0.34	52	9.35	0.50	25	9.16	0.54	17	9.27	0.53
BLUP2	24	9.27	0.59	11	8.36	0.78	18	9.02	0.48	50	9.22	0.54	24	9.26	0.55	18	9.28	0.39
BLUM1	24	11.64	0.50	7	11.07	0.48	16	11.21	0.42	49	11.49	0.47	45	11.47	0.50	18	11.45	0.44
BLUM2	24	11.54	0.66	11	10.67	0.83	16	11.16	0.62	51	11.53	0.62	48	11.26	0.59	20	11.55	0.56
BLUM3	11	10.79	0.63	4	10.23	0.78	8	10.09	0.40	35	10.72	0.86	13	10.50	0.98	10	10.41	0.64
BLLJ1	14	5.67	0.35	4	5.63	0.24	8	5.98	0.25	30	5.73	0.37	13	5.93	0.37	12	5.94	0.28
BLLJ2	17	6.15	0.47	7	6.02	0.35	9	6.54	0.34	39	6.10	0.38	18	6.28	0.31	15	6.35	0.31
BLLC	17	7.34	0.39	7	7.12	0.35	9	7.52	0.59	40	7.74	0.45	26	7.50	0.55	18	7.69	0.44
BLLP1	18	7.89	0.59	9	7.49	0.58	14	8.09	0.58	41	7.72	0.46	32	7.82	0.55	16	7.88	0.42
BLLP2	19	8.34	0.49	10	7.70	0.59	15	8.30	0.51	48	8.14	0.43	30	8.11	0.59	20	8.14	0.46
BLLM1	15	10.73	0.48	9	10.33	0.55	15	10.77	0.52	38	10.62	0.42	38	10.71	0.57	20	10.66	0.49
BLLM2	14	10.35	0.48	10	9.57	0.59	14	10.33	0.52	37	10.29	0.52	42	10.16	0.50	16	10.49	0.57
BLLM3	7	9.90	0.71	8	9.42	0.77	9	9.90	0.77	33	10.11	0.57	24	9.66	0.72	12	10.33	0.67
MDUI1	20	8.38	0.38	2	8.19	0.40	8	8.58	0.32	26	8.57	0.46	5	8.84	0.49	13	8.43	0.41
MDUI2	22	6.95	0.59	5	6.61	0.41	9	7.09	0.42	37	6.94	0.55	10	6.98	0.77	15	6.95	0.43
MDUC	24	7.39	0.35	7	7.30	0.26	13	7.80	0.47	45	7.83	0.54	23	7.82	0.45	16	7.71	0.24
MDUP1	25	7.12	0.44	7	6.89	0.48	13	7.11	0.36	51	7.19	0.33	25	7.04	0.46	17	7.23	0.40
MDUP2	24	6.71	0.34	11	6.30	0.54	17	6.45	0.55	46	6.59	0.47	25	6.72	0.47	18	6.95	0.37
MDUM1	24	10.22	0.48	7	9.91	0.77	17	9.84	0.47	49	10.31	0.47	43	10.18	0.54	18	10.14	0.51
MDUM2	24	9.57	0.65	11	8.91	0.71	15	9.47	0.56	51	9.48	0.55	47	9.34	0.59	20	9.58	0.72
MDUM3	11	8.24	0.82	3	8.56	0.42	7	8.49	0.82	36	8.87	0.77	13	8.73	1.07	10	8.58	0.85
MDLI1	14	5.33	0.36	3	5.12	0.27	8	5.33	0.37	29	5.23	0.36	12	5.39	0.41	12	5.50	0.30
MDLI2	17	5.92	0.38	7	5.75	0.31	8	6.07	0.44	38	5.93	0.38	18	5.89	0.47	15	6.06	0.31
MDLC	17	6.44	0.26	6	6.52	0.42	8	6.92	0.42	39	6.94	0.39	25	6.80	0.42	18	6.70	0.36
MDLP1	18	7.08	0.44	9	6.56	0.51	14	7.04	0.54	40	7.06	0.50	32	7.06	0.52	16	7.05	0.29
MDLP2	18	7.12	0.40	10	6.45	0.53	15	6.95	0.58	47	7.14	0.49	30	7.00	0.59	21	7.16	0.44
MDLM1	15	11.22	0.62	9	10.56	0.58	15	11.19	0.59	38	11.20	0.50	35	11.12	0.76	20	11.16	0.51
MDLM2	15	11.01	0.67	10	9.95	0.49	14	10.62	0.80	37	10.91	0.75	41	10.65	0.75	16	10.89	0.59
MDLM3	7	10.24	1.30	8	9.59	0.81	9	10.41	0.85	30	10.72	0.85	24	10.16	0.93	12	10.55	0.58

For abbreviations, see Table 8.

Table 10. Penrose's size (upper right) and shape (lower left) distances based on buccolingual and mesiodistal crown diameters: Male

	Jomon	Mashiki	T Yayoi	N Yayoi	D Yayoi	NW Yayoi	O Yayoi	S Kofun	S Neolithic	J Neolithic	H Shang	Q Bronze	S Han
Jomon	—	0.0926	0.0057	0.6045	0.3680	0.0206	0.0252	0.1295	0.0263	0.2113	0.0691	0.1342	0.1626
Mashiki	0.1502	—	0.0525	1.1702	0.8298	0.2005	0.2144	0.4410	0.0202	0.5835	0.3217	0.4496	0.5005
T Yayoi	0.1380	0.2665	—	0.7271	0.4649	0.0479	0.0547	0.1893	0.0075	0.2861	0.1143	0.1949	0.2289
N Yayoi	0.1942	0.3934	0.2318	—	0.0292	0.4019	0.3828	0.1744	0.8827	0.1010	0.2648	0.1691	0.1401
D Yayoi	0.1440	0.3296	0.1607	0.0672	—	0.2145	0.2006	0.0609	0.5909	0.0216	0.1182	0.0578	0.0414
NW Yayoi	0.1608	0.1597	0.2025	0.2631	0.2565	—	0.0002	0.0468	0.0934	0.0999	0.0142	0.0496	0.0674
O Yayoi	0.1413	0.2049	0.1814	0.1008	0.0986	0.1798	—	0.0404	0.1029	0.0905	0.0109	0.0431	0.0598
S Kofun	0.1801	0.3077	0.2269	0.0797	0.0895	0.2239	0.1315	—	0.2724	0.0100	0.0094	0.0000	0.0019
S Neolithic	0.1914	0.4036	0.2772	0.1351	0.1075	0.3930	0.2295	0.1062	—	0.3865	0.1806	0.2791	0.3195
J Neolithic	0.2509	0.4432	0.1518	0.2303	0.1024	0.3710	0.2089	0.2422	0.2295	—	0.0387	0.0087	0.0032
H Shang	0.1833	0.4054	0.2143	0.0591	0.1898	0.3369	0.1503	0.0708	0.0681	0.1898	—	0.0107	0.0197
Q Bronze	0.2190	0.4452	0.2122	0.1113	0.0964	0.3198	0.1874	0.1037	0.1570	0.1332	0.0998	—	0.0014
S Han	0.1861	0.4404	0.2177	0.0564	0.0642	0.3219	0.1658	0.0503	0.0570	0.1698	0.0369	0.0649	—

For abbreviations, see Table 8.

Table 11. Penrose's size (upper right) and shape (lower left) distances based on buccolingual and mesiodistal crown diameters: Female

	Jomon	Mashiki	T Yayoi	N Yayoi	D Yayoi	NW Yayoi	O Yayoi	S Kofun	S Neolithic	J Neolithic	H Shang	Q Bronze	S Han
Jomon	—	0.1058	0.0965	1.3675	0.9369	0.1185	0.6980	0.6428	0.0014	0.8642	0.8565	0.8302	1.0418
Mashiki	0.1614	—	0.4044	2.2339	1.6723	0.4481	1.3472	1.2701	0.0827	1.5746	1.5642	1.5286	1.8115
T Yayoi	0.1448	0.2408	—	0.7374	0.4320	0.0011	0.2754	0.2411	0.1214	0.3831	0.3779	0.3605	0.5041
N Yayoi	0.2330	0.2503	0.2791	—	0.0406	0.6809	0.1115	0.1352	1.4570	0.0575	0.0595	0.0667	0.0221
D Yayoi	0.1459	0.1716	0.1980	0.0593	—	0.3891	0.0175	0.0276	1.0113	0.0015	0.0018	0.0032	0.0028
NW Yayoi	0.1405	0.2031	0.1763	0.2031	0.1439	—	0.2413	0.2093	0.1458	0.3427	0.3378	0.3214	0.4577
O Yayoi	0.2144	0.1651	0.2242	0.1662	0.1169	0.1022	—	0.0011	0.7624	0.0089	0.0081	0.0057	0.0343
S Kofun	0.2047	0.2148	0.1751	0.1482	0.1109	0.1674	0.1908	—	0.7046	0.0164	0.0153	0.0120	0.0479
S Neolithic	0.2760	0.2653	0.3602	0.1094	0.1078	0.3221	0.1986	0.2490	—	0.9356	0.9276	0.9002	1.1202
J Neolithic	0.3000	0.4569	0.3675	0.2575	0.1921	0.3775	0.2954	0.3421	0.1308	—	0.0000	0.0003	0.0083
H Shang	0.2683	0.2920	0.2985	0.1222	0.0803	0.2836	0.2377	0.2038	0.1595	0.2158	—	0.0002	0.0091
Q Bronze	0.2601	0.2777	0.2731	0.1552	0.1207	0.3149	0.2142	0.2694	0.0949	0.1360	0.1095	—	0.0120
S Han	0.2953	0.3361	0.2537	0.1379	0.0824	0.2362	0.1726	0.1441	0.1336	0.1694	0.1195	0.1360	—

For abbreviations, see Table 8.

Figure 6. Results of principal coordinate analysis applied to Penrose's Size (left) and Shape (right) distances in males. For abbreviations, see Table 8.

Figure 7. Results of principal coordinate analysis applied to Penrose's Size (left) and Shape (right) distances in females. For abbreviations, see Table 8.

state of dental attrition, the Yayoi people of the Northern Kyushu and Yamaguchi regions were different. The teeth of the Doigahama Yayoi people showed a relatively high degree of attrition close to the condition seen in the Jomon and the Tanegashima Yayoi peoples, who were assumed to have lived mainly on fishing-gathering, whereas the elderly group of the Northern Kyushu Yayoi people showed a lower level of dental attrition. Regarding caries prevalence, a high carious teeth ratio was found even in the adolescent group in the Doigahama Yayoi people, whereas in the Northern Kyushu Yayoi people it was as low as in the Jomon people in the adolescent group, and increased sharply in the elderly group. The same tendency was found in the molar AMTL ratio. In view of such differences, it is evident that there must have been notable differences in the dietary habits and lifestyles between the Northern Kyushu and Doigahama Yayoi peoples.

The geographical locations of burial sites differ markedly between the Yamaguchi and Northern Kyushu regions. The Doigahama Yayoi people were buried on the seashore, whereas the Northern Kyushu Yayoi people were interred in the fields. Moreover, there are definite differences in skeletal morphology of upper and lower limb between the Yayoi people of the Yamaguchi Prefecture and the Northern Kyushu region. (Nakahashi and Nagai, 1997; Matsushita 2001). From this we can infer that while the Northern Kyushu Yayoi people are thought to have subsisted mainly on agricultural crops, the Doigahama Yayoi people might have relied on fishing, hunting and gathering, perhaps in combination with agriculture.

The Tanegashima Yayoi people

On the basis of the characteristics of their bone morphology or archaeological evidence, some researchers commented that the Tanegashima Yayoi people might be genetically affiliated to the Asian continental immigrants (Kanaseki, 1976; Matsushita, 2001). Generally, however, they are assumed to be the descendants of the Jomon people (Naito, 1984; Matsumura, 1995; Manabe et al., 2002). The present study revealed that, although the level of dental attrition among the Tanegashima Yayoi people was slightly lower than that of the Jomon people, the prevalence of dental caries was similar. Accordingly, it is difficult to suppose that either abrupt changes in life habits or immigration occurred during this period.

Lineage relationships among the people of the Yayoi period inferred from the size of the tooth crown

Measurements of the skeletal remains of the Jomon and Yayoi people of Kyushu and the Yamaguchi Prefecture (Kanaseki, 1976; Naito, 1984), studies of non-metric skeletal traits (Dodo and Ishida, 1990, 1992; Saiki et al., 2000), dental measurements (Brace and Nagai, 1982; Oyamada, 1992; Matsumura, 1994, 1995), and studies of non-metric dental traits (Matsumura, 1994, 1995; Manabe et al., 2002) have so far established that the Yayoi people of the Northwestern and Southern Kyushu re-

gions and its surrounding areas were closely related to the Jomon people, but that the Yayoi people of Northern Kyushu and the Yamaguchi Prefecture differed markedly from the Jomon people. Furthermore, comparative studies of the skeletal remains of the Yayoi people of the Northern Kyushu-Yamaguchi region, and those excavated in continental China have revealed many similarities between the two groups, and the Yayoi people of the Northern Kyushu-Yamaguchi region have been assumed to be genetically affiliated to immigrants from the Asian continent (Ogata et al., 1997; Han, 2000; Zhang, 2000; Matsushita, 2000; Manabe and Rokutanda, 2000; Oyama-da and Rokutanda, 2000).

The present study has shown that the proportion of the tooth crown size, which is generally assumed to represent lineage relationships more accurately than the total size of the tooth crowns, of the Northern Kyushu-Yamaguchi Yayoi people very much resembles that of the Chinese skeletal remains. To the contrary, the tooth size proportion of the outlier Yayoi people of the Southern Kyushu region (the Tanegashima) is similar to that of the Jomon people. Thus, the present study supports the hitherto proposed theory that the Yayoi people of the Northern Kyushu region and Yamaguchi Prefecture are genetically affiliated to the immigrants, whereas the Yayoi people of the Southern Kyushu region and its outlier populations are the descendants of the Jomon people.

Differences in skeletal morphology, including the neurocranium, face, and upper and lower limbs are known between the Yayoi people of the Northern Kyushu region and Yamaguchi Prefecture (Kananseki, 1976; Matsushita, 1994; Nakahashi and Nagai, 1997). The present study showed that, among the populations compared, the size proportion of the tooth crown was very similar between the Yayoi people of the Northern Kyushu region and the Yamaguchi Prefecture, and that there were no marked differences between the two groups in this regard.

Relevance of skeletal remains from China

In the present study, carious ratios of the ancient Chinese were significantly lower than the immigrant-affiliated Yayoi people. Except for studies based on small sample sizes, Chinese skeletal remains whose carious teeth ratio was as high as that of the Yayoi people of the Northern Kyushu region and Doigahama have not been reported (Inoue et al., 1997; Pechenkina et al., 2002). Taking these findings into consideration, we assume that it is likely that the carious teeth ratio increased after the ancestors of the Yayoi people immigrated to Japan.

Possible reasons for the increase in carious teeth ratio after immigration to Japan

The high carious teeth ratio occurring after the arrival of the ancestral Yayoi population in Japan could possibly be ascribed to several factors. These include differences in the soil and water properties between the ancestral Chinese areas and those

in Japan, and possible changes in dietary habits arising after immigration. For example, fluorosis caused by drinking water is found in 26 of 30 provinces of China (Li and Cao, 1994), and its incidence is distributed over wide areas in China, ranging from the central to the northeastern areas (Kondo and Fujita, 1998). Resistance to dental caries is increased by dental fluorosis (except for severe cases), and fluorine in the drinking water even in concentrations too low to develop fluorosis produces satisfactory caries-resistance. Increase in dental caries following the cessation of drinking fluorinated water have been reported (Way, 1964; Lemke et al., 1970; Stephen et al., 1987; Attwood and Blinkhorn, 1991). If caries frequencies in populations with a potentially carious diet had been suppressed by fluorosis in continental China, descendant populations with similar diets and habits but with lack of fluorinated water may have experienced higher frequencies of caries. This may be one underlying cause of the high carious ratios of the immigrant-affiliated Yayoi people.

In the present study, materials were divided into adolescent and elderly groups, and the extent and condition of dental caries were compared. Caries ratios of the Doigahama Yayoi people were high in both adolescent and elderly groups. The caries ratio of the adolescent group of the Northern Kyushu Yayoi people was as low as that of the Jomon people, but the prevalence of root caries increased sharply in the elderly group. In addition, the rapid increase in molar AMTL in the elderly group of the Northern Kyushu Yayoi people despite their relatively less severe attrition, suggests that periodontal diseases were widespread in this population. Archaeological evidence suggests that the Northern Kyushu Yayoi people depended mainly on agriculture (wet paddy rice cultivation). Rates of dental attrition also suggest that their dietary habits were more inclined to softer foods than in the Doigahama Yayoi people. Consequently, the Northern Kyushu Yayoi people might have suffered poor oral hygiene, and periodontal diseases might have been more widespread in the Northern Kyushu Yayoi people than in the Doigahama Yayoi people.

On the other hand, the caries and molar AMTL ratios of the Doigahama Yayoi adolescents were very high, and dental attrition in the elderly group was severe. It is possible that severe attrition had been caused by coarse and fibrous foods. Because coarse and fibrous foods could function as a self-cleaning factor, the high AMTL ratio in the Doigahama Yayoi people may have been caused by dental caries rather than periodontal disease. In the Doigahama Yayoi people, the presumed high sensitivity to dental caries might have been caused by some high cariogenic foods. Alternatively, their tooth quality might have been weak for some reason.

Conclusions

On the basis of the results of the present study, as well as those of previous studies, we are strongly convinced that the Yayoi people of the Northern Kyushu region and the Yamaguchi Prefecture were genetically affiliated with immigrant populations from

continental China. Either the present or other studies of dental caries of Chinese skeletal remains have as of yet not come across any population whose carious teeth ratio was as high as that of the Yayoi people of the Northern Kyushu and Yamaguchi regions. Taking these findings into consideration, it is possible that the carious teeth ratio increased after the ancestors of the Yayoi people immigrated to Japan. On the other hand, there were differences in attrition rates, and frequencies of dental caries and AMTL between the Northern Kyushu and the Doigahama Yayoi peoples. This could be a reflection of differences in dietary custom and subsistence between the two groups. In the future, comparison of the tooth substance itself will be necessary to more directly discuss the effects of fluorosis, even if this requires the destruction of valuable materials. In addition, further studies using comparative materials from the Asian continent, such as from the south of the Yangtze River and the Korean Peninsula, will be required.

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References

- Attwood D. and Blinkhorn A.S. (1991) Dental health in schoolchildren five years after water fluoridation ceased in south-west Scotland. *International Dental Journal*, 41: 43–48.
- Brace C.L. and Nagai M. (1982) Japanese tooth size: Past and present. *American Journal of Physical Anthropology*, 59: 399–411.
- Dep. of Anatomy, Kyushu Univ. (eds.) (1988) *Nihon-Minzoku Bunkanoseisei 2*. Yuzankaku Shuppan, Tokyo (in Japanese).
- Dodo Y. and Ishida H. (1990) Population history of Japan as viewed from cranial nonmetric variation. *Journal of the Anthropological Society of Nippon*, 98: 269–287.
- Dodo Y. and Ishida H. (1992) Consistency of nonmetric cranial trait expression during the last 2,000 years in the inhabitants of the central islands of Japan. *Journal of the Anthropological Society of Nippon*, 100: 417–423.
- Fujita T. (1949) On the standard for measurement of teeth. *Journal of the Anthropological Society of Nippon*, 61: 27–32 (in Japanese).
- Han K. (2000) Morphological study about the human skeletal remains excavated from Linzi, Shandong Province, China during the Zhou and Han period, and comparative study about them and the Yayoi people of western Japan. In: Matsushita T. (ed.), "Search of the Origin of Immigrant Yayoi into the Asian Continent," The Doigahama Site Anthropological Museum / Cultural Relics and Archaeology

- Institute of Shandong Province, pp. 112–163 (in Chinese).
- Hinton R.J. (1981) Form and patterning of anterior tooth wear among aboriginal human groups. *American Journal of Physical Anthropology*, 54: 555–564.
- Inoue N., Ito G., and Kamegai T. (1986) Microevolution and dental diseases, Study on tooth to denture discrepancy. Ishiyaku Publishing Co., Tokyo (in Japanese).
- Inoue N., Pan Q., Sakashita R., and Kamegai, T. (1997) Tooth and facial morphology of ancient Chinese skulls. Therapeia Publishing Co., Tokyo.
- Kanaseki T. (1976) The origin of the Japanese people. Hosei Daigaku Shuppan-Kyoku, Tokyo (in Japanese).
- Kiyono K (1969) *Nihon Kaizuka no Kenkyu*. Iwanamisyoten, Tokyo (In Japanese).
- Kondo T and Fujita K (1998) Dental fluorosis by coal smoke in a mountain village of Guizhou Province, China. *Journal of Dental Health*, 48: 432–433.
- Larsen C.S. (1983) Behavioral implications of temporal change in cariogenesis. *Journal of Archaeological Science*, 10: 1–8.
- Larsen C.S. (1984) Health and disease in prehistoric Georgia: The transition to agriculture. In: Cohen M.N. and Armelagos G.J. (eds.), “Paleopathology at the Origins of Agriculture,” Wiley, New York, pp. 179–202.
- Lemke C.W., Doherty J.M., and Arra M.C. (1970) Controlled fluoridation: the dental effects of discontinuation in Antigo, Wisconsin. *Journal of the American Dental Association*, 80: 782–786.
- Li J. and Cao S. (1994) Recent studies on endemic fluorosis in China. *Fluoride*, 27: 125–128.
- Lukacs J.R. (1992) Dental paleopathology and agricultural intensification in south Asia: new evidence from Bronze Age Harappa. *American Journal of Physical Anthropology*, 87: 133–150.
- Manabe Y. and Rokutanda A. (2000) Nonmetric traits of the tooth crown and root in the Neolithic and Han-aged Shandong populations, China. In: Matsushita T. (ed.), “Search of the Origin of Immigrant Yayoi into the Asian Continent,” The Doigahama Site Anthropological Museum / Cultural Relics and Archaeology Institute of Shandong Province, pp. 333–370 (in Japanese).
- Manabe Y., Kitagawa Y., Oyamada J., and Rokutanda A. (2002) Population history in the Japanese archipelago based on regional and temporal variations of dental morphology. *Dentistry in Japan*, 38: 9–16.
- Matsumura H. (1994) A microevolutional history of the Japanese people from a dental characteristics perspective. *Anthropological Science*, 102: 93–118.
- Matsumura H. (1995) Dental characteristics affinities of the Prehistoric to Modern Japanese with the East Asians, American Natives and Australo-Melanesians. *Anthropological Science*, 103: 235–261.
- Matsushita T., Saiki K., Orihara Y., Oyamada J., Ishida H., and Sakuma M. (1991) Human skeletal remains excavated from the Shiwaya-ropponmatsu-otsu site, Kanzaki Cho, Saga Prefecture. The excavational report of Saga Prefecture, 103 (4): 1–62 (in Japanese with English summary).
- Matsushita T., Wakebe T., Saiki K., Yamashita S., and Oyamada J. (1992) Human skeletal remains excavated from the Asahikita site, Kanzaki Cho, Saga Prefecture. The excavational report of the Kyushu Oudanjidoushadou-kankei Maizoubunnkazai, 15: 418–504 (in Japanese with English summary).
- Matsushita T. (1994) *The Japanese and Yayoi People*. Shoden-sha, Tokyo (in Japanese).
- Matsushita T. (2000) Human skeletal remains of the Zhou and Han periods in Linzi and those of the Yayoi period. In: Matsushita T. (ed.), “Search of the Origin of Immigrant Yayoi into the Asian Continent,” The Doigahama Site Anthropological Museum / Cultural Relics and Archaeology Institute of Shandong Province, pp. 198–332 (in Japanese).
- Matsushita T. (2001) *The Skull talks the root and future of Japanese*, Nagasaki-sinbunsha, Nagasaki (in

- Japanese).
- Molnar S. (1968) Some functional interpretations of tooth wear in prehistoric and modern man. Ph.D. Dissertation, University of California, Santa Barbara.
- Naito Y. (1984) The transition from the Jomon to the Yayoi skeletons in Kyushu. In: "Jinruigaku," Nissei-Sha, Tokyo, pp. 52–59 (in Japanese).
- Nakahashi T. and Nagai M. (1997) The Yayoi people. In: "Yayoi-Bunka no Kenkyu 1," Yuzankaku Shuppan, Tokyo, pp. 23–51 (in Japanese).
- Ogata T., Kim J.J., Mine K., and Takenaka M. (1997) Morphological characteristics of the prehistoric and protohistoric skeletons in the Korean Peninsula. *Seikyū-Gakujutsuronshu*, 10: 5–43 (in Japanese).
- Ono A. (1957) Anthropological studies on the teeth of the Yayoi-age men from Mitsu, Kanzaki-gun, Saga-prefecture. *Jinruigakukenkū*, 4: 423–462 (in Japanese with English summary).
- Oyamada J. (1992) Tooth crown size of Yayoi people in the North-west and the North of Kyushu. *Journal of the Anthropological Society of Nippon*, 100: 83–100 (in Japanese with English summary).
- Oyamada J., Manabe Y., Kitagawa Y., Rokutanda A., and Nagashima S. (1995) Tooth size of the protohistoric Kofun people in southern Kyushu, Japan. *Anthropological Science*, 103: 49–60.
- Oyamada J., Manabe Y., Kitagawa Y., and Rokutanda A. (1996) Dental morbid condition of hunter-gatherers on Okinawa Island during the middle period of the prehistoric shell midden culture and of agriculturalists in northern Kyushu during the Yayoi period. *Anthropological Science*, 104: 261–280.
- Oyamada J. and Rokutanda A. (2000) Relationship between the Shandong people during the Han period and prehistoric Japanese as regards tooth size. In: Matsushita T. (ed.), "Search of the Origin of Immigrant Yayoi into the Asian Continent," The Doigahama Site Anthropological Museum / Cultural Relics and Archaeology Institute of Shandong Province, pp. 371–399 (in Japanese).
- Pechenkina E.A., Benfer R.A. Jr., and Zhijun W. (2002) Diet and health changes at the end of the Chinese Neolithic: The Yangshao / Longshan transition in Shaanxi Province. *American Journal of Physical Anthropology*, 117: 15–36.
- Sahara M. (1987) *A New History of Japan, 1: Birth of Japanese*. Shougakukan, Tokyo.
- Saiki K., Wakebe T., and Nagashima S. (2000) Cranial nonmetrical analyses of the Yayoi people in the northwestern Kyushu area. *Anthropological Science*, 108: 27–44.
- Sanui Y. (1960) Anthropological researches on the teeth of the prehistoric Yayoi-ancients excavated from the Doigahama site, Yamaguchi-prefecture. *Jinruigakukenkū*, 7: 861–884 (in Japanese with English summary).
- Stephen K.W., McCall D.R., and Tullis J.I. (1987) Caries prevalence in northern Scotland before, and five years after, water defluoridation. *British Dental Journal*, 163: 324–326.
- Way R.M. (1964) The effect on dental caries of a change from a naturally fluoridated to a fluoride-free communal water. *Journal of Dentistry for Children*, 31: 151–157.
- Yamada H., Nakagawa K., Waniishi H., Sumiyoshi Y., and Nakanishi H. (1970) Anthropological studies on the teeth of the prehistoric Yayoi-ancients excavated from the Hirota site, Tanegashima, Kagoshima-prefecture. *The Journal of the Kyushu Dental Society*, 24: 34–62.
- Zhang Y. (2000) Human skeletal remains excavated from Houli site in Linzi, Shandong Province, China. In: Matsushita T. (ed.), "Search of the Origin of Immigrant Yayoi into the Asian Continent," The Doigahama Site Anthropological Museum / Cultural Relics and Archaeology Institute of Shandong Province, pp. 164–197 (in Chinese).