

Variability in stable isotope ratios in two Late-Final Jomon communities in the Tokai coastal region and its relationship with sex and ritual tooth ablation

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Abstract We analyzed stable carbon and nitrogen isotope ratios in a sample of human and nonhuman mammal bones excavated from the Yoshigo and Inariyama shell mounds of the Late-Final Jomon periods in Aichi Prefecture, Japan, with a view to determining individual dietary differences. To investigate possible reasons for the dietary variations identified, we related isotope ratios to sex and tooth ablation patterns. At both sites, large intra-site variations in $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values were found, compared with other Jomon populations previously studied, suggesting higher than usual levels of dietary variability, and at both sites there was a positive correlation between $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values. The diet of the Jomon people at both these sites had two main protein sources: marine (marine finfish and shellfish) and terrestrial (C_3 plants and terrestrial mammals) protein. The intra-site variability is probably explained by consumption of these resources in different proportions. Analysis of the Yoshigo shell mound data indicated that sex is one of the factors determining dietary difference. It was also found that individual differences in diet in Yoshigo males are greater than in females. This pattern was repeated in the Inariyama shell mound data. Dietary differences were found to be related to ritual tooth ablation characteristics, particularly in males. At Inariyama, type 4I ritual tooth ablation was associated with comparatively greater dependency on terrestrial resources, while type 2C tooth ablation was associated with greater dependency on marine resources. This may indicate that type 4I males engaged predominantly in hunting, and type 2C males in fishing, as a means of food acquisition. These results are possibly the earliest evidence of occupational differentiation in the Jomon people.

Key words: Jomon period, diet, stable isotopes, ritual tooth ablation, prehistoric subsistence

Introduction

The period of Jomon culture in the Japanese Islands lasted from 13000 to 2300 years BP. The Jomon people were hunter-gatherers, relying on marine and/or terrestrial food sources, without agriculture, despite their cultural acquisition of pottery and ground stone tools (Yamanouchi, 1964; Imamura, 1993; Kobayashi et al., 2004). This study is of human remains excavated from the Yoshigo and the Inariyama shell mounds of Aichi Prefecture in the Tokai coastal region of Honshu dating from the later part of the Late Jomon period through to the Final Jomon period (c. 3500–2300 years BP). During this period there were developmental changes in Jomon ritual practices and artifacts (Imamura, 1996), and climatically, as revealed by pollen ana-

lysis (Tsukada, 1986), the period was characterized by a cooling trend.

Many archaeological studies have investigated the daily food consumption of the Jomon people who, as hunter-gatherers, were dependent on seasonal food resources (Akazawa, 1986), and a variety of important food items have been suggested (Kaneko, 1994; Komiya, 1994; Hayashi, 2004). However, these studies based on faunal and floral remains are of limited potential for the reconstruction of diet, in that food items actually ingested disappear from the site and food remains are subject to taphonomic bias due to decomposition in the soil. A further limitation is that although food remains at a given site may indicate the consumption of particular food items by site-dwellers as a whole, they give no indication of individual differences of diet within the population.

Paleodietary reconstruction using carbon and nitrogen isotope analysis of human bone collagen is a recent development offering solutions to this problem (Ambrose and DeNiro, 1986; Sponheimer and Lee-Thorp, 1999; Bocherens and Drucker, 2003; Newsome et al., 2004; Bocherens et al., 2006). The turnover rate of bone collagen *in vivo* is about 10 years (Stenhouse and Baxter, 1979; Price et al., 2002), so

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that stable isotope ratios obtained from human skeletal remains record the proportion of protein in the diet over the 10 years prior to death. Thus, stable isotope analysis has potential for detecting individual differences in the diet of past human populations. If individuals in the same community ingested protein foods in different proportions, there should be intra-site variations in isotopic values. Furthermore, it may be possible to infer the influence of social positioning on diet by relating stable isotope ratios to such obtainable information as sex and social status, inferred from accompanying artifacts (e.g., ornaments) or from ritual dental modifications.

Numerous studies have employed stable carbon and nitrogen isotope analysis of human bones from the Jomon period (Chisholm et al., 1988; Minagawa and Akazawa, 1992; Minagawa, 2001; Yoneda et al., 1996, 2002, 2004). Minagawa (2001), for example, investigated differences in diet between a number of Jomon populations. He reported that the coastal Jomon people in Hokkaido, western Honshu and Kyushu were largely dependent on marine food sources, while inland Jomon people tended to consume food from terrestrial sources. Yoneda et al. (2004), however, emphasized the importance of salmon and trout for inland Jomon people, based on the isotope ratios of these populations.

While these studies focused on diet at the local population level, only a few studies have looked at intra-site individual differences. The possibility of sex-based dietary differences in Jomon people in Hokkaido (Chisholm et al., 1992), and in Nagano in central Japan (Yoneda et al., 1996), has been suggested. Chisholm et al. (1992) suggested that the sex-related differences in isotopic values they observed in Hokkaido resulted from different modes of food acquisition in males and females: males hunted, while females fished and gathered plant foods. The success of these studies suggests the possibility of inferring aspects of social organization in the prehistoric period from similar information.

Ritual tooth ablation, involving the deliberate extraction of frontal teeth, has been documented in prehistoric populations in Northwest Africa (Briggs, 1955), Italy (Robb, 1997), China (Han and Nakahashi, 1996), Thailand (Tayles, 1996), and Japan (Koganei, 1918; Watanabe M., 1966). In ethnographic records, ritual tooth ablation is performed on occasions varying from coming-of-age and marriage ceremonies to mourning for the death of a family member (Harunari, 1979).

It has been shown that, in Japan, the form of ritual tooth ablation changed through the Jomon period and into the Yayoi period (Watanabe M., 1966; Harunari, 1979, 1986). In Hokkaido, Honshu, and Kyushu in the Middle Jomon period (c. 5000–4000 years BP), one or two lateral maxillary incisors were extracted (Watanabe M., 1966; Harunari, 1986). From the Late Jomon to the Final Jomon period (c. 4000–2300 years BP), the removal of two maxillary canines plus two mandibular canines (type 2C) or four mandibular incisors (type 4I) was typically, and most actively, practiced in Honshu and Kyushu (Harunari, 1979). In the Yayoi period (c. 2300–1700 years BP, with an agricultural culture), extraction of the maxillary lateral incisors increased, suggesting a Chinese influence (Han and Nakahashi, 1996). The variety of forms and the frequency of extraction in the Late–Final Jomon period are high compared with that recorded in

the ethnographic data for Taiwan (Watanabe M., 1966). Tooth filing of the upper maxillary incisors is also found in Osaka and Aichi Prefectures during the Final Jomon period, and individuals with such filing are thought to be the leaders of a group (Harunari, 1986). Hasebe (1919) suggested that tooth ablation was a customary component of coming-of-age ceremonies among the Jomon people. This is supported by Watanabe M. (1966), Fujita (1997), and Funahashi (2003) on the grounds of estimated age at the time of tooth ablation.

Knowledge of the social structure of the Jomon people is important for the interpretation of ritual tooth ablation. Harunari (1979) classified ritual tooth ablation into five types, with type 0 (see Figure 1) denominating coming-of-age ablation. The people comprising a single community were also classified into types: type 4I people are local to the settlement, type 2C people are migrants from another settlement through marriage to type 4I people, and type 4I2C and type 2C2I are people who have remarried. It was because type 4I people are frequently buried with personal ornaments, such as hip accessories or shell bracelets, suggesting greater prestige, that Harunari identified them as original members of the community. A cranial nonmetric trait study provided support for this hypothesis (Mouri and Oku, 1998). However, Harunari's hypothesis has been questioned by Funahashi (2003) on the grounds that the tooth ablation took place before marriage and child birth. These suggestions re-

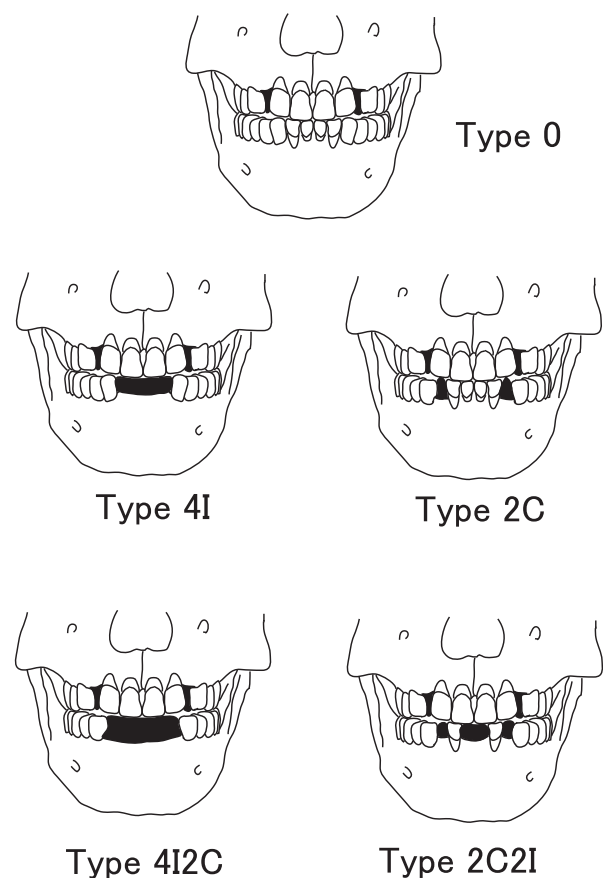


Figure 1. Ritual tooth ablation types, after Harunari (1979).

main hypothetical, and more investigations employing a variety of methods are needed in order to clarify the social function of ritual tooth ablation.

In the present study, we report the first stable isotope data from human and nonhuman mammal skeletal remains at the Yoshigo and Inariyama sites, as described above. Individual dietary differences can be inferred from the isotopic values, and we analyze their relation to sex, ritual tooth ablation characteristics, age at death, tooth filing, personal ornaments, and burial posture. The Yoshigo and Inariyama isotopic values are also compared with those from other Jomon populations, and differences and similarities in the protein food sources indicated by the data are discussed. Possible inferences from the isotopic values as to the social function of ritual tooth ablation are also raised and discussed.

Materials and Methods

Materials

Skeletons from the Yoshigo and Inariyama shell mounds dated to the later part of the Late Jomon period to the Final Jomon period (*c.* 3500–2300 years BP) were subjected to stable isotope analysis. The sites were dated using radiocarbon analysis and pottery-based chronology. Pottery chronology is an accurate method for estimation of the date of sites in the Jomon period because of the multiplicity of systematic studies of the chronology of Jomon pottery (see Imamura, 1996).

The Yoshigo shell mound is located in Tahara Town, Atsumi County, Aichi Prefecture, on the coast of the Bay of Mikawa (Figure 2). This site is dated as extending from the later part of the Late Jomon period (*c.* 3500–3000 years BP, as characterized by the Yoshigo-Kaso pottery type; Hisanaga, 1952) to the Final Jomon period (*c.* 3000–2300 years BP; Gokanmori pottery type; Sugihara and Toyama, 1964). The radiocarbon dates of two shells from the Yoshigo shell mound have been reported: 2870 ± 250 and 2800 ± 600 uncalibrated years BP (Watanabe N., 1966). In 1922, K. Kiyono excavated this site and recovered 304 hu-

man skeletons (Kiyono, 1969), and ritual tooth ablation can be recognized in about 100 individuals. The Inariyama shell mound is located in Kozakai Town, Hoi County, Aichi Prefecture (Figure 2). This site is dated to the middle of the Final Jomon period by the Inariyama pottery type (*c.* 2800–2500 years BP; Sugihara and Toyama, 1964). The radiocarbon dates of remains from the Inariyama shell mound have not been investigated. In 1922, the site was excavated by K. Kiyono and 53 human skeletons were recovered (Kiyono, 1969). These skeletal collections are stored in the Laboratory of Physical Anthropology, Department of Zoology, Graduate School of Science, Kyoto University. Because the Inariyama pottery type is also found in the Yoshigo shell mound (Sugihara and Toyama, 1964), the Inariyama people can be expected to be contemporary with the Yoshigo people.

The present study analyzed bone samples from a sample of 38 human skeletons from the Yoshigo shell mound and from 28 from the Inariyama shell mound, and also from two skeletons of Japanese macaque and two dogs from the Yoshigo shell mound. We made use of the ritual tooth ablation classification into five types (Figure 1) proposed by Harunari (1979), as follows: Type 0 (zero): removal of the two maxillary canines; Type 4I: removal of the four mandibular incisors in addition to the two maxillary canines; Type 2C: removal of the two mandibular canines in addition to the two maxillary canines. An additional two ablation types, which derive from type 4I and type 2C, respectively, were identified in the Yoshigo shell mound. Type 4I2C: removal of the four mandibular incisors and the two mandibular canines in addition to the two maxillary canines; and Type 2C2I: removal of the two mandibular canines and the two central mandibular incisors in addition to the two maxillary canines.

Methods

Bone samples were taken from the ribs of the Yoshigo skeletons and from the ribs or long bone shafts of the Inariyama skeletons. Extraction of bone collagen was carried out in the Laboratory of the Research Institute for Humanity and Nature. Extraction followed the procedure described by Yoneda et al. (2004). About 1 g of bone sample was ultrasonically cleaned in pure water in order to remove any soil. Humic and fulvic acids were removed from the sample by soaking in 0.2 M NaOH overnight and the sample was neutralized in pure water. The sample was lyophilized and crushed by a mill. The sample was then sealed in a cellulose tube and soaked in 1 M HCl overnight to remove hydroxyapatite. The remaining material was separated by centrifugation and lyophilized. The sample was heated at 90°C for 12 h in pure water. Both fractions were freeze-dried, and extracted gelatin samples were used for isotopic analyses.

About 0.5 mg of the extracted collagen was measured for carbon and nitrogen isotopic ratios, using an elemental analyzer (FLASH EATM) connected to an isotope ratio mass spectrometer (DELTA plus XPTM). The natural abundances of ¹³C and ¹⁵N are expressed as per mil (‰) deviation from international standards: $\delta^{13}\text{C}$ or $\delta^{15}\text{N} = (R_{\text{sample}}/R_{\text{standard}} - 1) \times 1000$, where R in $\delta^{13}\text{C}$ or $\delta^{15}\text{N}$ is ¹³C/¹²C or ¹⁵N/¹⁴N, respectively. Pee Dee Belemnite and atmospheric nitrogen

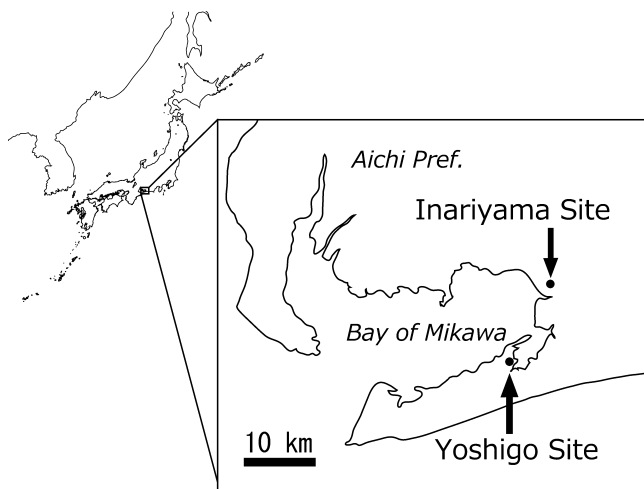


Figure 2. Geographical location of the Yoshigo and Inariyama shell mounds.

were used as the international standards for carbon and nitrogen, respectively. Based on the standard materials measured with unknown samples, the measuring errors for each measurement were less than 0.2‰ for $\delta^{15}\text{N}$ values and 0.2‰ for $\delta^{13}\text{C}$ values.

Statistical analysis

An analysis of covariance (ANCOVA) was used to test for linear regression between $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values and differences in the slopes of the regression lines for the Yoshigo and Inariyama data. Differences between the isotopic values for the Yoshigo and Inariyama subject groups, and between two subgroups defined by sex and by ablation types 4I and 2C, were analyzed using a two-sample *t*-test, and equality of variance in the groups was tested by an *F*-test. Differences between isotopic values in further subgroups based on the four ritual tooth ablation types and burial posture were analyzed by one-way analysis of variance (ANOVA).

Results

The carbon and nitrogen stable isotope ratios of all the subjects' bone samples are listed in Table 1, Table 2, Table 3. Based on the following three criteria, it was confirmed that diagenetic effects did not influence these ratios: first, C/N ratios are within the range 2.9–3.6 (DeNiro, 1985); second, concentrations of carbon and nitrogen in the sample were greater than 13% and 4.8%, respectively (Ambrose, 1990); and third, the recovery rate of collagen was more than 1% (Van Klinken, 1999). All samples met these criteria.

The carbon and nitrogen isotope ratios obtained are plotted in Figure 3. The average $\delta^{13}\text{C}$ value at the Yoshigo site was $-16.3 \pm 1.7\text{‰}$ (mean \pm 1 SD), and the average $\delta^{15}\text{N}$ value was $10.8 \pm 1.9\text{‰}$. The average $\delta^{13}\text{C}$ value at the Inariyama site was $-16.7 \pm 1.4\text{‰}$, and the average $\delta^{15}\text{N}$ value was $9.7 \pm 1.2\text{‰}$. The differences between the average $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values at the Yoshigo and Inariyama sites

Table 1. Characteristics of individual remains from the Yoshigo shell mound and results of the stable isotope analysis

Kiyono collection no.	Sex	Age class	Ritual tooth ablation type	Burial posture ¹	Tooth filing/ ornament ²	Col%	C%	N%	C/N	$\delta^{13}\text{C}$ (‰)	$\delta^{15}\text{N}$ (‰)
263	Female	Young adult	2C	U		3.3	43.0	15.5	3.2	-14.7	12.5
273	Male	Young adult	4I	FD		2.9	43.3	15.5	3.3	-17.9	8.7
280	Male	Young adult	4I	S		1.5	41.8	14.5	3.4	-14.6	12.7
281	Female	Middle adult	4I2C	FD	T	2.5	42.6	14.7	3.4	-19.3	7.7
287	Male	Middle adult	2C2I	S		3.8	42.3	15.2	3.2	-15.1	12.4
295	Female	Middle adult	4I	FD	T/O	2.7	41.7	14.8	3.3	-16.6	10.4
302	Female	Young adult	2C	FD		2.0	42.1	14.6	3.4	-16.6	10.7
305	Male	Young adult	No ablation	FL		4.0	43.0	15.5	3.2	-15.5	11.0
310	Female	Young adult	2C2I	S		3.3	42.0	14.9	3.3	-16.3	10.6
311	Female	Young adult	2C	S		3.2	42.8	15.3	3.3	-16.1	10.6
321	Male	Middle adult	2C2I	FD		4.0	41.8	15.0	3.2	-16.9	9.8
322	Female	Middle adult	4I2C	FD		3.1	43.3	15.2	3.3	-14.8	12.7
335	Female	Young adult	2C2I	FD		4.1	43.8	15.7	3.3	-16.4	11.4
341	Male	Adolescent	2C	FD		2.8	42.5	15.2	3.3	-13.5	14.0
342	Female	Middle adult	4I	FD		1.6	44.1	15.2	3.4	-13.6	14.2
345	Male	Middle adult	4I	FD	T/O	2.4	42.4	14.6	3.4	-15.7	11.5
352	Female	Adolescent	4I	HD	O	2.4	42.2	15.1	3.3	-15.6	11.0
354	Female	Old adult	4I	FD	O	3.5	42.0	14.8	3.3	-15.3	11.9
360 (I)	Male	Middle adult	2C	FD		2.6	44.4	15.7	3.3	-16.5	9.5
363	Male	Middle adult	2C	FD	O	3.7	44.7	15.9	3.3	-15.1	12.5
366	Male	Middle adult	4I	FD	O	3.0	43.1	15.2	3.3	-19.3	6.9
375	Male	Young adult	4I	FD	O	3.0	45.0	16.1	3.3	-14.6	12.7
380	Male	Young adult	4I	FD	T/O	3.8	42.7	15.3	3.2	-15.7	11.0
383	Male	Middle adult	2C	HD	O	1.3	43.3	14.9	3.4	-19.3	7.2
388	Male	Middle adult	4I	FD		2.0	43.2	14.7	3.4	-15.0	12.3
399	Female	Middle adult	4I	FD		3.4	44.5	15.8	3.3	-13.9	12.6
408	Female	Middle adult	4I	FD		2.2	44.2	15.3	3.4	-18.2	8.9
419	Male	Middle adult	2C2I	FD	O	2.0	42.8	14.3	3.5	-15.5	12.0
424	Male	Middle adult	2C	U		1.9	44.0	14.9	3.5	-17.8	10.4
435	Male	Middle adult	2C	D		2.0	42.9	15.0	3.3	-19.6	7.1
436	Male	Young adult	2C2I	S		3.1	42.4	14.7	3.4	-19.4	7.3
460	Female	Young adult	2C2I	FD		2.3	43.4	14.4	3.5	-18.1	9.1
488	Female	Middle adult	4I	S		1.8	43.8	14.8	3.5	-16.1	11.0
500	Female	Middle adult	2C	FD		1.6	43.4	15.1	3.4	-15.5	11.8
501	Male	Middle adult	2C	FD		1.5	45.2	15.3	3.4	-14.9	12.5
523	Female	Young adult	4I2C	FD		1.3	42.9	14.6	3.4	-16.6	10.5
540	Female	Middle adult	4I2C	FD	T	1.7	41.9	13.9	3.5	-17.0	10.4
560	Female	Young adult	2C	FD		2.9	43.8	15.5	3.3	-15.2	11.8

¹ FD: flexed dorsal burial; HD: hand-flexed dorsal burial; LD: legs-flexed dorsal burial; ED: extended dorsal burial; S: sitting burial; FL: flexed lateral burial; D: dorsal burial; V: ventral burial; U: unknown.

² T, tooth filing; O, ornament.

Table 2. Characteristics of individual remains from the Inariyama shell mound and results of the stable isotope analysis

Kiyono collection no.	Sex	Age class	Ritual tooth ablation type	Burial posture ¹	Tooth filing/ ornament ²	Bone element	Col%	C%	N%	C/N	$\delta^{13}\text{C}$ (‰)	$\delta^{15}\text{N}$ (‰)
211	Female	Young adult	4I	FD		Rib	1.9	42.2	14.6	3.4	-17.6	9.4
212	Male	Young adult	4I	U		Rib	2.1	43.7	15.1	3.4	-17.6	9.9
217	Female	Young adult	4I	FD		Rib	2.5	42.7	15.0	3.3	-17.0	9.7
218	Male	Young adult	4I	FD		Rib	3.6	44.4	15.5	3.3	-17.6	10.1
221	Female	Middle adult	4I	FD		Rib	2.2	44.9	15.5	3.4	-17.5	9.5
222	Male	Young adult	4I	FD		Long bone	3.3	42.9	14.9	3.4	-17.9	9.2
223	Male	Young adult	4I	LD		Rib	3.1	45.5	16.1	3.3	-17.6	9.8
224	Female	Middle adult	4I	U		Rib	2.7	44.6	15.6	3.3	-16.2	9.7
225	Female	Child	2C	U		Long bone	2.7	42.1	14.6	3.4	-17.4	8.9
228	Female	Adolescent	4I	HD		Rib	3.0	43.8	15.5	3.3	-18.2	8.5
229	Female	Middle adult	4I	FD		Rib	2.0	42.0	14.9	3.3	-15.4	9.9
230	Female	Young adult	4I	FD		Rib	1.6	44.7	15.1	3.5	-18.5	8.7
231	Male	Young adult	2C	ED		Rib	2.6	44.7	15.6	3.3	-15.0	11.2
232	Male	Young adult	2C	D		Rib	4.8	43.9	15.6	3.3	-15.1	10.4
233	Male	Middle adult	2C	V		Rib	2.6	43.3	15.3	3.3	-14.3	11.3
234	Male	Adolescent	2C	HD		Rib	3.5	43.6	15.4	3.3	-14.7	11.5
235	Male	Middle adult	2C	HD		Long bone	3.4	44.3	15.5	3.3	-14.9	10.7
236	Male	Adolescent	2C	V		Rib	1.8	43.6	14.5	3.5	-15.1	11.6
237	Female	Middle adult	No ablation	HD		Long bone	2.6	43.0	14.7	3.4	-14.6	10.8
238	Male	Young adult	2C	HD		Long bone	2.7	43.5	15.3	3.3	-14.5	10.4
241	Male	Middle adult	2C	V	O	Long bone	1.3	42.9	14.4	3.5	-17.7	7.3
242	Male	Middle adult	4I	V	T	Rib	2.0	43.4	14.8	3.4	-17.4	9.8
244	Male	Middle adult	4I	FD	T	Rib	3.5	43.6	15.2	3.3	-19.1	6.3
245	Female	Middle adult	4I	FD		Rib	3.1	43.5	15.4	3.3	-18.0	9.0
246	Male	Middle adult	4I	FD		Rib	2.4	42.5	15.0	3.3	-17.7	9.6
249	Male	Middle adult	4I	FL		Rib	1.7	42.2	14.7	3.3	-18.0	9.3
251	Male	Young adult	2C	HD		Rib	2.5	42.1	14.9	3.3	-15.1	10.2
253	Female	Adolescent	4I	HD		Rib	2.6	43.2	14.6	3.4	-16.8	9.3

^{1,2} See footnote to Table 1.

Table 3. Results of stable isotope analysis of nonhuman mammal bones from the Yoshigo shell mound

Sample no.	Species	Bone element	Col%	C%	N%	C/N	$\delta^{13}\text{C}$ (‰)	$\delta^{15}\text{N}$ (‰)
399	<i>Macaca fuscata</i>	Mandible	3.8	44.0	15.3	3.3	-20.7	4.9
400	<i>Macaca fuscata</i>	Mandible	3.4	42.8	13.8	3.6	-21.9	2.6
424	<i>Canis familiaris</i>	Rib	2.5	44.1	14.9	3.5	-17.4	9.0
425	<i>Canis familiaris</i>	Rib	3.0	45.4	16.1	3.3	-18.2	6.9

were not significant.

$\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values for both sites were linearly correlated, and the slopes of the regression lines at the two sites differed significantly (ANCOVA for $\delta^{15}\text{N}$ with site as independent variable and $\delta^{13}\text{C}$ as covariate: interaction of $\delta^{13}\text{C}$ and site effect: $F = 22.4$, $P < 0.001$; site effect: $F = 27.5$, $P < 0.001$; $\delta^{13}\text{C}$ effect: $F = 346.7$, $P < 0.001$). The Yoshigo people showed a significantly steeper slope than the Inariyama people.

The isotopic values of potential protein sources (C_3 plants, terrestrial herbivores, marine finfish, and marine shellfish) are also shown in Figure 3. The specific protein sources were selected based on the evidence of organic remains collected from both sites (Yawata, 1952; Nakamura and Deguchi, 1992). C_4 plants do not appear in Figure 3 because there is no archaeological evidence suggesting significant consumption of C_4 plants. Isotopic values of the protein sources are cited from Yoneda et al. (2004). In the process of assimilation, heavy isotopes accumulate in human tissue, and isotopic enrichment of the $\delta^{13}\text{C}$ or $\delta^{15}\text{N}$ values in col-

lagen occurs (DeNiro and Epstein, 1981; Ambrose and DeNiro, 1986). Therefore, 4.5‰ for the $\delta^{13}\text{C}$ values and 3.4‰ for the $\delta^{15}\text{N}$ values (Ambrose, 1993) were added to the isotopic values of the protein sources. The isotopic values of bone collagen at both sites were distributed within the range of the isotopic values of the selected protein sources.

The $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values found in the bones of the two dogs were very similar to those in the human bones, while the $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values in the bones of the two macaques were distributed within the range of isotopic values of C_3 plants. Because dogs are omnivorous and macaques are herbivorous, these results indicate that the isotope measurements and the isotopic values of the protein sources examined were valid.

The comparison of stable isotope ratios in the subgroups based on age at death, presence of tooth filing, and personal ornaments at the two sites produced no significant differences. However, an interesting difference was found in the comparison on the basis of sex. While there were no significant differences in average $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values between the

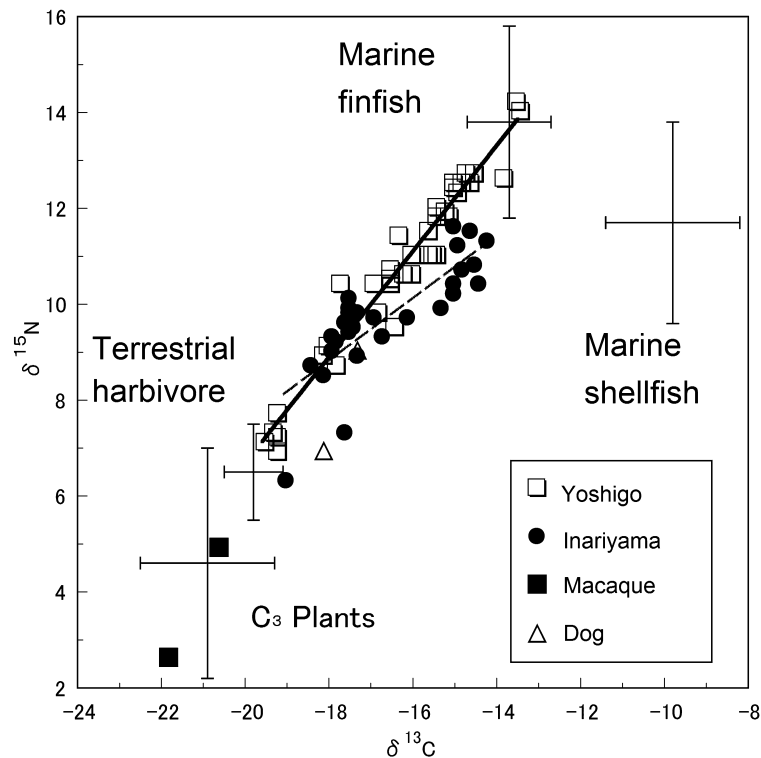


Figure 3. Regression lines of isotopic values from stable carbon and nitrogen isotope analysis of human bones recovered from Yoshigo (unbroken line) and Inariyama (dotted line) and nonhuman mammal bones recovered from Yoshigo. Data of estimated protein sources (Marine finfish, Marine shellfish, Terrestrial herbivore, and C_3 plants) from Yoneda et al. (2004): means \pm 1 S.D.

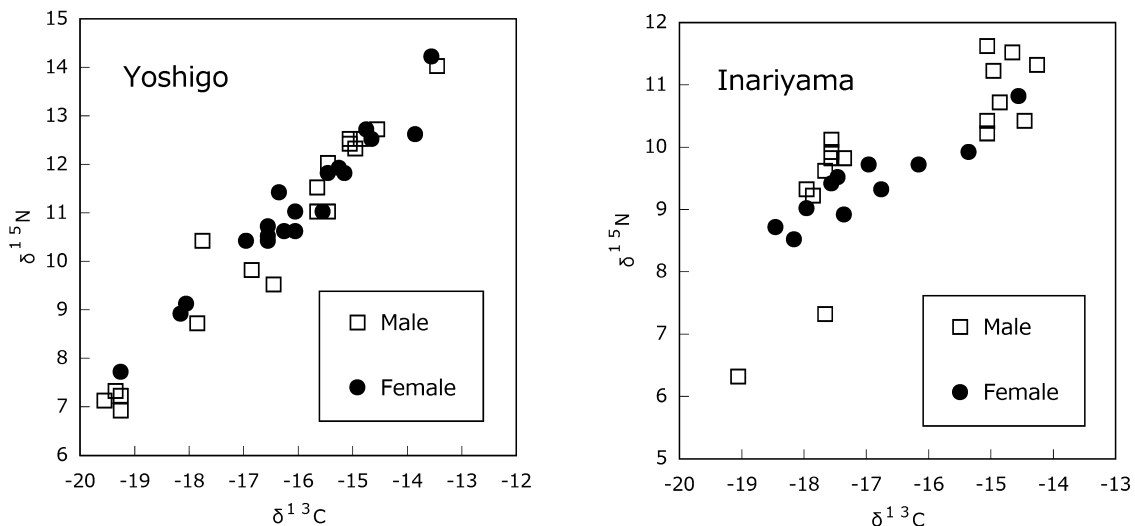


Figure 4. Stable carbon and nitrogen isotope ratios of the Yoshigo and the Inariyama samples, categorized by sex.

sexes at either site, the SDs of the $\delta^{15}N$ values were significantly different for males and females (F -test, $P < 0.05$; Figure 4). The SDs of the $\delta^{15}N$ values of males were higher by 0.7‰ than those of females at both sites.

At the Inariyama site, type of ritual tooth ablation was differentially associated with isotope ratio (Figure 5). Individuals with type 2C tooth ablation had significantly higher $\delta^{13}C$

and $\delta^{15}N$ values than individuals with type 4I ablation (t -test, $P < 0.01$ for $\delta^{13}C$; $P < 0.05$, for $\delta^{15}N$), and a similar difference occurred in relation to burial posture. Isotopic ratios of $\delta^{13}C$ and $\delta^{15}N$ values were significantly higher for extended dorsal burial and ventral burial than for flexed dorsal burial (ANOVA, $P < 0.05$). These associations were not identified in the Yoshigo sample.

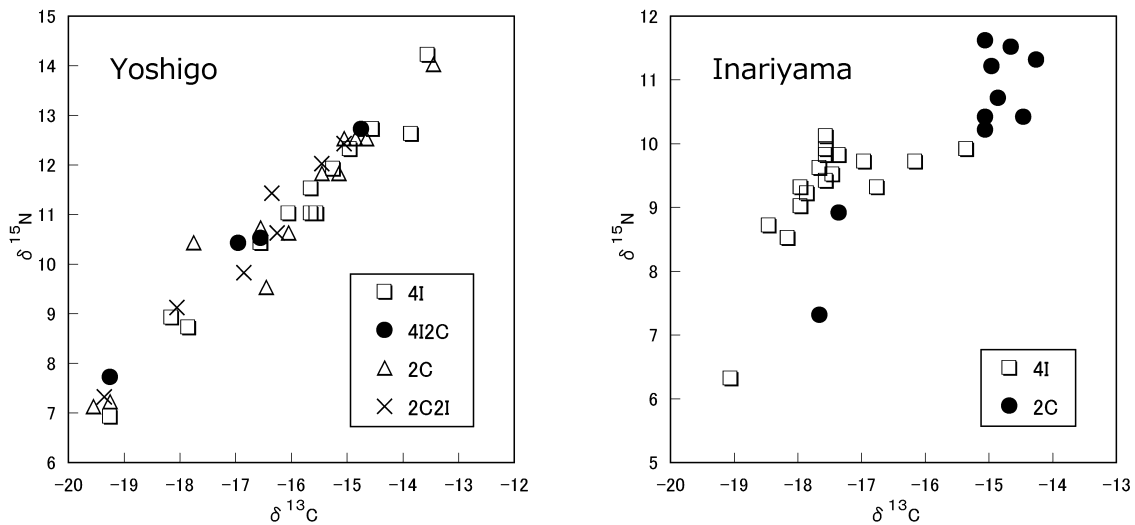


Figure 5. Stable carbon and nitrogen isotope ratios of the Yoshigo and Inariyama samples, categorized by ritual tooth ablation type.

Discussion

Comparison with other sites

The average $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values from the Yoshigo and Inariyama sites are very similar to those of other coastal Jomon populations in Honshu and Kyushu, but lower than those from the Kitakogane and Takasago sites of Hokkaido Jomon (Minagawa, 2001). It is considered that high isotopic ratios, as found in the Hokkaido Jomon populations, reflect a diet more heavily dependent on marine fauna than on land mammals (Minagawa, 2001). Inland Jomon populations such as the Boji (Yoneda et al., 2004) and the Tochibara (Yoneda et al., 2002) have lower isotopic ratios again, compared with the Honshu and Kyushu coastal Jomon populations. This trend is explicable as resulting from a relatively low consumption of marine food resources at inland sites. There are no features peculiar to the animal remains found at Yoshigo and Inariyama, compared to other Honshu and Kyushu coastal Jomon sites (Yawata, 1952; Nakamura and Deguchi, 1992), so it is not unexpected that Yoshigo and Inariyama populations should have isotopic ratios similar to those of other coastal Jomon communities in Honshu and Kyushu.

Individual variability

An interesting finding is the greater degree of dietary variability in the Yoshigo and Inariyama samples compared with other Jomon populations. The SDs of both the $\delta^{13}\text{C}$ and the $\delta^{15}\text{N}$ values at both sites were greater than 1‰. These values are surprisingly high, as SDs for Jomon sites are usually less than 1‰, with only a few exceptions greater than 1‰ (Minagawa, 2001). The high variability observed at these sites presumably reflects atypical individual differences in the daily protein consumption sources. Nevertheless the $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values correlated positively at both sites (Figure 3). This correlation suggests that the Jomon people at these sites mainly consumed two types of food as their main protein source, but with individual differences in the proportions

consumed, these being marine resources (marine finfish and shellfish) vs. terrestrial resources (C_3 plants and terrestrial mammals). Positive linear correlations between $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values are also reported from other Jomon populations (Minagawa, 2001), from southern Californian Native Americans (Walker and DeNiro, 1986), and from coastal Mesolithic people in Europe (Richards and Hedges, 1999). This correlation is probably characteristic of populations that have access to both marine and terrestrial food resources.

The slopes of the regression lines of $\delta^{13}\text{C}$ on $\delta^{15}\text{N}$ were significantly different in the Yoshigo and Inariyama data, being steeper in the former (Figure 3). The Yoshigo people might in general have consumed proportionally more marine finfish, which has higher $\delta^{15}\text{N}$ values, than marine shellfish, while the Inariyama people ate more marine shellfish than finfish. This explanation is in keeping with the archaeological evidence that only a few fragments of marine finfish were recovered from the Inariyama shell mound (Nakamura and Deguchi, 1992), and many kinds of marine finfish were found in the Yoshigo shell mound (Toizumi and Yamasaki, 2007). However, a quantitative comparison of marine finfish and shellfish remains at the Yoshigo and the Inariyama sites is needed to substantiate this explanation.

Furthermore a study of carious tooth and enamel hypoplasia in these two samples revealed a lower frequency of carious tooth and a higher frequency of enamel hypoplasia in the Inariyama people than in the Yoshigo people (Temple, 2007). This suggests that the Inariyama people suffered greater stress from seasonal resource depletion, while the Yoshigo people compensated with consumption of plant foods such as starchy roots, i.e. that environmental food availability affected their diets differentially.

We have interpreted the variability of isotopic data as reflecting individual variability of diet within the sites, but this variability could in fact reflect changes in diet over time resulting from environmental change during the Late-Final Jomon period. Pottery based chronology indicates that remains were accumulated for at most 1200 years at the

Yoshigo site and for 300 years at the Inariyama site. The quality and quantity of natural food resources may have changed because of environmental cooling during the Late–Final Jomon period (Tsukada, 1986). If diets changed in association with environmental change, then the variations in isotopic values we describe would not reflect individual dietary differences throughout the period, but rather changes in diet during the Late–Final Jomon period. Radiocarbon dating of the Yoshigo and Inariyama skeletons is needed in order to evaluate the time depth of these samples. Furthermore, environmental change as reflected in animal skeletal remains over the period should be investigated.

Relationship between isotopic values and sex

An important finding of this study is the effect of sex on variability of individual diets. Although there was no difference by sex in average $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values, the SD of $\delta^{15}\text{N}$ values in males was significantly greater than in females at both sites (Figure 4). This indicates that male diets differed more widely between individuals than did female diets.

It is largely accepted in anthropology that a sexual division of labor and food sharing between males and females is fundamental to hunter-gatherer subsistence economies (Ember, 1975; Bird, 1999), with the result that dietary differences by sex are not expected. Contrary to this expectation, variability in individual diets differed by sex in our Yoshigo and Inariyama samples. This may be because males were predominantly engaged in hunting or in fishing away from the village, and these males consumed large quantities of the foods acquired by their hunting or fishing while away. If so, then the larger SD of $\delta^{15}\text{N}$ values in males than in females reflects not only the sexual division of labor, but also occupational differentiation in males in the Yoshigo and Inariyama populations.

Reports from other Jomon sites have also suggested differences between the sexes in dietary intake. At the Kitamura site in Nagano, males had a higher average $\delta^{13}\text{C}$ value than females (Yoneda et al., 1996), while in Hokkaido, females had a higher average $\delta^{13}\text{C}$ value than males (Chisholm et al., 1992). The Hokkaido Jomon finding was explained as resulting from the sexual division of labor, whereby hunting was exclusively performed by males and fishing and plant gathering by females (Chisholm et al., 1992). It is not unreasonable that different environmental settings and differences in food resources should promote differences in the division of labor both between and within the sexes, and in turn result in differences in dietary profile between and within the sexes.

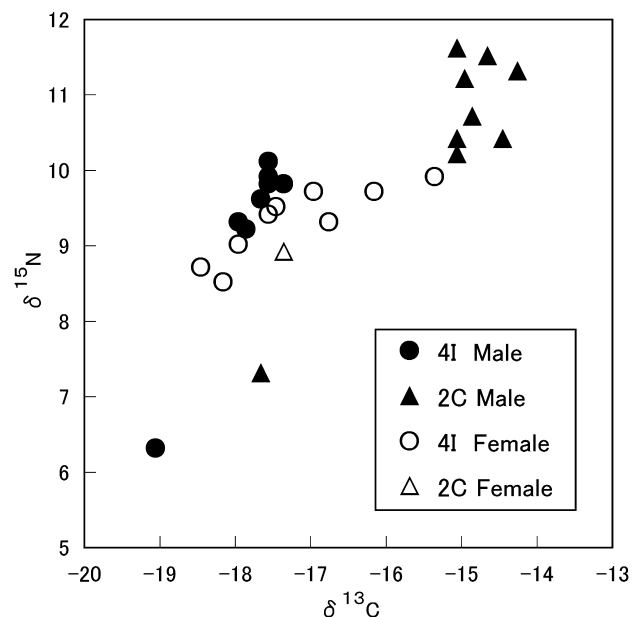
Relationships between isotopic values and ritual tooth ablation

The most important finding of the present study is the relationship between ritual tooth ablation type and $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values in the Inariyama population. Average $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values differed significantly between individuals with type 4I and type 2C ablation (Figure 5). These differences suggest that type 4I people were hunters and/or gatherers and more dependent on terrestrial resources, and type 2C people were fishers and more dependent on marine resources. The isotopic values of type 4I males are also clearly dif-

ferent from those of type 2C males (Figure 6). Unfortunately the number of type 2C females in our sample was too small for a reliable comparison with type 4I females. In hunter-gatherer subsistence societies, males usually hunt larger game while females gather plants and catch smaller animals (Bird, 1999). In males, at least, a differentiation in ritual tooth ablation associated with hunting vs. fishing as a male occupation might have occurred. Ethnographic observations of the Ainu record the presence of hunting-oriented and fishing-oriented families (or lineages) in the same population (Watanabe H., 1972, 1983, 1990). A similar occupational differentiation based on family and distinguished by ritual tooth ablation type might also have occurred in the Inariyama people.

Mizoguchi (2002) hypothesized that in Jomon societies the seasonal economies were associated with different procurement groups, membership of which endowed social identity. The present study supports this hypothesis with its evidence that the social identity endowed by ritual tooth ablation type relates to subsistence procurement group.

Occupational differentiation in Ainu society was tied to religious differentiation and social status (Watanabe H., 1972). Hunting-oriented families were more prestigious than fishing-oriented families, in that hunting-oriented families owned the ritual of the brown-bear deity, which was the Ainu's highest-ranking deity. Harunari (1979, 1986) proposed that type 4I people were more prestigious than 2C people on the basis of their personal ornaments, and the results of the present study suggest that type 4I people were the hunters among the Inariyama people. The Inariyama people and the Ainu people may have shared a common feature, as postulated by Watanabe H. (1990), that hunting-oriented families are more prestigious than fishing-oriented families.



Individuals 241 and 244 from the Inariyama site had unusually low $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values compared with other individuals of the same tooth ablation type from the same site (Figure 6). Ornaments were found with the remains of individual 241, and individual 244 showed filing of his anterior dentition. Both may be signs of a special social status, which may have resulted in dietary differences compared with ordinary members of the society.

A relationship between ritual tooth ablation type and diet did not appear in the Yoshigo data. A possible explanation is that ritual tooth ablation was primarily indicative of kinship, and not of subsistence procurement group, as postulated by Tanaka (1998) and Funahashi (2003). Studies of nonmetric cranial variants of the Yoshigo and Inariyama people (Mouri and Oku, 1998) and nonmetric tooth variants of the Inariyama people (Hashimoto and Baba, 1998) indicate the possibility that type 4I people are hereditarily different from type 2C people, in which case ritual tooth ablation type was a signifier of social identity in terms of kinship group. In Ainu society, there was lineage-based division of labor and both intrafamily and inter-lineage cooperation as regards access to food resources (Watanabe H., 1972). Cooperation was usually between families in the same settlement group.

We suggest that among the Yoshigo people, families that shared the same type of ritual tooth ablation would cooperate with other families regardless of type of tooth ablation; whereas among the Inariyama people, type 4I families shared food resources only with other type 4I families, and type 2C families cooperated only with other type 2C families. Thus, our findings of differing isotopic values may not, in fact, indicate that subsistence procurement group determined ritual tooth ablation and social identity among the Inariyama people, but not among the Yoshigo people: the determining factor may have been lineage in both groups.

It has been proposed that ritual tooth ablation in Jomon culture was a coming-of-age ceremony (Hasebe, 1919; Watanabe M., 1966; Fujita, 1997; Funahashi, 2003), based on observations that it is almost always present in adults and never in children. The typology of ritual tooth ablation indicates additional meanings. The findings of the present study, while consistent with the coming-of-age theory, suggest that ritual tooth ablation typology identified a lineage-based subsistence procurement group.

Harunari (1979) hypothesized that type 4I people were local to the Yoshigo and Inariyama settlements, and type 2C people were migrants to the settlements through marriage with type 4I people, a suggestion radically at odds with our own conclusions. Although studies of nonmetric cranial variants (Mouri and Oku, 1998) and nonmetric tooth variants (Hashimoto and Baba, 1998) suggest that type 4I people are hereditarily different from type 2C people, an analysis of dental and cranial measurements in the Yoshigo people indicates similar parameters and mobility patterns in type 4I and type 2C individuals (Temple and Sciulli, in press). Funahashi (2003) found that extraction of maxillary and mandibular canines and mandibular incisors occurred before marriage and childbirth. These studies and our conclusions refute the possibility that ritual tooth ablation signifies marriage patterns.

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References

- Akazawa T. (1986) Regional variation in procurement systems of Jomon hunter-gatherers. In: Akazawa T. and Aikens C.M. (eds.), *Prehistoric Hunter-Gatherers in Japan: New Research Methods*. The University Museum, The University of Tokyo, Bulletin, Tokyo, pp. 73–89.
- Ambrose S.H. (1990) Preparation and characterization of bone and tooth collagen for isotopic analysis. *Journal of Archaeological Science*, 17: 431–451.
- Ambrose S.H. (1993) Isotopic analysis of paleodiet: methodological and interpretive considerations. In: Sandford M.K. (eds.), *Biogeochemical Approaches to Paleodietary Analysis*. Gordon and Breach, Langhorne, pp. 59–130.
- Ambrose S.H. and DeNiro M.J. (1986) Reconstruction of African human diet using bone collagen carbon and nitrogen isotope ratios. *Nature*, 319: 321–324.
- Bird R. (1999) Cooperation and conflict: the behavioral ecology of the sexual division of labor. *Evolutionary Anthropology*, 8: 65–75.
- Bocherens H. and Drucker D. (2003) Trophic level isotopic enrichment of carbon and nitrogen in bone collagen: case studies from recent and ancient terrestrial ecosystems. *International Journal of Osteoarchaeology*, 13: 46–53.
- Bocherens H., Mashkour M., Drucker D.G., Moussa I. and Billiou D. (2006) Stable isotope evidence for palaeodiets in southern Turkmenistan during Historical period and Iron Age. *Journal of Archaeological Science*, 33: 253–264.
- Briggs L.C. (1955) The stone age races of Northwest Africa. *American School of Research Peabody Museum, Harvard University, Bulletin*, 18: 1–98.
- Chisholm B., Koike H., and Nakai N. (1988) A study of ancient diets revealed by stable carbon isotope ratio. *Archaeology and Natural Science*, 20: 7–16 (in Japanese).
- Chisholm B., Koike H., and Nakai N. (1992) Carbon isotopic determination of paleodiet in Japan: marine versus terrestrial sources. In: Aikens C.M. and Rhee S.N. (eds.), *Pacific North-east Asia in Prehistory: Research into the Emergence of Hunter-fisher-gatherers, Farmers and Socio-political Elites*. University of Washington Press, Washington, pp. 69–73.
- DeNiro M.J. (1985) Postmortem preservation and alteration of in vivo bone collagen isotope ratios in relation to palaeodietary reconstruction. *Nature*, 317: 806–809.
- DeNiro M.J. and Epstein S. (1981) Influence of diet on the distribution of nitrogen isotopes in animals. *Geochimica et Cosmochimica Acta*, 45: 341–351.
- Ember C. (1975) Residential variation among hunter-gatherers. *Behavior Science Research*, 10: 199–227.
- Fujita H. (1997) Ritual tooth ablation of Jomon skeletons excavated from Atsumi peninsula, Aichi [Aichiken Atsumihanto shutsudo no Jomon jidai jinkotsu no basshi]. *Kodai*, 104: 42–

- 64 (in Japanese).
- Funahashi K. (2003) A study of the timing of ritual tooth ablation and its meaning as rites of passage in Final Jomon period [Jomon jidai no basshi shikou nenrei to gireiteki imi]. *Quarterly of Archaeological Studies [Kokogaku Kenkyu]*, 50: 56–76 (in Japanese).
- Han K. and Nakahashi T. (1996) A comparative study of ritual tooth ablation in Ancient China and Japan. *Anthropological Science*, 104: 43–64.
- Harunari H. (1979) Postmarital modes of residence of the Final Jomon period [Jomon banki no kongo kyoju kitei]. *Okayama Daigaku Hobungakubu Gakujutsu Kiyō*, 40: 25–63 (in Japanese).
- Harunari H. (1986) Rules of residence in the Jomon period, based on the analysis of tooth extraction. In: Pearson R.J., Barnes G.L., and Hutterer K.L. (eds.), *Windows on the Japanese Past: Studies in Archaeology and Prehistory*. Center for Japanese Studies, University of Michigan, pp. 293–310.
- Hasebe K. (1919) On ritual tooth ablation in stone age people [Sekki jidai jin no basshi ni tsuite]. *Journal of Anthropological Society of Nippon*, 34: 385–392 (in Japanese).
- Hashimoto Y. and Baba H. (1998) Identification of groups of burials from dental nonmetric traits from Inariyama [Ha no hikeisokuteki tokucho ni motodoku kojinkotsu maiso shogun no kakunin]. In: Japanese Archaeological Association (eds.), *Abstracts of 64th meeting of Japanese Archaeological Association [Nihon kokogaku kyokai dai 64 kai kenkyu happyo yosi]*. Japanese Archaeological Association, Tokyo, pp. 58–60 (in Japanese).
- Hayashi K. (2004) *History of the Jomon Period 1 [Jomon jidaishi 1]*. Yuzankaku, Tokyo (in Japanese).
- Hisanaga H. (1952) West half of first trench and fourth trench. In: Saito T. (ed.), *The Shell Mounds of Yoshigo*. Yoshikawa Kobunkan, Tokyo, pp. 51–90 (in Japanese).
- Imamura K. (1993) Characteristics of subsistence of hunter-gatherers [Shuryo saishu keizai no nihonteki seikaku]. In: Tsuboi K. and Hirano K. (eds.), *Reviews of Ancient History [Kodaishi soron]*. Kadokawa-shoten, Tokyo, pp. 95–116 (in Japanese).
- Imamura K. (1996) *Prehistoric Japan: New Perspectives on Insular East Asia*. University of Hawaii Press, Honolulu.
- Kaneko H. (1994) The prey and technology of hunting [Shuryo taisho to gijutsu]. In: Kato S., Kobayashi T., and Fujimoto T. (eds.), *Studies of Jomon Culture 2: Subsistence [Jomon bunka no kenkyu 2: Seigyō]*. Yuzankaku, Tokyo, pp. 78–102 (in Japanese).
- Kiyono K. (1969) *Studies of Japanese Shell Mounds [Nihon kaizuka no kenkyu]*. Iwanami-shoten, Tokyo (in Japanese).
- Kobayashi T., Kaner S., and Nakamura O. (2004) *Jomon Reflections: Forager Life and Culture in the Prehistoric Japanese Archipelago*. Oxbow Books, Oxford.
- Koganei, Y. (1918) On the ritual ablation of upper canine in the stone age people of Japan. *Journal of Anthropological Society of Nippon*, 38: 229–238 (in Japanese).
- Komiya T. (1994) Fish [Gyo-rui]. In: Kato S., Kobayashi T., and Fujimoto T. (eds.), *Studies of Jomon Culture 2: Subsistence [Jomon bunka no kenkyu 2: Seigyō]*. Yuzankaku, Tokyo, pp. 192–210 (in Japanese).
- Minagawa M. (2001) Dietary pattern of prehistoric Japanese populations inferred from stable carbon and nitrogen isotopes in bone protein. *Bulletin of the National Museum of Japanese History*, 86: 333–357 (in Japanese).
- Minagawa M. and Akazawa T. (1992) Dietary patterns of Japanese Jomon hunter-gatherers: stable nitrogen and carbon isotope analyses of human bones. In: Aikens C.M. and Rhee S.N. (eds.), *Pacific Northeast Asia in Prehistory: Research into the Emergence of Hunter-fisher-gatherers, Farmers and Socio-political Elites*. University of Washington Press, Washington, pp. 59–68.
- Mizoguchi K. (2002) *An Archaeological History of Japan, 30000 B.C. to A.D. 700*. University of Pennsylvania Press, Philadelphia.
- Mouri T. and Oku C. (1998) A test of Harunari's hypothesis by nonmetric cranial variants. *Quarterly of Archaeological Studies [Kokogaku Kenkyu]*, 45: 91–101 (in Japanese).
- Nakamura F. and Deguchi T. (1992) Natural remains [Shizen ibutsu]. In: School board of Kozakai-town (eds.), *Hirai-inariyama. Seiryō-shobo*, pp. 57–64 (in Japanese).
- Newsome S.D., Phillips D.L., Culleton B.J., Guilderson T.P., and Koch P.L. (2004) Dietary reconstruction of an early to middle Holocene human population from the central California coast: insights from advanced stable isotope mixing models. *Journal of Archaeological Science*, 31: 1101–1115.
- Price T.D., Burton J.H., and Bentley R.A. (2002) The characterization of biologically available strontium isotope ratios for the study of prehistoric migration. *Archaeometry*, 44: 117–135.
- Richards M.P. and Hedges R.E.M. (1999) Stable isotope evidence for similarities in the types of marine foods used by late Mesolithic humans at sites along the Atlantic coast of Europe. *Journal of Archaeological Science*, 26: 717–722.
- Robb J. (1997) Intentional tooth removal in Neolithic Italian women. *Antiquity*, 71: 659–669.
- Sponheimer M. and Lee-Thorp J.A. (1999) Isotopic evidence for the diet of an early hominid, *Australopithecus africanus*. *Science*, 283: 368–370.
- Stenhouse M.J. and Baxter M.S. (1979) The uptake of bomb ¹⁴C in humans. In: Berkeley R. and Suess H. (eds.), *Radiocarbon Dating*. University of California Press, Los Angeles and Berkeley, pp. 324–341.
- Sugihara S. and Toyama K. (1964) Sites along the Toyo-river in the Final Jomon period [Toyogawa karyuiki niokeru Jomon jidai banki no iseki]. *Kokogaku-shukan*, 2: 37–101 (in Japanese).
- Tanaka Y. (1998) A reconsideration of the concept of descent in Japanese archaeology, *Japanese Archaeology [Nihon kokogaku]*, 5: 1–18 (in Japanese).
- Tayles N. (1996) Tooth ablation in prehistoric Southeast Asia. *International Journal of Osteoarchaeology*, 6: 333–345.
- Temple D.H. (2007) Dietary variation and stress among prehistoric Jomon foragers from Japan. *American Journal of Physical Anthropology*, 133: 1035–1046.
- Temple D.H. and Sciulli P.W. (in press) Intracemetery biological variation in Jomon period Japan: group migration patterns and identity determinants. *Journal of Comparative Human Biology*.
- Toizumi G. and Yamasaki K. (2007) Animal remains. In: School Board of Tahara city (eds.), *The Yoshigo Shell Mound (I) [Kuni shitei iseki Yoshigo kaizuka (I)]*, School Board of Tahara City, Aichi, pp. 27–50 (in Japanese).
- Tsukada M. (1986) Vegetation in prehistoric Japan: the last 20000 years. In: Pearson R.J., Barnes G.L., and Hutterer K.L. (eds.), *Windows on the Japanese Past: Studies in Archaeology and Prehistory*. Center for Japanese Studies, University of Michigan, pp. 11–56.
- Van Klinken G.J. (1999) Bone collagen quality indicators for palaeodietary and radiocarbon measurements. *Journal of Archaeological Science*, 26: 687–695.
- Walker P.L. and DeNiro M.J. (1986) Stable nitrogen and carbon isotope ratios in bone collagen as indices of prehistoric dietary dependence on marine and terrestrial resources in southern California. *American Journal of Physical Anthropology*, 71: 51–61.
- Watanabe H. (1972) *The Ainu Ecosystem*. University of Tokyo Press, Tokyo.
- Watanabe H. (1983) Occupational differentiation and social stratification: the case of northern pacific maritime food-gatherers. *Current Anthropology*, 14: 217–219.
- Watanabe H. (1990) *Jomon Stratified Society. Rokuichi-shobo*, Tokyo (in Japanese).
- Watanabe M. (1966) A study of ritual tooth ablation in the Jomon

- culture. *Kodaigaku*, 12: 173–201 (in Japanese).
- Watanabe N. (1966) Radiocarbon dates of the Jomon and Yayoi periods in Japan [Jomon oyobi Yayoi jidai no C¹⁴ nendai]. *The Quaternary Research [Daiyonki kenkyu]*, 5: 157–168 (in Japanese).
- Yamanouchi S. (1964) Introduction of Japanese prehistory [Nihon senshibunka gaisetsu]. In: *Japanese Prehistoric Art 1: Jomon Culture [Nihon genshibijutsu 1: Jomon-shiki doki]*. Kodansha, Tokyo, pp. 135–158 (in Japanese).
- Yawata I. (1952) Residues of foods [Shokuryo zansa]. In: Saito T. (eds.), *The Shell Mounds of Yoshigo*. Yoshikawa Kobunkan, Tokyo, pp 151–156 (in Japanese).
- Yoneda M., Yoshida K., Yoshinaga J., Morita M., and Akazawa T. (1996) Reconstruction of paleodiet in Nagano prefecture based on the carbon and nitrogen isotope analysis and the trace elemental analysis. *The Quaternary Research [Daiyonki kenkyu]*, 35: 293–303 (in Japanese).
- Yoneda M., Hirota M., Uchida M., Tanaka A., Shibata Y., Morita M. and Akazawa T. (2002) Radiocarbon and stable isotope analyses on the earliest Jomon skeletons from the Tochibara rockshelter, Nagano, Japan. *Radiocarbon*, 44: 549–557.
- Yoneda M., Suzuki R., Shibata Y., Morita M., Sukegawa T., Shigehara N., and Akazawa T. (2004) Isotopic evidence of inland-water fishing by a Jomon population excavated from the Boji site, Nagano, Japan. *Journal of Archaeological Science*, 31: 97–107.