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Mandibular morphological variation in the Jomon people of Japan

Yousuke Kaifu[1,2]

[1] Department of Anthropology, National Museum of Nature and Science,
3–23–1 Hyakunincho, Shinjuku-ku, Tokyo 169–0073, Japan
E-mail: kaifu@kahaku.go.jp
[2] Department of Biological Science, The University of Tokyo,
6–3–1 Hongo, Bunkyo-ku, Tokyo 113–0033, Japan

Abstract Jomon people were prehistoric hunter-gather-fishers in Japan. In order to examine chronological and regional variation in their mandibular morphology, a large metric data set were constructed based on the Jomon mandibles sampled from various regions (Hokkaido, eastern Honshu, western Honshu, and Kyushu) and periods (from the Initial through Final Jomon periods). The results of comparative analyses confirmed previous observation that the Jomon mandibles from the Initial period tend to be small, particularly in the corpus and ramus heights as well as in the thickness of the lateral corpus. The presence of marked regional variation is evident in the Early Jomon period, with the specimens from the Sanyo region exhibiting comparatively gracile morphology. There appear to be north and south clines in the overall mandibular size and width of the ramus during and after the Early Jomon period (north>south), which are consistent with the observation from the broader Asian regions. Implications of these trends are discussed.
Key words : Mandible, Regional variation, Chronological variation

Introduction

Jomon people on the Japanese archipelago were prehistoric hunter-gatherer-fishers. Documentation of chronological and regional variation in their physical characteristics is important to infer population structure, origins, and lifeway of the Jomon people. Six chronological cultural phases (Incipient, Initial, Early, Middle, Late, and Final) are defined within the Jomon period that lasted from c. 16,500 to cal 2,500 BP. Marked differences in craniofacial morphology between the Initial and Middle/Late/Final phases have been noted since the mid 20th century (Suzuki, 1950; Ogata, 1967, 1981; Ikeda, 1985, 1988). Furthermore, some limited but statistically significant regional or inter-site variation has also been detected in studies of Jomon craniofacial, dental, and postcranial morphology (Ogata, 1981; Suzuki, 1981; Yamaguchi, 1982; Dodo, 1982; Kondo, 1994; Takigawa, 2006; Matsumura, 2007).

As for the mandible, after the pilot studies by Ogata (1967, 1981), Kaifu (1995a) and Maeda (2002) conducted relatively large-scaled studies on morphological variation in the Jomon people. However, these later studies focused only on the regional factor of variation and did not consider chronological variation. Recently, Kaifu et al. (in press) briefly revisited this issue when they examined morphology of the late Pleistocene mandibles from the Minatogawa Fissure site, Okinawa. The present paper reports descriptive statistics of various Jomon regional and chronological samples used in Kaifu et al. (in press), and summarizes the morphological variation detected from this new metric data set.

Materials and Methods

Materials

A total of 199 mandibles from various phases of the Jomon period (the Initial [11,200–7,300 cal BP], Early [7,300–5,500 cal BP], Middle [5,500–4,500 cal BP], Late [4,500–3,200 cal BP], Final [3,200–2,500 cal BP]) were measured by the author (Table 1). These were sampled from both southern and northern regions of the Japanese archipelago (Kyushu, western Honshu, eastern Honshu, and Hokkaido) (Kaifu et al., in press). Most of them are from shell mounds formed in the coastal regions, but some are from inland rock shelters (Tochibara and Yosekura). Non-pathological adult mandibles of both sexes were selected from the collections of National Museum of Nature and Science, the University of Tokyo, Kyoto University, and Sapporo Medical College. The adult status was assessed by the complete eruption of third molars or state of occlusal wear in cases of congenital absence of third molars. Sex determination was based primarily on associated pelvises and crania. After examining male and female morphological patterns using specimens sexed in that manner, a limited number of isolated mandibles were assessed for sex based on the mandibular morphology (primarily by size). Those specimens with extensive antemortem tooth loss (more than two teeth in most cases) and obvious sign of resorption in the alveolar bone, ramus, and other parts of the mandible were excluded.

No well-preserved Jomon skeletal remains are known from the Incipient phase (15,000–11,200 BP), but some are known from the Initial phase. We observed and measured a small number of these (the specimens from the Tochibara and Hi-

Table 1. Materials used in this study.[a]

Region	Phase												Total	
	Initial	M	F	Early	M	F	Middle	M	F	Late/Final	M	F	M	F
Hokkaido				Kitakogane	5	3				Takasago	1	5		
				Higashikushiro	1					Funadomari	1			
				Kotan-Onsen		2				Shimamaki		1		
				Irie		1				Motowanishi	4	2		
(subtotal)					(6	6)				M6, F8	(6	8)	12	14
East Honshu	Tochibara	2	2	Koyaba	2		Chidorikubo	2		Ubayama	18	8		
	Hirasaka	1								Kasori	10	1		
	Yukura[b]		1							Yoyama	2	2		
	Myo-onji[c]	1								Horinouchi	2	1		
	Meotoiwa[d]	1								Sanganji	8	4		
	Shironodai[e]	1	1							Ebishima	1	4		
	Jyao-do[f]		1							others	4	7		
(subtotal)		(6	5)		(2	0)		(0	2)		(45	27)	53	34
West Honshu	Isoyamashiro[g]	2		Hikozaki	8	4	Ota	20	8	Tsugumo	10	3		
				Hashima	5	2	Funamoto	1	4	Kou	4	3		
										Yosekura	2	1		
(subtotal)		(2	0)		(13	6)		(21	12)		(16	7)	52	25
Kyushu	Iwashita[h]	2	2	Todoroki	2	5	Adaka	3	1	Futakawa	3	3		
(subtotal)		(2	2)		(2	5)		(3	1)		(3	3)	10	11
Ogata (1981)[i]	Oyaji etc.	7	8										7	8
Total		17	15		23	17		24	15		70	45	134	92

[a] Site name and the number of male and female specimens.

[b] Morimoto and Takahashi (1986). [c] Baba et al. (1998). [d] Yamaguchi (1992). [e] Shigehara (1994). [f] Jidoi (1997). [g] Ikeda and Kitagawa (1986). [h] Naito (1968).

[i] Ogata's pooled sample of specimens from Kawaharada (Kyuhu), Kamikuroiwa (Shikoku), Kan-nondo (West Honshu), Oyaji, and Muroya (eastern Honshu).

The Early Jomon female mandible from Muroya is included here because Ogata (1981) published only sample statistics.

rasaka sites). One of the female Tochibara mandibles had lost many teeth (all the incisors, canines, three premolars as well as one molar) during her life, but this nearly complete specimen was included in the sample in consideration of its rare derivation from the Initial Jomon phase. In order to maximize the sample from this important phase, we added metric data of 27 additional mandibles from literature (Table 1). These additional specimens are from a number of sites distributed in various places in Kyushu (Kawaharada, and Iwashita), western Honshu and Shikoku (Kamikuroiwa, Kan-nondo, and Isoyamashiro), and eastern Honshu (Yukura, Muroya, Shironodai, Oyaji, Meotoiwa, Myo-onji, and Jyao-do). The sample may include a small number of specimens from the Incipient or Early Jomon phases (Matsu'ura, 1993; Oguma, 2007).

Metric data and comparisons

The measurements used in the present study are given in Table 2. All the measurements were collected by the author. Many of these measurements were cited from Kaifu (1995a,b), but metrc data were newly obtained in this study for newly added specimens (Kaifu et al., in press). Also, five measurements (KdlM2, GoSn, GoKr, GoARM, and USA) were newly added in the present study, and the corpus height and thickness measurements were retaken following the change of their definitions. In order to maximize the sample size for bicondylar breadth, a key measurement to evaluate the overall size and shape of a mandible, we estimated this measurement when the kondylion laterale was damaged on one size.

In order to compare overall size of the mandible, "general size variable" (GSV) was defined as the cubic root of "bicondylar breadth× upper mandibular length×corpus height at M1." Similarly, the arithmetic mean of the five corpus height measurements was defined as the "corpus size variable" (CSV).

After calculating descriptive statistics for each regional/chronological subgroup, chronological and regional variation in the Jomon sample was investigated within each regional or chronological group by univariate comparisons of the sample means using *t*-test (Table 3). The significance level was set at 0.05 with Bonfferoni adjustment in cases where there are more than two subsam-

Table 2. List of measurements.

Measurements	Description	References
BCoB	Bicondylar breadth (kondylion laterale-kondylion laterale)	Martin No. 65
BGoB	Bigonial breadth (gonion-gonion: gonion is on the lower margin)	Kaifu (1995b)
BM2B	External dental arch breadth at the M2 alveolus	Kaifu (1995b)
UML	Upper mandibular length (distance between the infradentale and the line for BCoB)	Kaifu (1995b)
LML	Lower mandibular length (distance between the gnathion and the line for BGoB)	Kaifu (1995b)
DAL	Dental arch length (distance between the infradentale and the line for BM2B)	Kaifu (1995b)
CHS	Corpus height at symphysis (vertical distance relative to the alveolar plane)	Kaifu et al. (2005)
CHC	Corpus height at C (vertical distance relative to the alveolar plane)	Kaifu et al. (2005)
CHP1	Corpus height at P1 (vertical distance relative to the alveolar plane)	Kaifu et al. (2005)
CHP2	Corpus height at P2 (vertical distance relative to the alveolar plane)	Kaifu et al. (2005)
CHM1	Corpus height at M1(vertical distance relative to the alveolar plane)	Kaifu et al. (2005)
CHM2	Corpus height at M2 (vertical distance relative to the alveolar plane)	Kaifu et al. (2005)
CTM1	Corpus thickness below M1 (measured perpendicularly to the line for CHM1)	Kaifu et al. (2005)
KdlM2	Kondylion laterale-exernal M2 alveolar point distance	Kaifu (1995b)
LRW	Least ramus width (LRB of Kaiu, 1995b, 1997; LAPRL of Kaifu, 1997)	Martin No. 71a
SnW	Sigmoid notch width (SnB of Kaifu, 1995b)	Kaifu (1995b)
CoH	Condyloid height (gonion-top of the condyle)	Martin No. 70
GoSn	Gonion-sigmoid notch distance (minimum distance)	
GoKr	Gonion-koronion distance	
GoARM	Gonion-anterior ramus margin distance (minimum distance)	
USA	Upper symphyseal angle (between the alveolar plane and the infradentale-pogonion line)	Martin No. 79(1b)
MA	Mandibular angle (between the posterior ramus and basal mandibular borders)	Martin No. 79

Table 3a. Descriptive statistics for the chronological and regional Jomon subsamples (male).[a]

Phase	Region		GSV	BCoB	BGoB	BM2B	UML	LML	DAL	CHS	CHC	CHP1	CHP2	CHM1	CHM2
Late/Final (4)	Hokkaido (D)	N	3	4	4	6	4	4	6	4	4	4	5	5	5
		Mean	72.7	126.5	102.6	62.3	94.3	78.0 >B	33.8	32.5	31.8	32.1	31.5	30.7	29.3
		SD	2.9	6.0	6.0	2.2	2.8	5.8 >C	2.6	1.2	0.6	0.5	1.4	1.6	1.5
	E. Honshu (C)	N	20	30	32	41	27	32	39	40	41	41	42	42	42
		Mean	71.0 >1	128.2	99.4 >1	63.4	92.5	72.2 >1	34.5 >1	32.1	32.1	32.2	31.8	30.6 >1	28.8
		SD	2.6	5.6	5.7 <B	1.7	3.4	3.1 <D	1.8	2.3	2.1	2.0	1.9	1.9 >B	1.8
	W. Honshu (B)	N	8	13	13	11	10	11	8	10	9	11	13	13	13
		Mean	69.0	129.2	104.5 >C	62.8	90.7	70.4 <D	32.9	30.4	30.8	30.5	30.1	28.7 <C	27.4
		SD	2.5	6.7	3.7	2.2	4.2	5.9	1.9	2.3	2.5	2.5	2.6	2.3	1.6
	Kyushu (A)	N	—	1	—	1	—	—	1	—	1	1	2	2	2
		Mean	—	136.7	—	65.9	—	—	34.5	—	30.1	29.2	30.8	30.3	27.6
		SD	—	—	—	—	—	—	—	—	—	—	2.8	2.8	1.1
Middle (3)	W. Honshu (B)	N	8	14	11	18	12	12	17	17	20	20	20	20	20
		Mean	70.2	130.7 >2	102.4	63.8 >2	92.0	70.4	33.8	30.7	30.9	30.9	30.7	29.7	28.2
		SD	2.3	6.7	7.5	2.8	4.4	4.3	1.7	1.6	1.9	1.7	1.6	1.5	1.5
	Kyushu (A)	N	1	2	2	2	2	1	1	2	3	3	3	3	3
		Mean	70.2	132.2	102.3	63.4	87.2	68.9	33.8	31.6 >1	29.2	30.3	30.9	30.5	28.5
		SD	—	7.3	8.2	3.3	3.0	—	—	0.1	2.3	3.0	3.2	3.7	3.5
Early (2)	Hokkaido (D)	N	2	2	1	2	2	1	2	3	4	5	5	6	6
		Mean	71.8	125.0	92.0	60.8	95.1	83.1 >B	32.7	29.2	29.4	30.3	30.2	29.2	27.3
		SD	5.0	1.5	—	0.4	5.4	—	0.5	3.9	3.4	3.1	3.8	3.7	3.8
	E. Honshu (C)	N	2	2	2	2	2	2	2	1	1	2	2	2	2
		Mean	69.2	126.5	103.7 >1	64.0	90.6	71.3	34.1	34.8	34.1	31.4	30.4	29.0	27.4
		SD	3.0	1.6	9.0	0.9	6.8	1.3	4.3	—	—	2.8	1.4	1.2	2.8
	W. Honshu (B)	N	8	9	9	9	10	10	10	11	12	12	12	13	12
		Mean	67.8	121.9 <3	97.5	61.0 <3	90.1	68.3 <D	32.8	30.3	30.4	30.5	30.3	29.2	27.1
		SD	2.8	6.0	7.3	2.2	3.9	3.5	2.0	1.8	1.9	2.2	2.0	1.9	2.5
	Kyushu (A)	N	—	—	1	2	1	1	1	1	1	2	2	2	2
		Mean	—	—	95.6	60.6	95.2	69.4	30.5	33.5 >1	34.6	33.0	32.8	31.1	28.7
		SD	—	—	—	2.8	—	—	—	—	—	2.3	1.9	1.8	1.7
Initial (1)	E. Honshu (C)	N	1	2	3 >B	3	1	2	3	3	3	3	3	3	3
		Mean	63.8 <4	118.7	89.2 <2	61.2	84.5	65.8 <4	30.9 <4	29.8	29.6	29.7	29.1	27.6 <4	26.5
		SD	—	3.7	3.2 <4	1.2	—	1.3	2.1	1.2	1.4	1.6	1.4	1.2	1.4
	W. Honshu (B)	N		1	1					1			2		2
		Mean		130.0	106.0					31.0			31.5		25.0
		SD		—	—					—			0.7		1.4
	Kyushu (A)	N		2	2					2			2		
		Mean		123.0	94.5					27.5 <3			28.0		
		SD		2.8	0.7					0.7 <2			0.0		
Initial	Pooled	N		9	11					13			14		
		Mean		124.6	96.6					29.6			28.9		
		SD		—	—					—			—		

Table 3a. (Continued)

Phase	Region		CTM1	KdlM2	LRW	SnW	CoH	GoSn	GoKr	GoARM	USA	MA	UAL/ BCoB	LML/ BGoB	DAL/ BM2B
Late/Final (4)	Hokkaido (D)	N	5	4	6	6	4	5	5	5	4	5	4	4	6
		Mean	14.9	77.6	38.6 >A	31.3	61.8	44.5	64.6	39.2	104.7	115.2 <2	74.6	76.3	54.4
		SD	2.1	2.2	1.8 >B	2.3	2.2	1.7	3.1	1.3	7.2	4.4	1.7	9.0	4.5
	E. Honshu (C)	N	42	40	41	36	36	38	35	40	39	37	20	26	37
		Mean	14.8 >1	74.0 >1	36.5 >A	32.1	63.3 >1	48.6 >1	65.4 >1	37.4	99.1	118.1	72.9	73.3	54.4
		SD	1.2	3.6	2.5	3.3	3.4	3.4 >2	4.3	2.6	5.8	5.1	5.0	4.8	3.4
	W. Honshu (B)	N	13	11	15	14	12	13	13	13	8	13	8	9	6
		Mean	14.4 >1	72.4	35.1 <D	30.9	61.2	46.4	62.5	36.2	98.6	120.8	70.0	68.1	53.4
		SD	0.8	4.5	2.0	2.5	4.2	3.7	3.1	2.9	8.8	5.0	4.6	6.2	2.3
	Kyushu (A)	N	2	2	2	1	1	1	—	1	2	2	—	—	—
		Mean	13.9	71.5	30.5 <C	30.0	61.3	48.1	—	34.2	105.4	120.0	—	—	—
		SD	3.9	2.5	0.6 <D	.	—	—	—	—	1.7	0.0	—	—	—
Middle (3)	W. Honshu (B)	N	20	14	20	17	15	17	17	18	19	16	8	6	15
		Mean	15.2 >1	73.0	35.8 >2	30.8	62.4	48.5	62.9	36.3	104.7	120.7	70.6	71.2	53.3
		SD	1.1	3.8	2.2	3.3	4.1	3.0	4.2	2.2	4.2	5.2	4.6	6.5	3.5
	Kyushu (A)	N	3	3	3	3	3	3	3	3	3	3	1	—	—
		Mean	14.4	71.8	33.7	32.2	62.3	46.9	60.4	34.8	100.1	123.3	61.9	—	—
		SD	0.5	5.1	3.3	1.9	3.0	2.2	4.8	4.8	6.5	1.5	—	—	—
Early (2)	Hokkaido (D)	N	6	3	6	2	5	6	3	6	4	4	2	1	2
		Mean	14.6	73.8	38.9 >B	31.2	60.2	43.9	62.1	37.6	95.0	122.0 >4	76.1	90.3 >B	53.7
		SD	1.6	3.4	3.1	0.5	5.3	4.6	1.3	3.6	6.0	3.6	3.4	>C	1.1
	E. Honshu (C)	N	2	2	2	2	2	2	2	2	2	2	2	2	2
		Mean	15.3	71.3	36.4	34.5 <B	57.0	41.2 <4	62.3	39.2	89.8	122.5	71.7	69.0 <D	53.3
		SD	2.2	3.4	2.8	2.5	8.7	4.4	0.5	2.2	7.8	0.7	4.5	4.8	7.5
	W. Honshu (B)	N	13	10	11	9	11	11	10	12	10	11	8	7	8
		Mean	14.1	70.8	33.4 <3	28.6 >C	60.4	47.7	62.0	34.5	102.7	122.5	74.2	70.6 <D	53.6
		SD	1.2	4.0	2.0 <D	1.4	6.0	4.5	4.8	2.2	5.7	5.3	5.2	5.2	3.3
	Kyushu (A)	N	2	—	1	—	—	1	1	1	2	—	—	—	1
		Mean	14.8	—	36.9	—	—	44.1	60.7	39.3	105.9	—	—	—	48.7
		SD	1.3	—	—	—	—	—	—	—	3.2	—	—	—	—
Initial (1)	E. Honshu (C)	N	5	2	5	1	4	2	2	2	3	4	1	2	3
		Mean	12.8 <4	63.1 <4	35.4	29.6	56.1 <4	41.5 <4	55.8 <4	34.6	99.3	117.8	72.8	74.9	50.4
		SD	1.1	2.4	1.7	—	3.9	0.7	0.8	1.1	6.9	4.8	—	4.2	2.4
	W. Honshu (B)	N	2		2		2					2			
		Mean	12.0 <4		37.0		56.0					120.5			
		SD	0.0 <3		0.0		0.0					3.5			
	Kyushu (A)	N	2		2		2					2			
		Mean	13.0		34.0		54.0					117.5			
		SD	1.4		1.4		2.8					6.4			
Initial	Pooled	16		16		14					13				
			12.8		35.0		56.2					119.6			
		—		—		—					—				

[a] "<" and ">" indicate the presence of statistically significant difference ($p<0.05$) from the subsample indicated by the regional number (the first column) or chronological alphabet (the second column).

Table 3b. Descriptive statistics for the chronological and regional Jomon subsamples (female).[a]

Phase	Region		GSV	BCoB	BGoB	BM2B	UML	LML	DAL	CHS	CHC	CHP1	CHP2	CHM1	CHM2
Late/Final (4)	Hokkaido (D)	N	2	2	2	5	2	2	4	6	7	7	8	8	8
		Mean	64.8	118.2	90.7	61.0 >2	87.4	68.3	32.3	29.0	28.6	28.9	28.7	27.6	26.4
		SD	0.2	4.0	7.4	1.6	2.5	0.1	1.9	2.3	2.3	2.2	1.9	1.9	2.4
	E. Honshu (C)	N	15	18	18	23	16	18	22	23	23	23	26	26	26
		Mean	67.6	118.7	94.3 >1	61.2	89.8	70.0	33.9	30.1	29.6	29.8	29.5	28.3	26.7
		SD	2.7	5.3	5.2	1.9	4.0	3.4	2.1	2.1	1.7	1.8	1.9	1.9	2.0
	W. Honshu (B)	N	6	7	6	4	7	6	3	5	5	5	6	6	6
		Mean	66.6	122.8	94.5	60.0 <A	86.8	68.9	32.9	29.0	28.9	28.6	28.8	27.7	25.6
		SD	2.8	4.3	3.7	1.2	2.8	4.2	1.6	2.6	3.2	3.0	2.6	2.5	2.6
	Kyushu (A)	N	—	—	—	1	—	—	1	1	1	2	2	2	2
		Mean	—	—	—	65.7 >B	—	—	33.0	28.2	28.6	27.6	27.1	26.2	25.8
		SD	—	—	—	—	—	—	—	—	—	1.8	2.1	2.4	1.1
Middle (3)	E. Honshu (C)	N	5	2	2	2	1	2	1	1	1	2	2	2	2
		Mean	65.5	112.5	94.8	58.7	86.6	70.7	32.5	28.9	28.3	27.5	27.4	26.4	24.9
		SD	4.9	5.3	7.2	1.8		4.0	.			0.8	0.4	0.1	0.6
	W. Honshu (B)	N	1	8	9	9	6	8	8	6	7	8	8	9	8
		Mean	61.7	122.6	91.5	61.1	87.1	69.7	33.7	28.3	28.3	28.0	28.1	27.1	26.1
		SD	—	6.6	6.8	2.0	6.1	6.6	1.6	2.3	2.0	2.5	2.9	2.4	2.3
	Kyushu (A)	N	4	1	—	1	1	—	1	1	1	1	1	1	1
		Mean	66.5	122.1	—	60.8	78.9	—	31.1	29.0	28.7	29.0	28.8	24.4	22.7
		SD	2.8	—	—	—	—	—	—	—	—	—	—	—	—
Early (2)	Hokkaido (D)	N	1	4	4	4	4	4	4	3	3	5	5	6	6
		Mean	62.8	121.3	96.6	57.1 <4	89.2	69.3	31.1	31.4	31.0	29.0	29.2	29.2	28.0
		SD	—	0.9	5.4	2.1	3.9	1.5	2.2	0.9	1.1	3.0	3.5	3.7	3.9
	W. Honshu (B)	N	6	6	6	6	6	6	6	5	6	6	6	6	6
		Mean	66.2	115.6	91.3	59.6	89.2	67.5	32.3	29.9	29.6	29.8	29.7	28.2	26.4
		SD	2.5	5.7	9.4	1.7	3.4	5.5	1.4	2.0	2.3	2.2	2.4	2.4	2.4
	Kyushu (A)	N	2	2	2	4	2	2	1	1	1	1	5	4	4
		Mean	64.8	114.7	86.7	59.2	86.3	67.5	31.4	29.7	29.9	30.0	29.2	27.1	25.7
		SD	0.4	1.9	8.9	2.6	3.3	2.0	—	—	—	—	1.2	1.2	1.5
Initial (1)	E. Honshu (C)	N	1	2	2	—	1	2	—	1	1	1	1	2	2
		Mean	64.2	118.0	82.9 <4	—	82.8	65.5	—	31.1	29.2	28.6	27.8	29.0	27.5
		SD	—	3.0	4.2	—	—	4.9	—	—	—	—	—	2.0	1.3
Initial	Pooled	N		10	12					14			13		
		Mean		118.0	90.0					28.2			26.9		
		SD		—	—					—			—		

Table 3b. (Continued)

Phase	Region		CTM1	KdlM2	LRW	SnW	CoH	GoSn	GoKr	GoARM	USA	MA	UAL/ BCoB	LML/ BGoB	DAL/ BM2B
Late/Final (4)	Hokkaido (D)	N	8	6	7	4	5	5	5	6	6	3	2	2	4
		Mean	14.4	69.7	35.6 <2	30.7	57.6	42.5	58.0	36.6	99.9	119.0	74.0	75.6	53.0
		SD	1.1	5.7	2.8	3.0	3.4	3.3	2.1	3.0	5.2	5.3	0.4	6.1	3.3
	E. Honshu (C)	N	26	21	25	22	19	23	22	23	24	19	16	18	22
		Mean	14.5 >B	68.9	34.9	31.2	57.2	43.4	58.0	34.8	99.9	122.7 >3	75.4	74.5	55.3
		SD	0.9	4.0	2.6	2.7	3.4	3.2	4.2	2.3	4.7	4.4	4.4	5.8	3.7
	W. Honshu (B)	N	6	6	7	7	6	6	6	6	4	6	7	6	3
		Mean	13.1 <C	70.3	33.0	30.2	59.1	44.2	57.9	34.2	100.4	120.8	73.8	74.0	54.4
		SD	1.6	2.7	1.7	2.7	4.4	4.8	6.1	2.3	5.1	7.2	4.9	5.0	2.8
	Kyushu (A)	N	3	—	2	—	—	1	1	2	1	1	—	—	1
		Mean	14.0	—	32.4	—		49.0	53.4	33.6	107.1	111.0	—	—	50.2
		SD	0.8	—	1.1	—		—	—	2.8	—	—	—	—	—
Middle (3)	E. Honshu (C)	N	2	2	2	2	2	2	2	2	7	2	1	2	1
		Mean	15.5	68.8	36.9	31.4	57.0	42.2	59.3	38.2	106.1	114.0 <4	79.7	74.7	56.6
		SD	0.4	2.9	3.1	1.2	2.0	0.0	2.4	1.8	4.5	7.1	—	1.5	—
	W. Honshu (B)	N	9	9	11	10	8	8	8	8	—	8	8	9	10
		Mean	14.2	68.8	33.7	28.2	58.1	43.4	58.7	33.9	—	118.8	70.9	73.6	54.5
		SD	1.6	6.0	3.9	4.0	3.4	2.9	3.7	4.4	—	5.4	4.3	7.5	2.3
	Kyushu (A)	N	1	1	1	1	1	1	1	1	5	1	1	—	1
		Mean	12.7	63.1	27.5	30.0	56.2	39.1	50.1	28.5	98.5	130.0	64.6	—	51.2
		SD	—	—	—	.	—	—	—	—	—	—	—	—	—
Early (2)	Hokkaido (D)	N	6	5	6 >A	6	6	6	6	6	2	5	4	4	4
		Mean	13.7	72.4 <A	39.4 >B	34.1 >A	57.8	41.0	58.3	38.7 >B	100.9	116.8 <B	73.6	71.8	54.4
		SD	0.9	2.9	2.7 >4	2.7 >B	3.8	2.3	2.0	3.1	8.6	1.5	3.3	3.7	3.2
	W. Honshu (B)	N	6	6	6	6	6	6	6	6	5	6	4	5	4
		Mean	13.8	69.8	31.7 <D	27.9 <D	57.1	42.7	55.8	32.9 <D	102.2	125.7 >D	75.7	76.8	55.5
		SD	0.8	2.8	1.5	1.5	3.6	4.4	5.7	2.5	1.4	5.0	4.2	6.1	3.9
	Kyushu (A)	N	5	3	3	3	3	3	3	3	2	2	2	2	1
		Mean	13.4	66.0 >D	33.0 <D	29.0 <D	55.1	40.7	55.8	34.4	98.2	118.5	75.2	78.4	51.3
		SD	0.5	1.8	2.2	1.7	4.7	5.4	5.0	3.2	6.8	10.6	1.6	10.3	
Initial (1)	E. Honshu (C)	N	1	2	2	2	2	2	2	2	1	2	1	2	—
		Mean	15.1	67.5	34.7	30.4	54.0	39.9	53.0	33.3	92.2	125.0	71.4	78.9	—
		SD	—	2.5	1.1	4.0	1.2	0.2	0.8	0.5	—	1.4	—	1.9	—
Initial	Pooled		13		13		11					12			
			12.4		32.8		53.4					121.4			
			—		—		—					—			

[a] "<" and ">" indicate the presence of statistically significant difference (p<0.05) from the subsample indicated by the regional number (the first column) or chronological alphabet (the second column).

ples to compare.

Results

Except for the two large male mandibles from the Ishoyamashiro site (Ikeda and Kitagawa, 1986), both male and female mandibles from the Initial Jomon phase (eastern Honshu and Kyushu) exhibit comparatively small dimensions in most aspects (Table 3). Thus, the size of the Initial Jomon mandibles is variable but its general trend is small, and this is apparent in the corpus (CHS～CHM2) and ramus (CoH, GoSn, GoKr) height measurements as Ogata (1981) suggested. Other possible characteristics of the Initial Jomon mandibles include a thin lateral corpus (CTM1). The angle formed between the corpus and ramus (MA) is close to the average of the Jomon sample from the later phases (Ogata and Ishino, 1973).

Table 3 suggests no clear temporal trends among the Early, Middle, and Late/Final Jomon samples except for the followings: When statistically significant chronological differences are found in these regional series, chronologically later groups show greater dimensions than the Early Jomon in 5 out of 6 such cases. For example, the western Honshu Early male Jomon shows significantly narrower BCoB and BM2B, and smaller LRW compared to the Middle Jomon from the same region. Similar trends are also present in the females of western Honshu although the differences do not reach statistical significance. The exception of the above trend "Early Jomon＜later groups" is the LRW of the Hokkaido female.

Within each Jomon phase, particularly in the Late/Final phase where a larger sample is available, there are general north-and-south clines (southern groups＜northern groups) in the corpus heights (CHS～CHM2) and width of the ramus (LRW). The Early Jomon subsample from Hokkaido also exhibits a considerably broad mandibular ramus compared to the contemporary subsamples from the other regions.

Discussion

The small size of the present sample limits comprehensive documentation of the Jomon variation. Particularly, specimens from the Tokai region were not included in this study because of the prevalence of extensive ritual tooth ablation in this region. The available sample from Kyushu is considerably small. Still, the present sample includes a relatively large number of specimens taken from various different chronological phases and regions.

In his monumental review of the chronological variation in the Jomon skeletal morphology, Ogata (1981) concluded that the Initial Jomon mandibles are characterized primarily by their small overall sizes (see also Ikeda, 1985), although examinations of more recent discoveries emphasize the existence of some degree of variation in this and other mandibular characters (Ikeda and Kitagawa, 1986; Morimoto and Takahashi, 1986; Jidoi, 1997; Baba et al., 1998). The present comparisons based on the expanded sample support the previous observation that the Initial Jomon mandibles are generally small. This applies to all mandibular dimensions, but is particularly true for the corpus and ramus heights (Ogata, 1981), as well as lateral corpus thickness. On the other hand, these Initial Jomon mandibles are indistinguishable from the later Jomon populations in the mandibular angle (Ogata and Ishino, 1973). Ogata (1981) also noted that the early Jomon mandibles are significantly short anteroposteriorly but their breadths are only slightly narrower than the later Jomon specimens. Further comparative analyses based on standardized measurements and material selection criterion are required to confirm these points.

As for the mandibles from the Early Jomon phase, Ogata (1981) noted some "transitional" aspects that bridge between the gracile Initial Jomon condition and robust morphology manifested in the Middle Jomon phase. The present comparisons based on an expanded sample suggest the presence of significant regional differences in the Early Jomon mandibles. The mandibles from this phase are comparatively robust and difficult to distinguish from the later Jomon populations at least in Hokkaido and possibly in eastern Honshu and Kyushu as well. Only the western Honshu male Early Jomon sample (exclusively from the Sanyo region) showed considerable differences from the chronologically later sample, particularly in mandibular breadth and ramus width. Ikeda (1985) proposed that such skeletal variation in earlier Jomon phases may be ascribed, at least in part, to differences in subsistence between the mountain and coastal regions. However, all of the above Early Jomon mandibles are sampled from shell-mound sites formed in the seaside area and the observed variation cannot simply be explained by the Ikeda's dichotomic subsistence hypothesis.

Besides the above described uniqueness in the Initial Jomon and in the Early Jomon from western Honshu, chronological variations were not remarkable in the current sample. On the other hand, as had been suggested by previous studies (Kaifu, 1995a; Maeda, 2002), mandibles from Hokkaido exhibit significantly broader rami compared to the other Jomon regional samples. This characteristic is present in Hokkaido from the Early Jomon phase and persists through the Late/Final phases. This is in consistence with the general pattern of regional variation observed in modern populations from broader Asian and Arctic areas: In these areas, the Arctic populations (North America and Greenland) have the broadest rami, followed by Northeast Asians, and Southeast Asian populations (Humphrey et al., 1999; Nicholson and Harvati, 2006), although these modern mandibles may have experienced varying degree of size reduction due to reduced chewing stresses (cf. Kaifu, 1997).

The eastern Honshu sample also tended to be large in mandibular corpus dimensions and least ramus width compared to the cases in southwestern Japan in the Late/Final Jomon phase (Maeda, 2002). This result is consistent with the regional variation in body size. Takigawa (2006) observed a slight degree of north and south cline in the limb bone lengths (north>south) in the Jomon samples from Hokkaido to Kyushu. Nicholson and Harvati (2006) reported similar north-south clines in overall mandibular size in modern populations from Asia and the Americas.

At present, the causal factors of the above north and south clines in the Jomon mandibles are not clear. The regional variation in the ramus width and overall mandibular size may have resulted from different adaptation to each local climatic condition, or may reflect multiple origins of the Jomon people. As a support for the latter possibility, Adachi et al. (2009) found the presence of significant differences in mtDNA haplogroup profile between small Jomon skeletal samples from Hokkaido and Kanto (a southern district in eastern Honshu). Integration with archaeological evidence is also important in future studies. For example, Nagai (2007) demonstrated the presence of a distinct lithic production technique in Hokkaido from the beginning of the Jomon period (Incipient phase).

It should be noted, however, that most of the Hokkaido specimens of the present study are sampled from a narrow area in Hokkaido, the Funkawan (Uchiurawan) area in the southwestern region. Interestingly, one Early Jomon mandible from eastern Hokkaido included in this study, Higashikushiro, shows rather gracile corpus and ramus morphology. As is suggested by this instance, some degree of regional or inter-site variation may be present within each major region of the Japanese archipelago. In order to investigate the background factors of the Jomon morphological variation, future studies should be directed to such detailed aspects of variation within each region as is exampled by Ikeda (1988).

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