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Secular Changes in Craniofacial Morphology during the Edo Period of Japan

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Abstract Although significant differences in craniofacial morphology can be recognized among the townsmen, the lower-middle-class samurai, and the higher-class samurai (including shogun's wives and territorial lords) from the middle-late Edo period (Sakaue, 2012), there has been no study on secular changes in craniofacial morphology during the Edo era. The purpose of this study is to investigate the morphological differences in the skull between the early Edo period and the middle-late Edo period. The subjects included 44 males and 22 females from the early Edo period, and 181 males and 118 females from the middle-late Edo period. A total of 67 measurements were examined, and multivariate analyses were employed to test the significant differences between the early Edo period skulls and the middle-late Edo period skulls. The results showed that the cranial morphology of the early Edo period was similar to that of the middle-late Edo period townsmen, but apparently different from that of the middle-late Edo period samurai of both sexes. The early Edo period subjects had somewhat stouter mandibles than those of the middle-late Edo period male townsmen and relatively larger skulls than those of the middle-late Edo period female townsmen. Thus it can be said that secular changes in cranial morphology occurred during the Edo period.

Key words: Edo, Skull, Craniofacial morphology, Secular change

Introduction

In a previous study, group differences in craniofacial morphology could be recognized statistically between the skeletal remains buried in circular wooden coffins "*Hayaoke*" and those buried in ceramic coffins "*Kamekan*" during the middle to late Edo period (from the late 17th century to the late 19th century) (Sakaue, 2012). Because the "*Hayaoke*" was utilized by the townsmen and the "*Kamekan*" by the lower-middle-class samurai, it could be said that one's craniofacial morphology was affected by one's social class among the Edo period people. These differences among social classes can be investigated by using the skeletal remains after the late 17th century because the "*Kamekan*" burial style commenced after that time (Tanigawa, 2004).

In order to answer the question of why these morphological changes occurred, it will be helpful to know the time when the people in the samurai class acquired the unique features of the skull. However, there has been no study on secular changes in craniofacial morphology during the Edo era. The large number of skeletal remains newly excavated from the early Edo period (the 17th century) makes it presently possible to investigate this secular change.

Thus, the purpose of this study was to investigate the morphological differences in the skull between the early Edo period and the middle-late Edo period.

Materials and Methods

The materials of this study were composed of human skeletal remains excavated from three cemetery sites located in Tokyo (Table 1). The

Table 1. Sites and sample sizes used in this study.

site	location	period	Male	Female
Early Edo				
Hatchobori-Sanchyome (1st)	Chuou-ku	the last 16th A.D. to the middle17th A.D.	2	2
Hatchobori-Sanchyome (2nd)	Chuou-ku	the last 16th A.D. to the middle17th A.D.	15	9
Shitaya-Dohochyo	Taitou-ku	the last 16th A.D. to the late 17th A.D.	1	4
Hitotsubashi Senior High School	Chiyoda-ku	the last 16th A.D. to the late 17th A.D.	26	7
sum			44	22
Middle-late Edo			181	118

excavation results, historical records, and old maps of the Edo indicated that all temples of these cemeteries had been relocated to the other places during the 17th century. Although most of the skeletal remains excavated at these cemeteries are thought to be those of townsmen, some people of the samurai class may have been also buried at these cemeteries judging from epitaphs and burial accessories, such as weapons (Toritu Hitotsubashi koukou Iseki Chosa-dan, 1985; Hatchobori Sanchome iseki (dainiji) Chosa-kai, 2003).

The criteria for selecting the samples were as follows: 1) complete closure of the sphenooccipital synchondrosis; 2) at least one remaining tooth or socket of the maxillary central incisors; 3) at least one remaining tooth or socket of molars for each maxilla and mandible; 4) no contamination by another individual or, if any, restricted contamination easily identifiable of another individual; and 5) almost a complete skull without deformation or missing values for all measurements.

The sexual assessment of individuals was basically carried out with craniofacial traits (Sakaue and Adachi, 2009). When these traits were insufficient for identification of the sex, some pelvic features, such as a greater sciatic notch, ventral arc, or ischiopubic proportion, were used (Bruzek, 2002). A total of 67 measurements were examined (Table 2), and their definitions followed those of Martin's measurements (Baba, 1991). When both sides were available, the left side was basically measured.

Statistical analyses were performed as follows: 1) The Shapiro-Wilk test was conducted for all variables in each group in order to test for any deviations from a normal distribution; 2) In order to compare the relative significance of differences between the early Edo period group and the middle-late "*Hayaoke*" Edo period group or between the early Edo period group and the middle-late Edo "*Kamekan*" period groups, the Dunnett's tests were conducted for variables of normal distributions, or the Steel's tests were carried out for variables of doubtful normal distributions as a multiple comparison procedure (Nagata and Yoshida, 1997) ; 3) Forty-seven variables which had been chosen in the previous study (Sakaue, 2012) were also used for multivariate analysis in this study. In addition, Wilks' lambdas were calculated and their statistical significances were tested in order to test the differences of these groups for a combination of dependent variables; 4) The plot of factor scores were made in order to elucidate group differences in cranial variation of the early Edo period people and the middle-late Edo period people. The principal component scores of the early Edo period people were calculated by the component coefficients resulting from the principal component analysis on correlation matrix in the middle-late Edo period samples (Sakaue, 2012); and 5) The principal component analysis on correlation matrix was carried out with 12 variables of the mandibular bone, which showed distinct differences between the early Edo period people and the middle-late Edo period people of both sexes. This analysis was conducted on the middle-late Edo period people, and then the scores of the early Edo period people were calculated by its component coefficients. All statistical analyses were carried out with SYSTAT 13.

Table. 2 Summary statistics of all measurements and Indexes

Martin No.	Variables	Male								Female							
		Early (N = 44)		Middle-late (Hayaoke) (N = 131)			Middle-late (Kamekan) (N = 50)			Early (N = 22)		Middle-late (Hayaoke) (N = 70)			Middle-late (Kamekan) (N = 48)		
		Mean	S.D.	Test	Mean	S.D.	Test	Mean	S.D.	Mean	S.D.	Test	Mean	S.D.	Test	Mean	S.D.
1	Maximum length	181.8	6.7		181.5	6.4	⩾	177.4	6.1	174.5	4.7		172.3	6.7	⩾	169.1	5.5
8	Maximum breadth	138.3	5.1		138.5	4.5	⩽	141.3	5.3	135.0	5.8		133.2	5.7		135.3	4.4
17	Basion-Bregma height	137.1	4.9		136.2	4.7		138.0	5.7	129.5	4.3		130.6	3.9	<	132.0	4.0
9	Least frontal breadth	93.4	4.7		93.5	4.2		94.4	4.9	90.5	3.8		89.3	4.8		89.5	3.3
10	Maximum frontal breadth	115.4	3.9		114.7	4.2	<	117.2	5.4	111.8	4.7	>	109.4	4.8		110.1	3.9
5	Basion-Nasion length	101.9	3.5		101.8	4.5	>	99.9	4.2	95.3	3.0		94.9	3.7		95.1	3.6
11	Biauricular breadth	125.3	4.4		126.0	4.3		125.0	4.3	120.2	4.7		119.2	4.4		118.8	4.6
12	Biasterionic breadth	108.9	3.9		108.5	4.6		108.2	5.2	106.7	4.0	>	104.4	4.0	>	104.2	3.8
13	Mastoid width	103.3	4.5		103.2	4.7		102.2	4.8	98.3	5.0		97.2	5.9		96.4	4.3
40	Basion-Prosthion length	98.7	4.6		99.3	4.9	>	96.0	6.0	93.8	4.2		94.4	5.3		92.7	3.8
14	Minimum cranial breadth	67.9	3.0		68.7	3.5	⩽	69.7	4.0	65.0	2.5		64.1	3.3		65.1	3.7
7	Foramen magnum length	35.6	2.1		35.8	2.2		35.3	2.4	33.7	1.9		33.7	2.0		33.7	2.0
16	Foramen magnum breadth	29.2	1.6		29.6	2.0		29.9	2.2	28.5	2.0		28.3	1.7		28.1	1.9
23	Horizontal circumference	516.5	16.6		518.2	13.9		514.9	13.0	502.7	12.8	≥	494.6	14.0	⩾	491.1	11.9
24	Transverse arc	313.1	9.5		312.8	9.4	⩽	321.0	11.7	301.8	10.7		301.7	11.3		304.6	9.9
26	Frontal sagittal arc	127.5	5.6		125.9	5.7		126.9	5.3	121.6	5.0		121.3	5.9		119.8	5.7
27	Parietal sagittal arc	126.2	6.9		126.3	8.1		125.7	8.3	120.6	8.6		120.9	7.1		119.8	11.1
28	Occipital sagittal arc	116.6	6.1		118.2	8.3		117.7	5.4	116.4	8.5		115.1	8.1		113.9	6.6
25	Total sagittal arc	370.3	12.2		370.4	13.3		370.2	12.5	358.6	12.3		357.3	12.9		353.4	13.0
29	Frontal sagittal chord	111.7	4.3		110.6	4.4		110.8	4.4	106.6	3.4		106.3	4.2		105.6	4.2
30	Parietal sagittal chord	113.2	5.5		112.7	6.4		112.2	6.5	109.9	6.0		108.9	5.7	>	106.5	7.0
31	Occipital sagittal chord	98.3	4.2		98.4	5.3		99.3	4.1	97.5	5.3		96.8	5.4		97.6	4.2
43	Outer biorbital breadth	104.6	3.6		104.7	4.0		104.0	4.0	100.5	3.0		99.2	3.7	>	98.7	3.0
43a	Bifrontal breadth	97.5	3.8		97.3	4.0		96.8	3.7	93.4	2.8		92.3	3.6		92.1	2.8
	Nasion subtence (calculated)	14.5	2.1		14.1	2.4		14.5	3.1	12.7	1.4		12.5	2.3		13.1	2.3
44	Biorbital breadth	98.5	3.7		97.9	3.8		97.3	3.7	95.3	3.1	>	93.6	3.5	⩾	92.8	3.1
45	Bizygomatic breadth	134.8	4.3		134.9	4.5		133.1	5.1	126.6	4.2		125.0	3.8	>	123.8	4.6
46	Bimaxillary breadth (zm)	99.8	5.2		99.9	4.7	>	97.3	5.0	94.7	4.1		93.3	3.8	>	92.2	4.8
46b	Bimaxillary breadth (zm:a)	100.3	5.4		99.9	4.7	>	97.6	4.9	95.2	4.7		94.1	4.2		92.7	4.9
	Subspinale subtence (calculated)	22.3	2.9		22.7	3.3	<	23.9	2.9	19.5	2.8		20.5	3.0	⩽	22.0	2.3
48	Upper facial height	71.9	3.8		72.2	4.2	<	73.7	3.3	66.4	4.1		66.7	4.2	<	68.5	3.4
48H	Upper facial height (Howells)	68.1	3.5		68.3	4.0	<	69.9	3.2	62.9	3.9		63.4	4.4	<	65.1	3.6
48d	Malar height	23.7	2.4		24.3	2.5		23.7	2.5	22.1	1.9		22.0	2.0		21.9	1.9
49a	Interorbital breadth	21.2	1.8		21.0	2.0		20.7	2.1	20.8	1.7		20.3	2.1	>	19.7	2.0
50	Anterior interorbital breadth	16.9	2.1		16.9	2.1		16.9	2.1	16.8	1.7		16.4	1.9		16.3	1.7
51	Orbital breadth	43.0	1.9		43.3	2.0		43.4	1.8	41.1	1.8		40.8	1.9		41.2	1.5
52	Orbital height	33.9	1.9		34.1	1.9	⩽	35.6	1.9	33.1	1.9		33.3	1.8	⩽	34.6	1.7
54	nasal breadth	24.9	1.6	<	25.6	1.9		24.5	1.7	24.2	1.3		24.4	1.6		24.5	1.9
55	nasal height	51.9	2.8		52.3	3.1	⩽	53.6	2.6	47.5	2.9		48.5	2.7	<	49.4	2.6
55(1)	Height of piriform aperture	30.2	2.9		29.6	2.6		30.7	2.5	26.1	2.4		26.5	2.2	≤	27.5	2.7
56	Length of nasal bone	23.8	3.1		24.4	2.8		24.9	3.0	22.4	2.4		22.6	2.5		22.9	2.8
57(1)	Maximum breadth of nasal bone	17.9	1.8		18.2	1.9		17.7	1.6	17.5	1.5		16.9	1.6		17.1	1.9
57	Least nasal breadth	7.1	1.9		7.3	1.6		7.2	2.0	7.6	1.6		7.0	1.9		7.8	1.6
	Nasal subtense (calculated)	2.2	0.9		2.5	1.0	<	2.6	1.1	1.8	0.9		1.8	0.9	<	2.3	0.9
60	External palate length	51.6	3.7		52.3	3.0		50.4	3.5	49.0	2.5		50.3	3.6		48.9	2.3
61	External palate breadth	64.9	3.8		65.7	3.8		65.5	3.8	61.5	3.8		61.4	3.4		61.5	3.6
62	Internal palate length	44.6	2.7		45.5	2.7		44.7	2.7	42.4	2.5	<	44.0	2.7		43.4	2.1
63	Internal palate breadth	40.7	2.7		40.7	3.3	>	39.5	3.3	39.4	3.0		38.1	2.6		38.6	3.0
66	Bigonial breadth	102.6	5.8	>	100.2	5.8	⩾	98.9	5.9	95.2	5.4		93.8	5.6	⩾	90.9	4.5
68	Projective length of mandible	72.1	4.9		70.7	5.0		69.8	4.9	67.0	3.5		66.2	4.3		65.6	4.3
65	Bicondylar breadth	120.7	5.5		121.6	5.7		120.8	5.8	116.1	5.1		113.8	5.2	⩾	110.8	5.8
65(1)	Bicoronoid breadth	97.3	5.5		97.4	4.8		98.1	5.2	94.4	4.1	⩾	90.5	4.5	⩾	90.5	5.0
67	Bimental breadth	47.7	3.0		47.5	2.5		47.4	2.5	46.5	2.7		45.8	2.2		45.2	2.0
69	Height of mandibular symphysis	35.0	3.6		35.6	3.2		36.0	3.1	30.5	3.4		31.6	3.2	≤	32.2	2.8
69(1)	Mandibular body height	31.4	2.3		31.6	2.7		32.1	2.4	28.9	2.8		28.7	2.5		28.9	2.1
69(2)	Mandibular body height at M2	27.0	2.0		26.8	2.5		26.5	2.7	25.1	2.3		24.8	2.2		24.3	2.0
69(3)	Mandibular body breadth	13.8	1.5	⩾	13.2	1.4	⩾	12.5	1.4	13.3	1.4		12.7	1.2	⩾	12.2	1.1
69b	Mandibular body breadth at M2	18.0	1.5	⩾	17.1	1.6	⩾	16.6	1.3	17.1	1.1		17.0	1.4	>	16.3	1.5
70	Height of mandibular ramus	63.6	4.9	<	64.9	4.4		64.8	4.3	57.9	3.4		57.6	3.9		57.6	3.9
71a	Minimum width of ramus	34.7	2.9		34.7	3.3	⩾	32.4	2.6	33.2	2.2		33.1	2.7	⩾	31.2	2.4
71(1)	Condylo-cornoid breadth	35.5	3.9		36.2	3.2	>	33.4	3.9	32.8	2.4	<	34.1	3.0		32.7	2.9
	Mandibular condyle breadth	20.2	1.8		20.7	2.0		20.6	1.9	18.5	1.8		18.5	1.7		17.9	1.4

Table. 2 Continued

Martin No.	Variables	Male								Female							
		Early (N = 44)		Middle-late (Hayaoke) (N = 131)			Middle-late (Kamekan) (N = 50)			Early (N = 22)		Middle-late (Hayaoke) (N = 70)			Middle-late (Kamekan) (N = 48)		
		Mean	S.D.	Test	Mean	S.D.	Test	Mean	S.D.	Mean	S.D.	Test	Mean	S.D.	Test	Mean	S.D.
8/1	Cranial index	0.76	0.04		0.76	0.03	≪	0.80	0.04	0.77	0.03		0.77	0.05	≪	0.80	0.03
17/1	Index	0.75	0.03		0.75	0.03	≪	0.78	0.03	0.74	0.03	<	0.76	0.03	≪	0.78	0.03
17/8	Index	0.99	0.04		0.98	0.04		0.98	0.04	0.96	0.04		0.98	0.05		0.98	0.03
9/10	Index	0.81	0.04		0.82	0.03		0.81	0.03	0.81	0.03		0.82	0.04		0.81	0.03
9/8	Index	0.68	0.04		0.68	0.03		0.67	0.04	0.67	0.03		0.67	0.04		0.66	0.03
8/12	Index	1.27	0.06		1.28	0.05	≪	1.31	0.06	1.27	0.06		1.28	0.06	<	1.30	0.05
40/5	Index	0.97	0.04		0.98	0.04		0.96	0.05	0.98	0.04		0.99	0.04		0.98	0.03
16/7	Index	0.82	0.06		0.83	0.06	<	0.85	0.06	0.85	0.05		0.84	0.05		0.84	0.05
27/26	Index	0.99	0.06		1.00	0.07		0.99	0.07	0.99	0.08		1.00	0.07		1.00	0.09
28/26	Index	0.92	0.05		0.94	0.08		0.93	0.06	0.96	0.07		0.95	0.08		0.95	0.08
29/26	Index	0.88	0.01		0.88	0.02		0.87	0.02	0.88	0.01		0.88	0.02		0.88	0.02
30/27	Index	0.90	0.02		0.89	0.02		0.89	0.03	0.91	0.05		0.90	0.02		0.89	0.04
31/28	Index	0.84	0.02	≥	0.83	0.03		0.84	0.02	0.84	0.02		0.84	0.03	≪	0.86	0.02
(1 + 8	Modulus	152.39	3.71		152.03	3.54		152.24	4.09	146.32	3.52		145.35	3.59		145.49	3.37
+ 17)/3	Frontal index of flatness	0.15	0.02		0.14	0.02		0.15	0.03	0.14	0.01		0.13	0.02		0.14	0.02
	Zygomatic index of flatness	0.22	0.03		0.23	0.03	≪	0.25	0.03	0.21	0.03		0.22	0.03	≪	0.24	0.03
43/8	Index	0.76	0.04		0.76	0.03	≫	0.74	0.03	0.75	0.03		0.75	0.04	≥	0.73	0.03
46/45	Index	0.74	0.03		0.74	0.03		0.73	0.03	0.75	0.03		0.75	0.03		0.74	0.03
48/45	Index	0.53	0.03		0.54	0.03	≪	0.55	0.03	0.52	0.04		0.53	0.03	≪	0.55	0.03
48/46	Index	0.72	0.04		0.72	0.04	≤	0.76	0.04	0.70	0.06		0.72	0.05	≪	0.75	0.05
9/45	Index	0.69	0.04		0.69	0.03	<	0.71	0.03	0.72	0.03		0.71	0.03		0.72	0.03
45/8	Index	0.98	0.04		0.97	0.04	≫	0.94	0.04	0.94	0.04		0.94	0.04	>	0.92	0.03
50/44	Index	0.17	0.02		0.17	0.02		0.17	0.02	0.18	0.02		0.17	0.02		0.18	0.02
52/51	Index	0.79	0.05		0.79	0.04	≪	0.82	0.05	0.81	0.05		0.82	0.04	≤	0.84	0.05
54/55	Index	0.48	0.04		0.49	0.04	≫	0.46	0.03	0.51	0.03		0.51	0.04	≥	0.50	0.04
54/55(1)	Index	0.83	0.10	<	0.87	0.10		0.80	0.08	0.93	0.08		0.93	0.09		0.90	0.13
	Simotic index	0.32	0.13		0.34	0.12	<	0.37	0.13	0.23	0.11		0.25	0.12	≤	0.29	0.11
57/57(1)	Index	0.40	0.10		0.40	0.09		0.41	0.11	0.44	0.10		0.41	0.10		0.46	0.09
61/60	Index	1.26	0.11		1.26	0.08		1.30	0.10	1.26	0.10		1.22	0.09		1.26	0.09
63/62	Index	0.92	0.08		0.90	0.08	≥	0.87	0.16	0.93	0.09	≫	0.87	0.07		0.89	0.08
68/65	Index	0.60	0.05	≥	0.58	0.04		0.58	0.05	0.58	0.04		0.58	0.05		0.59	0.04
69(3)/ 69(1)	Index	0.44	0.06	≥	0.42	0.05	≫	0.39	0.05	0.46	0.05		0.44	0.04	≫	0.42	0.04
69b/ 69(2)	Index	0.67	0.06	>	0.64	0.07	≫	0.63	0.08	0.69	0.08		0.69	0.07		0.68	0.09
71/70	Index	0.55	0.06		0.54	0.05	≫	0.50	0.05	0.57	0.05		0.58	0.06	≥	0.54	0.05
72	Total profile angle	83.6	3.2		83.3	3.1		84.4	3.6	82.9	2.8	>	81.3	3.4		82.7	2.5
73	Nasal prof ile angle	93.0	2.8		92.4	3.1		92.8	4.0	91.8	2.3	≫	89.1	5.8		91.8	3.0
74	Alveolar profile angle	66.4	5.1		64.8	6.3		67.5	6.7	63.9	4.7		62.8	6.2		64.3	5.2
75	Profile angle of nasal bone	64.8	5.7		63.4	6.0	>	62.2	5.5	68.4	4.9	≫	65.1	5.1	≫	64.7	5.0
79	Mandibular angle	124.0	6.2		124.5	6.9	≤	126.5	6.9	123.7	4.9	<	126.5	6.8	≤	129.6	7.2

"＜" and "≪" mean the results of the Dunnett's test or the Steel's test for multiple comparison between "Early Edo" group and "Hayaoke" or "Kamekan" respectively

"＜" means $P<0.05$ and "≪" means $P<0.01$ respectively.

The means with under bar indicate that the normal distribution of its variable is denied with the Sapiro-Wilk test.

The signs of inequality with under bar indicate that these tests were performed by the Steel's test.

Results

Table 2 shows the descriptive statistics of cranial variables of the early Edo period people, the middle-late Edo period people buried in "*Hayaoke*" (the townsmen), and the middle-late Edo period people buried in "*Kamekan*" (the lower-middle-class samurai). Figure 1 shows the relative deviation curve of all liner variables based on means of the early Edo period people. In males, only 5 variables showed statistically significant differences between the early Edo period people and the middle-late "*Hayaoke*" Edo period people, and 4 of the 5 variables were related to the mandible (bigonial breadth, two mandibular body breadths, and height of mandibular ramus). On the contrary, there are 21 variables showing statistically significant differences between the early Edo period people and the middle-late "*Kamekan*" Edo period people. These variables

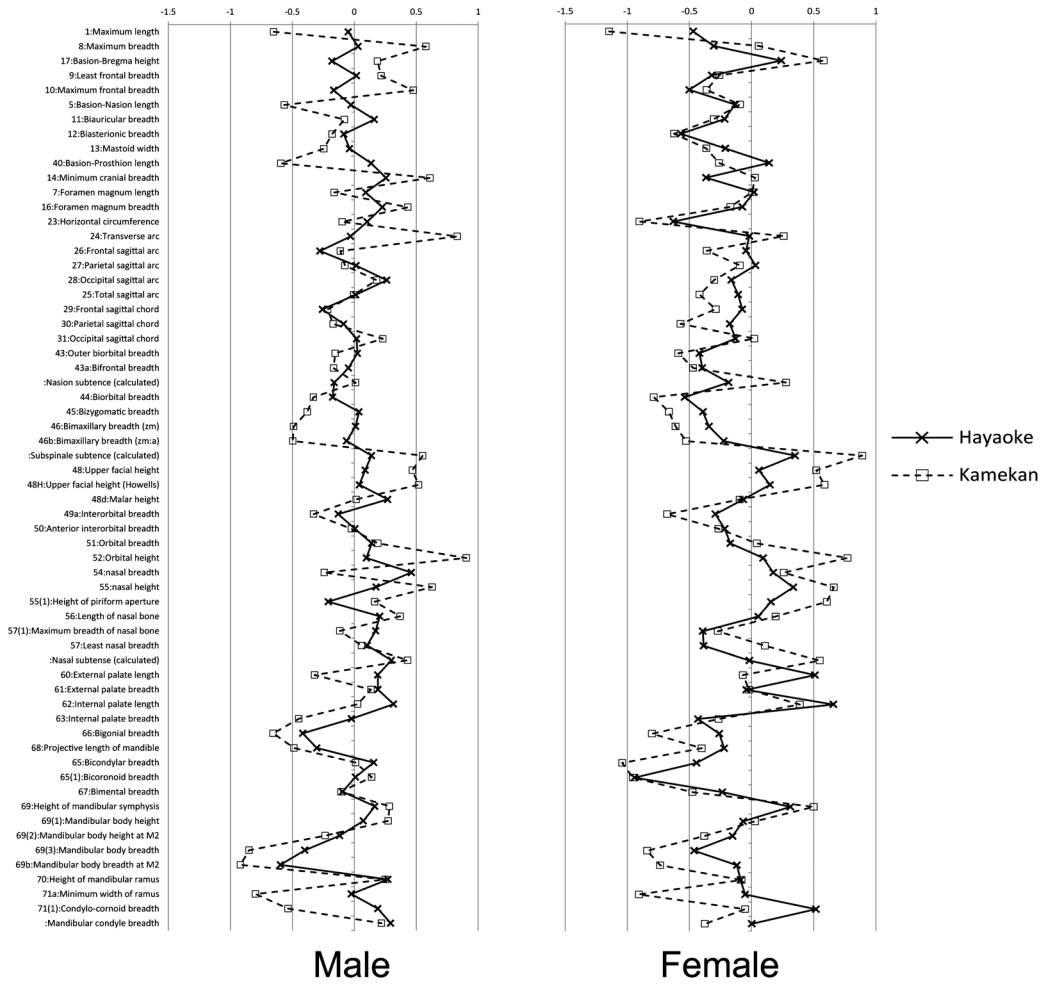

Fig. 1. The relative deviation curve of all liner variables based on means of the early Edo period.

were almost the same as those showing statistically significant differences between the "*Hayaoke*" group and "*Kamekan*" group (Sakaue, 2012). In females, 7 variables (maximum frontal breadth, biasteric breadth, horizontal circumference, biorbital breadth, internal palate length, bicoronoid breadth, and condylo-cornoid breadth) showed statistically significant differences between the early Edo period people and the middle-late "*Hayaoke*" Edo period people. As seen in Figure 1, many variables of the early Edo period people (47 out of 62 variables) tend to be larger than those of the middle-late "*Hayaoke*" Edo period females. Likewise in males, the variables showing statistically significant differences between the early Edo period people and the middle-late "*Kamekan*" Edo period people resembled those between the "*Hayaoke*" group and "*Kamekan*" group.

Table 3. Results of Wilk's lambda between the early Edo and the middle-late "*Hayaoke*" Edo or the middle-late "*Kamekan*" Edo

	Male		Female	
	Hayaoke	Kamekan	Hayaoke	Kamekan
Wilks' λ	0.586	0.270	0.406	0.113
p-Value	0.002	0.001	0.130	0.000

The Wilks' lambdas and their probabilities are in Table 3. Statistically significant differences of the 47 variables existed between the early Edo

period people and the middle-late "*Hayaoke*" Edo period males, and between the early Edo period people and the middle-late "*Kamekan*" Edo period people of both sexes, but there were no statistically significant differences between the early Edo period people and the middle-late "*Hayaoke*" Edo period females.

The scatter plots of the second and third principal component scores are presented in Figure 2 for males and Figure 3 for females. In this analysis, the second principal component was interpreted as the relationship among calvarial breadth, orbital height, and sagittal diameter of the facial structure, and the third principal component was interpreted as the relationship among facial flatness and the heights of the orbit and nose (Sakaue, 2012). The letters in these plots correspond to the photographs in Figure 4 for males and Figure 5 for females. In these plots, most of the early Edo period people are scattered within the standard deviation ellipse of the middle-late "*Hayaoke*" Edo period people of both sexes. Therefore, it was difficult to classify the early Edo period people and the middle-late "*Hayaoke*" Edo period people with these characteristics; conversely, the "*Hayaoke*" group, the "*Kamekan*" group, and the higher-class samurai group (including shogun's wives "*Ooku*" and territorial lords "*Daimyo*") of the middle-late Edo period were easily classifiable.

Table 4 shows the results of the principal component analysis with 12 mandibular variables of middle-late Edo period males. The first principal component, accounting for 29.1% of the total variance, has relatively high loading values for all measurements. Therefore, this component can be interpreted as indicating total mandibular size. The second principal component can be interpreted as indicating the relationship between mandibular breadth and mandibular size in sagit-

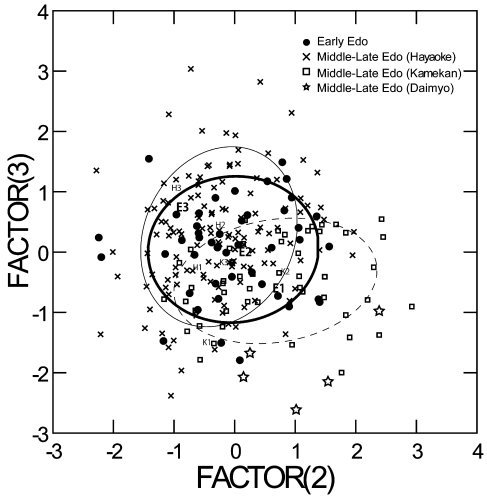

Fig. 2. Plot of the second and third principal component scores of males.
The ellipses represent the 68.27% confidence interval for the early Edo period (thick line), the middle-late "*Hayaoke*" Edo period (thin line), and the middle-late "*Kamekan*" Edo period (dash line). The letters in the plot correspond to those of Figure 4. "E", "H", and "K" correspond to "Early Edo", "*Hayaoke*", and "*Kamekan*", respectively. The measurements of the higher-class samurai (Daimyo) were done with elaborative casts (Sakaue, 2012).

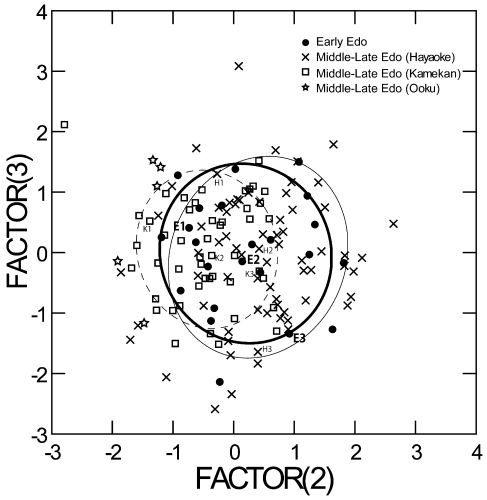

Fig. 3. Plot of the second and third principal component scores of females.
The ellipses represent the 68.27% confidence interval for the early Edo period (thick line), the middle-late "*Hayaoke*" Edo period (thin line), and the middle-late "*Kamekan*" Edo period (dash line). The letters in the plot correspond to those of Figure 5. The measurements of the higher-class samurai (Ooku) were done with elaborative casts (Sakaue, 2012).

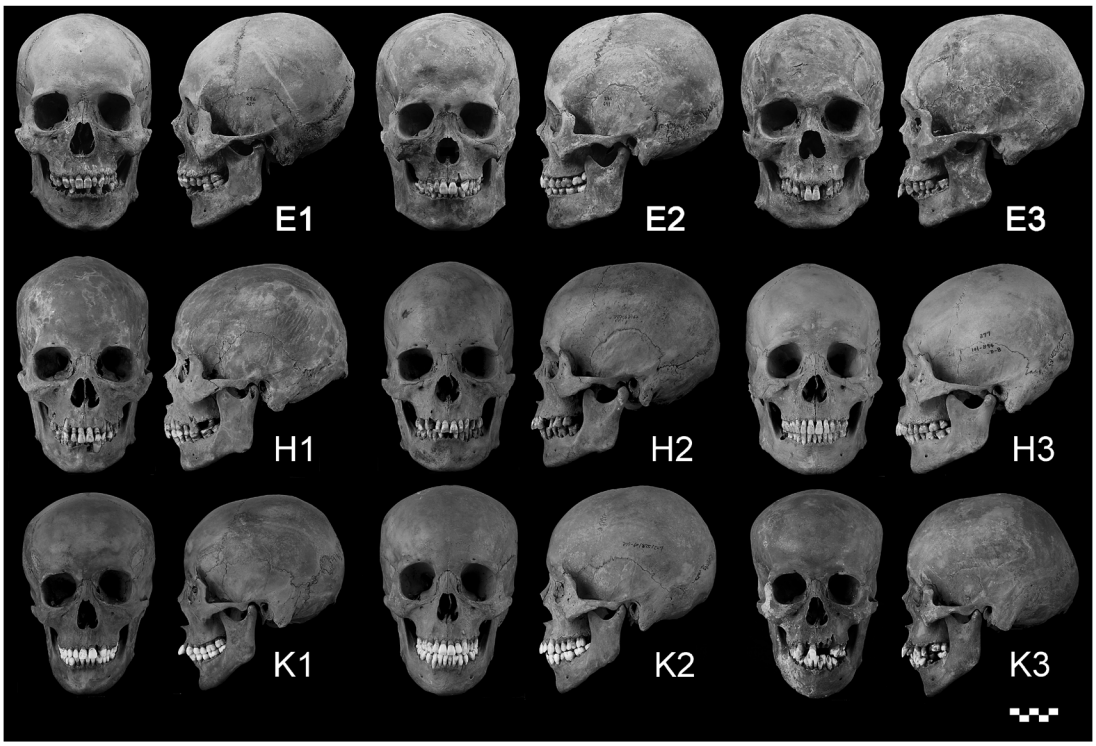

Fig. 4. Male examples of each group. The letters correspond to those of Figure 1. "E" corresponds to early Edo period, "H" corresponds to middle-late "*Hayaoke*" Edo period, and "K" corresponds to middle-late "*Kamekan*" Edo period. The numbers after letters within ellipses correspond to the following: "1" is "having features of a samurai; "2" is "the closest to the centroid of ellipse"; "3" is "having features of a townsman"

tal direction. The third principal component can be interpreted as mandibular body size. Table 5 shows the results of the principal component analysis with 12 mandibular variables of middle-late Edo period females. As in males, the first principal component can be seen as the total size of the mandible. For the second principal component, the breadth between coronoid processes correlates with the variables mandibular body height and sagittal diameter of the mandible. The third principal component can be interpreted as indicating the relationship between mandibular body size and mandibular breadth.

The scatter plots of the first and third principal component scores of mandibular variables are presented in Figure 6 for males and Figure 7 for females. Component scores of the early Edo period people were calculated by their coefficients. In these plots, the distributions of the samples of each group may indicate the morphological cline from the early Edo period specimens to the "higher class" specimens ("star" in these plots) with some overlapping in both sexes. This result indicates that the whole size of the mandible and mandibular body size may show secular changes from the early Edo period to the middle-late Edo period.

Discussion

This study revealed that the craniofacial morphology of the early Edo period is similar to that of the middle-late "*Hayaoke*" Edo period, but apparently different from that of the middle-late "*Kamekan*" Edo period in both sexes. In addition, the early Edo period people had somewhat stouter mandibles than the middle-late "*Hayaoke*" Edo period males, and the early Edo period

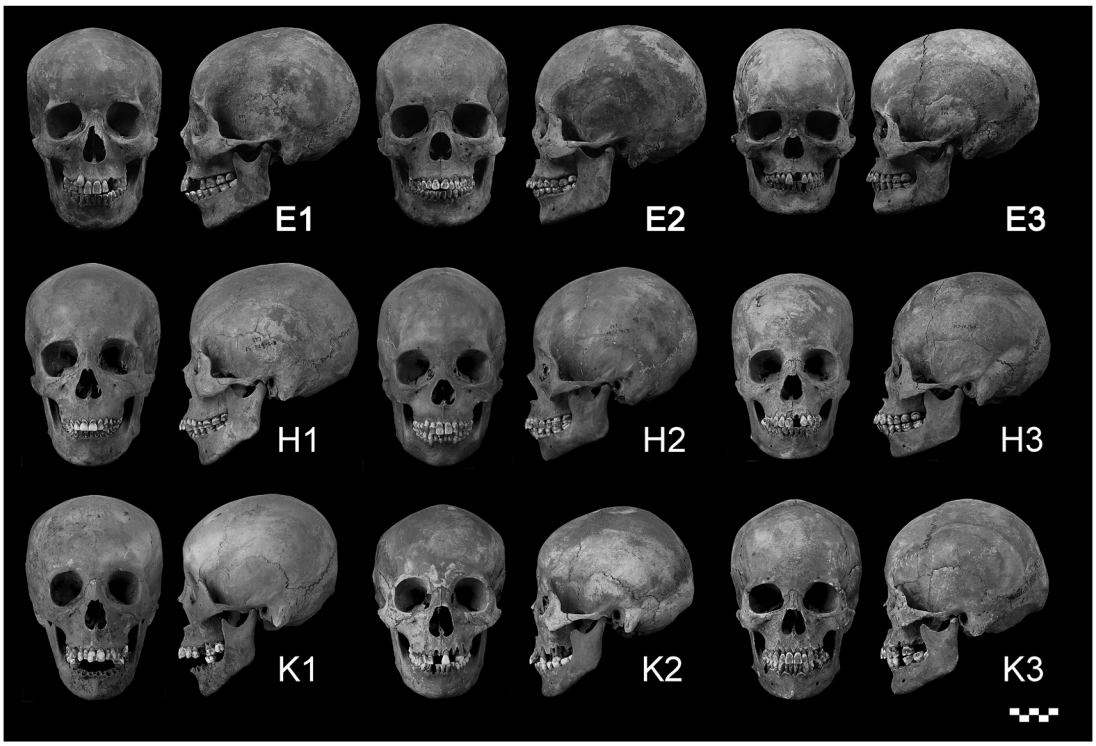

Fig. 5. Female examples of each group. The letters correspond to those of Figure 1. "E" corresponds to early Edo period, "H" corresponds to middle-late "*Hayaoke*" Edo period, and "K" corresponds to middle-late "*Kamekan*" Edo period.
The numbers after letters within ellipses correspond to the following: "1" is "having features of a samurai; "2" is "the closest to the centroid of ellipse"; "3" is "having features of a townsman"

Table 4. Results of principapal component analysis with 12 mandibular variables of the middle-late Edo male.

Martin No.	Variables	1	2	3	4
66	Bigonial breadth	**0.495**	**0.385**	0.276	0.277
68	Projective length of mandible	**0.609**	−0.220	−0.057	0.037
65	Bicondylar breadth	**0.620**	**0.518**	0.103	−0.228
65(1)	Bicoronoid breadth	**0.406**	**0.725**	−0.048	0.152
67	Bimental breadth	**0.581**	0.085	0.136	**0.598**
69	Height of mandibular symphysis	**0.410**	−0.202	**−0.728**	0.263
69(1)	Mandibular body height	**0.531**	−0.228	**−0.658**	0.105
69(3)	Mandibular body breadth	**0.420**	**−0.374**	**0.474**	**0.340**
70	Height of mandibular ramus	**0.523**	0.032	−0.252	**−0.376**
71a	Minimum width of ramus	**0.684**	**−0.443**	**0.331**	−0.066
71(1)	Condylo-cornoid breadth	**0.506**	**−0.501**	0.237	**−0.386**
	Mandibular condyle breadth	**0.601**	0.298	0.014	**−0.495**
	Eigenvalues	3.49	1.77	1.53	1.25
	Percent of explained (%)	29.1	14.7	12.7	10.4

A bold number means its loading score is greater than 0.3

people had relatively larger skulls than the middle-late "*Hayaoke*" Edo period females. Thus it can be said that secular changes in cranial morphology occurred during the Edo period.

It is interesting that craniofacial morphology can change during such a short period of time.

Table 5. Results of principapal component analysis with 12 mandibular variables of the middle-late Edo female.

Martin No.	Variables	1	2	3	4
66	Bigonial breadth	**0.522**	**0.347**	**−0.367**	−0.081
68	Projective length of mandible	**0.568**	**−0.371**	0.122	−0.226
65	Bicondylar breadth	**0.699**	0.099	**−0.449**	0.263
65(1)	Bicoronoid breadth	**0.465**	**0.544**	**−0.355**	0.043
67	Bimental breadth	**0.495**	0.161	−0.082	**−0.737**
69	Height of mandibular symphysis	**0.197**	**0.519**	**0.653**	0.184
69(1)	Mandibular body height	**0.442**	**0.434**	**0.650**	0.222
69(3)	Mandibular body breadth	**0.495**	−0.084	**0.339**	**−0.416**
70	Height of mandibular ramus	**0.427**	0.213	0.174	**0.178**
71a	Minimum width of ramus	**0.607**	**−0.578**	0.207	−0.018
71(1)	Condylo-cornoid breadth	**0.464**	**−0.634**	0.239	**0.341**
	Mandibular condyle breadth	**0.529**	−0.135	**−0.477**	**0.338**
	Eigenvalues	3.07	1.85	1.81	1.19
	Percent of explained (%)	25.6	15.4	15.0	9.9

A bold number means its loading score is greater than 0.3

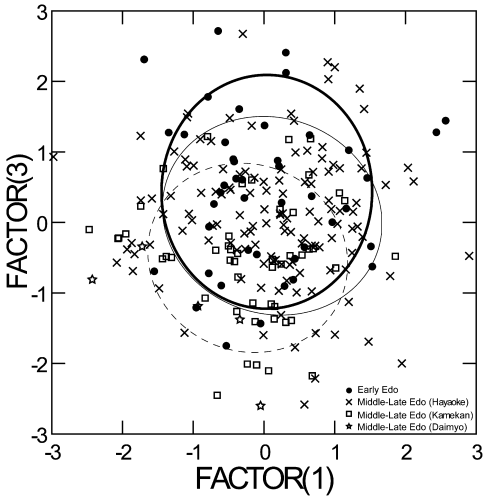

Fig. 6. Plot of the first and third principal component scores of male mandible.
The ellipses represent the 68.27% confidence interval for the early Edo period (thick line), the middle-late "*Hayaoke*" Edo period (thin line), and the middle-late "*Kamekan*" Edo period (dash line).

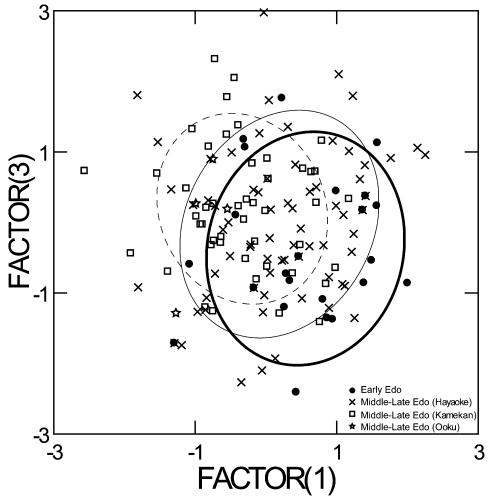

Fig. 7. Plot of the first and third principal component scores of female mandible.
The ellipses represent the 68.27% confidence interval for the early Edo period (thick line), the middle-late "*Hayaoke*" Edo period (thin line), and the middle-late "*Kamekan*" Edo period (dash line).

During the 17th century, Edo city underwent drastic changes in terms economics, logistics, labor characteristics, culture, and demographics (Kito, 2010). These changes affected the lifestyles of the common people, which might have led to variations in the morphological structure of the mandible and cranium among the Edo people.

It is questionable whether the morphological differences between the early Edo period and the middle-late "*Kamekan*" Edo period can be regarded as secular change. These differences may only reflect differences in social class, and it is difficult to determine what social class a person of the early Edo period belonged to. Unfortunately, there is presently no reliable way to deter-

mine the social class from the burial method or accessories of the early Edo period. The social status of the temple where the cemetery is located might be helpful in roughly estimating the social class of the buried people at a particular archaeological site. More samples and a new method for determining social class are needed in future studies.

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