

Morphological analysis of the skeletal remains of Japanese females from the Ikenohata-Shichikencho site

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SUMMARY The aim of this study was to assess morphological differences between early-modern (Edo) Japanese and contemporary Japanese using recently uncovered human female remains at the Ikenohata-Shichikencho site in the Tokyo urban area. In this study, 30 female skeletal remains that still retained the upper and lower first molars and central incisors were selected [early-modern (Edo) Japanese group]. Forty contemporary female Japanese were selected as a control. Analyses by standard methods of geometric morphometrics revealed some morphological differences between the early-modern (Edo) Japanese group and the contemporary Japanese group. For example, the early-modern (Edo) Japanese group exhibited bimaxillary dentoalveolar protrusion, a flat occlusal plane, and a large S–N length. On the other hand, the contemporary Japanese group exhibited slight protrusion of the anterior nasal spine. These findings may be of interest to orthodontists who are studying age variation or temporal differences and could lead to a better understanding of morphological diversity and variability.

Introduction

In Japan, there has recently been an increase in the number of ancient human skeletons discovered as a result of construction projects. Most of these archaeological sites are investigated by government or public officials who are affiliated with local universities or museums. When human remains are uncovered *in situ* at an archaeological site, important information can be obtained. However, most of the results of such studies on human remains are only published in the reports of local investigation committees and are seldom made accessible to a wider audience.

The early-modern Edo period (from 1603 to 1867) is the time in Japanese history during which the Tokugawa Shogunate governed the country. The Shogun was a hereditary commander-in-chief in feudal Japan. Due to the concentration of military power in his hands and the consequent weakness of the formal head of state (the Emperor), the shogun was generally considered to be the actual ruler of the country until feudalism was abolished in 1867. In the Edo period, the social structure was stratified, with ‘samurai’ (warriors) at the top, then farmers, technical labourers, and then merchants. Beneath the merchants were the lowest classes: i.e. ‘eta hinin’ or butchers and non-humans. The feudal capital, Edo (now Tokyo), was a major city with a population of approximately 1 million (Nagaoka, 2007). Archaeological sites of Edo in the Tokyo urban area have yielded thousands of human skeletal remains (Kajigayama and Mizoguchi, 2004). Previous investigators have studied human remains from Edo phylogenetically,

paleopathologically, and paleodemographically (Suzuki, 1978; Nagaoka, 2003). A morphological analysis of early-modern (Edo) skeletons can throw light on not only the morphology and size of people who lived during that time but also on the trends in early-modern (Edo) Japanese morphology and morphological variation in contemporary Japanese.

The morphological characteristics of patients are important for diagnosis and treatment planning in orthodontics (Profit, 2000). Furthermore, a comparison of the morphological characteristics of early-modern (Edo) Japanese to those of contemporary one may provide important information regarding age variation or temporal differences, which could lead to a better understanding of morphological diversity and variability. Secular trends in the facial skull have been of considerable interest in orthodontics (Smith *et al.*, 1986). Jonke *et al.* (2007, 2008) studied secular trends with regard to environmental effects and also noted that there were implications for orthodontists interested in growth trends or growth prediction in ethnically mixed patient samples. A previous study reported that the frequency of malocclusion was increased since medieval times (Evensen and Ogaard, 2007). In addition, the secular increases in malocclusion frequency seem to have accelerated in modern industrial societies during the last 150 years (Corruccini, 1984; Weiland *et al.*, 1997). Since the morphological characteristic is closely related to the malocclusion, clarifying the secular change in the facial morphology during last couple of 100 years may

also provide helpful information regarding the prevalence of malocclusion to approach the subject from a different angle.

The aim of this investigation was to study the morphological differences between early-modern (Edo) Japanese and contemporary Japanese using newly uncovered human female remains at the Ikenohata-Shichikencho site in urban Tokyo.

Material and methods

The materials used in this study were human skeletal remains from the Ikenohata-Shichikencho site. The Ikenohata-Shichikencho site is located in Taito-ku, Tokyo, Japan, and excavated between 1993 and 1995, uncovering about 600 graves that were from the late 17th to the 19th centuries (Nagaoka, 2007). The graves belong to samurai and townsmen because they contained ceramic and wooden coffins, which were used for samurai and commoners, respectively (Omata, 1997). The remains are stored at the Department of Anthropology, National Museum of Nature and Science, Tokyo. In this study, 30 female skeletal remains that still retained their upper and lower first molars and central incisors were used because we could thereby assess molar and incisor relationships (Figure 1). Several of the skeletal remains did not have molars or incisors due to decomposition and burial practices and some had clearly lost their molars and incisors due to antemortem periodontal disease. Gender was determined based on a macroscopic assessment of pelvic features: ventral arc, subpubic concavity, medial aspect of the ischiopubic ramus, greater sciatic notch, preauricular sulcus, composite arch, inferior pelvis, and ischiopubic proportion (Phenice, 1969; Bruzek, 2002). Age-at-death was estimated based on the articular surface of the ilium (Lovejoy *et al.*, 1985). Fifteen individuals were less than 30 years of age, 14 were 30–39 years old, and 1 was age 40–49 years. A standard lateral cephalometric radiograph was made of each individual with the teeth in centric occlusion using the same cephalostat (CEPHASTAR; Kinki Roentgen, Kyoto, Japan; Figure 2). Each skull was held using ear posts and a posterior rod and in some cases, another support was required (an anterior rod; Figure 2). Before a lateral cephalometric radiograph was taken, the skull and mandible were positioned together using thermoplastic cement.

Forty female subjects who visited the orthodontic clinic, Health Sciences University of Hokkaido, Hokkaido, Japan, were selected as a control. Before starting this study, all the subjects were informed of the experimental protocols and signed an informed consent form that was approved by the Institutional Review Board. The subjects' rights were protected at all times. The selection criteria were a full complement of permanent teeth, small to moderate arch length discrepancies (less than -5.0 mm), no apparent craniofacial deformities, and no history of dental or orthodontic treatment. All the control subjects were born

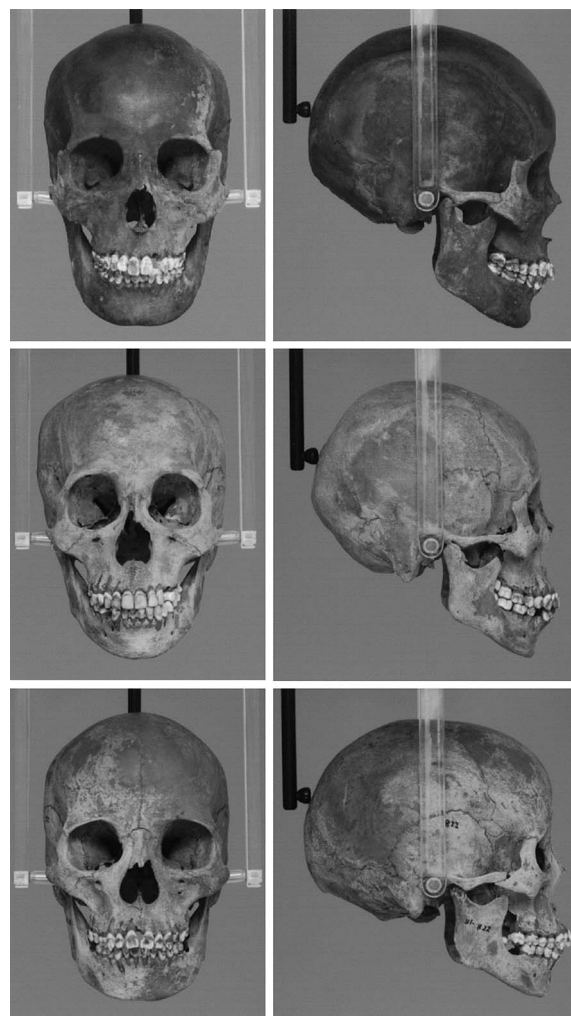


Figure 1 Photographs of three female skeletal remains from the Ikenohata-Shichikencho site. All samples used in this study had retained their upper and lower first molars and central incisors, with which we were able to assess molar and incisor relationships.

after 1970. To create an age-matched control group, the subjects were prospectively selected. Thirty subjects were less than 30 years of age and 10 were 30–39 years old. The mean age of these subjects was 24.92 years (range: 19.08–36.83 years).

All cephalometric radiographs were traced and digitized by the same investigator (KH). Sixteen landmarks were registered using a cephalometric system at the Health Sciences University of Hokkaido (Ogasawara *et al.*, 1989). The landmarks and reference planes are defined in Figure 3. Errors in landmark identification were estimated by examining the duplicate tracings of 15 randomly selected subjects that were made 15 days after the originals. Intra-observer reproducibility was evaluated by the intra-class correlation (ICC) and the standard deviation of measurement error (SDME). ICC was estimated by the between-subject variance divided by the sum of the two components. SDME



Figure 2 An example of a lateral cephalogram used in this study. Such a standard lateral cephalometric radiograph was obtained for each skull with the teeth in centric occlusion.

was estimated by the square root of the within-subject component.

Shape differences were quantitatively assessed using a principal component analysis (PCA) of Procrustes scaled shape variables and quantitatively assessed using a thin-plate spline in morphologica (O'Higgins and Jones, 1998). To assess the relationship between size and shape variables, individual principal component (PC) scores were regressed against centroid values derived from the coordinate landmarks. Student's *t*-test with a significance level of 5 per cent was used for comparison followed by the Kolmogorov–Smirnov test and the homogeneity of variances with the *F*-test. All statistical analyses were performed using the SAS statistical software package (version 8; SAS Institute, Inc., Cary, North Carolina, USA).

Results

The results of the geometric morphometrics analysis revealed a clear difference in craniomandibular shape between the early-modern (Edo) Japanese group and the contemporary Japanese group. The distribution of Procrustes shape coordinates is shown in Figure 4a. The average shapes of the early-modern (Edo) Japanese group and the contemporary Japanese group are shown in Figure 4b, which indicates that the differences were minor and located in some parts of the facial cranium.

PCA produced 28 PCs of shape for the 16 data points (landmarks). For the purpose of this study, the first seven PCs, which accounted for approximately 80 per cent of the

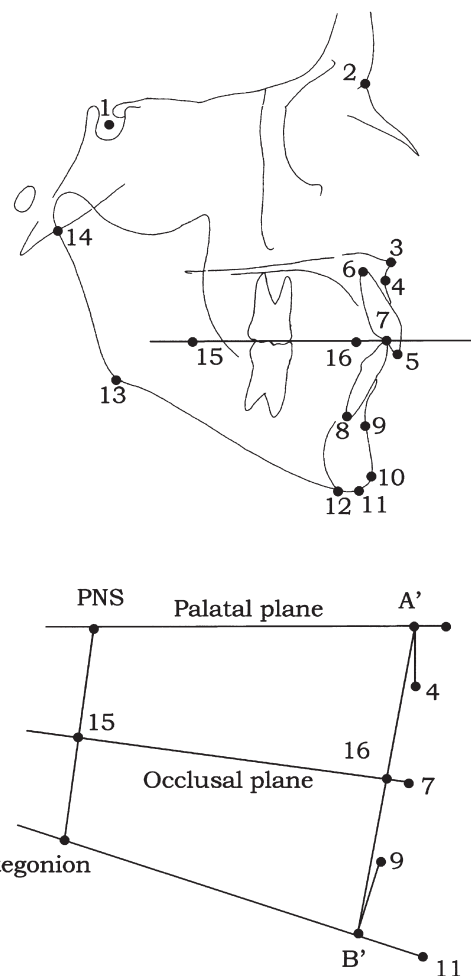


Figure 3 Anatomic landmarks used in this study. 1, sella turcica (S); 2, nasion (N); 3, anterior nasal spine (ANS); 4, point A (A); 5, incisal tip of the maxillary central incisor (U1); 6, root tip of the maxillary central incisor (UIA); 7, incisal tip of the mandibular central incisor (LI1); 8, root tip of lower incisor (LIA); 9, point B (B); 10, pogonion (Pog); 11, gnathion (Gn); 12, menton (Me); 13, gonion (Go); 14, articulare (Ar); 15, posterior occlusal point (POP); 16, anterior occlusal point (AOP).

total variance, were retained (Table 1). Student's *t*-test showed that the components that differed significantly were PC2 and PC4 (Table 2). PC2, which explained 14.9 per cent of the variation in the sample, separated the early-modern (Edo) Japanese group from the contemporary Japanese group. With respect to the mid-sagittal plane, there were some morphological differences between the early-modern (Edo) Japanese group and the contemporary Japanese group along PC2. Figure 5a shows thin-plate splines, which demonstrate the effect of PC2 on the average shape by warping the average shape (middle) by 2 SDs of the PC. The early-modern (Edo) Japanese group exhibited bimaxillary dentoalveolar protrusion, a flat occlusal plane, and a large S–N length. On the other hand, the contemporary Japanese group exhibited slight protrusion of the anterior nasal spine (ANS). In a preliminary study, the average value of the maximum head length in the early-modern (Edo)

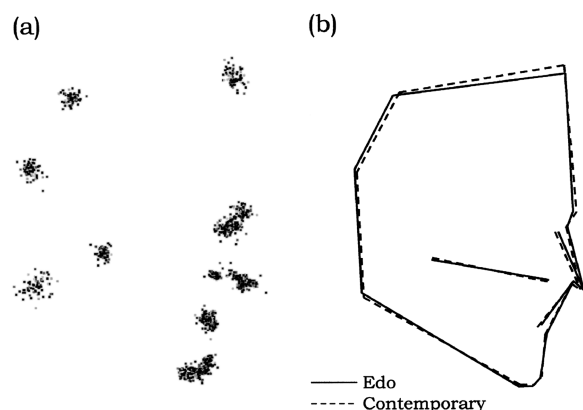


Figure 4 a) Conventional scatter plots of Procrustes shape coordinates for the full data. (b) The average shape in the early-modern (Edo) Japanese group (solid line) and the contemporary Japanese group (dashed line).

Table 1 Percentage variance and cumulative variance explained by the first seven principal components (PCs).

PC	Variance (%)	Cumulative variance (%)
PC1	28.3	28.3
PC2	14.9	43.2
PC3	12.7	55.9
PC4	8.4	64.3
PC5	6.4	70.7
PC6	5.3	76.0
PC7	4.5	80.5

Table 2 Comparison of principal components (PCs) between the groups.

PC	Edo people		Contemporary people		<i>t</i> -test <i>P</i>
	Mean	SD	Mean	SD	
PC1	-0.001	0.03	0.000	0.03	0.89
PC2	0.015	0.02	-0.012	0.02	0.00*
PC3	0.006	0.02	-0.005	0.02	0.05
PC4	0.007	0.02	-0.009	0.01	0.00*
PC5	0.001	0.02	0.000	0.02	0.64
PC6	-0.003	0.02 0	0.002	0.01	0.06
PC7	0.004	0.01	-0.003	0.01	0.05

* $P < 0.05$.

Japanese group was larger than that in the contemporary Japanese group. A large N-S length in the early-modern (Edo) group suggested that this group may have tended to have dolichocephaly. PC4, which explained 8.4 per cent of the variation in the sample, also separated the early-modern (Edo) Japanese group from the contemporary Japanese group. With respect to the mid-sagittal plane, there were morphological differences between the early-modern (Edo) Japanese group and the contemporary Japanese group along

PC4. Figure 5b shows thin-plate splines that demonstrate the effect of PC4 on the average shape by warping the average shape (middle) by 2 SDs of the PC. The early-modern (Edo) Japanese group also exhibited a relatively steep mandible with an obtuse gonial angle. Allometry within the group was investigated by calculating the correlation between centroid size and the PCs. In this study, centroid size was found to be correlated with the shape coefficients in PC1 of the Edo group and PC3 of the contemporary group, but the correlation was relatively weak (Table 3).

For the two measures that were used to characterize the intra-observer error (ICC and SDME), ICCs of the coordinate values of all landmarks were over 0.99 in both groups and SDMEs were from 0.10 to 0.12 mm, which indicated that the intra-observer reliability was satisfactory.

Discussion

In this study, only 30 female skeletal remains could be used for morphological analysis, and several possible reasons, other than the selection criteria, have been advanced to explain this limitation. In Edo, there was a large gender imbalance (Mizoguchi, 1997; Nagaoka, 2007). The over-representation of males in Edo was due to gender-selective infanticide and other cultural practices (Hanley, 1997). The Ikenohata-Shichikencho samples also showed a biased gender ratio.

In this study, 40 adult subjects were selected as a control group. According to census figures in Japan, the mean age of the Japanese population in 2008 was 44 years. By comparison, younger adult subjects (mean age: 24.92 years) were selected to create an age-matched control group. This study used a control sample population from Hokkaido rather than Tokyo. It was impossible to create a control sample from Tokyo in this study because of the location of our orthodontic clinic. However, Hokkaido is the home of people who have immigrated from other areas of Japan. Thus, the sample from Hokkaido is considered to be a better representation of the average Japanese than other local areas except Tokyo. According to a study of historical census records, it has been demonstrated that females had a shorter lifespan than males in the Edo period and that females died at a median age of 20–40 years, which corresponds to their reproductive period (Kito, 2000). A previous study on the Ikenohata-Shichikencho site indicated that the median age of death of females was less than 30 years and that females had a significantly shorter lifespan than males (Kobayashi, 1967; Nagaoka, 2007).

Some research suggests that considerable differences in biological characteristics can arise when differences between social classes persist for a long time, as in the Edo period (Suzuki, 1985). Therefore, it would be desirable to identify the social class of a subject prior to a physical anthropology comparison or examination. Unfortunately, it

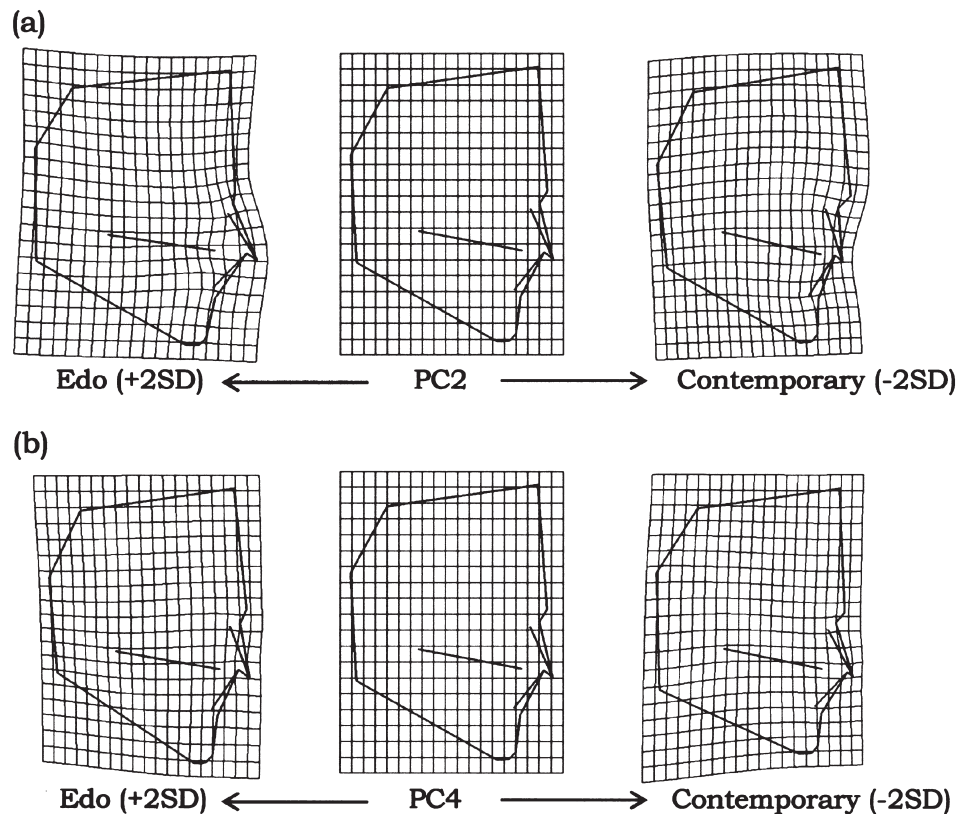


Figure 5 Thin-plate splines show the effect of principal component 2 (PC2) on the average shape by warping the average shape (middle) by 2 SDs of the PC (a) and the effect of PC4 on the average shape by warping the average shape (middle) by 2 SDs of the PC.

Table 3 Correlations between principal components (PCs) and centroid size.

PC	Edo people		Contemporary people	
	r^2	P	r^2	P
PC1	0.18*	0.02	0.00	0.68
PC2	0.01	0.72	0.00	0.93
PC3	0.04	0.25	0.26*	0.00
PC4	0.01	0.54	0.00	0.68
PC5	0.09	0.11	0.01	0.60
PC6	0.07	0.14	0.05	0.14
PC7	0.00	0.97	0.01	0.91

*Correlation significant at the 0.05 level (two tailed).

was usually impossible to identify a deceased person by a family name on a tombstone because of the small number of gravestones at the Ikenohata-Shichikencho site (in the Edo period, the family name was strongly related to the social class). However, the names of samurai family members and merchants survived tombstones that were later used differently (Mizoguchi, 1997). Using cluster analysis of male human remains, local investigative

committees reported that the morphological characteristics of human remains from the Ikenohata-Shichikencho site were similar (Mizoguchi, 1997).

The control group used in this study tended to have a skeletal Class II relationship based on cephalometric standard values used in our orthodontic clinic. This standardization set was developed more than 20 years ago using longitudinal cephalometric data obtained from people who lived in Hokkaido (Ogasawara *et al.*, 1989). In Japan, most orthodontists claim that the craniofacial morphological characteristics of Japanese have changed during the last several decades, as supported by a previous epidemiological study on the prevalence of malocclusion (Fujii *et al.*, 1997). That study reported that the occurrence of maxillary prognathism in Japan in 1996 (9 per cent) was greater than that in 1971 (5 per cent; Fujii *et al.*, 1997). Thus, the control group selected in this study, which tended to have a skeletal Class II relationship, may indeed reflect the skeletal characteristics of contemporary Japanese. In this study, the thin-plate splines illustrating PC2 demonstrate slight protrusion of the ANS point in the contemporary group (Figure 5a). However, if the clinical standard values in our orthodontic clinic were used as a control, the thin-plate splines illustrating PC2 might not demonstrate a tendency

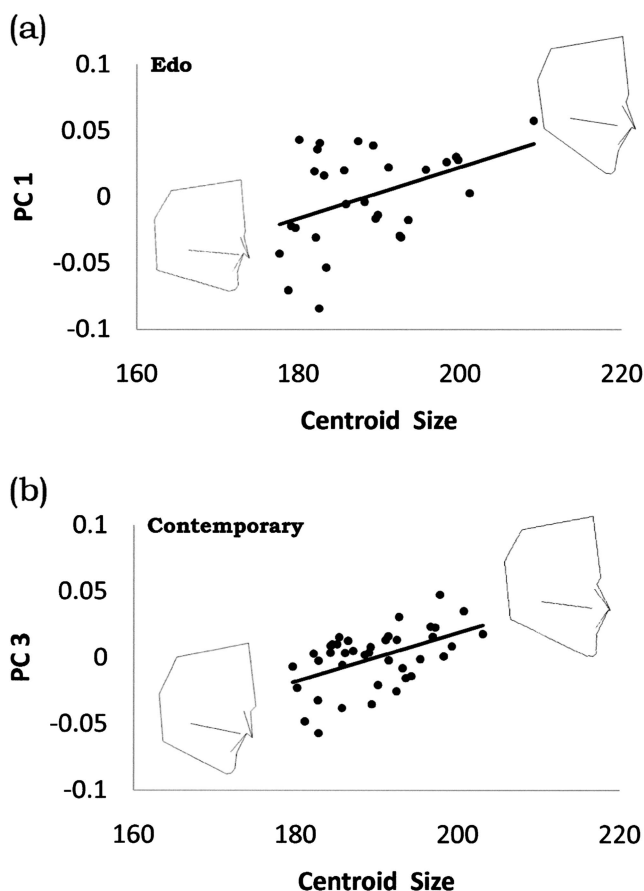


Figure 6 Scatter plot of individual principal component 1 (PC1) scores versus individual centroid size in the Edo group (a). Scatter plot of individual PC3 scores versus individual centroid size in the contemporary group (b). The shapes show the effect of PC1 and PC3 by warping the average shape, respectively.

for a skeletal Class II relationship in the control group. These findings suggest that craniofacial morphological characteristics have continued to change, and these changes could occur within several decades.

In this study, the thin-plate splines illustrating PC2 demonstrate that the early-modern (Edo) Japanese group had a low-angled occlusal plane (Figure 5a). The Wits appraisal is influenced by the occlusal plane angle (Jacobson, 1975, 1976, 1988). A small variation of the occlusal plane angle has a greater effect on the Wits measurement than of points A and B, the nasion, or the ANB angle (Del Santo, 2006). Although traditional cephalometric measurements were not performed in this study, large Wits appraisal values would be expected in the early-modern (Edo) Japanese group.

Kaifu (1999) found that there was a difference in the inter-incisal angle between Japanese in the Edo period (115 degrees) and the modern era (122 degrees). This is supported by the present study. The thin-plate splines illustrating PC2 demonstrated that the early-modern (Edo) Japanese group exhibited bimaxillary dentoalveolar protrusion (Figure 5a). A previous study found that medieval crania (especially in the

later periods of the medieval ages) from the Kanto District in Japan had dolichocephalic, chamaeprosopic, and alveolar-protrusive characteristics, which were similar to those of the Edo period (Kaifu, 2000; Nagaoka *et al.*, 2006). In this study, a large N-S length in the early-modern (Edo) Japanese group indicated that this group had dolichocephaly expected.

In this study, the early-modern (Edo) Japanese group may have been slightly older than the control group. This could account for variation in the N-S length. Behrents (1985) reported an increase of +2.0 mm in Caucasian females from age 21–30 to 31–50 years. Pecora *et al.* (2008) found that the N-S length increased by approximately 1.6 mm from age 17 to 47 years. If difference in the N-S length between the two groups in this study is due to age, the detailed mechanism remains unclear. Kaifu (1997) also found mandibular reduction with a decrease in bicondylar breadth from the Kofun (AD 300–900) to Edo periods using skeletal remains from the Kanto District of Japan. Among various possibilities, Kaifu (1997) concluded that the most likely primary cause was a reduction of chewing stress. Suzuki (1985) also found that the Edo people in the highest social class, like the Tokugawa clan and the feudal lords, had a craniofacial shape with modern Japanese-like morphological characteristics due to a reduction of chewing stress. In contrast, many ordinary Edo people had a medieval craniofacial morphology (Suzuki, 1969). Corruccini *et al.* (1983) found that younger individuals of Pima Amerinds who were raised on refined commercial foods had relatively narrower palates. Luther (1993) also found that the modern mandible has a more obtuse gonial angle compared to medieval skulls. However, Mizushima (2000) who compared the dry skulls of contemporary Japanese with the skeletal remains of Edo people did not find a reduction in the sizes of the maxilla and mandible due to a reduction of chewing stress in female data. In this study, the early-modern (Edo) Japanese group exhibited a relatively steep mandible with an obtuse gonial angle (Figure 5b), which was unexpected. The results of the present study may be due to the fact that we only used female data from the Hokkaido area as a control or to the possibility that the Edo group included people who were in a higher social class; the actual reason remains unclear.

PC1 was correlated with centroid size in the Edo females, and the coefficient of determination (r^2) was close to 18 per cent. This signifies that a size increase was associated with an acute inter-incisal angle (bimaxillary dentoalveolar protrusion) and an obtuse gonial angle in the Edo group (Figure 6a). PC3 was correlated with centroid size in contemporary females, and the coefficient of determination (r^2) was close to 26 per cent. This indicates that a size increase was associated with mandibular prognathism (Figure 6b). Sato *et al.* (1990) found that contemporary Japanese females who had skeletal Class III were taller than those who had skeletal Class I. This result may be supported by the results of the present study. However, evidently more work is required to clarify the cause and effect relationship.

Conclusions

The results of this study revealed morphological differences between early-modern (Edo) Japanese women and contemporary Japanese women using human female remains that were recently uncovered at the Ikenohata-Shichikencho site in the Tokyo urban area. The morphological changes revealed in this study may be due to not only environmental changes but also genetic variation over the past 100 years. These findings may be of interest to orthodontists who are studying age variation or temporal differences and could lead to a better understanding of morphological diversity and variability in populations as their lifestyles changes.

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References

- Behrents R G 1985 Growth in the aging craniofacial skeleton. In: Monograph No. 17, craniofacial growth series, Center of human growth and development, University of Michigan, Ann Arbor, p. 46
- Bruzek J 2002 A method for visual determination of sex using the human hip bone. *American Journal of Physical Anthropology* 117: 157–168
- Corruccini R S 1984 An epidemiologic transition in dental occlusion in world population. *American Journal of Orthodontics* 86: 419–426
- Corruccini R S, Potter R H, Dahlberg A A 1983 Changing occlusal variation in Pima Amerinds. *American Journal of Physical Anthropology* 62: 317–324
- Del Santo M Jr 2006 Influence of occlusal plane inclination on ANB and Wits assessments of anteroposterior jaw relationships. *American Journal of Orthodontics and Dentofacial Orthopedics* 129: 641–648
- Evensen J P, Ogaard B 2007 Are malocclusion more prevalent and severe now? A comparative study of medieval skulls from Norway. *American Journal of Orthodontics and Dentofacial Orthopedics* 131: 710–716
- Fujii G *et al.* 1997 Epidemiological study on prevalence of malocclusion in young population. *Journal of Hokkaido Orthodontic Society* 25: 69–75 (in Japanese)
- Hanley B S 1997 Everyday things in premodern Japan: the hidden legacy of material culture. University of California Press, Berkeley
- Jacobson A 1975 The “Wits” appraisal of jaw disharmony. *American Journal of Orthodontics* 67: 125–138
- Jacobson A 1976 Application of “Wits” appraisal. *American Journal of Orthodontics* 70: 179–189
- Jacobson A 1988 Update on the “Wits” appraisal. *Angle Orthodontist* 58: 205–219
- Jonke E, Prossinger H, Bookstein F L, Schaefer K, Bernhard M, Freudenthaler J W 2007 Secular trends in the facial skull from the 19th century to the present, analyzed with geometric morphometrics. *American Journal of Orthodontics and Dentofacial Orthopedics* 132: 63–70
- Jonke E, Prossinger H, Bookstein F L, Schaefer K, Bernhard M, Freudenthaler J W 2008 Secular trends in the European male facial skull from the Migration Period to the present: a cephalometric study. *European Journal of Orthodontics* 30: 614–620
- Kaifu Y 1997 Changes in mandibular morphology from the Jomon to modern periods in eastern Japan. *American Journal of Physical Anthropology* 104: 227–243
- Kaifu Y 1999 Changes in alveolar prognathism and anterior teeth protrusion in Japan. *Anthropological Science* 107: 3–24
- Kaifu Y 2000 Tooth wear and compensatory modification of the anterior dentoalveolar complex in humans. *American Journal of Physical Anthropology* 111: 369–392
- Kajigayama M, Mizoguchi Y 2004 Cranial and postcranial measurements of early modern Edo people from 19 archeological sites in the Tokyo urban area and suburbs. *Anthropological Science (Japanese Series)* 112: 37–57 (in Japanese with English summary)
- Kito H 2000 Jinko Kara Yomu Nihon No Rekishi. Kodansh, Tokyo (in Japanese)
- Kobayashi K 1967 Trend in the length of life based on human skeletons from prehistoric to modern times in Japan. *Journal of the Faculty of Science 2, University of Tokyo, Tokyo*, pp. 109–160
- Lovejoy C O, Meindl R S, Pryzbeck T R, Mensforth R P 1985 Chronological metamorphosis of the auricular surface of the ilium: a new method of determining adult age at death. *American Journal of Physical Anthropology* 68: 15–28
- Luther F 1993 A cephalometric comparison of medieval skulls with a modern population. *European Journal of Orthodontics* 15: 315–325
- Mizoguchi Y 1997 Ikenohata-Shichikencho Iseki. Taito-ku Ikenohata-shichikencho chousakai, Tokyo (in Japanese)
- Mizushima S 2000 Soshakuryou no genshou to kizokukeisitu no kakutoku. *Anthropological Science (Japanese series)* 108: 1–16 (in Japanese)
- Nagaoka T 2003 Secular changes in Japanese crania from the late Edo period to the modern period. *Anthropological Science* 111: 1–29
- Nagaoka T 2007 Demographic structure of the human skeletal remains from the Ikenohata-Shichikencho site, Tokyo. *Bulletin of the National Museum of Nature and Science, Series D* 33: 21–38
- Nagaoka T, Shizushima A, Sawada J, Hirata K 2006 Morphological variation of crania of the medieval period Japanese. *Anthropological Science (Japanese series)* 114: 139–150 (in Japanese with English summary)
- Ogasawara J *et al.* 1989 Assessment of dentofacial growth change using quadrilateral analysis. *Journal of Japan Orthodontic Society* 48: 329–343 (in Japanese with English summary)
- O’Higgins P, Jones N 1998 Facial growth in *Cercopithecus torquatus*: an application of three-dimensional geometric morphometric techniques to the study of morphological variation. *Journal of Anatomy* 193: 251–272
- Omata S 1997 Ikenohata-Shichikencho Iseki. Taito-ku Ikenohata-shichikencho chousakai, Tokyo (in Japanese)
- Pecora N G, Baccetti T, McNamara J A Jr 2008 The aging craniofacial complex: a longitudinal cephalometric study from late adolescence to late adulthood. *American Journal of Orthodontics and Dentofacial Orthopedics* 134: 496–505
- Phenice T W 1969 A newly developed visual method of sexing the os pubis. *American Journal of Physical Anthropology* 30: 297–301
- Profit W R 2000 Contemporary Orthodontics, 3rd edn. Mosby, St Louis
- Sato K, Jinno K, Mitani H 1990 Growth timing of standing height, mandible and hand bones in skeletal Class III females. *Tohoku University Dental Journal* 9: 65–72 (in Japanese)
- Smith B H, Garn S M, Hunter W S 1986 Secular trends in face size. *Angle Orthodontist* 56: 196–204
- Suzuki H 1969 Microevolutional change in the Japanese population from the prehistoric age to the present-day. *Journal of the Faculty of Science, University of Tokyo, Sect. V. Vol. 3. Part 4*, pp. 279–309
- Suzuki H 1978 A paleopathological study of the vertebral columns of the Japanese from Jomon to Edo periods. *Journal of Anthropological Society of Nippon* 86: 321–336 (in Japanese with English summary)
- Suzuki H 1985 Manifestation of the physical characteristics of Japanese aristocrats in the Edo era of Japan. *Journal of Anthropological Society of Nippon* 93: 1–32 (in Japanese with English summary)
- Weiland F J, Jonke E, Bantleon H P 1997 Secular trend in malocclusion in Austrian men. *European Journal of Orthodontics* 19: 355–359