Introduction

Ritual tooth ablation during the Jomon period has been long documented and intensively discussed in the fields of both physical anthropology and archaeology. Anthropologists first identified a pattern of antemortem tooth loss in the anterior dentition as a cultural behavior among the local communities; archaeologists have drawn inferences from these customs by combining osteological evidence with associated archaeological data, as well as with information from related fields such as ethnology (see Harunari, 2002; Funahashi, 2010 for reviews). Harunari (2002) proposed several hypotheses concerning the Jomon social structure on the basis of tooth extraction customs found in the Late and Final Jomon sites in western Japan, in which bilateral upper canine extraction (categorized as ‘0-type’) was assumed to be a coming-of-age ritual, and the succeeding two patterns of lower teeth extraction were a reflection of marriage. The latter two patterns, termed the ‘2C’ and ‘4I’ types, could express a distinctive identification at the time of marriage, i.e. indicating the individuals’ genealogical origins or clans (Harunari, 1973).

Harunari’s hypothesis of relationship among the tooth ablation types and their genealogical origins has been variably tested by means of anthropological approaches. Studies based on non-metric cranial traits (Mouri and Oku, 1998) or tooth crown diameters (Tanaka and Doi, 1988; Tanaka, 2001) have generally agreed that individuals with the same type of tooth ablation possibly represent relatives, but failed to discriminate distinct lineages between the 2C and 4I types. In addition, the order of tooth extraction events (initial 0-type and later 2C/4I-type tooth ablation) has been questioned, i.e. both upper and lower tooth ablation were probably performed during the same juvenile period, between the ages of 10 and 20 years (Funahashi, 2003). Recent isotope analyses revealed that the strontium isotope signals of immi-

Abstract  Ritual tooth ablation was a characteristic form of body expression for the prehistoric Jomon people. During the 2010–2013 excavation at the Hobi shell-mound site, Aichi Prefecture, Japan, a new case of secondary collective burial, banjo-shuseki-bo, was discovered, in which additional cases of ritual tooth ablation were present in human skeletal remains. Here we describe the morphology and tooth extraction status of individual mandibles, and assess the interindividual relationships on the basis of tooth crown diameter. Although a certain degree of kin relation was predicted among individuals from the new collective burial, which seems comparable to those found in modern Japanese twin pairs, almost the same degree of close kin relationship was detected in interindividual variation and in intersite variation with the neighboring Jomon sites.

Key words: ritual tooth ablation, Final Jomon period, kin relationship, tooth crown metrics, banjo-shuseki-bo
grants/locals from the human skeletal remains do not match the 2C/41 tooth ablation types, which, by contrast, coincide with temporal changes of diet (Kusaka et al., 2009, 2011, 2018).

One of the focal areas of Jomon sites for these discussions is at and around the Atsumi peninsula, Tokai region, central Japan. The peninsula contains a handful of famous Jomon sites of the Late to Final Jomon periods (c. 4400–2400 BP), of which the Hobi shell-mound site has yielded many human skeletons in several different types of burials, including a unique type of collective secondary burial, banjo-shuseki-bo, or square-shaped bone-pile burial (Habu, 2004). Recent excavations at the Hobi shell-mound site conducted by the archaeologist Yasuhiro Yamada and colleagues from 2010 to 2013 uncovered a new example of banjo-shuseki-bo and collected the human bones (referred to as Accumulation 2010).

In this material report, we document maxillae and mandibles recovered from Accumulation 2010 and describe the morphology of tooth ablations with associated tooth crown metrics.

Materials and Methods

The Hobi shell-mound site, located on the Atsumi peninsula, Aichi Prefecture, is a famous human-bearing Jomon site in central Honshu, Japan. Recent excavations in 2010–2013 uncovered a new collective burial consisting of an assemblage of human bones in which the limb bones had been placed to form a rectangular parallelogram, and was thus identifiable as a banjo-shuseki-bo (Mizushima et al., 2022).

We identified seven mandibles and five maxillae specimens from the total of more than a thousand specimens recovered from Accumulation 2010. We observed and described six mandibles and two maxillae with alveolar sockets, which are indispensable for determining whether tooth loss was ante- or postmortem. One mandible is young and immature, with the deciduous dentition. Two mandibles are associated with facial (and maxillary) fragments. The remaining three mandibles are single, and two of them were quarantined to permit chemical and ancient DNA analyses after preliminary observation at the time of recovery.

Methods to confirm ritual tooth ablation and to distinguish it from unplanned absences such as congenital or traumatic absence related to caries or periodontal disease have long been discussed (see Funahashi, 2010 for review). Ohtawa (1983) systematically described these identification methods and suggested several points to assess the chronological order of tooth removal events: a proximal shift in the position of the adjacent tooth and protrusion of the contra-occlusal tooth; no recession of the alveolar socket in an apical direction; and no approximal facet on the adjacent tooth. We identified five adults and one immature individual in the six mandibles and three sets of facial bones (Figure 1). The observations and measurements of the six mandibles and tooth crown diameters are presented in Table 1.

Description of the tooth ablation

We identified five adults and one immature individual in the six mandibles and three sets of facial bones (Figure 1). The observations and measurements of the six mandibles and tooth crown diameters are presented in Table 1.

Mandible B1284 (associated face B1174/B1175/B1328)

The mandible is associated with two bilateral zygomatic bones and the left alveolar portion of the maxilla, possibly from the same individual. No upper teeth and five lower teeth are preserved. The left alveolar portion of the maxilla retains the P2 and M1–M3 sockets. The mesial portion of the alveolar process is damaged for I1–C. However, the mesial-most socket for P2 shows clear rightward torsion of the root and a relatively wide gap to the M1 socket, which indicates mesial displacement and root rotation caused by possible antemortem tooth extraction for upper C and P1. The mandibular corpus and alveolar process are almost intact. The sex indicators of the mandible are ambiguous; the bone is moderate in size and not very robust, with a small mental eminence pointed centrally. The corpus height at the symphysis (32.5 mm) is above the female interquartile range (27–31 mm, n = 161), and the height at M2 (27.1 mm) is also above the female interquartile range (23.4–26.7 mm, n = 33), suggesting a masculine corpus. A small mandibular torus is found in the left corpus in the P2–M1 gingival area. The alveolar corpus preserves the right M2 and the left I1 and M1–M3 teeth. They do not exhibit caries. Tooth wear is flat and moderate, with point- to small-sized patches of dentin exposure seen separately at each molar cusp. The tooth socket is closed at the right C–P1 and the left C–P1 positions, and the intersocket distance of I2–P2 becomes short, with the P2 socket showing a degree of root torsion. This individual manifests 2C type tooth ablation.
Mandible B1038 (associated face B1033)

These mandibular and maxillary fragments are identified as a single individual on the basis of both close in situ positions and well-fitting occlusion between the preserved tooth rows. The maxillary fragment retains the right P2–M3 teeth and the isolated left M2, the wear of which is almost flat and moderate. Caries was detected both at the occlusal and neck portions of M2–M3; in addition, the crown rims of right M3

Table 1. Mandibles and tooth crown diameters (mm) from the collective burial discovered in 2010–2013 at the Hobi shell-mound site

|       | M3 | M2 | M1 | P2 | P1 | C  | I2 | I1 | I2 | C  | P1 | P2 | M1 | M2 | M3 |
|-------|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|
| B1284 (male?) | Tooth socket | op | op | op | cl | op | op | op | op | op | op | op | op | op | op |
|       | MD  | 9.9 | 10.0 | 9.9 | 11.0 | 5.0 | 6.1 | (10.6) | 9.9 | 11.0 |
| B1038 (male) | Tooth socket | op | op | br | cl | cl | op | op | ? | ? | ? | ? | ? | ? | ? |
|       | MD  | 9.6 | 9.7 | 10.6 | 9.6 | 10.6 | 10.6 | 10.6 | 10.6 | 10.6 | 10.6 | 10.6 | 10.6 | 10.6 | 10.6 |
| B1123 (male) | Tooth socket | op | op | op | cl | cl | cl | cl | op | op | cl | cl | cl | cl | cl |
|       | MD  | 10.8 | 6.9 | 7.1 | 7.1 | 7.1 | 7.1 | 7.1 | 7.1 | 7.1 | 7.1 | 7.1 | 7.1 | 7.1 | 7.1 |
| B136 (male) | Tooth socket | op | op | op | cl | cl | ? | ? | ? | ? | ? | ? | ? | ? | ? |
|       | MD  | 10.2 | 10.2 | 11.3 | 7.3 | 7.3 | 7.3 | 7.3 | 7.3 | 7.3 | 7.3 | 7.3 | 7.3 | 7.3 | 7.3 |
| B221 (?) | Tooth socket | op | op | op | cl | cl | ? | ? | ? | ? | ? | ? | ? | ? | ? |
|       | MD  | 6.8 | 6.8 | 6.8 | 6.8 | 6.8 | 6.8 | 6.8 | 6.8 | 6.8 | 6.8 | 6.8 | 6.8 | 6.8 | 6.8 |
|       | BL  | 8.1 | 8.1 | 8.1 | 8.1 | 8.1 | 8.1 | 8.1 | 8.1 | 8.1 | 8.1 | 8.1 | 8.1 | 8.1 | 8.1 | 8.1 |

Tooth: ○, crown present; br, broken crown or root.
Socket: op, open; cl, close; br, broken; ?, unobservable; /, missing.
Mandible B1123
The mandible lacks the right ramus, but retains all the corpus and the left ramus. It is large in size and massive, with a developed mental eminence. The ramus height (72.6 mm) exceeds the range of Jomon females (43–69 mm, \( n = 144 \)) and the symphysis corpus height (35 mm) falls near the upper range of Jomon females (15–36 mm, \( n = 161 \)). These values indicate this mandible to be that of a male. The following teeth are anchored in the alveolar process: M2, P2 on the right and I1, P2–M3 on the left. The nearly flat wear is moderate with a few dentin patches uniting together on the molar occlusal surfaces. A large caries is seen in the distolingual portion of the left M1 crown. A round swelling of the mandibular torus is seen in both sides of the inner wall (P1–P2 area) of the corpus. The anterior alveolar portion shows only three incisors, of which two root sockets are open, and the remaining relatively large gaps provide room for antemortem tooth extraction of the right I2–C–P1 and the left C–P1, respectively. This individual also displays 2C type ablation.

Mandible B136
The large-sized mandible, lacking only the left ramus process, possesses a developed mental eminence and everted gonial angles. The bigonial breadth (117 mm) falls within the upper first quartile range of Jomon males (range = 82–126 mm, \( n = 194 \)) and exceeds the range of Jomon females (range = 75–115 mm, \( n = 144 \)), thus indicating this individual to be a male. The mandibular corpus preserves P2, M1–M3 teeth in both sides of the socket. The bottom of the corpus is straight and a weak degree of mandibular torus occurs on the inner wall of M1. The wear is flat and moderate, with small, isolated dentin patches, indicating a relatively young adult age at death of this individual. C–P1 teeth were bilaterally extracted before death. The other anterior teeth (I1–I2s) are missing, and their socket status is obscure but open in the left I1–I2. The type of tooth ablation appears to be 2C.

Mandible B221
The sex is ambiguous because this specimen is moderate in size and the corpus is not so robust with a less demarcated chin. The specimen preserves only three teeth: P2 on the right, and P1 and M1 on the left. The wear is a little advanced on M1 but weak on P1–P2. The sockets for the right C–P1 are closed, indicating the teeth were seemingly extracted before death. That for the left C is closed but the P1 is still present in the socket. The incisor portion is unobservable because of attached matrix. This individual also exhibits 2C type tooth ablation.

Mandible B813
This specimen is an immature mandible with only deciduous teeth dm1 and dm2 erupted and M1/M2 still embedded in the alveolus. The age of this specimen is under 6 years, and probably 2–5 years old. The wear of these deciduous molars is minimal. Both sides of the di–dc sockets are all open, indicating no antemortem tooth extraction at around the age of this child individual.

Interindividual distances based on crown metrics
We measured MD and BL diameters of the survived mandibular tooth crowns with an accuracy of 0.1 mm (Table 1). As a result of the secondary burial situation and antemortem ablation of the anterior dentition, measurable teeth were not abundant; thus, we were obliged to use as many crown measurements as possible, irrespective of the variable degree of efficiency for each tooth crown measurement as a heritable trait (Doi et al., 1986). First, we compared interindividual pairs of Accumulation 2010 and those of modern Japanese MZ and DZ twin pairs. We were limited to only three crown metrics, namely MD and BL diameters of the second premolar and BL diameter of the first molar, because most of the twin pairs were children and thus had not yet erupted their second molars (M2). When we compare the Euclidean distances between three pairs from Accumulation 2010 and those of MZ and DZ twin pairs, the three Accumulation 2010 pairs fall within the range of MZ and DZ variation. Two of the Accumulation 2010 pairs are smaller, and fall into the interquartile range of MZ, and the smallest pair is below the interquartile range of DZ, suggesting a plausible close kinship among these pairs (Figure 2).

Next, we changed the comparative group to the neighboring four Jomon sites in the Tokai region. These sites (Ikawazu, Inariyama, Yoshigo, and Hobi) all fall within the local Mikawa region in Aichi Prefecture, and belong to almost the same time range of the Late to Final Jomon period. Interindividual distances were compared between the pairs from Accumulation 2010 and those of each site. We used three crown metrics in the PC score calculation: BL of the first molar and MD and BL of the second molar, for which data for four individuals from Accumulation 2010 were available (Figure 3). The calculated distances for all six pairs are within the range of variation of the within-site pairs. The three smallest pairs exhibit values lower than the median for each
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Jomon site, and the smallest pair (B1284–B136) is below all the interquartile ranges. Interindividual and intersite relationships can be detected in the two-dimensional plot of PC1 and PC2 (Figure 4), in which the four individuals from Accumulation 2010 do not plot close together, but are dispersed among the wide range of all the individual variation. In addition, there is comingling of intra- and inter-site variation, i.e. site-specific isolation is unclear, as had already been found for a larger number of tooth crown metrics (Matsumura, 2000).

These two comparisons using mandibular tooth crown diameter yielded uncertain results. The comparison of pairwise distances from the new collective burial at the Hobi site (Accumulation 2010) with those of MZ and DZ twin pairs indicates possible close kin relationships among the observed pairs of Accumulation 2010, at least with the same degree found in the MZ and DZ twin pairs. In contrast, in the intra- and intersite comparison of the neighboring Jomon sites, the pairwise distances of the new burial are almost comparable to those of the intrasite pairs and to those of the intersite variation of the neighboring Jomon sites. These contrasting results may have been caused by several factors, one of which is low effectiveness of the available crown metrics. In the present comparisons, we used only three tooth crown metrics, which may be too few and thus ineffective for determining a degree of close kin relationship (Doi et al., 1986). The other factor is plausible high consanguinity among regionally local Jomon sites, which has been suggested on the basis of intra- and interregional morphological variation such as cranial metrics and dental non-metric traits (Kondo, 1994; Matsumura, 2007).

All the observed examples of tooth ablation were identified as type 2C on the basis of the criteria of Harunari (1973), and all the diagnosable specimens were sexed as male. A previous study of ritual tooth ablation from square-shaped bone-pile burials reported male dominance and 2C-type tooth ablation among nine identifiable specimens (Harunari, 2013). Our finding of the new examples with type 2C tooth ablation strengthens the male and 2C-type dominance in this special type of burial. The implications of this finding, however, will remain unclear until several key issues have been resolved, such as clear kinship recognition based on ancient DNA analyses, clarification of chronological and/or environmental specification based on chemical analyses, and intensive assessment of tooth ablation in terms of the behavioral norms of the Jomon people.

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