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Isotopic evidence of breastfeeding and weaning practices in a hunter–gatherer population during the Late/Final Jomon period in eastern Japan

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ABSTRACT

Jomon hunter–gatherers in Japan commonly show Neolithic characteristics, such as intensive utilization of potteries, grinding stones, and many plant food sources. In this study, breastfeeding and weaning practices in a Jomon hunter–gatherer population are investigated to evaluate two hypotheses concerning the relations between utilization of potteries/plant foods and early weaning and children's diet around and after the weaning process. Stable carbon and nitrogen isotope ratios were investigated for 46 subadult and 47 adult human skeletons excavated from the Yoshigo site of the Late/Final Jomon period (approximately 4000–2300 years BP) in eastern Japan. A new analytical procedure was developed and residuals of nitrogen isotope ratios were calculated to cancel out the effect of positive correlation in the carbon and nitrogen isotope ratios. Age changes in the residuals showed that the age at the end of weaning in the Yoshigo population was 3.5 years (2.3–5.5 years in 95% credible interval), which is not younger than that in typical non-industrialized populations and the other skeletal hunter–gatherer populations. Furthermore, most infants were probably weaned using a combination of the same food sources as those eaten by adults. These results suggest that the utilization of pottery and plant food *per se* is not a sole determinant of the age at the end of weaning in past human populations, and a special diet was not always applied during and just after the weaning process.

1. Introduction

1.1. Breastfeeding and weaning in hunter–gatherers

Breastfeeding and weaning practices in past hunter–gatherer populations are of interest in anthropology and archaeology for the two reasons. First, the relationships between weaning ages and subsistence transition in Neolithic cultures have only been hypothesized. The age at the end of weaning can provide an indication of fertility in past human populations. Resumption of ovarian activity is suppressed during the period of breastfeeding because of the hormonal changes and nutritional costs of lactation, especially in populations with poor nutrient status (Valeggia and Ellison, 2009; Wood, 1994). Therefore, a later age at the end of weaning is related to longer interbirth intervals and thus lower fertility in the population. Agricultural populations in the Holocene typically experienced higher fertility than hunter–gatherer populations worldwide (e.g., Bocquet-Appel, 2002; Gage and DeWitte, 2009; Kohler and Reese, 2014). There is a hypothesis that the utilization of plant crops and potteries for boiling in Neolithic cultures increased the availability of suitable weaning foods, and these changes led to an earlier age at the end of weaning and resulting shorter interbirth intervals and higher fertility (Buikstra et al., 1986; Larsen, 1995; Molleson et al., 1993). Similar hypotheses have also been put forward to explain the difference in fertility between relatively recent agricultural and hunting–gathering populations

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(Helle et al., 2014; Kolata, 1974).

Second, weaning foods seem to be important from a perspective of the evolution of human life history. While the age at the end of weaning is relatively younger for humans than that for great apes, human children still depend on older individuals for their feeding and safety, in contrast to other primates, such as non-human great apes (Bogin, 1997; Bogin and Smith, 1996; Hawkes et al., 1998). Around and just after the weaning process, it is hypothesized that human children were provisioned with specially chosen and prepared foods owing to their immature dentitions, digestive systems, and foraging skills; this allowed the weaning process to end at an earlier age, without increasing the subadult mortality rate (Bogin, 1997; Bogin and Smith, 1996; Humphrey, 2010; Kaplan et al., 2000).

A detailed study of infant feeding practices in past hunter–gatherer populations is necessary to evaluate these hypotheses. A meta-analysis of ethnographic descriptions indicated that the age at the end of weaning was younger in populations that depended more on agriculture and weaning foods tended to comprise starchy foods in general although meat, fish, and fruits were also used in a higher proportion by hunter–gatherer than by agricultural populations (Sellen and Smay, 2001). However, as subsistence differences include differences in other potentially influential parameters of breastfeeding and weaning practices, such as maternal working patterns, nutritional status, and familial relationships, comparison with subsistence modes does not necessary reveal the effect of potteries and plant foods utilization *per se*. Additionally, quantitative data on the weaning foods consumption cannot usually be obtained from ethnographic descriptions.

In this regard, Jomon hunter–gatherers provide a good case to investigate such topics. Jomon hunter–gatherers subsisted in the Japanese archipelago from approximately 12,000 years to 2300 years ago. The Jomon people are often described as "Neolithic hunter–gatherers," because Jomon cultures, especially in mainland Japan, commonly show Neolithic characteristics, such as intensive utilization of potteries, grinding stones, and many plant food sources (Imamura, 1996). Jomon culture is characterized by several kinds of cord-mark (*jomon*) pottery, which is one of the oldest potteries in the world (Craig et al., 2013; Habu, 2004). Archaeological studies indicated that Jomon people utilized and even managed several kinds of plant foods for a certain proportion of their dietary intake (Crawford, 2008; Matsui and Kanehara, 2006). Investigation of Jomon hunter–gatherer populations enables the evaluation of the effect of potteries and plant foods utilization *per se* on the breastfeeding and weaning practices.

Analyses of hunting, gathering, and food-processing tools (Akazawa, 1986) and stable isotopes in human bones (Kusaka et al., 2008; Minagawa and Akazawa, 1992; Yoneda et al., 2004) have indicated that the Jomon people utilized foods from C_3 terrestrial and marine ecosystems in different proportions according to their local environment. Carbon and nitrogen stable isotope ratios ($\delta^{13}C$ and $\delta^{15}N$ values, respectively) of terrestrial and marine food sources differ distinctly. Thus, consumption during the weaning process of the different food sources than ordinary adult diet could be detected by stable isotope analyses.

The objective of this study is to reconstruct breastfeeding and weaning practices in a hunter–gatherer population from the Yoshigo site in the Late/Final Jomon period of the Tokai region, eastern Japan, using stable isotope analysis. This reconstruction enables us to discuss the effect of potteries and plan foods utilization on the age at the end of weaning, and the content of weaning foods in hunter–gatherers.

1.2. Carbon and nitrogen stable isotope analysis

Carbon and nitrogen stable isotope analyses have been used to reconstruct past human diet (Katzenberg, 2008; Lee-Thorp, 2008). The $\delta^{13}C$ values differ between plants with different types of photosynthesis: C_3 and C_4 plants display lower and higher $\delta^{13}C$ values, respectively, and this difference persists in higher consumers in the ecosystem (Schoeninger and DeNiro, 1984; Smith and Epstein, 1971). Both $\delta^{15}N$ and $\delta^{13}C$ values are higher in organisms at higher trophic levels (Schoeninger et al., 1983; Schoeninger and DeNiro, 1984). Organisms from marine ecosystems typically show higher $\delta^{15}N$ values than those from terrestrial ecosystems and $\delta^{13}C$ values intermediate between those from C_3 and C_4 terrestrial ecosystems (Lee-Thorp, 2008). Because the $\delta^{13}C$ and $\delta^{15}N$ values of bone collagen reflect those of consumed dietary proteins (Ambrose and Norr, 1993), food sources can be estimated from isotopic analysis of ancient human skeletons.

Carbon and nitrogen stable isotope analyses are also used to reconstruct past weaning ages (Humphrey, 2014; Tsutaya and Yoneda, 2015). Exclusively breastfed infants display a 2–3‰ increase in $\delta^{15}N$ values compared to their mothers, because maternal milk is enriched in ^{15}N due to bioenrichment (Fogel et al., 1989; Fuller et al., 2006). Subadult $\delta^{15}N$ values decrease during the weaning process and decline to similar values to those of adults after the end of the weaning process (Fogel et al., 1989; Fuller et al., 2006). By analyzing subadult skeletons that died at various ages, chronological changes in $\delta^{15}N$ values during weaning can be reconstructed cross-sectionally (Tsutaya and Yoneda, 2015). An approximately 1‰ increase in $\delta^{13}C$ values in infants due to breastfeeding has also been reported in modern humans (Fuller et al., 2006), but this is not necessarily evident in archaeological populations (e.g., Choy et al., 2010; Schurr and Powell, 2005; Tessone et al., 2015; Tsutaya et al., 2015a; Waters-Rist et al., 2011). Weaning ages have been reconstructed in various ancient hunter–gatherer populations by analyzing stable isotopes in subadult skeletons (Clayton et al., 2006; Gardner et al., 2011; Howcroft et al., 2014; Schurr and Powell, 2005; Tessone et al., 2015; Tsutaya et al., 2015b; Waters-Rist et al., 2011). Although the stable isotopes of other elements, such as oxygen (Wright and Schwarcz, 1998; Britton et al., 2015) and calcium (Reynard et al., 2013) have also been used for the reconstruction of breastfeeding and weaning practices, carbon and nitrogen are the most widely-used elements for human skeletal populations (Tsutaya and Yoneda, 2015).

2. Materials and methods

2.1. Yoshigo site

The Yoshigo site is located on the northern coast of the Atsumi Peninsula, Aichi Prefecture, Tokai region, eastern Japan, and is a famous shell mound from the Late/Final Jomon period (Fig. 1). The Jomon period is subdivided into six chronological periods (Habu, 2004: 39): Incipient (12,000–9500 BP); Initial (9500–6000 BP); Early (6000–5000 BP); Middle (5000–4000 BP); Late (4000–3000 BP); and Final (3000–2,300 BP). The Yoshigo site was first excavated in 1922 and yielded over 300 human skeletons (Kiyono, 1969). Since 1922, several researchers additionally excavated the site and found human skeletons (see Tahara City Board of Education, 2007: 15–16). The typology of potteries demonstrated that the site was used during the Late and Final Jomon periods (The Commission for the Protection of Cultural Properties, 1952). Radiocarbon ages of marine shell samples were 2800 ± 600 BP and 2870 ± 250 BP (Crane and Griffin, 1958; see also Watanabe, 1963), and those of three (Kusaka et al., 2009) and five (Yamada, 2013) human skeletons are approximately within the ranges 3200–2800 calBP and 3500–2400 calBP, respectively. Although the site was assumed to have been used during the Late and Final Jomon periods, recent excavations and analyses have indicated that the site