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ORIGINAL PAPER

Isotopic evidence for diet in the Middle Chulmun period: a case study from the Tongsamdong shell midden, Korea

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Abstract This article presents the first isotopic investigation of human and animal bone remains from the Middle Chulmun (3500–2000 BC) period in southeastern Korea. We have obtained a single human and associated faunal stable carbon and nitrogen isotope results from the Tongsamdong site, a coastal shell midden. Despite the discovery of domesticated plants and the existence of large amounts of terrestrial mammal bones from the shell midden, the human and dogs we measured were heavily dependent on marine protein resources for their lives. Although our stable isotope results are based on a small number of individuals due to the lack of human remains at this period, isotopic evidence suggests the possibility that Tongsamdong people in the Middle Chulmun period depended largely on marine protein resources. This isotopic evidence is consistent with the archaeological evidence from the site.

Keywords $\delta^{13}C$ and $\delta^{15}N$ · Paleodiet · Agriculture · Chulmun · Korea

Introduction

The investigation of changes in subsistence patterns and the adoption of domesticated plants and animals has always been a key area of research for archaeology. The change in subsistence strategies from foraging to agriculture in Korea gradually occurred during the Middle Chulmun (3500–2000 cal. BC) and Mumun (1500–300 cal. BC) periods (Lee 2001; Choe and Bale 2002; Norton 2007). Before the adoption of agriculture, human subsistence during the Chulmun period largely consisted of plant gathering, fishing, and hunting of marine and terrestrial animals. At the beginning of the Middle Chulmun period (3500–2000 BC), domesticated plants (millet and rice) were introduced from central China to the Korean peninsula (Crawford and Lee 2003; Norton 2007). The spread of agriculture in Korea had been a slow and gradual process over the several thousand years (Lee 2001; Choe and Bale 2002). Plant cultivation eventually became important in the subsistence economy during the Mumun period. Associated with the increasing use of domesticated plants, there was evidence of extended social stratification in settlement patterns and megalithic burials from the Late Chulmun to Mumun periods (Bale 2001; Bale and Ko 2006; Norton 2007).

Although the question of the subsistence strategies in the Chulmun period is a central topic of discussion in Korean archaeology, the changes in subsistence patterns have been investigated on the basis of indirect evidence of preserved faunal and floral remains. Most previous studies on subsistence patterns have focused on the quantitative analysis of floral and faunal remains preserved in the shell middens (Lee 2001; Choe and Bale 2002; Lee 2003; Norton 2007). While this approach has made progress in estimating the dependence on various food resources, it may overestimate the importance of the well-preserved skeletal and shell remains.

To better understand subsistence activities in prehistoric Korea, we employed stable carbon ($\delta^{13}C$) and nitrogen ($\delta^{15}N$) analysis of bone collagen from skeletal remains

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from archaeological sites belonging to the Chulmun period. Stable carbon and nitrogen analysis of collagen extracted from archaeological bones is a well-established method to evaluate past human diets (see Lee-Thorp 2008 for a recent review). The $\delta^{13}C$ and $\delta^{15}N$ ratios in human bone collagen reflect the isotope ratios of dietary protein consumed over long periods of life (Schoeninger et al. 1983; Schoeninger and DeNiro 1984; Ambrose and Norr 1993; Hedges et al. 2007). Thus, the measurement of stable isotope ratios in bone collagen can provide direct evidence for paleodiets in prehistoric populations. The application of stable isotope analysis to prehistoric human diets has been often used to determine the amounts of C_3 vs. C_4 plants or the amounts of marine vs. terrestrial proteins in human diets. Consequently, this approach is particularly effective in detecting the relative importance of domesticated plants and animal protein resources in the Chulmun period in Korea.

Relatively little isotopic work has been applied in Asia, where the spread of agriculture was a long and complex process, especially in the Korean Peninsula. This study investigated the $\delta^{13}C$ and $\delta^{15}N$ values of human and animal skeletal samples from the Tongsamdong (TSD) shell midden. A main reason for choosing this site is that it is one of the most representative shell midden sites belonging to the Middle Chulmun period (3500–2000 BC). This site is considered as a main indicator of the beginning of plant cultivation in Korean prehistory (Crawford and Lee 2003). This research attempted to measure stable isotope compositions of bone remains from the shell midden and to compare these isotopic measurements with the floral and faunal evidences from the same site in order to investigate the proportion of exploitation of marine and terrestrial proteins in whole human diets.

Diversity of subsistence strategies in the Chulmun period

The Chulmun culture is regarded as a hunter-gathering society, with a wide range of subsistence activities, unique pottery, and sedentary villages with pit-houses (Lee 2001). The plant and animal remains from the Chulmun sites show that the Chulmun people had practiced a wide subsistence strategy from the forest, riverine, and coastal environments (Lee 2001; Choe and Bale 2002; Kim 2002; Lee 2003). Collection of wild plants and nuts was an important part of the Chulmun subsistence economy (Kim 2002). Hunting of terrestrial animals like deer and wild boar was also important in the overall subsistence strategy. In addition, the presence of large shell middens along the coasts indicates that there were intensive marine resource exploitations. The abundance of fish bones and fishing tools suggests that fish was an important resource for the Chulmun people. Faunal data show that sea mammals, such as sea lions, whales, and dolphins, were favored food resources on the coasts and islands. Generally, there were two distinct regional subsistence strategies in the Chulmun period practiced on the Korean Peninsula (Choe and Bale 2002). Eastern and southern people like Tongsamdong and Osanni depended on fishing, collecting shellfish, and hunting both sea and land animals. On the other hand, inhabitants of the western area like Amsadong and Jitamni depended on more broad-spectrum subsistence including hunting, fishing, and gathering wild plants.

However, subsistence patterns in the Chulmun people are more diverse and complex along with different adaptations to local environments (Norton 2007). Analysis of faunal remains from the Konamri shell midden in western coastal regions shows that western people were heavily dependent on marine food, especially fish (Norton 2000). Furthermore, archaeobotanical studies in the inland river regions show that Chulmun people had started to use domesticated plants as a supplement to existing foodstuffs in the Middle Chulmun period (Bale 2001; Lee 2003). This evidence suggests that there was a dietary difference between inland and coastal people in Chulmun diets. Therefore, dietary variation in the Chulmun people is likely related to regional differences in natural resources.

The Tongsamdong shell midden

The site of Tongsamdong (TSD) is a large open-air shell midden site located on the eastern coast of a small island, Yongdo, offshore from Busan city, South Korea (Fig. 1). Radiocarbon dates on animal bone and charcoal from each layer reveal that this site was occupied from about 4800 to 1700 cal. BC (Sample 1974). A direct accelerator mass spectrometry measurement of foxtail millet grains from a pit-house floor was dated to 3360 cal. BC (Crawford and Lee 2003). This shell midden was first identified and excavated by two Japanese archaeologists, S. Yokoyama and T. Oikawa, in the early 1930s. The further excavation was conducted by a team led by L.L. Sample and A. Mohr at the University of Wisconsin from 1962 to 1964, and then, most of the site was investigated by the Korean National Museum over three field seasons from 1969 to 1971 (Ha 2001, 2004). Recently, additional excavation was conducted by the Busan City Museum in 1999. This site consists of a sequence of shell layers containing both natural and cultural materials from the Incipient Chulmun to Late Chulmun period. Each stratum contained Chulmun pottery, stone tools, shell ornaments, and bone-fishing tools. There was a variety of pottery types representing the chronological sequence. Some Jomon pottery and obsidians from northern Kyushu were excavated indicating product exchanges between southern Korea and western Japan (Ha 2001; Lee 2003). The Tongsamdong site has played a significant role in the establishment of Chulmun chronology in Korean prehistory.

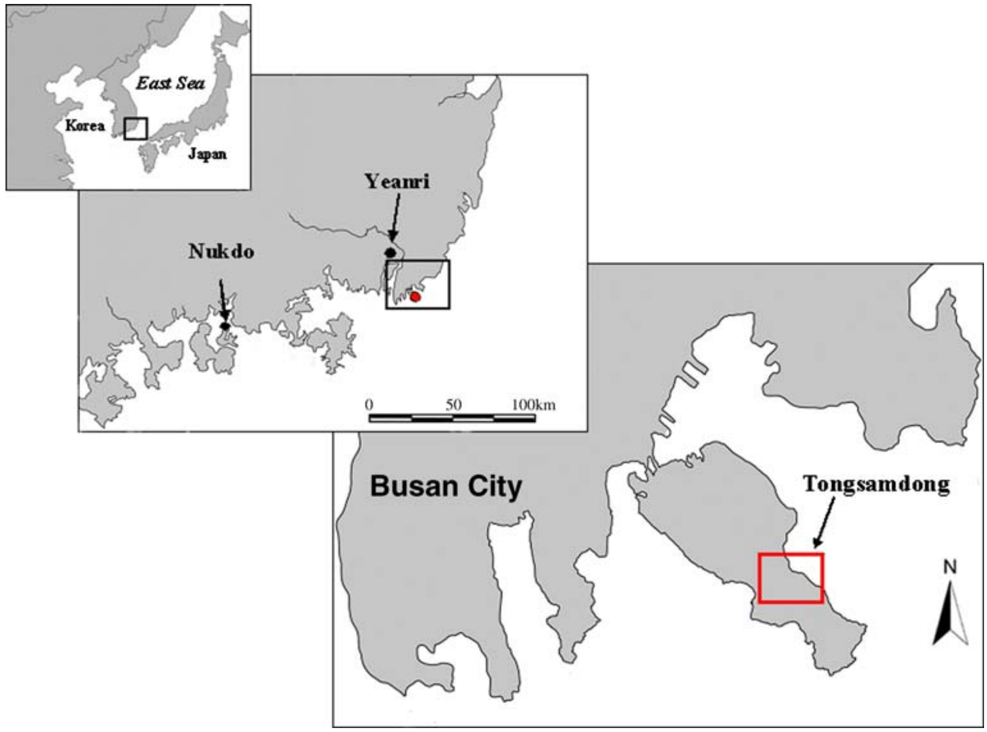

Fig. 1 Location map of the Tongsamdong shell midden and other two later sites, Nukdo (550 BC–1 AD) and Yeanri (300–652 AD) site, on the map of Korea. All archaeological sites mentioned in this study are located on the southeastern coastal regions of the Korean Peninsula

Evidence of human subsistence activities

Floral and faunal evidence from the Tongsamdong shell midden provided evidence for a wide range of human subsistence activities during the Chulmun period. Overall, plant and animal remains suggest that the subsistence economy of the Tongsamdong people was associated with a variety of foraging activities such as gathering, fishing, and hunting. The analysis of archaeobotanical remains recovered from a house floor showed that cultigens consisted of foxtail (*Setaria italica*) and broomcorn millet (*Panicum miliaceum*), comprising 45% of all carbonized grains (Crawford and Lee 2003; Fig. 2). Seeds of chenopod (*Chenopodium sp*.) were recovered in the same proportion as cultivated plants (Ha 2001; Lee 2003).

Terrestrial animal bones were recovered in the shell middens (Fig. 3). No domesticated mammals were found in the faunal assemblages. The most represented terrestrial mammals were deer (*Cervus nippon hortulorum*) and wild boar (*Sus scrofa*). However, the proportion of wild boar was not as large as deer, unlike the other shell midden sites in the same regions (Kaneko and Oh 2002). A large variety of bird bones were exposed, and migratory birds such as velvet scoter (*Melanitta fusca*), cormorant (*Phalacrocoracidae*), and grebe (*Podicipedidae*) were frequently identified.

The middens contained a large amount of marine animal remains. The shell middens were composed of a variety of marine molluscs and gastropods. Unlike other prehistoric shell midden sites in Korea, mussel (*Mytilus coruscus*) comprised the largest proportion in whole shellfish species, with oyster (*Crassostrea gigas*, *Crassostrea ariakenisis*) being the next most common species (Kaneko and Oh 2002; Lee 2002). Abalone (*Nordotis discus*), turban shell (*Batillus cornutus*), and top shell (*Chlorostoma argyrostoma lischkei*) together contribute about 10% of total shellfish remains (Lee 2001). The most abundant fish species excavated from the middens were great porgy (*Pagrus major*), pacific cod (*Gadus macrocephalus*), tuna (*Thunnus*), gray mullet (*Mugil cephalus*), shark (*Lamnidae*), and sea bass (*Lateolabrax japonicus*; Sample 1974; Kaneko and Nakayama 1994). Tuna and porgy were the main fish species in the fish bone assemblage. The marine mammals mainly consisted of sea lions (*Zalophus japonicus*), dolphin (*Delphinidae*), and whale (*Cetacea*). Most of the sea lions were females and young pups, and some sea mammal bones had cutting marks associated with butchering (Sample 1974; Kaneko and Oh 2002).

Stable isotope analysis

Stable isotope analysis of bone collagen has been widely used to reconstruct the protein portion of diets in archaeology (Schwarcz and Schoeninger 1991; Katzenberg 2000; Lee-Thorp 2008). In contrast to traditional methods of subsistence reconstruction, such as quantitative analysis of floral and faunal remains, this approach provides a direct measurement of past human diets. This method provides information about whether individuals derived the protein in their diet from plant or animal sources. The two most common elements studied for reconstructing paleodiets are

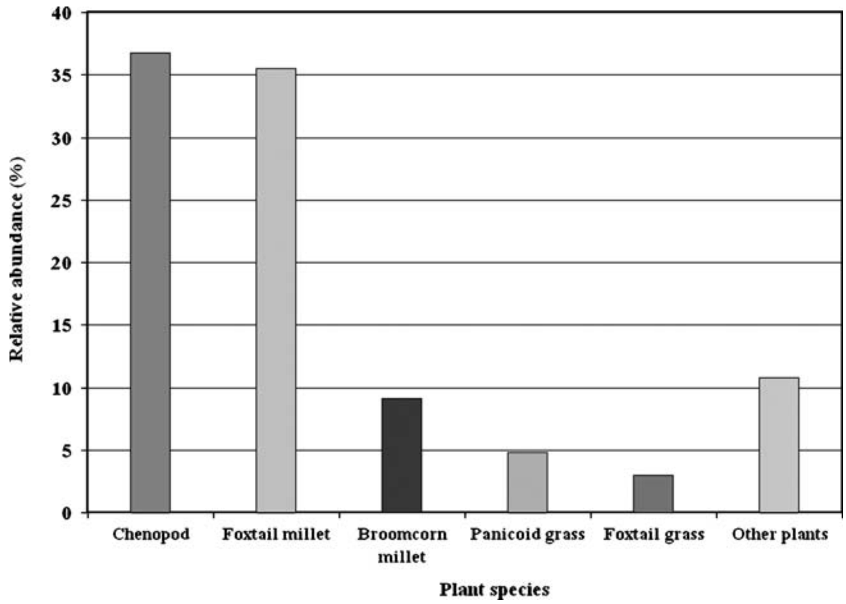

Fig. 2 Relative abundance of major plant species excavated from Tongsamdong shell midden in the Middle Chulmun period modified after Crawford and Lee (2003)

carbon ($\delta^{13}C$) and nitrogen ($\delta^{15}N$). In a terrestrial ecosystem, the ratio of carbon isotopes is determined by the particular photosynthetic pathway of a plant. The two main photosynthetic pathways are known as C_3 and C_4. C_3 plants have $\delta^{13}C$ values between −20‰ and −34‰, and C_4 plants have $\delta^{13}C$ values ranging over from −9‰ to −16‰ (Van der Merwe 1982; Krueger and Sullivan 1984; Ehleringer 1991; O'Leary 1995; Sage and Monson 1999). Rice (C_3 plant) and millet (C_4 plant) were important crops in the spread of agriculture in Korea. Thus, we can discriminate between the consumption of rice and millet in this region with respect to the plant cultivation. However, humans who consume a great deal of marine foods can also have $\delta^{13}C$ values close to C_4 pathway plants. Nitrogen isotope ratios can help to separate the consumption between C_4 plants and marine foods in the diet (Schwarcz and Schoeninger 1991).

Nitrogen stable isotope ratios reflect trophic position within an ecosystem, since body tissues show 2–5‰ enrichment in $\delta^{15}N$ values relative to consumed foods with each trophic level increase (Minagawa and Wada 1984; Bocherens and Drucker 2003; Hedges and Reynard 2007). The enrichment of $\delta^{15}N$ values at higher trophic levels is apparent for the marine system because the marine food chain has many more trophic levels than the terrestrial one (Schoeninger and DeNiro 1984). $\delta^{13}C$ values close to −12‰ and $\delta^{15}N$ values close to 20‰ indicate a diet of

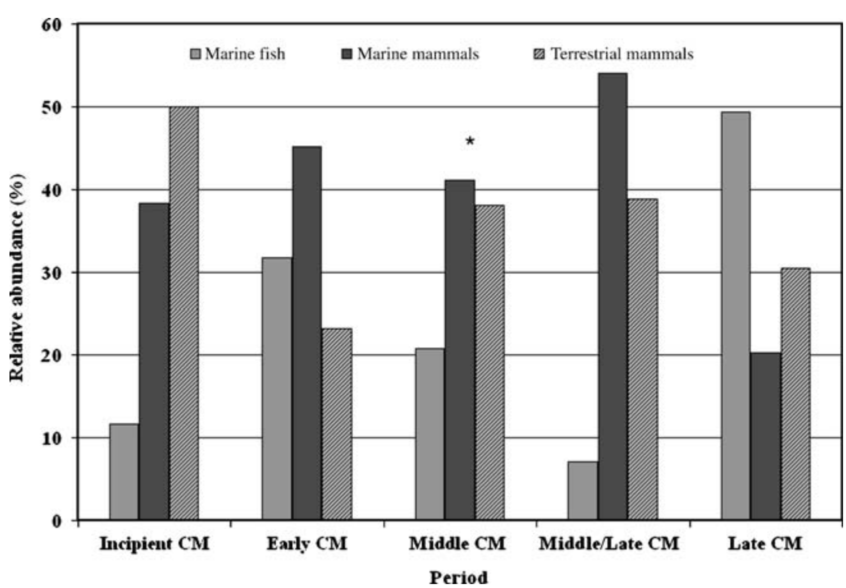

Fig. 3 Relative abundance of major faunal species excavated from Tongsamdong shell midden modified after Lee (2002). *Asterisk* The Middle Chulmun period, *CM* Chulmun

almost 100% marine protein (Richards and Hedges 1999). Nevertheless, it is expected to be only in areas where the terrestrial ecosystem is in C_3 plants and the environment is not an arid climate. If humans consume both C_4 plants and marine proteins, it is difficult to separate terrestrial and marine diets with carbon isotope ratios. Thus, we can measure a proportion of whole diets, depending on the different nitrogen values of trophic level between C_4 plants and marine animals.

Materials and methods

We obtained small (500 mg) bone specimens of a single human and a number of animal skeletons (n=20) from the Tongsamdong collections housed in the Busan City Museum, South Korea. Most of the bone samples measured in this study were excavated in 1999 and belonged to the Middle Chulmun period (3500–2000 cal. BC). One adult human bone sample was obtained from House II (2950 cal. BC), and two dog samples were selected from the Middle Chulmun period level 5 (3935–3000 cal. BC) for stable isotope analysis. Samples of marine (n=7) and terrestrial mammals (n=11) were also selected from various levels (4000–3000 cal. BC).

All bone samples were prepared and analyzed at the Max Planck Institute for Evolutionary Anthropology (Leipzig, Germany) following methods outlined in Richards and Hedges (1999) and Brown et al. (1988). About 500 mg of bone powder was demineralized in 0.5 M HCl solution at 4°C for 5 to 10 days, and the solid material was then gelatinized at 70°C in a pH 3 solution. After removing insoluble residues with a 5–8-μm Ezee® mesh, the remaining solution was filtered to remove contaminants using 30-kDa filters and dried for 48 h. The dried collagen (0.5 mg) was placed in tin foil capsules and combusted to CO_2 and N_2 in a ThermoFinnigan Flash EA coupled to a Delta Plus XP continuous-flow isotope ratio monitoring mass spectrometer. The elemental analyzer supplied carbon and nitrogen contents at the same time. The carbon and nitrogen isotope values were calculated relative to the Vienna Peedee Belemnite (VPDB) for δ^{13}C and Ambient Inhalable Reservoir (AIR) for δ^{15}N, respectively. Replicate measurement errors on known standards were less than ±0.2‰ for both δ^{13}C and δ^{15}N.

Stable isotope results

In all skeletal samples, the C/N ratios showed that the extracted collagen was well preserved with ratios between 2.9 and 3.6 (DeNiro 1985). The δ^{13}C and δ^{15}N values for human and faunal bone collagen are presented Table 1 and plotted in Fig. 4. In terrestrial animals, the δ^{13}C and δ^{15}N

Table 1 Results of stable carbon and nitrogen isotope analyses of all human and faunal samples from the Tongsamdong shell midden

S-EVA	Location	Species	Element	Collagen yield (%)	δ^{13}C	δ^{15}N	%C	%N	C:N
1736	TSD House II	*Homo sapiens* (human)	Metacarpal	4.6	−14.8	18.1	43.9	15.9	3.2
1719	TSD B-2	*Canidae* (dog)	Leg bone	1.3	−13.4	18.2	44.1	16.2	3.2
1737	TSD 5-1	*Canidae* (dog)	Tibia	1.1	−12.5	16.1	43.9	15.6	3.3
1734	TSD 5-1	*Capreolus capreolus* (roe deer)	Tibia	4.4	−21.5	3.6	44.8	16.3	3.2
1723	TSD 5-2	*Cervus nippon hortulorum* (deer)	Rib bone	4.7	−19.9	4.9	40.4	14.7	3.2
1724	TSD 5-2	*Cervus nippon hortulorum* (deer)	Rib bone	10.8	−21.4	2.7	45.7	16.5	3.2
1725	TSD 5-1	*Cervus nippon hortulorum* (deer)	Tibia	16.5	−21.3	3.3	46.6	16.9	3.2
1726	TSD 5-2	*Cervus nippon hortulorum* (deer)	Tibia	8.7	−21	4.8	46	16.7	3.2
1732	TSD 2	*Cervus nippon hortulorum* (deer)	Tibia	12.4	−20.8	2.7	46.3	16.5	3.3
1729	TSD 5-1	*Sus scrofa* (wild boar)	Mandible	8.3	−20.9	3.7	45	16.2	3.2
1733	TSD House I	*Sus scrofa* (wild boar)	Mandible	3.1	−20.8	3.9	33.8	12.1	3.2
1735	TSD 5-1	*Sus scrofa* (wild boar)	Tibia	4.2	−19.6	4.6	46	16.5	3.2
1721	TSD 5	*Zalophus japonicus* (sea lion)	Scapula	15.2	−14.3	19.4	44.9	16.4	3.2
3919	TSD 4	*Zalophus japonicus* (sea lion)	Tibia	10.9	−14	17.6	38.9	13.9	3.3
3920	TSD 5	*Zalophus japonicus* (sea lion)	Scapula	7.1	−14.4	17.2	36	13	3.2
1720	TSD B-4	*Thunnus* (tuna fish)	Vertebra	23.1	−12.8	11.4	31.4	11.4	3.2
1727	TSD 5	*Cetacea* (whale)	Vertebra	20.3	−14.1	13.2	42.7	15.4	3.2
1730	TSD 2	*Cetacea* (whale)	Vertebra	21.7	−16.9	11.2	43.5	15.3	3.3
3918	TSD 5-2	*Delphinidae* (dolphin)	Vertebra	17.8	−12.7	12.8	40.8	14.7	3.2
1738	TSD House II	Bird (?)	Leg bone	3.0	−10.7	14.8	45.2	16.2	3.3
1731	TSD 2	*Phalacrocoracidae* (cormorant)	Leg bone	1.9	−18.3	8.6	46.4	16.5	3.3

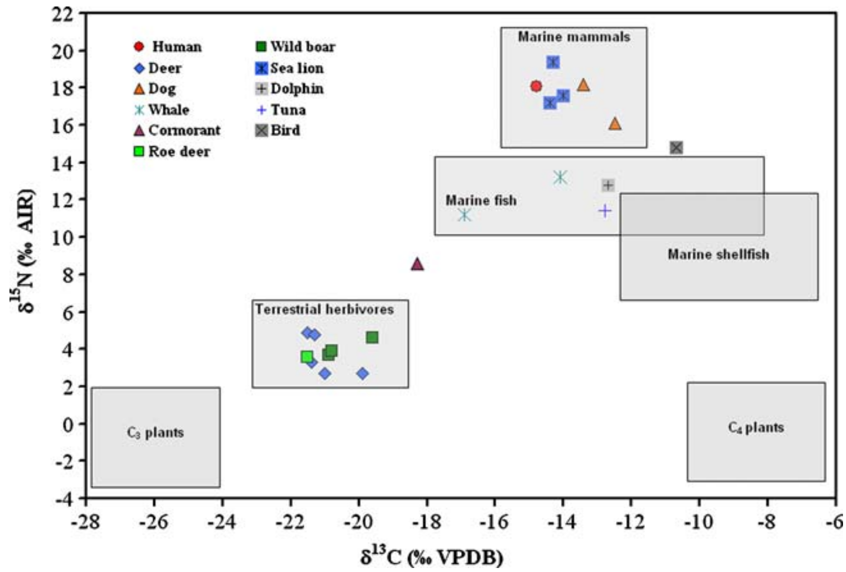

Fig. 4 Plot of all isotopic data showing human and faunal remains from the Tongsamdong shell midden. *Boxes* represent dietary categories presented in Korean Peninsula

values for deer and wild boar are consistent within those of Korean terrestrial herbivores. These two herbivores fell within the range of C_3 plant consumers, averaging to $\delta^{13}C=-21.0\pm0.6$‰ and $\delta^{15}N=3.7\pm1$‰ for deer ($n=5$) and $\delta^{13}C=-20.4\pm0.7$‰ and $\delta^{15}N=4.1\pm0.5$‰ for wild boar ($n=3$). These isotope values indicate that the human food source animals in the area did not consume C_4 plants and instead the deer and wild boar samples have values indicating mainly C_3 plant diets. The isotope ratios obtained from two bird samples indicate that the cormorant has terrestrial signatures, and the other, unidentified bird has marine signatures. For the marine mammals, the $\delta^{13}C$ and $\delta^{15}N$ values of sea lions, whale, dolphin, and tuna fish are as expected. The mean $\delta^{13}C$ and $\delta^{15}N$ values from three sea lions are $\delta^{13}C=-14.2\pm0.2$‰ and $\delta^{15}N=18.1\pm1.2$‰. The two whale bones have average $\delta^{13}C=-15.5\pm2.0$‰ and $\delta^{15}N=12.2\pm1.4$‰ values. Isotope results of the dolphin are $\delta^{13}C=-12.7$‰ and $\delta^{15}N=2.8$‰, and those of the tuna fish are $\delta^{13}C=-12.8$‰ and $\delta^{15}N=11.4$‰ values. The sea lion $\delta^{15}N$ values are approximately 7‰ higher than the tuna fish, indicating that these fish were the food sources for the sea lion.

The stable isotope ratios of the single human (S-EVA 1736) recovered from this site are $\delta^{13}C=-14.8$‰ and $\delta^{15}N=18.1$‰. This result showed almost the same isotopic features as do sea lions suggesting that humans and sea lions shared similar dependence on marine resources. The two dog bones (S-EVA 1719 and 1737) have isotope ratios similar to those of the human. This outcome is commonly observed in isotope studies of domesticated dogs (Cannon et al. 1999; Richards et al. 2003; Barton et al. 2009). The mean $\delta^{13}C$ and $\delta^{15}N$ values for two dogs is $\delta^{13}C=-13\pm0.6$‰ and $\delta^{15}N=17.2\pm1.5$‰, and this is likely due to the consumption of marine mammals or animals that consumed marine food.

Discussion

Isotopic evidence of diet from the Tongsamdong shell midden

The stable isotope compositions from the animal bone samples can provide information about past environment in southeastern part of Korean Peninsula. Since the isotope results from deer and wild boar from the Tongsamdong site fell within the range of C_3 consumers, we infer that the vegetation of the Tongsamdong site in the Middle Chulmun period was composed of predominately C_3 plants. This indicates the low importance of C_4 plants in the diets of herbivores in the southern part of the Korean peninsula at this time. Stable isotopic ratios from marine animals reflected ancient coastal ecosystems close to nontidal ocean. It suggests that the southeast coast of the Korean Peninsula had numerous habitats suitable for marine mammals such as sea lions, whales, and dolphins.

Humans that obtain their protein from marine food typically have $\delta^{13}C$ values close to −12‰ and $\delta^{15}N$ values between 12‰ and 22‰, while humans that consume only C_3-based terrestrial protein sources have $\delta^{13}C$ values of about −20‰ and $\delta^{15}N$ values ranging from 5‰ to 12‰. Humans that have a mixture of marine and C_3-based terrestrial protein would have isotope values somewhere between those end points (Richards et al. 2006; Schoeninger and Moore 1992). Overall, average isotope values of the Tongsamdong human are close to those of sea lions, having $\delta^{13}C$ 6–7‰ and $\delta^{15}N$ 13–14‰ higher than terrestrial herbivores. This huge $\delta^{13}C$ and $\delta^{15}N$ level shifts in the trophic level can be interpreted as a strong influence of marine food on whole diets (Fig. 4). These isotopic results demonstrate that the individual had a diet in which a large amount of the dietary protein came from marine resources. The Tongsamdong human seems to have heavily depended on marine protein resources for the overall diet. Two dogs in Tongsamdong seem to have similar dietary pattern of marine diet to the human, showing that they had benefited from a close association with the humans. The high $\delta^{15}N$ values in human and dog bones imply that higher trophic level species, such as tuna fish, sea lion, whale, and dolphin, made a significant contribution to the protein component of their diets.

The isotopic data from the Tongsamdong site can be compared to the published results from the later Nukdo shell midden from the Mumun period and the Yeanri cemetery dating to the Three Kingdoms period. The isotopic data of human and faunal bone collagen from all three sites is plotted in Fig. 5. The isotopic evidence from the site of Nukdo (550 BC–1 AD) showed that the main protein sources were obtained from terrestrial foods (Choy and Richards 2009). Although Nukdo is situated on a small island, the inhabitants of Nukdo consumed fewer marine protein resources than the human from Tongsamdong. The isotopic results from the Yeanri cemetery (300–652 AD) revealed that the people from the Three Kingdoms period consumed terrestrial proteins and a C_3-based diet (Choy et al. 2009), similar to Nukdo humans. The comparison of stable isotopic ratios between the Tongsamdong and Nukdo people suggests that different subsistence strategies were used between the two shell midden sites in the southeastern coastal regions of Korea. Figure 6 illustrates the different isotopic compositions of humans and dogs among three different time periods.

Interestingly, the reconstructed dietary patterns in Tongsamdong have a close similarity with two prehistoric Jomon people in Hokkaido, Japan that depended heavily on large marine animals such as seal, dolphin, and tuna fish. The $\delta^{13}C$ (−14.8‰) and $\delta^{15}N$ (18.1‰) values of Tongsamdong are consistent with those of Japanese Jomon in Hokkaido. As shown in Table 2, the isotopic values from Kitakogane shell midden of the Early Jomon period (4800–3000 BC) average to $\delta^{13}C=-14.2\pm0.4$ and $\delta^{15}N=18.1\pm0.5$ and the isotopic data from the Usu shell midden of the Epi–Jomon period (100 BC–500 AD) are $\delta^{13}C=-13.2\pm0.7$ and $\delta^{15}N=18.1\pm0.6$, respectively (Minagawa and Akazawa 1992).

Comparison between isotopic data and possible dietary resources

Based on floral and faunal evidence from the Tongsamdong shell midden, we can estimate some possible food species used by the Tongsamdong people. These dietary groups can be divided into terrestrial plants (C_3 and C_4 plants), terrestrial herbivores, and marine animals (shellfish, fish, whale, and sea lion). Our stable isotope data can refer to these species groups to estimate the dependence on each dietary source. Archaeobotanical evidence from the Tongsamdong site has suggested the possibility that some cultigens (e.g., foxtail millet, broomcorn millet) and wild plants (e.g., chenopod, panicoid grass) were used in the Middle Chulmun period (Lee 2002, 2003). Stone tools such as hoes and grinding stones in the Tongsamdong site (Sample 1974) indicate consumption of plant food resources. However, our isotopic evidence indicates that the contribution of cultivated C_4 plants (e.g., foxtail millet, broomcorn millet) to the whole diet was also relatively small relative to animal proteins from marine animals. These isotopic results cannot discriminate the exact proportion of the C_4 plant contribution to all diets due to strong influence of marine animals to whole diet. Furthermore, our isotopic data suggest that there is no isotopic

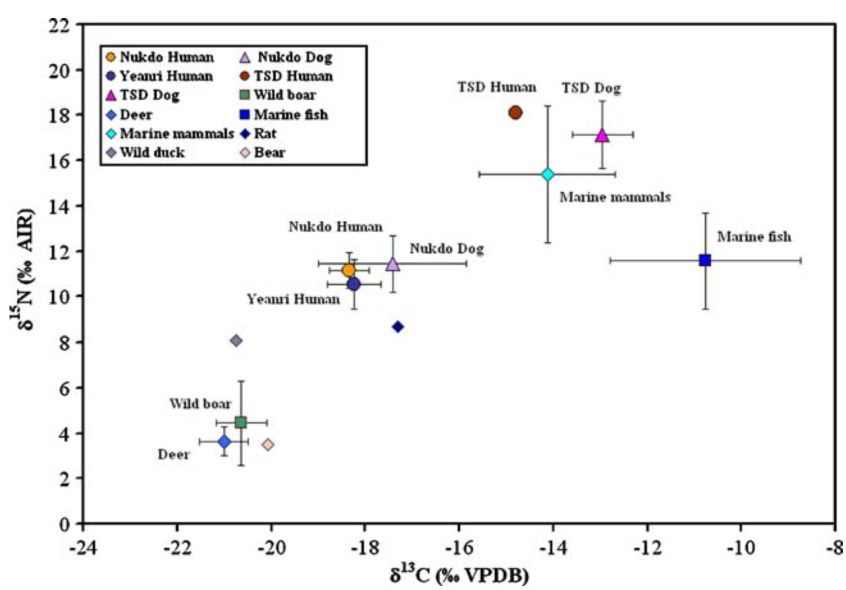

Fig. 5 Plot of stable carbon and nitrogen isotope values on all human and faunal remains from the Tongsamdong, Nukdo, and Yeanri sites in southeastern regions of Korea. Isotopic values of terrestrial and marine animals are combined with both the Tongsamdong and Nukdo sites

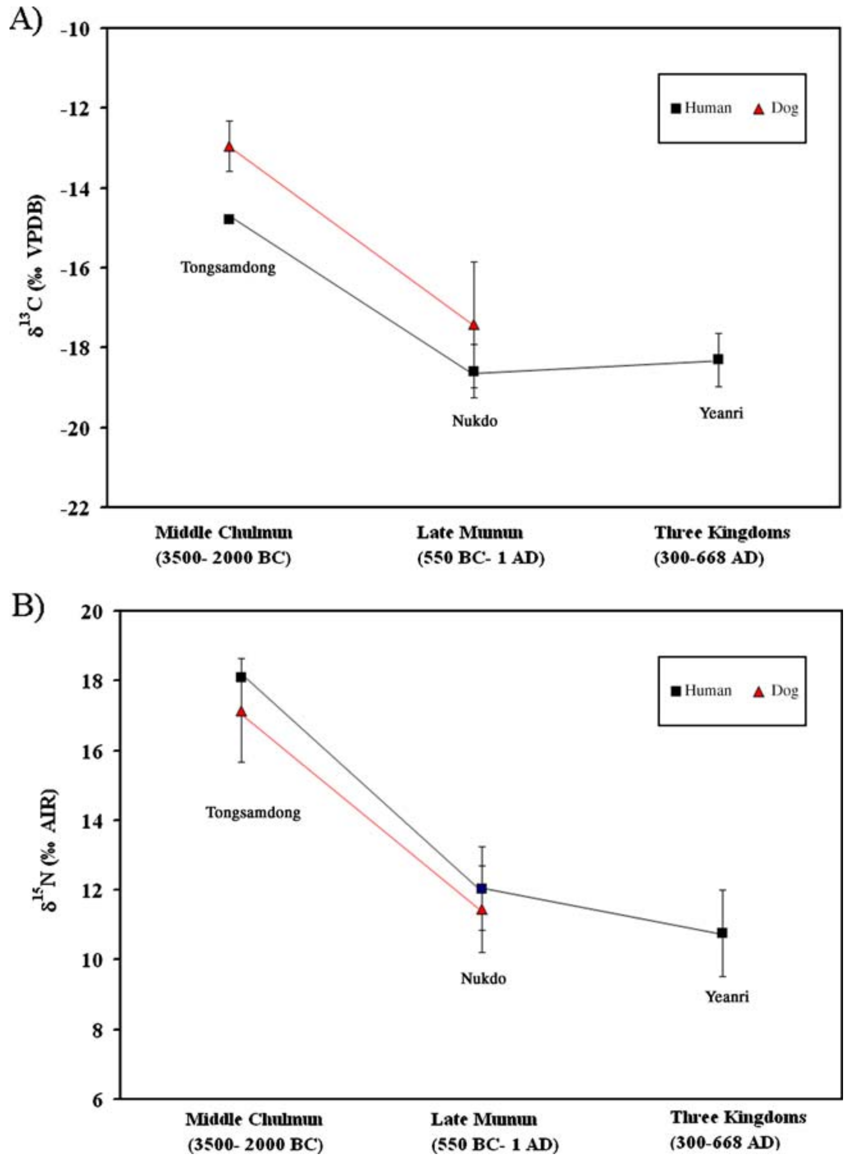

Fig. 6 Comparison of $\delta^{13}C$ (**a**) and $\delta^{15}N$ (**b**) values of humans and dogs from the Chulmun to Mumun and Three Kingdoms periods in southeastern Korea. There are clear isotopic differences in humans and dogs between the Chulmun to Mumun period

indication of a significant contribution to dietary protein from C_3 plants such as rice in the Tongsamdong site. Isotopic analysis cannot identify the occasional consumption of C_3 plants, or if they were consumed only for their carbohydrates.

Zooarchaeological evidence shows that the Tongsamdong people in the Middle Chulmun period hunted the terrestrial herbivores like deer and wild boar. Despite the large number of deer bones excavated, our isotope data

Table 2 Isotopic results of human samples from all three archaeological sites in Korea and Jomon sites in Japan

Location	Site name	Sample number	Mean $\delta^{13}C$	Mean $\delta^{15}N$	Age of the site
Southeast Korea	Tongsamdong shell midden	1	−14.8	18.1	Middle Chulmun (3500–2000 BC)
Southeast Korea	Nukdo shell midden	48	−18.3±0.4	11.2±0.7	Late Mumun (550 BC–1 AD)
Southeast Korea	Yeanri cemetery	109	−18.3±0.7	10.8±1.2	Three Kingdoms (300–668 AD)
Hokkaido, Japan	Kitakogane shell midden	9	−14.2±0.4	18.1±0.5	Early Jomon (4000 BC)
Hokkaido, Japan	Usu shell midden	10	−13.2±0.7	18.1±0.6	Epi–Jomon (1 AD)
Honshu, Japan	Sanganji shell midden	13	−18.3±0.6	8.6±0.9	Middle Late to Final Jomon (3000–500 BC)
Honshu, Japan	Kosaku shell midden	20	−17.7±0.6	10.5±0.9	Late Jomon (2100 BC)
Honshu, Japan	Kitamura cemetery	2	−19.5±0.3	6.4±0.7	Late Jomon (2000 BC)

Japanese data are quoted from Minagawa and Akazawa (1992) show that the Tongsamdong human and dogs we measured did not have a heavy reliance on terrestrial herbivores. The Tongsamdong site is located on the southeastern coastal line of the Korean Peninsula, and Tongsamdong people in the Middle Chulmun period would have had much easier access to high trophic marine animals than to terrestrial herbivores. In addition, isotopic compositions of bone collagen reflect the average of the food intake in over long periods. Thus, terrestrial herbivores might be not consumed as regular food items for a long time.

The zooarchaeological evidence from the shell midden indicates that marine shellfish, large fish (e.g., tuna fish and shark), and marine mammals (e.g., sea lion, whale, and dolphin) were important dietary components. Our isotopic results confirm this, indicating that the Tongsamdong human seems to have mainly depended on protein resources from marine animals such as shellfish, fish, and large marine mammals. The clear marine focus at this time is also supported by the artifactual evidence which includes manufactured bone tools and ornaments made from bone from sea lions, whales, dolphins, and large fish (Sample 1974). Bone and shell artifacts include diverse fishing implements, shell ornaments, and composite bone fish hooks. Drilled vertebra from shark and tuna were used for ornaments such as bone beads and buttons, and dog cockle (*Glycymeris albolineata*) shells were used to make bracelets (Sample 1974; Kaneko and Nakayama 1994; Lee 2001).

Conclusions

In this study, the analysis of stable isotope compositions in bone collagen has provided direct evidence for the diet of a human and two dogs from the Middle Chulmun Tongsamdong shell midden in southeastern Korea. The isotopic data indicated that the human and two dogs had diets where the protein mainly came from marine sources, likely shellfish, fish, and marine mammals. These isotopic results are much more similar to contemporary Hokkaido Jomon populations in Japan than later populations from southeastern Korea. This isotopic evidence is largely in agreement with the archaeological evidence from the same site. However, this isotopic research is based on a small number of individuals due to the lack of human remains at this period. Thus, more neighboring Chulmun sites need to be studied to examine larger-scale dietary patterns at this time period.

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