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Dietary reconstruction of the Iron Age population at the Fantzuyuan site, Taiwan, revealed by isotopic analysis on human and faunal bone collagen

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ABSTRACT

In this study, we analyzed the carbon and nitrogen stable isotopic composition of human bone collagen in 33 individuals found at the Fantzuyuan site in Taiwan in order to investigate the dietary patterns of this Iron Age group. Forty-three faunal collagen samples were also analyzed to ascertain the variability of baseline isotopic signatures in the area. Mean $\delta^{13}C$ and $\delta^{15}N$ values of $-12.5 \pm 0.7‰$ and $8.1 \pm 0.5‰$, respectively, were found in 26 human individuals. In conjunction with archaeological evidence, this study showed that human diet at this site derived mainly from terrestrial animals, with a minor component derived from marine shellfish. No significant difference in isotopic compositions was detected between male and female adults or between adults and juveniles. However, six individuals had dietary patterns that were different from others, which probably reveals that they had special social status and/or non-local origins.

1. Introduction

The Iron Age (2000–400 cal. yr BP, Liu, 1999) in Taiwan witnessed the development of complex societies and the construction of dynamic trading networks. During this period, Taiwan was occupied by several regional cultural groups, one of which was the Fantzuyuan (hereafter FTY) cultural group. Archaeological sites belonging to the FTY culture are distributed along the foothills of Houli and Dadu tablelands, as well as over the basins and coastal plains of central Taiwan (Fig. 1), a pivotal region connecting northern and southern Taiwan (Ho, 2003; Liu, 1999). Therefore, investigating social structure and human mobility of the FTY culture can contribute to an increased understanding of material flow, agricultural spread, and relationships between different prehistoric groups both within Taiwan and between Taiwan and adjacent regions.

The FTY culture is characterized by gray-black pottery, iron tools, and foreign trade items, such as glass beads, porcelain, and fired clay artifacts. Based on these findings, it is suggested that the FTY culture may have played an important role in ancient trading networks. For example, iron tools produced in northern Taiwan, as evidenced by iron smelting workshops and large amounts of iron slag (Liu, 2002), appear to have been exchanged and moved through central Taiwan to southern and inland regions (Ho and Yan, 2009). The finding of foreign items also leads to the suggestion of that there was interaction with China or Southeast Asia (Ho and Yan, 2009). With such a context, some scholars suggest that non-locals may have moved or migrated by following material flow to the FTY community (Ho and Yan, 2009). One possible source of evidence for this is that most individuals buried in the FTY culture sites did not have any of their teeth removed. However, one individual buried at the FTY site and another buried at the Luliao site did (Ho et al., 2007; Song, 1962). This feature could imply the special status or non-local origins of these two individuals in the FTY community, though the meaning of the dental extraction remains unclear (Ho et al., 2007). At the FTY site, for example, the location of the teeth ablation of M15 was not in accordance with the typical type, i.e. $2I^2 2C$ type, found in Taiwan (Chiu, 2010). As a result, it cannot be precluded that the teeth were ablated naturally. If this was the case, then there would not be enough evidence to infer that M15 was a non-local individual.

Another important feature of the FTY culture is extended prone burials, and males were buried with their hands placed over their pelvis, while the females and children were buried with both of their arms placed straight by their side (Ho, 1996, 2003). Moreover, certain burials were found with pottery covering the faces of the deceased, for example

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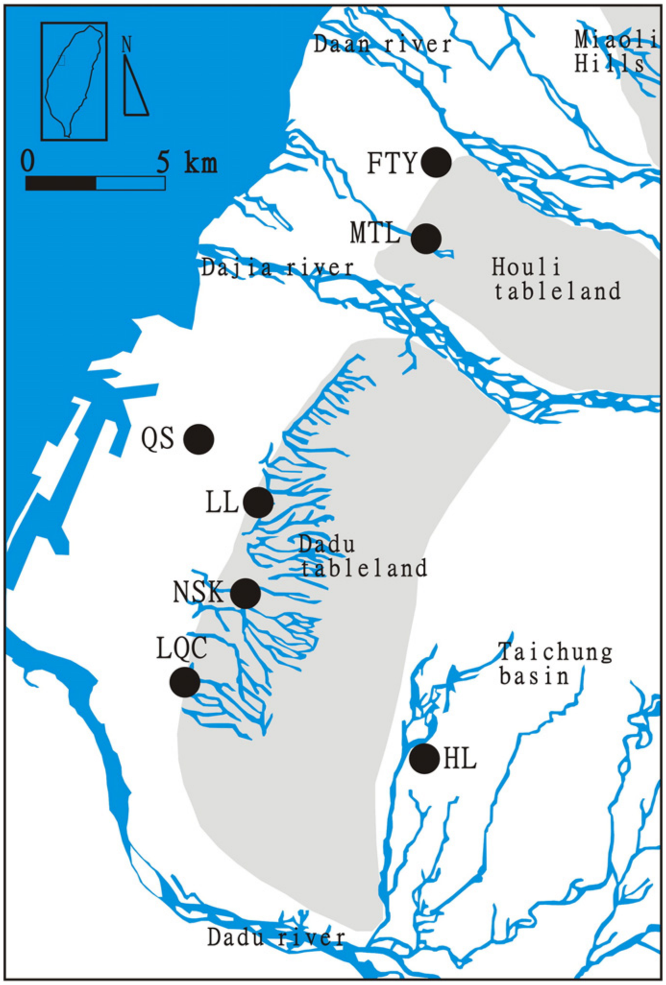

Fig. 1. Archaeological sites relevant to the FTY culture, including Fantzuyuan (FTY), Matoulu (MTL), Qingshui (QS), Longquancun (LQC), Huilai (HL), Luliao (LL), and Nanshikeng (NSK).

one burial at the Matoulu site and two burials at the Huilai site (Ho, 2003; Shih and Song, 1956), probably reflecting special funeral rituals for individuals of high social status (Ho, 2003). These findings lead to the suggestion of that the FTY culture may have been socially differentiated and that males and females/children were treated in different ways.

Except for evidences from burial context and artifact remains, reconstruction and comparison of dietary patterns within a population could provide another line of evidence for social structure and human mobility in FTY culture. One of the methods used to reveal information on paleodietary patterns is stable carbon and nitrogen isotopic analysis applied to human bone collagen (Katzenberg, 2008; Lee-Thorp, 2008). This technique may be able to reveal a pattern of food consumption for an individual over a long period of time, and it has been used to reflect the ways in which members of different social status, gender, and age groups access food (e.g. Ambrose et al., 2003; Kinaston et al., 2013c; Valentin et al., 2006). It may also be possible to detect non-locals whose original diets differed from the dietary patterns of a majority group (e.g. Pollard et al., 2011). Although this technique has been applied widely to reconstruct subsistence activities of ancient groups or specific individuals all over the world, it has not been applied much to Taiwanese archaeological bone remains.

This study presents the application of stable carbon and nitrogen isotopic analysis to human and faunal bones excavated from the FTY site in central Taiwan. The aim of this study was to obtain information on dietary pattern and potential dietary differences between individuals in this Iron Age cultural group. The human skeletons buried at the FTY site were chosen as the material for isotopic analysis because of the large number of burials found at this site (up to 32 burials). Such a large assemblage provides a good opportunity to reconstruct dietary patterns of the FTY culture, to pinpoint potential immigrants, and to understand the social structure by comparing the diets between genders and among different age groups.

1.1. Study site - the Fantzuyuan site

The FTY site, at an altitude of 70 m above mean sea level, is located in the northwest region of the Houli tableland (Fig. 1). The FTY site faces the Daan River on the north and the alluvial plain of the Daan River on the west. The distance from the FTY site to the modern coast is approximately six kilometers. After one human skull and one shell midden were found unexpectedly in 1955 by Dr. Chao-Chi Lin of the Department of Geology, National Taiwan University (NTU), several excavations were undertaken at the FTY site in 1955, 1957, 1961, and 1964. These excavations were led by Dr. Chang-Ju Shih and Dr. Wen-Hsun Song of the Department of Archaeology and Anthropology of NTU.

From the surface downwards, the strata of the FTY site consisted of a gray soil layer, a brown soil layer, and a gravel layer (Shih and Song, 1956; Song, 1962). Shell middens of small size and various shell remains were found at this site. There was also abundant pottery but few stone tools. Other important findings included iron knives, glass bracelets, and 32 burials. Only the context of 16 burials (M1–M16), which were unearthed mainly in gray and brown soil, has been published (Table 1). The 16 individuals included eight male adults, two female adults, three adults with unknown gender, two juveniles, and one individual with unknown information (Ho, 1996). All were interred in extended prone position oriented toward the southeast with no burial goods or coffin pit (Shih and Song, 1956; Song, 1962). No specific data for the burials have been reported so far, but based on pottery characteristics, cultural stratum, and one ^{14}C dating from shell, the site age is estimated to be between 2000 and 400 cal. yr BP (Liu, 1999).

1.2. Archaeological evidence for the paleodiet of the FTY culture

Remains of food uncovered from the FTY site included the bones of deer (*Cervus* sp.), muntjac (*Muntiacus reevesi*), pig (*Sus* sp.), turtle, and fish (Shih and Song, 1956). In addition, twelve species of shellfish have been identified in the FTY middens, of which the most common are Pacific oyster (*Crassostrea gigas*), followed by *Melanoides crenulatus* and *Venerupis variegate* (Shih and Song, 1956). No plant remains have been found at the FTY site so far, limiting our ability to understand which plant foods were consumed as part of the human diet at this site. However, artifacts at this site, such as saddle-shaped stone knives, do provide evidence for plant harvesting (Shih and Song, 1956).

Faunal remains were found at the Luliao site as well, consisting of sika deer (*Cervus nippon taiouanus*), muntjacs (*Muntiacus reevesi*), wild pigs, goats (*Capra* sp.), badgers (*Meles meles*), rats, birds, fish and various shellfish (Ho et al., 2007). The faunal remains found at the Huilai site are dominated by *Cervus* sp., accompanied by muntjacs, pigs, rats, turtles, fish and birds. Some of the fish remains were identified as catfish (Siluriformes), a kind of freshwater fish (Ho and Chu, 2007). Plant remains unearthed at the Huilai site include Zingiberaceae and Pandanaceae, as well as rice grains (Ho and Chu, 2007). Moreover, harvesting tools, such as saddle-shaped stone knives and stone hoes, hunting tools, such as stone arrowheads, and knives for meat and animal bone processing, were found from Huilai (Ho, 2003). Based on these findings, it was assumed that the FTY cultural group practiced hunting, gathering, and maybe rice cultivation (Ho and Chu, 2007).

Table 1
Information of the burials excavated in 1955, 1957, 1961, and 1964 respectively.

Burial no.	Gender	Age-to-death	Burial context	References
M1	Male	Adult	– Buried in the lower part of gray soil layer. – Four limbs were remained and preserved well; others were lost virtually.	Shih and Song (1956)
M2	Male	Adult	– Buried in the lower part of brown soil layer. – The skeleton was well preserved and intact, only pelvis was destroyed. Lower part of both lower limbs was lost due to intrusion of M1. – Wooden coffin (?) or wooden burial good (?)	Shih and Song (1956)
M3	Male	Adult	– Buried in the upper part of brown soil layer. – Most of skeleton were remained and preserved well, but left radius and ulna were lost. Ischium and vertebrae were decayed.	Song (1962)
M4	Male	Adult	– Buried in the upper part of gray soil layer. – Only parts of skull and limbs were remained. Others were lost virtually.	Song (1962)
M5	Male	Adult	– Buried in brown soil layer. – Only parts of skull and limbs were remained. – More than 20 sherds were found in the soil around individual's face	Song (1962)
M6	Male	Adult	– Buried in gravel layer. – Most of skeleton were remained, but lower part of right upper limb was lost. Both lower limbs were preserved well, others were not.	Song (1962)
M7	Unknown	Adult	– Buried in the lower part of gray soil layer. – Only vertebrae, pelvis, both lower limbs and parts of skull and ribs were remained.	Song (1962)
M8	Unknown	Adult	– Buried in the lower part of brown soil layer. – Only the skeleton above waist, parts of upper limbs and foot bones were remained due to an intruded pit.	Song (1962)
M9	Unknown	Adult	– Buried in between gray and brown soil layer. – Only parts of lower limbs were remained, others were lost due to an intruded pit.	Song (1962)
M10	Unknown	Unknown	– Buried in grown soil layer. – Only skull fragments were remained.	Song (1962)
M11	Unknown	Juvenile (ages 6)	– Buried in gravel layer – Skull was crushed. Only parts of four limbs were remained due to an intruded pit.	Song (1962)
M12	Female	Adult	– Buried in the lower part of gray soil layer. – Most of skeleton were remained, but left femur was lost.	Song (1962)
M13	Male	Adult	– Buried in brown soil layer. – Most of skeleton were remained, but parts of skull, ribs and vertebrae and whole right upper limb were lost due to an intruded pit.	Song (1962)
M14	Unknown	Juvenile	– Buried in brown soil layer. – Most skeleton were remained, but parts of limbs was lost.	Song (1962)
M15	Female	Adult	– Buried in the lower part of brown soil layer. – Most of skeleton were remained and preserved well. – Tooth ablation behavior: both M1 s and left M2 on mandible were removed.	Song (1962)
M16	Male	Adult	– Buried in the lower part of brown soil layer. – Most of skeleton were remained and preserved well. – This individual was reburied after excavation.	Song (1962)
M17	Male	Adult (ages > 20)	No data	
M18	Male	Adult (ages 30–39)	No data	
M19	Unknown	Unknown	No data	
M20	Unknown	Juvenile (ages 1–2)	No data	
M21-1	Unknown	Adult (ages > 20)	No data	
M21-2	Unknown	Adult (ages 35–44)	No data	
M22	Unknown	Juvenile (ages 2.5–3)	No data	
M23	Unknown	Unknown	No data	
M24	Male	Adult (ages 22–26)	No data	
M25	Unknown	Juvenile (ages 5–9)	No data	
M26	Unknown	Adult (ages > 20)	No data	
B1	Unknown	Unknown	No data	
B3	Unknown	Unknown	No data	
B4	Unknown	Unknown	No data	
B5	Unknown	Unknown	No data	
B6	Unknown	Juvenile (ages 3)	No data	

2. Analytical materials and methods

2.1. Sample selection

Altogether, 32 human individuals were recovered from the excavations conducted during the 1950s and 1960s. The information of the age at death and the gender for individuals M1–M16 is provided by Ho (1996). The other individuals were re-examined, and their age at death and gender were determined by Dr. Yun-Ysi Siew of Academic Sinica in 2016. In addition to this, three more individuals were identified during the examination (Table 2).

Table 2
Other possible individuals that were identified during the re-examination of FZY human bones in 2016.

Sample no.	Gender	Age-to-death	Preservation condition
E01c - 2	Unknown	Unknown	Only one skull remained
E01e - 2	Unknown	Unknown	Only one skull remained
E01e - 3	Unknown	Unknown	Only four limbs remained

Except for skeletons M10 and M16, bone samples from the other individuals were collected for carbon and nitrogen isotopic analyses. One to four bone samples were collected from each individual. In total, 62 human bone samples belonging to 33 individuals were included in this study.

In order to provide an isotopic reference baseline for the human data, 43 faunal bone samples, including 24 cervids, 13 pigs, four muntjacs, and two fish, were also collected. Preferentially mandible or maxilla bones were sampled to reduce the risk of duplicate samplings of the same individual. If they were not available, other bone types were used (Table 3). We selected bone samples from different excavation areas to ensure that the samples came from different individuals.

2.2. Bone collagen extraction

All samples were prepared according to a modified Longin method as described in Pollard et al. (2011). To summarize, samples were cleaned with the aid of a diamond-studded drill bit to remove surface contaminations. Surface-cleaned samples of c. 200–500 mg were crushed manually in pestle and mortar and placed in 0.5 M HCl at 4 °C for several days. Once fully demineralized, samples were rinsed to neutrality with ultrapure water. HCl was added to give a pH of 3, and samples were gelatinized in sealed tubes at 75 °C for 48 h. Residues were filtered through Ezee™ filters and the supernatant liquid was freeze dried. Upon removal from the freeze drier, the samples were weighed to calculate collagen yield.

To assess the sample quality and to calculate the sample amount for isotope analysis, carbon content (%C), nitrogen content (%N), and carbon-to-nitrogen (C/N) molar ratio were determined by using an elemental analyzer (EA) at the Institute of Oceanography, NTU, before isotope analysis.

2.3. Isotopic analysis

Collagen samples of approximately 1.0 mg were weighed into tin capsules and analyzed for $\delta^{13}C_{VPDB}$ and $\delta^{15}N_{AIR}$ on an automated

Table 3
Fauna bone collagen samples with information on faunal species, collagen yield, C and N contents, and isotopic data.

Species	Sample no.	Skeletal element	Collagen yield (%)	% N	% C	C/N atom	δ^{13}C in ‰ vs. VPDB	δ^{15}N in ‰ vs. AIR
Cervus sp.	E01h − 3	Humerus	4.1	14.99	42.68	3.3	−13.7	4.1
Cervus sp.	E01h − 4	Radius	7.3	14.76	39.96	3.2	−16.3	5.1
Cervus sp.	E01h − 6	Maxilla	6.5	16.43	43.37	3.1	−6.9	1.6
Cervus sp.	E01h − 8	Humerus	8.3	14.90	39.58	3.1	−11.9	3.4
Cervus sp.	E01h − 9	Maxilla	5.5	14.79	39.66	3.1	−9.6	3.9
Cervus sp.	E01h − 11	Pelvis	2.2	15.17	41.29	3.2	−10.8	4.0
Cervus sp.	E01h − 16	Limb	8.6	16.55	44.39	3.1	−11.0	2.3
Cervus sp.	E01h − 18	Maxilla	12.7	14.13	37.06	3.1	−14.1	5.0
Cervus sp.	E01h − 20	Humerus	1.6	15.07	42.85	3.3	−12.5	4.7
Cervus sp.	E01h − 21	Limb	10.5	17.68	45.65	3.0	−14.4	3.4
Cervus sp.	E01h − 22	Humerus	12.2	16.93	44.44	3.1	−10.5	2.7
Cervus sp.	E01h − 23	Scapula	1.6	14.94	43.09	3.4	−15.0	4.3
Cervus sp.	E01h − 24	Limb	3.0	17.36	46.32	3.1	−17.9	2.7
Cervus sp.	E01h − 26	Pelvis	4.2	15.72	42.10	3.1	−14.5	6.1
Cervus sp.	E01h − 27	Limb	10.8	17.08	45.02	3.1	−14.1	3.4
Cervus sp.	E01h − 30	Limb	3.2	16.52	44.37	3.1	−8.8	5.5
Cervus sp.	E01h − 31	Maxilla	6.0	15.96	42.90	3.1	−15.2	4.0
Cervus sp.	E01h − 35	Pelvis	5.5	14.34	38.96	3.2	−7.1	5.1
Cervus sp.	E01h − 36	Scapula	2.3	14.70	40.20	3.2	−11.1	4.9
Cervus sp.	E01h − 37	Limb	2.9	15.59	42.13	3.2	−10.8	3.4
Cervus sp.	E01h − 41	Limb	4.5	16.84	44.75	3.1	−8.6	4.3
Cervus sp.	E01h − 42	Scapula	4.9	15.96	42.64	3.1	−11.1	5.3
Cervus sp.	E02j − 3	Limb	10.5	14.75	40.52	3.2	−13.9	2.9
Cervus sp.	E03l − 1	Limb	7.5	14.11	39.85	3.3	−10.2	3.0
Pig	E01h − 1	Rib	3.3	13.16	36.23	3.2	−12.3	4.0
Pig	E01h − 2	Maxilla	2.6	13.03	37.76	3.4	−15.8	6.5
Pig	E01h − 5	Mandible	5.8	14.65	38.68	3.1	−12.6	6.8
Pig	E01h − 7	Maxilla	5.2	14.66	39.25	3.1	−18.4	6.8
Pig	E01h − 10	Vertebra	3.5	16.05	43.60	3.2	−13.7	5.2
Pig	E01h − 13	Scapula	8.2	14.49	38.61	3.1	−13.7	6.3
Pig	E01h − 15	Mandible	7.3	15.91	42.57	3.1	−18.6	4.1
Pig	E01h − 17	Maxilla	9.6	15.62	41.52	3.1	−16.4	4.7
Pig	E01h − 38	Mandible	6.1	16.12	45.13	3.3	−17.0	8.5
Pig	E01h − 39	Humerus	2.9	16.96	45.18	3.1	−14.4	6.1
Pig	E01h − 25	Maxilla	4.5	15.88	42.27	3.1	−14.4	7.1
Pig	E01h − 32	Maxilla	6.8	16.83	45.41	3.1	−14.6	7.1
Pig	E01h − 34	Vertebra	11.4	16.19	42.30	3.0	−9.3	3.4
Muntjacs	E01h − 12	Scapula	10.0	16.87	44.20	3.1	−18.5	4.4
Muntjacs	E01h − 14	Maxilla	6.1	15.56	41.17	3.1	−20.8	3.0
Muntjacs	E01h − 28	Maxilla	13.4	16.14	42.04	3.0	−21.0	5.1
Muntjacs	E01h − 40	Maxilla	4.6	15.89	42.74	3.1	−21.9	5.9
Fish	E01h − 19	Fishbone	3.2	15.15	42.60	3.3	−11.4	10.7
Fish	E01h − 33	Spine	11.9	16.88	43.47	3.0	−8.6	12.8

elemental analyzer coupled to a Thermo Finnigan MAT 253 isotope ratio mass spectrometer at the Department of Geosciences, NTU. Carbon and nitrogen isotopic values were calibrated against an in-house casein standard ($\delta^{13}C = -27.0$‰; $\delta^{15}N = 5.9$‰). During the time of analysis, replicate analysis of the in-house casein standard yielded a mean $\delta^{13}C$ value of -27.3 ± 0.1‰ and a mean $\delta^{15}N$ value of 5.9 ± 0.1‰ (1σ, $n = 28$).

2.4. Statistical analysis

Descriptive statistics (means and standard deviations) were computed for the human data and for each faunal group. Quartiles and interquartile ranges were used to recognize outliers. The dataset did not fulfill the conditions for the application of parametric statistical tests (sample sizes, equality of variances) and had other properties (presence

Table 4
Human bone collagen samples with information on skeletal element, collagen yield, C and N contents, and isotopic data. Ps. Boldface indicates poor persevered samples.

Skeleton no.	Sample no.	Skeletal element	Collagen yield (%)	% N	% C	C/N atom	$\delta^{13}C$ in ‰ vs. VPDB	$\delta^{15}N$ in ‰ vs. AIR
M1	E01l−2	Rib	7.4	14.72	40.51	3.2	−12.2	8.3
	E01l−2	Fibula	7.4	14.14	38.09	3.1	−12.0	8.6
	E01l−3	Phalange	6.1	13.86	37.12	3.1	−11.7	8.5
	E01l−1	Rib	4.5	14.07	37.74	3.1	−12.0	8.8
M2	E01m−1	Sternum	6.9	12.88	35.91	3.3	−12.3	8.7
	E01m−2	Limb	7.4	15.03	42.24	3.3	−12.6	8.1
M3	E03i−1	Skull	14.6	12.09	33.68	3.3	−12.0	8.1
	E02b−2	Scapula	11.1	11.92	33.09	3.2	−11.9	8.3
	E02b−1	**Phalange**	1.0	**8.18**	**24.44**	3.5	−12.1	8.8
M4	E02c−1	Rib	3.1	13.32	39.04	3.4	−15.5	9.8
	E02c−2	Clavicle	5.3	14.12	39.38	3.3	−15.5	9.4
M5	E02c−3	Femur	5.7	14.43	39.64	3.2	−12.0	8.5
M6	E02h−1	Tibia	11.3	13.53	36.57	3.2	−12.1	8.6
	E02g−2	Scapula	4.1	13.66	36.81	3.1	−12.4	8.2
	E02g−1	Phalange	4.3	12.68	33.61	3.1	−12.2	8.5
M7	E02i−1	Fibula	1.7	12.61	34.54	3.2	−13.7	7.8
	E02i−2	Fibula	5.0	11.19	30.68	3.2	−13.4	7.4
M8	E02j−1	Phalange	13.0	14.53	39.55	3.2	−12.4	7.8
	E02j−2	Limb	15.9	14.90	39.92	3.1	−12.1	7.4
M9	E01c−1	Limb	7.6	13.79	38.09	3.2	−10.7	8.9
	E01c−3	Metatarsal	8.0	14.28	39.58	3.2	−10.9	8.1
M11	E03i−4	Skull	6.4	13.18	36.52	3.2	−13.2	7.8
	E02a−1	Fibula	2.5	13.90	38.04	3.2	−13.3	6.9
	E02a−2	Phalange	4.7	13.71	36.18	3.1	−14.1	7.2
M12	E02l−2	Humerus	4.5	10.54	30.17	3.3	−12.2	8.2
	E02l−2	Fibula	7.7	11.97	33.34	3.2	−12.4	7.7
	E02l−1	Humerus	4.7	12.59	34.62	3.2	−12.2	8.0
	E02l−3	Humerus	3.3	11.12	30.76	3.2	−12.0	8.4
M13	E02d−1	Femur	3.8	14.47	41.96	3.4	−13.4	9.8
M14	E02e−1	Rib	9.8	14.66	39.92	3.2	−10.2	7.3
	E03i−2	Fragment	9.2	13.64	36.90	3.2	−11.8	7.8
M15	E03b−1	Pelvis?	9.7	12.61	35.53	3.3	−12.5	7.7
	E03a	Scapula	4.7	12.97	35.65	3.2	−13.0	8.0
M17	E02e−2	Rib	14.4	15.16	41.01	3.2	−12.3	7.8
	E02e−3	Vertebra	8.8	13.81	38.46	3.2	−12.3	8.3
	E02f−1	Clavicle	9.2	14.93	41.14	3.2	−11.7	8.1
	E02f−2	Humerus	9.5	13.87	38.75	3.3	−12.6	7.9
M18	E03l−2	Vertebra	9.3	12.06	34.86	3.4	−20.3	11.3
	E03l−3	Sternum	11.4	13.77	38.91	3.3	−19.8	11.0
M19	E03e−2	Phalange	13.0	15.09	40.68	3.1	−12.0	9.1
	E03e−1	Skull	9.9	14.94	40.13	3.1	−11.5	9.5
M20	E01m−3	Skull	11.8	13.24	36.37	3.2	−15.0	9.4
M21−1	E03f−1	Skull	7.6	14.92	41.44	3.2	−12.5	8.0
	E03f−3	Rib	4.6	13.98	41.21	3.4	−13.4	8.1
M21−2	**E03f−2**	**Skull**	1.4	**8.12**	31.98	**4.6**	−14.7	8.6
M22	E01m−4	Phalange	5.5	14.63	41.65	3.3	−13.1	8.2
M23	E01d−1	Scapula	10.3	14.81	41.04	3.2	−12.5	8.5
	E01d−2	Rib	14.2	12.42	33.75	3.2	−12.2	8.1
M24	E03j	Limb	6.5	14.35	40.25	3.3	−12.8	8.7
	E03g−1	Rib	8.5	12.52	34.50	3.2	−12.8	8.1
M25	E03g−2	Skull	11.1	13.13	35.85	3.2	−12.8	8.8
M26	E02k−1	Humerus	3.6	13.15	36.16	3.2	−12.9	8.2
	E02k−2	Clavicle	15.9	14.26	37.98	3.1	−12.4	8.6
	E03i−3	Skull	16.9	14.43	38.81	3.1	−13.2	9.1
B1	E01c−1	Skull	11.1	14.50	39.75	3.2	−13.1	7.9
B3	E03d−1	Rib	14.5	14.73	39.74	3.1	−13.2	6.3
B4	E03d−2	Fragment	9.3	14.95	40.78	3.2	−12.5	8.1
B5	E03d−3	Limb	6.6	14.49	40.99	3.3	−12.9	8.0
B6	E01c−2	Skull	21.3	14.11	40.17	3.3	−19.2	10.0
Unknown	E01c−2	Skull	7.4	14.53	40.22	3.2	−12.8	8.1
Unknown	E01e−2	Skull	8.0	13.63	38.22	3.3	−13.2	7.0
Unknown	E01e−3	Limb	3.5	12.96	36.24	3.3	−13.0	7.8

of outliers, large differences in group sizes) that made it unsuitable for the application of the Student *t*-test. Therefore, the nonparametric equivalent, the Kruskal-Wallis one-way analysis (K-W test for two or more independent groups), was chosen to compare differences in $\delta^{13}C$ and $\delta^{15}N$ values among age groups (adults and juveniles), genders (male adults and female adults), and faunal species. Statistical assessments were conducted using SPSS.21 for Windows.

3. Results

The sample information, collagen yield (%), carbon and nitrogen contents (%C and %N), and carbon and nitrogen isotopic data are given in Tables 3 and 4. The isotopic data are plotted in Figs. 2 and 3 as well. The collagen yields were variable, ranging from 1.0 to 21.3% (mean of $7.4 \pm 4.0\%$, n = 105). Although some researchers indicate that collagen yield is a good criterion for evaluating collagen preservation (e.g. Ambrose, 1990; van Klinken, 1999), others do not agree (e.g. Sealy et al., 2014). In this study, we evaluated collagen quality according to the carbon content (%C), nitrogen content (%N) and carbon-to-nitrogen (C/N) molar ratio rather than collagen yield.

The carbon and nitrogen content in bone collagen ranged from 30.17 to 46.32%C and from 10.54 to 17.68%N, respectively, exclusive of two human samples (E02b-1 of M3 and E03f-2 of M21-2) whose carbon or nitrogen content fell outside the range of modern bone collagen (27–47%C and 11–17%N, Ambrose, 1990; van Klinken, 1999). Hence, there was a good comparison of the weight percentages of carbon and nitrogen in collagen derived from our study with the published values. The C/N ratios of these samples fell within the acceptable range for modern bone, i.e. 2.9–3.6 (DeNiro, 1985), except for the sample E03f-2 (M21-2). In total, 103 bone (60 human and 43 faunal samples) samples yielded well-preserved collagen for isotopic analysis.

3.1. Faunal isotopic data

Faunal isotopic data are presented in Fig. 2 and Table 3; statistical comparisons are presented in Table 5. The $\delta^{13}C$ and $\delta^{15}N$ values for *Cervus* sp. ranged from −17.9 to −6.9‰ and from 1.6 to 6.1‰, respectively. The mean $\delta^{13}C$ and $\delta^{15}N$ values were $-12.1 \pm 2.9‰$ and $4.0 \pm 1.1‰$ (1σ, n = 24), respectively. The isotope ranges of muntjacs fell between −21.9 and −18.5‰ for $\delta^{13}C$ values and between 3.0 and 5.9‰ for $\delta^{15}N$ values. These muntjacs displayed a mean $\delta^{13}C$ value of $-20.5 \pm 1.4‰$ and a mean $\delta^{15}N$ value of $4.6 \pm 1.2‰$ (n = 4). There was no clear difference between the $\delta^{15}N$ values of *Cervus* sp. and muntjacs (H = 1.179, p = 0.277, Table 5). However, the $\delta^{13}C$ values of *Cervus* sp. were higher than those of muntjacs (H = 9.939, p = 0.002). Combining the isotopic data of *Cervus* sp. and muntjacs produced $\delta^{13}C$ ranges from −21.9 to −6.9‰ (mean $\delta^{13}C$ value of $-13.3 \pm 4.0‰$, n = 28) and $\delta^{15}N$ ranges from 1.6 to 6.1‰ (mean $\delta^{15}N$ value of $4.1 \pm 1.1‰$, n = 28), which could be considered to be the isotopic baseline for herbivores found at the FTY site.

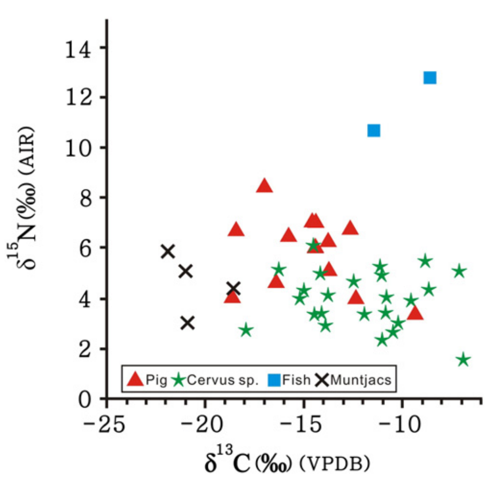

Fig. 2. Animal bone collagen $\delta^{13}C$ and $\delta^{15}N$ values plotted by species.

The isotope range of the 13 pig samples was between −18.6 and −9.3‰ for $\delta^{13}C$ values and between 3.4 and 8.5‰ for $\delta^{15}N$ values. The mean $\delta^{13}C$ and $\delta^{15}N$ values were $-14.7 \pm 2.6‰$ and $5.9 \pm 1.5‰$, respectively. These pigs presented similar $\delta^{13}C$ values but higher $\delta^{15}N$ values compared to those of the herbivores (H = 2.124, p = 0.145 for $\delta^{13}C$, H = 11.433, p = 0.001 for $\delta^{15}N$, Table 5).

The fish samples showed relatively high $\delta^{13}C$ values (−8.6 and −11.4‰) and had the highest $\delta^{15}N$ values (10.7 and 12.8‰) of all of the faunal samples studied here.

3.2. Human isotopic data

The isotopic data of human samples are shown in Fig. 3 and Table 4. Two samples showed poor collagen preservation, which means only 32 individuals were included in the following discussion (M21-2 was excluded). For the individuals with isotopic values derived from two or more subsamples of different skeletal elements, an average was calculated and used as the representative value. The analysis of carbon and nitrogen isotope compositions of 32 individuals resulted in $\delta^{13}C$ values ranging from −20.0 to −10.8‰ and in $\delta^{15}N$ values ranging from 6.3 to 11.1‰. Six outliers were identified by the quartiles and interquartile range, inclusive of M4, M13, M18, M20, B3 and B6 (Fig. 3). Analysis that excluding these individuals produced smaller isotopic ranges ($\delta^{13}C$ values fell between −13.6 and −10.8‰; $\delta^{15}N$ values fell between 7.0 and 9.3‰) with a mean $\delta^{13}C$ value of $-12.5 \pm 0.7‰$ and a mean $\delta^{15}N$ value of $8.1 \pm 0.5‰$ (n = 26).

Two of the six individuals, M18 and B6, showed much lower $\delta^{13}C$ values while having higher $\delta^{15}N$ values within the group, which makes their isotopic values fall near the upper left corner on the scatter plot of $\delta^{13}C$ and $\delta^{15}N$ values (Fig. 3). The isotopic values of M4, M13 and M20 roughly fall in the center on the scatter plot. B3 had the lowest $\delta^{15}N$ value of all of the human individuals studied here.

3.3. Diet difference between age groups

Exclusive of the six outliers, the remaining individuals were subdivided into two subgroups, adults and juveniles. The adult group included 14 individuals, showing mean $\delta^{13}C$ and $\delta^{15}N$ values of $-12.4 \pm 0.6‰$ and $8.2 \pm 0.3‰$, respectively. Four individuals were identified as juveniles. Their mean $\delta^{13}C$ value was $-12.6 \pm 1.0‰$, and their $\delta^{15}N$ value was $8.0 \pm 0.6‰$. No difference was found in stable isotopic values between the adult and juvenile groups (H = 1.034, p = 0.309 for $\delta^{13}C$, H = 0.483, p = 0.487 for $\delta^{15}N$, Table 5).

3.4. Diet difference between genders

The juvenile group was excluded in the comparison of male and female data. Seven male adults displayed mean $\delta^{13}C$ and $\delta^{15}N$ values of $-12.2 \pm 0.3‰$ and $8.4 \pm 0.2‰$, respectively. Although both isotopic values of the two female adults were slightly lower than the mean values of the male adults, there is no significant difference between male adults and female adults in terms of the $\delta^{13}C$ and $\delta^{15}N$ values (H = 0.105, p = 0.293 for $\delta^{13}C$, H = 3.220, p = 0.073 for $\delta^{15}N$).

4. Discussion

To better understand the local isotopic framework for the interpretation of the human diet, the faunal isotopic results are discussed first. The archaeological evidence inclusive of the artifacts and ecofact remains from the FTY site and other sites of the FTY culture are combined with the isotopic results in order to discuss the dietary patterns at the FTY site. Since there is no clear offset in either carbon or nitrogen isotopic

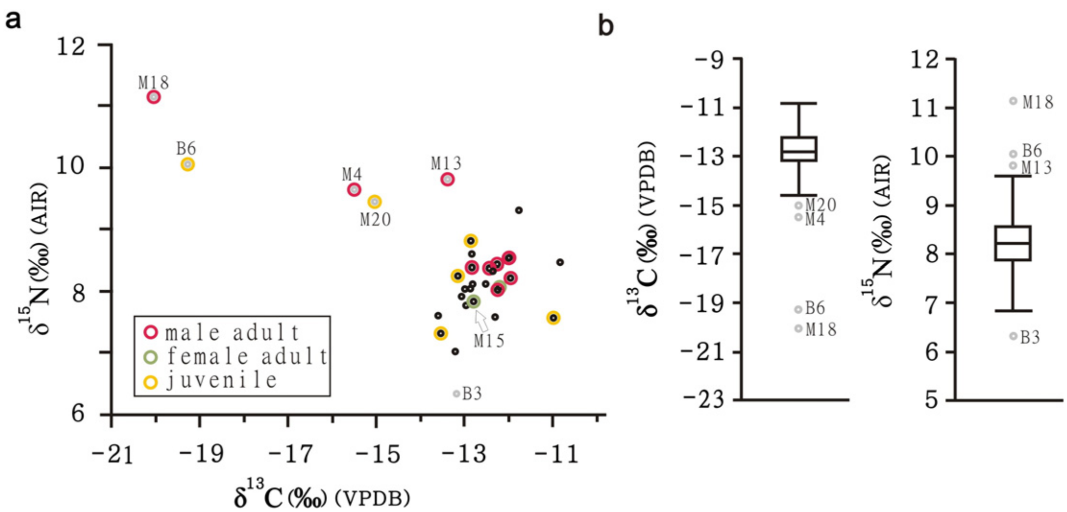

Fig. 3. (a) Scatter plot of human bone collagen $\delta^{13}C$ and $\delta^{15}N$ values. (b) Box plot. The middle line represents the median, the bottom of the box is the 25th percentile, the top of the box is the 75th percentile, and the T-bars extend to 1.5 times the height of the box. The gray dots on both panels indicate the individuals with diet different from the others.

signatures between genders (male adults and female adults) or among ages (adults and juveniles), only the isotopic difference between the six outliers and the other 26 individuals is discussed.

4.1. Isotopic values from faunal remains

The $\delta^{13}C$ and $\delta^{15}N$ ranges of FTY herbivores are from −21.9 to −6.9‰ and from 1.6 to 6.1‰, respectively. The nitrogen isotopic ranges are generally in agreement with those of terrestrial herbivores from East Asia and the Pacific islands during the Neolithic period (e.g. Hu et al., 2008; Kinaston et al., 2013a; Yoneda et al., 2004). However, their carbon isotopic ranges are wider than other data. The difference is caused by lower $\delta^{13}C$ values in muntjacs (mean − 20.5 ± 1.4‰) than in *Cervus* sp. (mean − 12.1 ± 2.9‰). Assuming a mean $\delta^{13}C$ value of −25.4‰ for C_3 plants (Yoneda et al., 2004) and taking into account a subsequent trophic shift of $\delta^{13}C$ values from plant to herbivore bone collagen ($\delta^{13}C_{diet} = \delta^{13}C_{collagen}$ - 5, Ambrose and Norr, 1993; Tieszen and Fagre, 1993), a herbivore consuming wholly C_3 plants should display a $\delta^{13}C_{collagen}$ value of −20.4‰. In other words, the muntjacs at the FTY site were eating predominantly C_3 plants. This result concurs with modern faunal observations that muntjacs occupy broad-leaved forests in Taiwan and consume various forbs and browses, especially *Fatsia polycarpa*, *Schefflera taiwaniana*, *Viburnum luzonicum*, and *Deutzia pulchra* that are classified as C_3 plants (McCullough et al., 2000).

By contrast, the $\delta^{13}C$ values of *Cervus* sp. point to a mixed intake of C_3 and C_4 food resources. When the mean $\delta^{13}C$ value of −10.0‰ for C_4 plant is considered (Yoneda et al., 2004), it is very likely that some individuals of the *Cervus* sp., such as E01h-6 and E01h-35 that displayed relatively high $\delta^{13}C$ values, consumed large amounts of C_4 plants. Even though the *Cervus* species cannot be identified by the morphological features of the samples, this dietary pattern concurs with the foraging strategies of Formosan Sambar (*Rusa unicolor*) and Formosan sika deer (*Cervus nippon taiouanus*), the other two native deer species in Taiwan. The sika deer are mixed feeders, eating grass, forbs, and browses on the lowlands, marshes, and plains of Taiwan (McCullough, 2009), while sambar deer occupy higher elevation habitats and prefer consuming Poaceae grass and browse (Yen et al., 2014). No detailed information about the plant taxa consumed by the two deer species is available. However, isotopically, it has been shown that there are C_4 plants in Taiwan, for example, the Poaceae and Cyperaceae species (e.g. Ku et al., 2007; Lin et al., 2007). It is therefore conceivable that the C_4 isotopic signature enter into the body of sika deer or sambar deer when they search for foods, especially grass.

The mean $\delta^{13}C$ and $\delta^{15}N$ values for the pigs are − 14.7 ± 2.6‰ and 5.9 ± 1.5‰, respectively. The $\delta^{13}C$ values from the samples of pigs and herbivores are comparable, while the $\delta^{15}N$ values are significantly higher in pig samples than in the herbivore samples. This could be due to more input from animal protein in the diet of pigs at the FTY site.

When the highest $\delta^{15}N$ value of herbivores (6.1‰) is considered as an upper limit, then six pigs with $\delta^{15}N$ values lower than 6.1‰ could be viewed as having consumed a plant-based diet (mean $\delta^{13}C$ value = −14.1 ± 3.2‰ and mean $\delta^{15}N$ value = 4.6 ± 0.9‰). There is no clear offset between both values of the six pigs and the herbivores ($H = 0.400$, $p = 0.527$ for $\delta^{13}C$, $H = 1.039$, $p = 0.308$ for $\delta^{15}N$, Table 5). By contrast, the $\delta^{15}N$ values of the other seven pigs are significantly higher than that of the herbivores, though not for $\delta^{13}C$ values ($H = 2.458$, $p = 0.117$ for $\delta^{13}C$, $H = 16.379$, $p < 0.001$ for $\delta^{15}N$), which could be the result of their having more omnivorous diets (mean $\delta^{15}N$ value = 7.0 ± 0.7‰). This result is consistent with a review paper indicating that wild pigs have various foraging behavior, including browsing and grazing (grass, herbs, stems, leaves), foraging on the ground (fruits, fungi, animal matter), rooting (rhizomes, roots, invertebrates), and predation (vertebrates) (Ballari and Barrios-García, 2014). However, the same paper also highlighted that around 90% of the wild pig's diet is plant-based by preference. In addition, the isotopic dietary studies on modern and ancient wild pigs from Europe (Dürrwächter et al., 2006), western Asia (Lösch et al., 2005), northern China (Barton et al., 2009) and Japan (Minagawa et al., 2005) also suggested that the $\delta^{15}N$ values of most wild pigs are comparable to herbivores, such as deer, caprids and bovines. As a result, for the seven pigs that displayed higher $\delta^{15}N$ values at the FTY site, consumption of leftovers by the humans cannot be ruled out.

Table 5
Statistical result for comparison of isotopic values among (a) age groups and genders, and among (b) faunal species.
Boldface indicates the difference between two groups is significant.

(a)	Adults vs. juveniles	Male adults vs. female adults
$\delta^{13}C$ value	H = 1.034, p = 0.309	H = 0.105, p = 0.293
$\delta^{15}N$ value	H = 0.483, p = 0.487	H = 3.220, p = 0.073

(b)	*Cervus* sp. vs. muntjacs	Pigs vs. herbivores	Pigs with low $\delta^{15}N$ values vs. herbivores	Pigs with high $\delta^{15}N$ values vs. herbivores
$\delta^{13}C$ value	H = 9.939, **p = 0.002**	H = 2.124, p = 0.145	H = 0.400, p = 0.527	H = 2.458, 0 = 0.117
$\delta^{15}N$ value	H = 1.179, p = 0.277	H = 11.433, **p = 0.001**	H = 1.039, p = 0.308	H = 16.379, **p < 0.001**

Only two fish samples were available for this study. There was considerable difficulty in identifying the species or their habitats since the remains were non-diagnostic fish bone or spines. By comparing their isotopic values with that of 41 archaeological marine fish and seven freshwater fish remains derived from other Pacific islands, including French Polynesia, Fiji, New Zealand, Korea and Japan (Choy and Richards, 2009; Field et al., 2009; Jones and Quinn, 2009; Kinaston et al., 2013b; Naito et al., 2010a, 2010b; Richards et al., 2009; Tsutaya et al., 2014; Yoneda et al., 2004), their provenance could be clarified. The $\delta^{13}C$ and $\delta^{15}N$ values of the two FTY fish samples fall within the isotopic ranges of 41 marine fish ($\delta^{13}C$ values from −15.2 to −1.5‰ and $\delta^{15}N$ values from 7.1 to 17.3‰), but outside that of seven freshwater fish ($\delta^{13}C$ values from −21.3 to −18.4‰ and $\delta^{15}N$ values from 6.0 to 10.5‰), which indicates that the two fish samples collected from the FTY site may have been marine fish.

4.2. Human dietary patterns

Of the 32 human individuals analyzed in this study, six were isotopically different from the others, and these six are discussed separately. The mean isotopic values of the remaining 26 human individuals ($\delta^{13}C = -12.5 \pm 0.7$‰ and $\delta^{15}N = 8.1 \pm 0.5$‰) indicate that their diets derived from a mix of C_3 and C_4 foods, and were probably dominated by terrestrial animal protein. To confirm this, the mean isotopic values of human bone collagen were compared with those of faunal bone collagen found at the FTY site. In general, the trophic shift of $\delta^{15}N$ values between the collagen of prey and predator is suggested to be 2–6‰ ($\Delta^{15}N_{predator\ collagen\text{-}prey\ collagen} = 2$–6‰, DeNiro and Epstein, 1981; O'Connell et al., 2012), while the shift of $\delta^{13}C$ values is smaller, between 0 and 2‰ ($\Delta^{13}C_{predator\ collagen\text{-}prey\ collagen} = 0$–2‰, Bocherens and Drucker, 2003; Lee-Thorp, 2008). The mean $\delta^{13}C$ and $\delta^{15}N$ values of the 26 human individuals are approximately 0.8–2.2‰ and 2.2–4.0‰, respectively, and are higher relative to those of pigs and herbivores at the FTY site. In consequence, the differences in isotopic values are in agreement with a diet-consumer relationship between humans and terrestrial fauna. This result is supported by the faunal remains as well as by the artifacts for hunting and for meat processing found at the FTY, Luliao, and Huilai sites (Ho, 2003; Ho et al., 2007; Ho and Chu, 2007; Shih and Song, 1956).

By contrast, since the offsets in isotopic values between the 26 human individuals and marine fish samples from the FTY site do not fall within the expected ranges for one trophic level, it seems that marine fish did not greatly contribute to the diets of these individuals, though fish remains were also recovered at the FTY culture sites (Ho et al., 2007; Ho and Chu, 2007; Shih and Song, 1956). Freshwater fish or shellfish appear to have been consumed as well (Ho et al., 2007; Ho and Chu, 2007; Shih and Song, 1956). However, it is difficult to assess the contribution of these two aquatic resources to the diets of the 26 human individuals because no isotopic data of shellfish or freshwater fish were available from the studied area and time period.

Evaluating the contribution of plant resources to the human diets is also difficult since, thus far, no plant remains have been found at the FTY site during the excavation period when recovery techniques such as flotation were not used. However, the finding of harvesting implements and archaeobotanical evidence at the other FTY sites suggest that people of the FTY culture ate some C_3 plants, as well as rice (Ho, 2003; Ho and Chu, 2007; Shih and Song, 1956).

In order to reconstruct the dietary patterns of the 26 human individuals from the FTY site, Fig. 4 is used to compare the carbon and nitrogen isotopic compositions in the human diet with those in potential food resources (edible part). The isotopic compositions in the human diet are inferred from the collagen values by taking into account the difference in isotopic values between a consumer's bone collagen and his diet ($\delta^{13}C_{diet} = \delta^{13}C_{collagen} - 5$, $\delta^{15}N_{diet} = \delta^{15}N_{collagen} - 3$; Ambrose and Norr, 1993; Tieszen and Fagre, 1993). Potential food resources considered here include terrestrial herbivores, pig, marine fish, marine

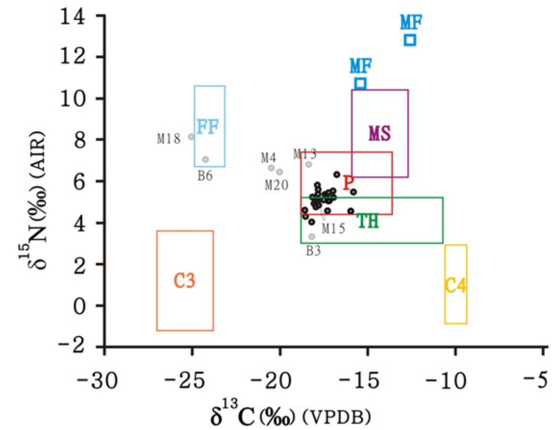

Fig. 4. $\delta^{13}C$ and $\delta^{15}N$ values of human diet are shown as black/gray dots. Squares represent one sigma range of potential food resources (Table 6). C_3: C_3 plants; C_4: C_4 plants; TH: terrestrial herbivores; P: pigs; FF: freshwater fish; MF: marine fish; MS: marine shellfish. The P, TH, and MF data come from this study, while others are cited from the study of Yoneda et al. (2004).

shellfish, freshwater fish, as well as C_3 and C_4 plants. For the previous three food resources, the isotopic ranges for the edible parts, the flesh, are constructed from the isotopic data analyzed in this study by considering the difference in isotopic values between bone collagen and flesh (see Table 6 for details). Due to isotopic data being unavailable in this study, the reported values of archaeological freshwater fish and of the modern counterparts for the other three food resources are cited from a study done in Japan (Yoneda et al., 2004). It should be noted that because the relation between the isotopic values of a consumer's bone collagen and his diet have not been understood thoroughly, this comparison may contain some uncertainties. The possibility of temporal and geographical variability among isotopic dataset (Iron Age Taiwan vs. Neolithic Japan) has to be kept in mind as well.

This rough comparison shows that the dietary patterns of the community at the FTY site, as suggested above, were composed of mainly terrestrial animal proteins (Fig. 4). It seems that the contribution of marine shellfish was significant as well. By contrast, the other food resources were less important, including marine fish, freshwater fish and plants. It remains unclear why freshwater fish were not an important dietary resource at the FTY site, even though the Daan River is nearby. Likewise, there is no isotopic evidence for significant marine fish consumption in spite of the proximity of FTY to the coast. The intake of plants, which are low-protein foods, may be under-estimated by collagen isotopic values, as both carbon and nitrogen elements in collagen, especially the latter one, are directly acquired from dietary protein (Ambrose and Norr, 1993).

4.3. Dietary differences within the population

Six individuals showed diets different from the dietary patterns of the other 26 individuals (Fig. 3). Based on their isotopic values, the six individuals could be subdivided into at least two sub-groups: M4, M13, M18, M20, and B6 in one group and B3 in another. The lower $\delta^{13}C$ but higher $\delta^{15}N$ values from M18 and B6 can be attributed to a diet dominated by freshwater resources, especially freshwater fish (Fig. 4). M4, M13, M20 also showed a similar pattern but at a smaller degree, which probably points to a mixed diet of freshwater resources and terrestrial animals. The lowest $\delta^{15}N$ value, from B3, indicates that this individual consumed less meat than the others.

Several possible explanations are proposed for the dietary patterns observed for these individuals. First, they may have had special status in this community, which allowed them more opportunities to get some particular foods. For example, it has been shown that in some ancient societies, individuals of high social status had higher $\delta^{15}N$ values

Table 6
Carbon and nitrogen isotope ranges of potential food resources for comparison with the isotope values of human individual's diet.

Food resources	δ^{13}C mean	Corrected δ^{13}C	δ^{15}N mean	Corrected δ^{15}N
Data from Yoneda et al. (2004)				
Modern terrestrial C_3-plant (n = 16)	−25.4 ± 1.6[a]	–	1.2 ± 2.4	–
Modern terrestrial C_4-plant (n = 5)	−10.0 ± 0.5[a]	–	1.0 ± 1.9	–
Modern shellfish flesh (n = 13)	−14.3 ± 1.6[a]	–	8.3 ± 2.1	–
Archaeological freshwater fish (n = 7)	−20.0 ± 0.9	−24.0 ± 0.9[c]	8.6 ± 1.9	8.6 ± 1.9[d]
This study				
Terrestrial herbivores (n = 28)	−13.3 ± 4.0	−14.8 ± 4.0[b]	4.1 ± 1.1	4.1 ± 1.1[d]
Pigs (n = 13)	−14.7 ± 2.6	−16.2 ± 2.6[c]	5.9 ± 1.5	5.9 ± 1.5[d]
Marine fish	−11.4	−15.4[c]	10.7	10.7[d]
	−8.6	−12.6[c]	12.8	12.8[d]

[a] The Suess effect has been corrected for the reported values.
[b] $\delta^{13}C_{muscle} = \delta^{13}C_{collagen} - 1.5$ for terrestrial animals (Kinaston et al., 2013a).
[c] $\delta^{13}C_{muscle} = \delta^{13}C_{collagen} - 4$ for fish (Ambrose and Norr, 1993; Beavan−Athfield et al., 2008).
[d] $\delta^{15}N_{soft\ tissue} = \delta^{15}N_{collagen}$ (Ambrose and Norr, 1993).

than commoners, which was interpreted as more intake of foods from higher trophic levels, such as animal protein (e.g. Ambrose et al., 2003; Kinaston et al., 2013c). If this was the case in our study, then M4, M13, M18, M20, and B6 could be considered to have high social status, while B3 had low social status. Additionally, freshwater resources may have been the foods for those with high social status in this community. However, without archaeological evidence to indicate social status, the difference in diet revealed here cannot be attributed with certainty to a difference in social status.

Second, these individuals could be non-locals. If this was the case, then they may have originated from at least two different regions. Assuming that the group that includes M4, M13, M18, M20, and B6 originated from the same region, and considering the fact that the turnover rate of adult bone collagen is quite low (Hedges et al., 2007), they may have moved to the FTY site at different stages during their life history. For example, M18 (male adult) may have migrated to this area during later in his life because he retained the initial isotope values that are significantly different from the local signatures at the FTY site. By contrast, the other two male adults, M4 and M13, may have lived a significant proportion of their lives in this area such that the previous isotopic compositions in their bone collagen would have been replaced. Due to the dental extraction feature, M15 could have been an immigrant. However, the isotopic values suggest that M15's diet was not different than that of the others (Fig. 4), thus possibly indicating a local origin. However, from the current stable isotopic result, the possibility either that M15 had migrated and stayed for quite a long time at the FTY site or that she subsisted on a diet similar to that of the natives of the FTY site before migrating there cannot be ruled out.

Third, there could be dietary shift over time at the FTY site. Nevertheless, only archaeological context for 14 individuals analyzed here is available (Shih and Song, 1956; Song, 1962). According to the stratum order of each burial, the 14 individuals could be assigned to several relative chronological groups. The rough comparison showed no considerable temporal trend in either δ^{13}C or δ^{15}N values (Supplementary Fig.), which could give an indication of uniform diet over time at the FTY site. However, it is not certain that the individuals buried in the same stratum belonged to the same chronological phase. Radiocarbon dating for each human individual could help shed light on dietary shift over time (e.g. Atahan et al., 2014).

5. Conclusion

The carbon and nitrogen isotope ratios indicate that the human group that lived at Fantzuyuan during the Iron Age mainly consumed terrestrial animals such as pigs, deer, and marine shellfish. Plants contributed little to the diet. The consumption of marine or aquatic fish does not seem to have been important, in spite of the proximity of the site to the river and the coast. The results of this study also indicate a uniform diet for the group, with no differences among age groups and between genders. However, six individuals may have had special social status or were non-locals, as evidenced by their isotopic compositions, which were different from the others.

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