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Stable isotope analysis of Joseon people skeletons from the cemeteries of Old Seoul City, the capital of Joseon Dynasty

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Abstract: Stable carbon and nitrogen isotope analysis reveals the diets of different human populations in history. In this study, we performed stable isotope analysis on human skeletons from Joseon-period cemeteries discovered around Old Seoul City (Hansung). Our data clearly showed that Joseon individuals consumed more C_3-based than C_4-based foods as the main staples, and that the proteins they ate were mainly of terrestrial, but not of marine origin. Stable isotope values exhibited unique patterns in each of our sample subgroups. Whereas the $\delta^{13}C$ values did not show any statistical differences among the subgroups, significantly higher values of $\delta^{15}N$ were found in males than in females, which might reflect dietary differences between the sexes. For a fuller understanding of the dietary patterns of pre-industrial (pre-20th century) Koreans, additional studies on Joseon samples from Korean archaeological sites will be necessary.

Key words: Stable isotope analysis, Human bones, Nitrogen, Carbon, Joseon Dynasty

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Introduction

Diets of the past and the related environmental factors can be studied by stable carbon and nitrogen isotope analysis, one of the well-established techniques of archaeological science [1-7]. Such analyses are based on the principle that the carbon and nitrogen isotope values of specific foods are reflected in the isotope compositions of human or animal bodies [6, 8]. The stable isotope results derived from those analyses are proven to represent the average diet over at least the last several years prior to the individual's death [9]. Generally, different historical populations utilize the food resources that are available in their respective environments [10-13]. Carbon and nitrogen stable isotope analyses on skeletal series representing various spatial and temporal ranges therefore reveal the paleodietary patterns of historical peoples even in the absence of other scientific evidence.

To acquire the information on the diets of the past, some of the pioneering stable isotope analyses have also focused on ancient samples from Korean archaeological sites [6, 14, 15]. In the cases, information invaluable to any comprehensive understanding of historical dietary habits in Korea has been obtained. However, the data required to reveal the general patterns of the diets representing the relatively recent later-Joseon period (1392–1910 CE) still remains insufficient. In fact, most completed studies on Joseon samples are case reports on just a few individuals at a time.

Even though Joseon-period samples are of relatively recent chronology in Korean history, their academic meaning

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is not at all insignificant. Indeed, between Joseon and modern Korean samples, there is an intervening period of rapid industrialization and modernization. We expect that there would be many and significant differences in the biological traits of the bones representative of those respective periods, as induced by the very divergent socio-economic environments.

Over the past several years, we have endeavored to build a human sample collection consisting of skeletons discovered in 16th–18th century Joseon cemeteries in Korea. In fact, our previous studies have yielded clarifying data on the health and disease statuses of pre-modern Joseon peoples [16-22]. In the present study, to contribute to a better understanding of the food-intake patterns of pre-modern Joseon populations in Korean history, we tried to perform a stable isotope analysis on skeletons from the same Joseon collection.

Materials and Methods

The samples of this study were obtained from the bones of Joseon Human Skeletal Series (JHSS) maintained in Department of Anatomy, Seoul National University College of Medicine. Briefly, the skeletal individuals were collected from the tombs identified in the archaeological sites of Sinnae (SN) and Eunpyeong (EP) (by Hangang Institute of Cultural Heritage, Seoul, Korea). Both sites were known to be the cemeteries for Seoul people of Joseon period. Rescue archaeology was done on the sites before an urban redevelopment plan began. In the site, archaeologists found many tombs where human skeletons were discovered (Fig. 1).

Fig. 1. Examples of skeletons used in this study. (A) SN 2-8. (B) EP C-8. SN, Sinnae; EP, Eunpyeong.

The bones were moved to Seoul National University, being maintained as a part of skeletal series.

Anthropologists among us did sex and age estimation on the samples. Sex was determined by methods recommended by Buikstra and Ubelaker [23]. Briefly, the estimation of the individuals' sexes was based on the anatomical differences of the pelvic bone (e.g., sciatic notch, preauricular sulcus, ischiopubic ramus, and subpubic angle). Additional clues obtained from the skull, such as the nuchal crest, mastoid process, supraorbital margin, and the palate, also were considered [24, 25]. Age was also estimated by auricular-surface degeneration of the hip bone, based on the degree of transverse organization, granularity, apical activity, retroauricular area degeneration, and auricular-surface porosity [26]. The age was accordingly categorized into eight phases: 1–2, young adult (20–35 years old); 3–6, middle-aged (36–50 years old); and 7–8, old adult (over 50 years old).

For studying carbon and nitrogen stable isotope ratio, collagen is extracted from archaeologically obtained bones because it is regarded as an ideal experimental sample for stable carbon and nitrogen isotope analysis. All samples were prepared for isotopic analysis following a modified Longin method [27], with the addition of an ultrafiltration step [28]. Briefly, 200 mg of powdered bone were demineralized in 0.5 M HCl solution at 4°C for 16 hours. The collagen was then gelatinized in pH 3 water at 75°C for 48 hours. After removing insoluble residues with a 5–8 μm Ezee mesh filter (Elkay Laboratory Products, Hampshire, UK), the remaining solution was filtered using 30-kDa filters once again to remove impurities [29].

Content and isotope ratios of C and N were determined using a continuous-flow stable isotope ratio mass spectrometer (IsoPrime-EA, Micromass, Manchester, Milan, UK) linked with a CN analyzer (NA Series 2, CE Instruments, Milan, Italy). Carbon and nitrogen isotope compositions ($\delta^{13}C$ and $\delta^{15}N$) were calculated as: δ (‰)=$[(R_{sample}/R_{standard})-1]\times1000$ where R is the ratio of $^{13}C/^{12}C$ or $^{15}N/^{14}N$; and the standards were the Pee Dee Belemnite (PDB) for carbon and atmospheric (AIR) for nitrogen. Two replicate analyses were performed for each sample; and the averages were used for the statistical analysis in this study. Multiple replicate analyses indicated that standard deviations for the $\delta^{13}C$ and $\delta^{15}N$ measurements were <0.1‰ and <0.2‰, respectively.

It is crucial for researchers to seek out outliers or extreme values that could make a serious negative influence on the statistical analysis [30]. Among the 40 samples examined in

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this study, we tried to find out the outliers by general boxplot methods [30, 31]. Briefly, a simple method for constructing inner and outer fences could be applied to our data. Inner fences in this study (f_1 and f_3) were made by the equations of $f_1=q_1-1.5\times IQR$ and $f_3=q_3+1.5\times IQR$. The probability of the mild outlier beyond the inner fences is 0.006976. As for the extreme outlier beyond the outer fences (probability, 0.00000235), we used the equations, $F_1=q_1-3\times IQR$ and $F_3=q_3+3\times IQR$. Mild or extreme outliers identified were finally removed from our dataset.

Dataset before and after removal of outlier were evaluated by Shapiro test for distribution and by variance equality test. Two sample *t* test for independent samples was used for testing differences in $\delta^{13}C$ and $\delta^{15}N$ values between each sex and cemetery group. Differences of $\delta^{13}C$ and $\delta^{15}N$ among age groups (young, middle, old) were tested using one-way analysis of variances (ANOVA). All statistical analyses were performed using the R version 3.1.1 [32]. Differences at the

Table 1. Sample information and analytical value

Sample	Sex	Age	Collagen (mg)	Total C (%)	$\delta^{13}C$ PDB (‰)	Total N (%)	$\delta^{15}N$ AIR (‰)	C:N
SN 4-15	M	Old	6.9	43.184	−20.43	14.626	12.02	3.4
SN 2-3	M	Old	14.3	44.672	−20.06	16.178	11.41	3.2
SN 1-2	M	Old	1.3	38.539	−20.95	14.399	11.29	3.1
SN 2-4	F	Young	7.4	43.216	−19.71	15.156	9.5	3.3
SN 3-14	M	Old	16.6	44.706	−19.81	15.649	12.621	3.3
SN 2-10	F	Middle	11.1	42.788	−19.95	15.282	9.34	3.4
SN 2-7	F	Young	9.1	43.193	−21	14.942	11.32	3.3
SN 4-27	M	Middle	8.8	43.85	−19.65	15.448	12.25	3.4
SN 2-8	F	Young	15.2	44.985	−20.79	15.653	9.76	3.5
SN 1-1(2)	F	Middle	16.8	44.868	−20.32	15.062	10.63	3.0
SN 4-25(1)	M	Middle	8.9	40.161	−21.4	15.449	11.36	3.0
SN 4-25(2)	F	Young	8.7	39.883	−20.53	15.35	10.87	3.3
SN 1-60	M	Middle	11.0	42.607	−19.59	14.936	11.13	3.4
SN 1-57	F	Old	37.0	47.69	−20.22	16.491	10.15	3.2
SN 2-15(1)	F	Old	13.1	40.553	−20.85	14.862	10.62	3.3
SN 2-15(2)	M	Young	13.5	46.272	−19.45	16.381	11.62	3.1
SN 4-18(1)	M	Old	14.0	46.382	−20.13	17.232	11.29	3.4
SN 4-18(2)	F	Middle	17.0	46.55	−20.69	15.877	11.12	3.3
SN 2-19(1)	M	Old	5.0	45.444	−19.51	15.884	11	3.3
SN 2-19(2)	F	Old	16.0	47.033	−19.43	16.383	11.01	3.3
Mean±SD (SN)			12.58±7.17	43.83±2.55	−20.22±0.59	15.56±0.71	11.01±0.85	3.27±0.14
EP 3-D 1-360	M	Middle	9.8	44.491	−18.54	15.645	12.28	3.3
EP 3-D 1-47	F	Young	9.2	43.575	−19.72	15.349	11.26	3.3
EP 3-D 1-155	M	Middle	13.3	44.337	−19.65	15.812	10.69	3.3
EP 3-C 4-30	M	Young	19.4	43.821	−19.76	15.503	11.22	3.3
EP 3-D 1-384	F	Middle	9.8	43.827	−17.26	15.193	11.22	3.4
EP 3-D 1-194	F	Young	18.0	43.068	−20.27	14.924	10.68	3.4
EP 3-D 1-257	M	Old	16.4	43.19	−19.47	15.144	11.51	3.3
EP 3-D 1-380	M	Middle	16.6	43.102	−20.51	15.361	11.52	3.3
EP B 2 III-1(1)	M	Old	20.0	46.159	−19.46	16.276	12.49	3.3
EP 3-C 4-32	F	Young	14.5	45.732	−20.27	16.191	12.32	3.3
EP 3-C 4-14	M	Middle	4.1	43.89	−18.86	14.164	11.63	3.6
EP 3-C 4-24	F	Middle	11.4	44.553	−19.07	15.386	12.47	3.4
EP C-8(1)	M	Middle	11.3	44.449	−19.25	15.702	12.66	3.3
EP 3-D 1-379(1)	M	Middle	6.0	46.813	−19.35	15.898	12.56	3.4
EP 2-43(1)	M	Middle	9.2	43.345	−20.69	15.45	11.43	3.3
EP 2-43(2)	F	Middle	6.8	40.75	−20.33	15.392	11.3	3.1
EP 3-D 1-188(1)	M	Middle	6.0	46.492	−20.35	16.243	12.3	3.3
EP 3-D 1-188(2)	F	Middle	13.1	46.386	−20.27	16.558	11.84	3.3
EP C-10(1)	M	Middle	13.3	43.228	−20.49	15.588	11.52	3.2
EP C-10(2)	F	Middle	13.0	46.304	−20.52	16.301	12.53	3.1
Mean±SD (EP)			12.06±4.56	44.38±1.54	−19.70±0.85	15.60±0.56	11.77±0.63	3.31±0.11
Mean±SD (total)			12.32±5.93	44.10±2.09	−19.96±0.77	15.58±0.63	11.39±0.83	3.29±0.12

PDB, Pee Dee Belemnite; AIR, atmospheric; SN, Sinnae; EP, Eunpyeong; SD, standard deviation.

0.05 level are reported as significant.

Results

The stable isotope results of Joseon people buried in the cemeteries around Old Seoul City are summarized in Table 1. The $\delta^{13}C$ and $\delta^{15}N$ results are also summarized in the same Table. As for the preservation status of collagen in this study, we analyze the atomic C/N ratios and the yield of extracted gelatin [7]. Considering C/N ratios of 2.9–3.6 as acceptable [7, 8, 33], every sample in this study (C/N ratios, 3.0 to 3.6) looks fall within the acceptable range, being used as a dataset for the analysis.

By the outlier-finding analysis suggested by Schwertman et al. [30], EP-3-D1-384 was removed as outlier from our original dataset (Fig. 2). The $\delta^{13}C$ value of EP-3-D1-384 is −17.26, that is greater than inner fence f_3 ($\delta^{13}C$ value, −18), but not beyond the outer fence F_3 ($\delta^{13}C$ value, −16.7). As EP-3-D1-384 falls into *mild* outlier, we remove it from the dataset.

Stable isotope results of new dataset (n=39) ranged −18.54‰ to −21.4‰ (mean, −20.03±0.64‰) for $\delta^{13}C$, and 9.34‰ to 12.66‰ (mean, 11.40±0.84‰) for $\delta^{15}N$. The results of the different sex, age, and cemetery groups are also summarized in Table 2, and plotted in Fig. 3.

Briefly, *t* test showed that there are no significant differences in $\delta^{13}C$ values between sex (male and female; t=−1.756, P=0.087), and between cemeteries (SN and EP; t=−1.989; P=0.054). One-way ANOVA test also exhibited no significant

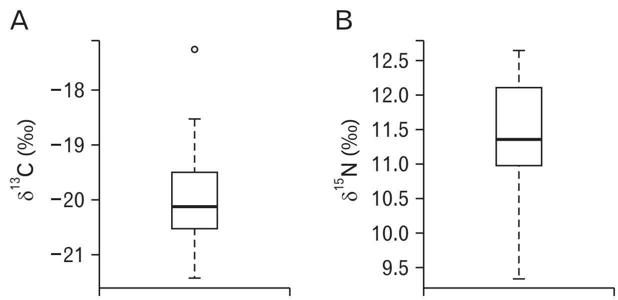

Fig. 2. (A) Box plot for $\delta^{13}C$ (‰), exhibiting median, 1st and 3rd quartiles, the lowest datum still within the 1st quartile−1.5×IQR and the highest datum still within of the 3rd quartile+1.5×IQR. Mild outlier is seen beyond inner fence. (B) Box plot for $\delta^{15}N$ (‰). No outliers were found.

Table 2. Summary of carbon and nitrogen isotope ratios (‰) of groups

Characteristic		No.	δ13C (‰)			δ15N (‰)		
			Mean±SD		*P*-value	Mean±SD		*P*-value
Sex	M	22	−19.88±0.69	*t*=−1.756[a)]	0.087	11.71±0.58	*t*=−2.779[b)]	0.010*
	F	17	−20.23±0.52			10.98±0.96		
Sample	SN	20	−20.22±0.59	*t*=−1.989[a)]	0.054	11.01±0.85	*t*=−3.247[a)]	0.002**
	EP	19	−19.83±0.63			11.80±0.63		
Age	Young	9	−20.17±0.54	*F*=0.274[c)]	0.762	10.95±0.88	*F*=1.951[c)]	0.157
	Middle	19	−19.97±0.74			11.61±0.84		
	Old	11	−20.03±0.55			11.40±0.75		

SD, standard deviation; M, male; F, female; SN, Sinnae; EP, Eunpyeong. [a)]Pooled variance *t* test. [b)]Welch *t* test. [c)]ANOVA. *P<0.05, **P<0.01.

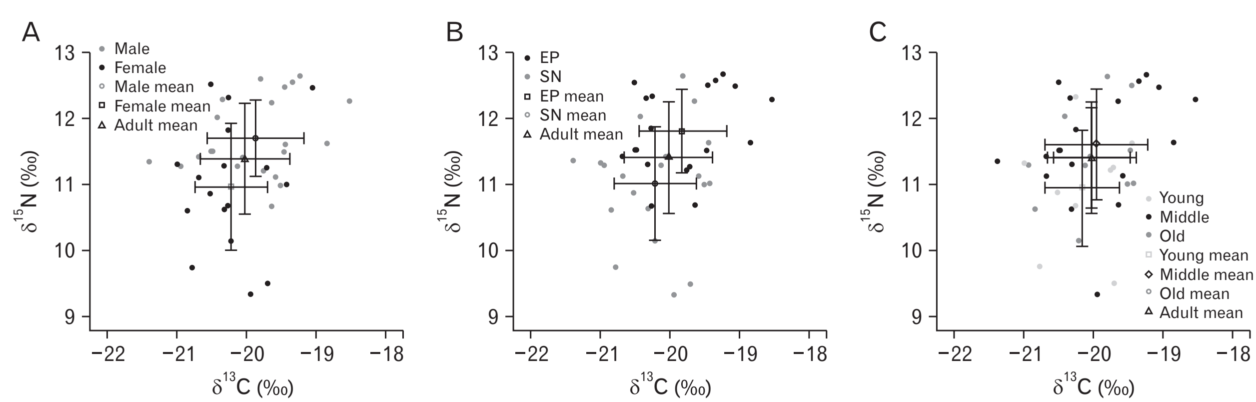

Fig. 3. Distribution of $\delta^{13}C$ and $\delta^{15}N$ values. (A) Analysis by sex. Gray dots for males; black dots for females. Mean±standard deviations are marked for male mean, female mean and adult mean. (B) Analysis by cemeteries. Black dots for Eunpyeong (EP); gray dots for Sinnae (SN). Mean±standard deviation are marked for EP mean, SN mean and adult mean. (C) Analysis by age groups. Light gray dots for young-aged; black dots for middle-aged; gray dots for old-aged. Mean±standard deviation are marked for young-aged mean, middle-aged mean, old-aged mean and adult mean.

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difference in $\delta^{13}C$ values between age groups (young, middle and old; F=0.274, P=0.762). On the other hand, in case of nitrogen values by t test, we observed significant differences in $\delta^{15}N$ between sexes (t=−2.779; P=0.010) and cemeteries (t=−3.247, P=0.002). Significantly lower $\delta^{15}N$ values were for females and cemetery SN. However, ANOVA test exhibited that there were no statistical difference of $\delta^{15}N$ values between age groups (F=1.951, P=0.157) (Table 2).

Table 3. Comparison of mean isotope ratios from different site by sex

Characteristic		C (‰)			N (‰)			No.
		Mean±SD	*t*	*P*-value	Mean±SD	*t*	*P*-value	
EP	Female	−20.06±0.52	−1.227	0.237	11.77±0.96	−0.148	0.884	7
	Male	−19.70±0.68			11.81±0.58			12
SN	Female	−20.35±0.52	−0.949	0.355	10.43±0.97	−4.196	0.001**	10
	Male	−20.10±0.69			11.59±0.58			10

SD, standard deviation; EP, Eunpyeong; SN, Sinnae. ** P<0.01.

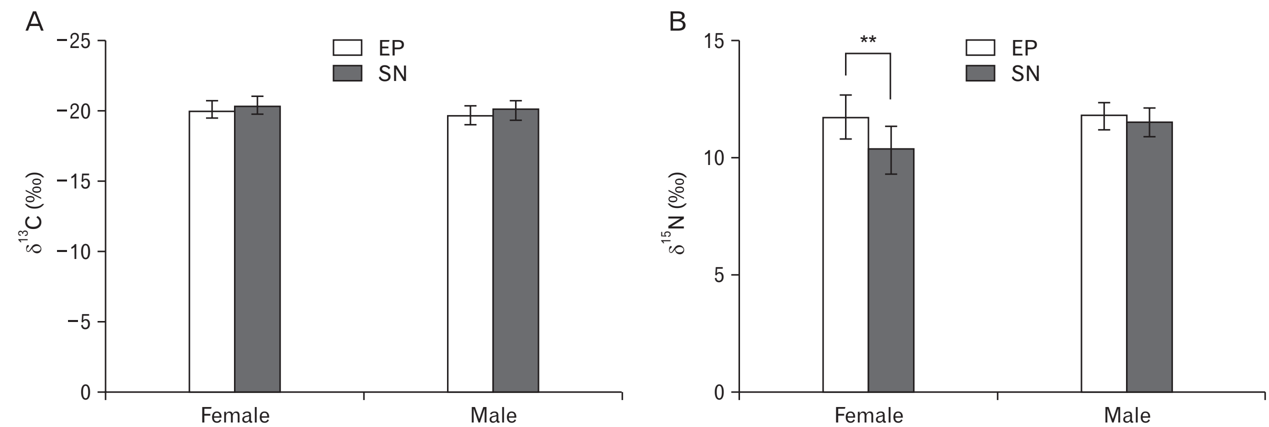

Fig. 4. Bar plot (mean and standard deviation) for $\delta^{13}C$ (A) and $\delta^{15}N$ (B) isotope ratios of female and male from different cemeteries (Eunpyeong [EP] and Sinnae [SN]). (A) No statistical differences in $\delta^{13}C$ values between males and females of both cemeteries. (B) Significant difference detected between females between both cemeteries while males of both cemeteries did not show the difference. ** P<0.01.

Table 4. Comparison of mean isotope ratios of adult human from different site and period

Location		Period	Sex	No.	Mean±SD		Source
					C (‰)	N (‰)	
Korea	Yeanri	Gaya	F	41	−18.5±0.50	10.1±0.90	Choy et al. (2010) [29]
			M	28	−18.0±0.60	11.2±0.90	
	Imdang	Silla	F	4	−17.6±0.50	9.40±0.90	Shin and Lee (2009) [14]
			M	5	−17.7±0.60	11.20±0.40	
	Nukdo	Late mumun–Early Iron	F	8	−18.41±0.52	10.90±0.40	Choy and Richard (2009) [6]
			M	5	−18.26±0.23	11.70±1.00	
	Mungyeong	Joseon	F	1	−19.00	11.40	Kang and Shin (2012) [35]
	Seocheon	Joseon	F	2	−20.35±0.35	11.25±0.21	Kang et al. (2010) [15]
			M	2	−20.05±0.07	11.80±0.28	
	Eunpyeong	Joseon	F	9	−20.06±0.52	11.77±0.96	Present study
			M	10	−19.70±0.68	11.81±0.58	
	Sinnae	Joseon	F	8	−20.35±0.52	10.43±0.97	
			M	12	−20.10±0.69	11.59±0.58	
	-	Modern[a)]	F	4	−19.85±0.44	11.93±0.44	Kang and Shin (2012) [35]
Japan	Hitotsubashi	1657–1683 AD	F	17	−19.30±0.50	10.60±0.80	Tsutaya et al. (2014) [7]
			M	29	−19.40±0.50	11.30±0.70	
	Unseiji	1732 AD	F	1	−19.80	13.90	Nagaoka et al. (2013) [34]

[a)]Hair keratin.

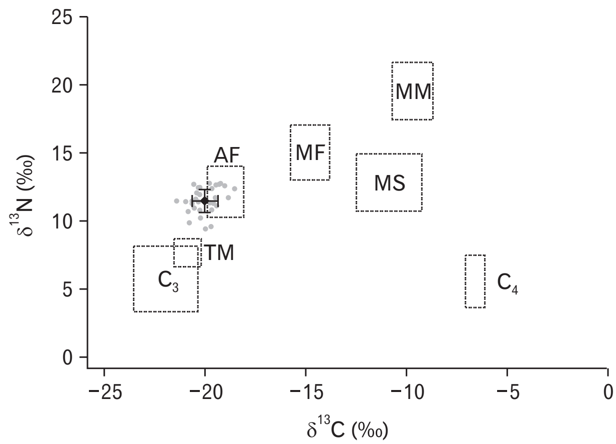

Fig. 5. Mean±standard deviation of the $\delta^{13}C$ and $\delta^{15}N$ values from Joseon cemetery samples of this study. Mean±standard deviation of isotope ratios reported for Japanese food groups are shown as dotted squares. C_3, C_3 plants; C_4, C_4 plants; TM, terrestrial mammals; AF, aquatic fishes; MS, marine shellfishes; MF, marine fishes; MM, marine mammals.

The isotope ratios in each cemetery were analyzed further by sexes. There were no statistical differences in $\delta^{13}C$ values between males and females of EP (P=0.237) and SN (P=0.355) cemetery populations. However, in case of $\delta^{15}N$ values, SN showed significant difference between sexes (lower values for female; P=0.001) while EP did not exhibit the difference (P=0.884) (Table 3).

There were no statistical differences in $\delta^{13}C$ values between males (P=0.180) of both cemeteries. Females in SN and EP did not show the difference in $\delta^{13}C$ values either (P=0.279). However, as for the $\delta^{15}N$ values of females from both cemeteries (EP and SN), we found significant difference between them (t=−3.8441, P=0.002) while males of both cemeteries did not show the difference in $\delta^{15}N$ values between them (t=−0.8778, P=0.3905) (Fig. 4). The isotope ratios from the current and previously reported data from historical populations in Korea and Japan are summarized in Table 4 [6, 7, 14, 15, 29, 34, 35]. Mean and one standard deviation of the $\delta^{13}C$ and $\delta^{15}N$ values from Joseon cemetery samples are also compared with the ranges of isotope ratios of Japanese food groups (Fig. 5) [36-38].

Discussion

Stable carbon and nitrogen isotope analysis has become a kind of routine technique for application to archaeologically obtained samples. Analyses of the carbon and nitrogen isotope ratios $\delta^{13}C$ and $\delta^{15}N$ have revealed patterns of the consumption of specific foods by various peoples in history [39-41]. The carbon isotope ratio $\delta^{13}C$ provides the dietary proportions of C_3 (wheat, rice and potatoes)- and C_4 (maize, millet and other tropical grains)-based foods consumed in the past. By analysis of $\delta^{13}C$ data, researchers can isolate the important crops for the people inhabiting a given region [6]. In general, C_4-based foods show higher $\delta^{13}C$ values than do C_3-based foods [41-44]. Previous studies have shown that the $\delta^{13}C$ value of a C_3 crop is −25.4±1.6‰ while that of a C_4 crop is −10.0±0.5‰ [36, 45].

In Korea, a number of pioneering studies subjecting ancient samples to stable isotope analysis already have provided researchers with clearer pictures of historical Joseon dietary patterns. Briefly, Kang et al. [15] revealed a diet of C_3 crops such as rice, barley, wheat and beans in their stable isotope analysis of four sets of human-skeletal remains from Joseon Dynasty tombs. Kang and Shin [35], having performed a stable isotope study on a female mummy discovered in a Joseon tomb in Mungyeong City of South Korea, hypothesized a dietary dependence of the case on protein-rich C_3 crops [35]. Considering the relevant previous studies' obtained $\delta^{13}C$ values together, it seems that the Joseon staples were mainly C_3-based foods. Similarly, in the current study, we also see that Joseon people buried around Old Seoul City consumed more C_3-based than C_4-based foods as the main staples.

Meanwhile, the nitrogen stable isotope also has been applied to the study of the trophic level, and has been integral to successful reconstructions of food webs of the past [6, 46]. In fact, nitrogen stable isotope data has provided information on the dietary influence by marine proteins [47, 48]. The nitrogen isotope ratio, $\delta^{15}N$, is higher in cases of ingestion of marine food than of terrestrial resources. By knowing that $\delta^{15}N$ increases in the order of plants, herbivores, carnivores, researchers could reconstruct animal versus plant protein consumption patterns among historical populations [46, 48-50]. In general, when a $\delta^{13}C$ value is measured at about −12‰ and a $\delta^{15}N$ value between 12‰ and 22‰, it is likely that the main protein source was marine food. For C_3-based terrestrial protein, on the other hand, the $\delta^{13}C$ value is about −20‰ and the $\delta^{15}N$, between 5‰ and 12‰ [6, 51, 52].

In this regard, the current study on the Joseon skeletal series provides a new perspective on the dietary patterns of Koreans prior to industrialization and modernization. Based on our $\delta^{13}C$ (−18.54‰ to −21.4‰; mean, −20.03±0.64‰) and $\delta^{15}N$ (9.34 to 12.66; mean, 11.40±0.84‰) results, we can

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conclude that the Joseon people (especially those living in Old Seoul City, the Joseon capital) represented by our samples consumed protein mainly of terrestrial origin.

Yet in a sense, it is natural that the Joseon people living inland Old Seoul City might have ingested more foods containing terrestrial-origin protein. However, based on the previous historical study, the diet ingestion pattern of Joseon people looks much complicated. According to Oh [53], seafood was commonly consumed by Joseon people because salted fishes were widely available at the period. Considering that the Joseon people of Old Seoul City easily bought salted or dried fishes in the nearby markets, studying how large proportion of protein they ingested was actually originated from the seafood looks very meaningful to concerned researchers.

Also, the values of stable isotope analysis in this study showed unique patterns within each age, sex and cemetery group. For example, although the $\delta^{13}C$ values did not reveal any statistical differences between the groups we examined, significantly higher values of $\delta^{15}N$ were observed among the male samples. This result corresponds well with the data previously reported by Tsutaya et al. [7], who found that the $\delta^{15}N$ values representative of 17th century Edo males were higher than those of females. Similarly to the data interpretation of Tsutaya et al. [7], on this sex difference among pre-modern Joseon people's $\delta^{15}N$ values, we also speculated that dietary differences between the sexes could have been determinative.

Actually, we should consider that food-sharing pattern among people were different at each stage of human history. While most reports showed that the $\delta^{15}N$ values were lower in women than in men of the historical populations [7, 29, 54], the other studies reported that there is also a kind of fare share of food between sexes [55-57]. In this regard, to know whether males and females' protein diets in pre-modern Korea were similar to the specific historical society already reported, we admit that stable isotope analyses should be done on more cases of archaeologically obtained human remains in this country. In this regard, the current study can be the stepping-stone for revealing the changes in dietary share between sexes in historical Korean population.

Differences in $\delta^{15}N$ values also were observed among the sampling sites (i.e., cemeteries). Briefly, the values were higher for the EP cemetery individuals than for the SN ones. In fact, previous studies have already established that distinct groups show different patterns in their dietary components: more and higher-quality food for higher-status individuals than for their lower-status counterparts [14, 58]. However, we were unable to confirm whether the difference in $\delta^{15}N$ values between the cemetery groups of our study also reflect such a socioeconomic difference. Additional studies are still needed for revealing what made such differences in $\delta^{15}N$ values among the sampling sites.

In conclusion, our purpose of this study is to contribute to a better understanding of the food-intake patterns of pre-modern populations in Korean history, by a stable isotope analysis on human skeletons from Joseon-period cemeteries discovered around Old Seoul City. Our data clearly showed that Joseon individuals consumed mainly C_3-based foods as the main staples, and that the proteins they ingested were mainly of terrestrial, but not of marine origin. We also found that significantly higher values of $\delta^{15}N$ were identified in males than in females, which might reflect dietary differences between the sexes.

Certainly, as compared with their modern counterparts, stable isotope analysis of Joseon samples contribute greatly to an understanding of the dietary patterns of contemporary Koreans' ancestors. However, in Korea, whereas a number of studies subjecting ancient samples to stable isotope analysis have provided researchers with general pictures of historical Korean dietary patterns, we admit that further studies of this type, on samples temporally and spatially more wide-ranging, are still necessary.

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