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Reconstruction of the diet in a mediaeval monastic community from the coast of Belgium

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Abstract

Stable isotope analysis was applied to a Belgian coastal population from the Late Middle Ages: the monastic community of the Dunes abbey in Koksijde (12–15th century). Carbon and nitrogen isotope ratios were measured in bone collagen from 19 humans (11 adults and eight children) and 10 animals. Results show that diets were largely based on terrestrial foods, but marine resources also formed a source of protein. Results also suggest differences in human diets that may be related to social status.

Keywords: Europe; Mediaeval Belgium; Stable-carbon isotopes; Stable nitrogen isotopes; Palaeodiet

1. Introduction

The diet of mediaeval populations is mostly known from written and iconographic sources [23,25,26]. However, these documents mainly concern the upper classes of the population and the reality may have been, in some cases, embellished [7]. It is therefore necessary to combine these cultural data with those derived from other fields of research such as the study of artefacts related to food use and the analysis of remains of animals, plants and humans [14].

Human remains constitute a precious source of information and the morphological and chemical analyses of bones and teeth may provide clues for reconstructing diets and for detecting nutritional stress [24,33].

Stable isotope analysis of bone collagen has proven efficient for reconstructing human diets. Stable carbon and nitrogen isotopes have been used to reveal variations in the proportions of terrestrial versus marine food [8] and animal versus vegetal dietary resources (reviewed by Schwarcz and Schoeninger [41]). They can show the introduction of new plant species such as maize into the diet [45] and they can also detect changes in diet, as for example in weaning [20].

Few isotopic studies have been carried out on European mediaeval populations. They include studies on populations from Norway [18], Germany [46], England [29] and France [6,16].

The aim of the present article is to report the results of stable carbon and nitrogen isotope analysis on skeletons from a Belgian mediaeval population, and to look at variations in diet that may relate to age and social status.

2. Material

This study was performed on skeletons coming from the cemetry of the Dunes abbey of Koksijde (Fig. 1). The collection belongs to the Royal Belgian Institute of Natural Sciences (inventoried as I. G. 18922).

The Dunes abbey, located on the Belgian coast (Province of Western Flanders), was founded in 1107. In the 13th century it was the largest Cistercian monastery in Flanders with more than 180 monks and 350 lay-brothers [17]. It was abandoned at the beginning of the 17th century. The excavations of the site started in 1948 and are still in progress. Many objects (kitchen utensils, tools), household refuse as well as a great number of

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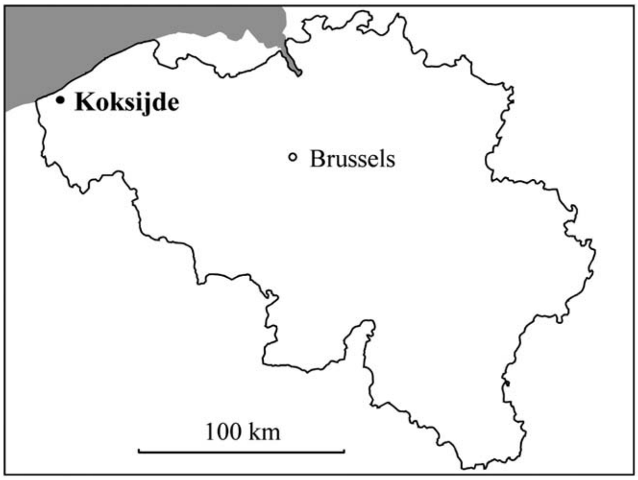

Fig. 1. Map of Belgium showing the location of Koksijde.

human skeletons were exhumed from the ruins of the abbey (*De Duinen* 1 (1960) to 22 (1992)). The majority of these skeletons come from a vast cemetery located north of the abbey church and mainly date from the 12th to the 15th century AD [10,44]. The total number of burials is estimated at about 2000. They were devoid of grave goods except for the presence in certain burials of a scallop shell laid on the chest of the deceased (thought to be a reference to the pilgrimage to Santiago de Compostela). People buried in this cemetery were mainly monks and lay-brothers, as more than 90% of them are men and very few (1%) are children [44]. The origin of these subadults is uncertain. They could have been children entrusted to the monastery when they were very young (at least 7 years old according to Riché and Alexandre-Bidon [37]); they would have lived there for a while and would have died there. It is also possible that these children were related to the monks: certain historical documents attest that the latter were sometimes authorized to bury one of their kin in the cemetery of their monastery (Aubert, 1943 quoted by Termote [43]). Alternatively, they could have been children of the servants working in the abbey.

A total of 29 samples were selected for isotope analysis: 19 humans (11 adults and eight children) and 10 animals. The animal remains originated from midden layers of the monastery [13], except for two bones sampled from complete skeletons found near the cemetery: a foal less than 1 year old (*Equus cabalus*) and a wolf (*Canis lupus*).

3. Methods

3.1. Removing bone preservatives

When the bones of the Koksijde collection arrived in the Royal Belgian Institute of Natural Sciences in the 1950s, they were treated with beeswax in order to consolidate them. Given that this organic substance could interfere with the isotope measurements, it was necessary to remove it. Moore et al. [30] have already demonstrated that, for some substances, an adequate treatment can solve this problem. They used acetone to remove Alvar (polyvinyl acetaldehyde acetal) but, as beeswax is a lipid (more precisely: a complex mixture of aliphatic acids, esters and other components), this treatment would be inefficient on our material. We decided to apply a methylene chloride (CH_2Cl_2) extraction because this solvent of low molecular weight has the highest solvency power of the chlorinated solvents—higher than chloroform:methanol usually used to remove native lipids from bone [12]. Methylene chloride is currently used as an extraction agent for waxes. Moreover, it is very volatile and can be evaporated by heating at low temperature (boiling point 39.75 °C).

In order to test the effectiveness of the extraction procedure, a series of samples was prepared. One archaeological bone (a piece of Bison scapula from a western Canadian site) was used for this purpose. After cleaning it with distilled water, the bison bone was divided into three parts (A, B and C). A did not undergo any processing, B and C were soaked in melted beeswax. C underwent the extraction process consisting of soaking in 50 ml methylene chloride for 24 h, followed by repeated washes with fresh methylene chloride under agitation. The sample was then dried overnight at 50 °C.

The collagen of the three fragments of the bone was extracted according to the protocol developed below and then analysed for carbon and the nitrogen isotopes.

3.2. Collagen extraction procedure

Bone protein was extracted following the method of Bocherens et al. [5]. Briefly, between 200 and 300 mg of cleaned bone powder was left to demineralize in 1 M hydrochloric acid at room temperature for 20 min. After filtration, the resultant residue was soaked in 0.125 M sodium hydroxide for 20 h in order to remove the humic contaminants. The remaining solid was gelatinized at 100 °C for 17 h at pH 2. After filtration, the solution was freeze-dried.

3.3. Analysis by mass spectrometry

The isotopic composition of freeze-dried ‘collagen’ was analysed at the Department of Physics and Astronomy of the University of Calgary, using a Finnigan Mat ‘Tracermat’ mass spectrometer. The $\delta^{13}C$ and $\delta^{15}N$ values were measured relative to the Pee Dee Belemnite carbonate and atmospheric nitrogen standards, respectively.

The precision for the $\delta^{13}C$ and the $\delta^{15}N$ determinations is ±0.3‰. To check for the collagen integrity,

Table 1
Bison bone collagen: Wt% C, Wt% N, C:N ratio, stable C-isotope ratio, stable N-isotope ratio

Sample	Treatment	n	Wt% C	Wt% N	C/N	$\delta^{13}C$ (‰)	$\delta^{15}N$ (‰)
A	–	3	44.2	15.5	3.3	−19.5	6.3
B	+beeswax	3	40.1	14.7	3.2	−19.3	6.3
C	+beeswax+CH_2Cl_2	1	44.6	15.8	3.3	−19.2	6.3

Collagens from samples A and B were divided into three subsamples.

C/N ratios were determined from sample combustion in a Carlo Erba NA 1500 gas analyser.

4. Results

4.1. Effectiveness of the preservative-removing procedure

The results of the isotopic analysis of the bison bone are presented in Table 1. The three samples display identical $\delta^{15}N$. For the $\delta^{13}C$, the maximum difference is 0.3‰. This difference is within the analytical precision.

Given that the isotopic and the C/N ratios of the three samples are similar, one can consider that the protocol of extraction of Bocherens et al. [5] that includes soaking in sodium hydroxide eliminates wax. It is indeed well known that sodium hydroxide saponifies the lipids. The methylene chloride treatment appears in this case unnecessary. We decided nevertheless to apply this treatment to the bones of Koksijde because:

- we do not know whether the substance used to consolidate them was pure beeswax (this product is unfortunately no longer available);
- it seems that the treatment of bones with NaOH does not always eliminate all of the lipids [28,30].

The removal procedure with methylene chloride seems successful because the C/N ratio of the extracted material from Koksijde bones lies within the range of native collagen (2.9–3.6; [9] (Table 2).

4.2. Collagen yields

The yields of the extraction are expressed in milligrams of collagen per gram of bone powder (Table 2). For the fresh bones, they are of about 200 mg g^{-1} [5]. Only one specimen of Koksijde, a horse, produced a yield below the minimum value of 10 mg g^{-1} (5% of the original protein content) generally accepted for reliable specimens [1] and was not used for the isotope analysis. The other samples range from 73 to 154 mg g^{-1} with an average of 102 mg g^{-1}.

4.3. Isotopes

Carbon and nitrogen isotope ratios from collagen of humans and fauna are presented in Table 2 and Fig. 2.

Carbon isotope values from the five herbivores (two *Bos* sp., one ovicaprid and two *Equus cabalus*) range from −20.4 to −22.0‰. They are typical of mammals feeding on C_3 plants [4]. The $\delta^{13}C$ of the omnivore (*Sus scrofa*) also lies within this range. In the carnivores, the $\delta^{13}C$ values are higher: −17.1, −18.5 and −19.6‰ for the adult cat the juvenile cat and the wolf, respectively. The humans (n=19, mean=-19.1 ± 0.46‰) are closest to the carnivores.

Nitrogen isotope ratios are lowest in herbivores (from 4.5 to 6.7‰) and highest in carnivores (10.4, 10.9 and 13.8‰). The $\delta^{15}N$ of the pig (4.5‰) lies within the range of the herbivores. The humans (mean=11.1 ± 0.92‰) are most similar to the carnivores.

On average, the increase from herbivores to carnivores is +3.5‰ for the $\delta^{13}C$ values and +6.5‰ for the $\delta^{15}N$. These differences are not what is expected within a single food web: 0–1‰ for the carbon isotopes and 3–5.7‰ for the nitrogen isotopes [4]. This can be due to the fact that the carnivores (at least the adult cat) also consumed marine food which is richer in ^{13}C and ^{15}N than terrestrial food and the fact that this sample is not representative of a food web. While humans may have included the domesticated pig and cattle in their diet, they did not consume cats and horses.

5. Discussion

The methylene chloride treatment appears to be an effective solvent of beeswax and makes it possible to analyse the skeletons of Koksijde.

The isotopic analysis of the animals distinguishes herbivores from carnivores but also brings further information on the diet of some of these animals. The $\delta^{15}N$ and the $\delta^{13}C$ of the pig found in a midden layer of the abbey show that it was exclusively vegetarian (Fig. 2). The high isotopic values of the adult cat are most probably related to marine food consumption. Using the linear mixing model of Mays [29] in which an entirely terrestrial diet leads to a $\delta^{13}C$ of −21.5‰ and a wholly marine-based one to −12‰, we obtain a proportion of 46% of the marine component. The two juvenile animals, the kitten and the foal, were certainly weaned because their collagen is not richer in ^{15}N than that of the adults of the same species (Fig. 2). Nursing animals (including humans) typically have $\delta^{15}N$ values about 3‰ higher than their mother [3,22]. The kitten's diet does not seem to include marine food.

The high $\delta^{15}N$ in human bone collagen indicates that their dietary protein was mainly from animal foods. As this result is accompanied by high $\delta^{13}C$, it can be explained by the fact that a part of their food came from the sea. This hypothesis is confirmed by other sources. Firstly, as they were living on the coast, marine resources were directly available. Then, the low rate of caries in Koksijde could be the consequence of the

Table 2
Koksijde: bone, sex, age, stable C-isotope ratio, stable N-isotope ratio, C:N ratio and extraction yield

Sample no.	Species	Bone	Sex	Age	δ^{13}C	δ^{15}N	C/N	Yield (mg/g)
134	Human	Rib	M	>60	-20.2	11.5	3.1	85
177	Human	Rib	M	20–40	-19.1	9.9	3.3	92
197	Human	Rib	M	20–40	-18.7	10.6	3.0	86
210	Human	Rib	M	>60	-19.0	11.5	3.1	90
215	Human	Rib	M	40–60	-18.7	11.1	3.0	84
217	Human	Rib	M	>60	-18.7	11.0	3.4	82
240	Human	Rib	M	40–60	-19.1	10.0	3.1	103
249	Human	Rib	M	40–60	-19.3	9.7	3.2	93
C37	Human	Rib	M	20–40	-19.1	12.3	3.3	92
D91	Human	Rib	M	40–60	-18.1	12.3	3.1	82
D93	Human	Rib	M	20–40	-18.8	12.7	3.3	97
116B	Human	Rib		5–6	-19.6	10.6	3.0	154
70.B1.3.29	Human	Rib		4–5	-19.7	12.1	3.1	148
C39	Human	Rib		9–10	-19.5	9.8	3.1	104
D123	Human	Rib		±13	-18.8	12.3	3.2	101
G21	Human	Rib		16–17	-19.1	10.9	3.3	90
H18	Human	Rib		12–13	-19.1	11.3	3.2	73
H20	Human	Rib		±7	-18.9	10.8	3.3	89
12	Human	Rib		10–11	-19.5	10.9	3.3	74
Wolf	*Canis lupus*	Rib			-19.6	10.4	3.0	140
Cat	*Felis catus*	Skull			-17.1	13.8	3.1	132
Kitten	*Felis catus*	Tibia			-18.5	10.9	3.3	67
Pork	*Sus scrofa*	Tibia			-21.3	4.5	3.3	113
Sheep/goat	Ovicapridae	Coxal			-21.5	6.6	3.2	121
Cattle 1	*Bos* sp.	Humerus			-22.0	5.8	2.9	132
Cattle 2	*Bos* sp.	Femur			-20.4	4.5	3.2	118
Foal	*Equus cabalus*	Rib			-21.1	6.5	3.3	142
Horse 1	*Equus cabalus*	Axis			-21.1	6.7	3.1	72
Horse 2	*Equus cabalus*	Vertebra			n.d.	n.d.	n.d.	<10

beneficial effect of marine food rich in fluorine [33]. In the same way, the high strontium concentrations in the humans of the abbey, compared to the herbivorous and the carnivorous animals found on the site, could result from a consumption of marine food rich in this element [33]. In addition, the study of household refuse of the abbey highlighted a strong proportion of marine fish bones (mainly Gadids) and mollusc shells [13,38]. Moreover, historical documents, such as the *Cronica monasterii de Dunis* written by four monks, attest that the abbey had herring fisheries and salting workshops [17]. Lastly, the Cistercians must observe the Benedictine rule that proscribes meat consumption but allows that of fish [31, pp. 75–76]. If we apply the method of Mays [29], we obtain a marine contribution that varies, according to individuals, between 14 and 30%. The actual proportion of marine food in their diet must have been rather lower since collagen is largely formed from dietary protein [2].

Freshwater fish consumption can, however, not be totally excluded: even if the monastery did not have ponds, the monks could have consumed catadromous fishes such as eels. Skeletal remains of eels were found in 15th century AD latrines in Raversijde, a village located around 10 km away from Koksijde [32]. Eels remain a culinary speciality of the Polders region today. Consumption of high trophic level freshwater or catadromous fish would elevate δ^{15}N values [19]. δ^{13}C values are highly variable in freshwater fish, depending on their habitat and feeding habits [21].

In order to go further in the interpretation of the results, we compared Koksijde with two inland Belgian mediaeval samples: Ciply and Torgny, both dating back to the 6–7th century AD [33]. To compare the means of the three mediaeval samples (Table 3), we applied an analysis of variance. As the sample sizes are limited and as we know little or nothing about the expected distribution of the variables, a non-parametric test should be adopted to assess the significance of the observed results. The null hypothesis (the three groups are sampled from one population) was tested by a randomization test [11,35]. This method creates its own distributions made with a chosen number of random samples drawn from the original dataset without replacement. These random samples display the same size as this dataset. The observed distributions are then compared with these random distributions on the basis of their correlation ratios (Z=between-groups variance/total variance). The decision to reject or accept the null hypothesis is based on the proportion of random samples displaying a more pronounced groups' separation than that observed (this is $Z_{\text{calculated}} \geq Z_{\text{observed}}$). In

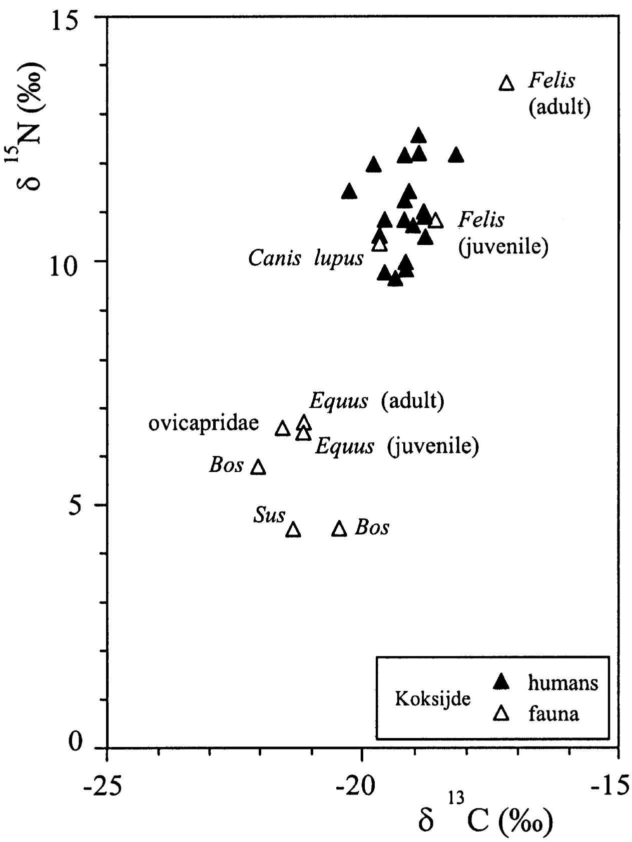

Fig. 2. Plots of the δ^{13}C and δ^{15}N values for the collagen of human and animal from Koksijde.

contrast to other homogeneity tests, the self-comparison method is sensitive neither to small sample size nor to a non-normality of the distributions. The null hypothesis (no difference between the three mediaeval groups) is rejected for both δ^{13}C and δ^{15}N (Table 4). This rejection results from the fact that Ciply and Torgny present low values and Koksijde high values. Indeed, in almost 100% of the cases the averages of the δ^{13}C and δ^{15}N of the 200 random samplings are higher than the means observed for the two Merovingian samples and lower than that observed for Koksijde. Unplanned comparisons among means were carried out by the Scheffé method [42, pp. 242–262]. This test (Table 5) shows that the differences are only significant (for a=0.05) between Koksijde and the two Merovingian samples but not between these last ones. The isotopic ratios of Koksijde are thus well differentiated from those of inland mediaeval samples.

We also compared graphically the sample of Koksijde with other historical populations found in the literature (Fig. 3). Koksijde displays higher isotopic ratios than samples with exclusively terrestrial diet such as the Belgian Merovingian people of Torgny and Ciply, the German mediaeval sample of Weingarten [46], the French mediaeval sample of Grenoble [16] and the low status individuals from the British Late Roman cemetery of Poundbury Camp [36]. The isotopic ratios of the individuals of Koksijde are, however, far lower than those of samples whose proteins were exclusively of marine origin like Haida and Tlingit Indians from the Northwest Coast of North America with a diet mainly based on salmon, and Alaskan Eskimos who rely on marine fish and mammals [40]. Their carbon isotope ratios are also lower than those of the high status Late Roman individuals from the British Poundbury Camp cemetery who had a mixed terrestrial/marine diet [36]. The population, which presents isotopic ratios closest to those of Koksijde is composed of Dutch whalers having lived in the 17–18th century [39]; Table 3). Their diet is known in detail thanks to the study of animal and plant remains and to the historical documents: it was largely composed of bread, cheese, salted or smoked fish and meat (pig and beef), goat, peas and beer. If we exclude meat, these different food items have most probably also constituted the daily menu of the monks of the Dunes abbey. The peculiar position the mediaeval individual of Besançon (France) is due to its high value of δ^{15}N and is explained by the consumption of terrestrial animals of high trophic level such as carnivores [6].

The randomization method [11,35] was also applied to compare the 11 adults and the eight subadults of Koksijde. The tests do not reject the null hypothesis "these two groups are sampled from one population" (Table 6) and indicate that children and adults could not be differentiated on the basis of their isotopic ratios.

As all these children were certainly not full members of the monastic community (except maybe for the four oldest), the isotopic similarity can be explained by the fact that

- these children stayed for a while (at least a few months) as boarders in the monastery and ate roughly the same food as the monks and the lay-brothers;
- they did not live inside the monastery but came from surrounding populations with diets not very different from that of the monastic community.

The study of a non-specific stress indicator, enamel hypoplasia, also produced interesting results. Enamel hypoplasia consists in a reduction of the thickness of the dental enamel [15]. This defect has been linked to malnutrition (vitamin A or D deficiency), to illness (high fever or infection), to low birthweight, to congenital infections and to parasitic infestation [27].

At the Dunes abbey, unlike other mediaeval populations, the skeletons without enamel hypoplasia are in the minority, representing only 20% of the sample [33]. These individuals, that have been less affected by diseases and/or malnutrition during their childhood, were inhumed in two privileged areas: in the central nave of the abbey church and inside (or nearby) two small

Table 3
Carbon and nitrogen stable isotopes for Koksijde, two inland Belgian mediaeval samples (Torgny and Ciply; Polet and Katzenberg, submitted) and Dutch whalers [39]

Site/population	Location	Period (century AD)	n	$\delta^{13}C$ (‰)		$\delta^{15}N$ (‰)	
				Mean	SD	Mean	SD
Koksijde	Coastal	12–15	19	−19.1	0.46	11.1	0.92
Torgny	Inland	6–7	20	−19.8	0.33	9.1	0.66
Ciply	Inland	6–7	9	−20.2	0.54	9.1	0.45
Dutch whalers		17–18	6	−19.2	0.5	12.2	0.9

Table 4
Randomization tests for the three Belgian mediaeval samples for the $\delta^{13}C$ and the $\delta^{15}N$ (results of 200 random samples)

Variable	Prop. (%)[a]	Correlation ratio Z (%)		Cases where the means are higher than observed values (%)		
		Observed	Calculated	Torgny	Ciply	Koksijde
$\delta^{13}C$ (‰)	0.0	52.41	4.39	2	0	100
$\delta^{15}N$ (‰)	0.0	65.92	4.54	0	1	100

[a] Proportion of random samples displaying a more pronounced groups' separation than that observed. The signification level is 5%.

Table 5
Probabilities of the Scheffé multiple comparison test of the three Belgian mediaeval samples for the $\delta^{13}C$ and the $\delta^{15}N$

	$\delta^{13}C$ (‰)			$\delta^{15}N$ (‰)		
	Torgny	Ciply	Koksijde	Torgny	Ciply	Koksijde
Ciply	0.110			0.998		
Koksijde	0.0	0.0	–	0.0	0.0	–

chapels. They could therefore originate from favoured classes of the society. These 'more favoured' individuals display higher $\delta^{13}C$ and $\delta^{15}N$ (the test is however only significant for the carbon isotopic ratios) than those presenting hypoplasia (Table 7 and Fig. 4). This may be explained by the fact that they ate more terrestrial or marine animal protein than the rest of the monastic community. This hypothesis is strengthened by the trace elements study [34]. Indeed, the individuals without hypoplasia are characterized by lower Sr concentrations than the other individuals. This indicates that they received a diet richer in meat (poor in strontium).

In addition, Mays [29] also highlighted differences in diet within another mediaeval monastery. The lay-folks of York Fishergate (England, 12–14th century) exhibit lower $\delta^{13}C$ values than those of the monks, indicating that the latter consumed more protein of marine origin. This assumption is in agreement with the rules of life of St Benedict which these monks had to observe and with the rate of dental caries, which is lower in the monks.

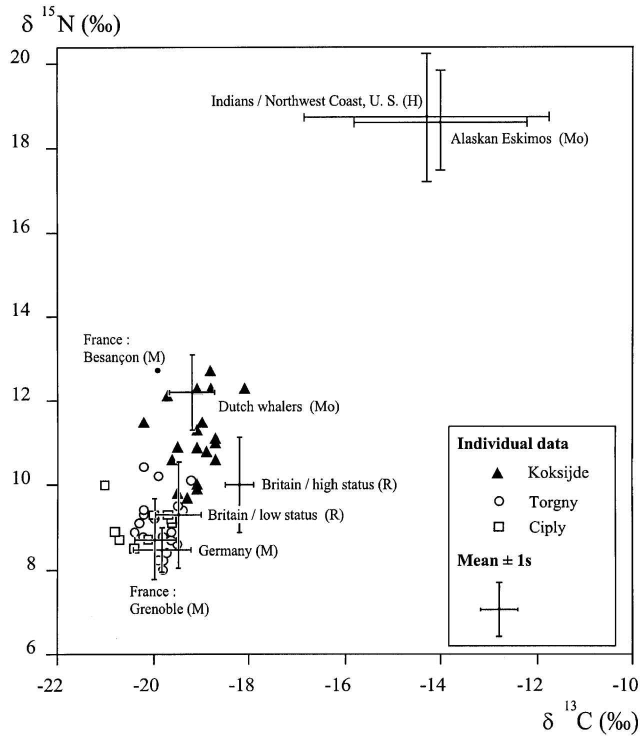

Fig. 3. Human collagen $\delta^{13}C$ and $\delta^{15}N$ values from the three Belgian mediaeval populations (Koksijde; Ciply and Torgny) and other historic samples. H, historic; M, mediaeval; Mo, modern; and R, roman.

6. Conclusions

The application of isotope biogeochemistry to the skeletons coming from the Dunes abbey in Koksijde

Table 6
Randomized analysis of variance of the children and the adults of Koksijde for the δ^{13}C and δ^{15}N (results of 200 random samples)

Variable	Prop. (%)[a]	Correlation ratio Z (%)		Cases where the mean are higher than observed values (%)	
		Observed	Calculated	Adults	Children
δ^{13}C (‰)	17.5	10.24	5.64	90	10
δ^{15}N (‰)	91.5	0.10	5.02	59.5	42

[a] Proportion of random samples displaying a more pronounced groups' separation than that observed. The signification level is 5%.

Table 7
Randomized analysis of variance for individuals of Koksijde with and without enamel hypoplasia for the δ^{13}C and δ^{15}N (results of 200 random samples)

Site	Variable	Prop. (%)[a]	Correlation ratio Z (%)		Cases where the means are lesser than observed values (%)	
			Observed	Calculated	With hypoplasia	Without hypoplasia
Koksijde	δ^{13}C (‰)	0.5	31.20	5.38	0.5	99.5
	δ^{15}N (‰)	28.5	5.62	4.72	13	86

[a] Proportion of random samples displaying a more pronounced groups' separation than that observed. The signification level is 5%.

contributes to a better knowledge of the dietary patterns of coastal mediaeval and/or monastic communities. More particularly, our analyses showed that dietary proteins were primarily in animal form. The high values of δ^{15}N and δ^{13}C in the monks, the lay-brothers and the children are most probably due to the consumption of marine products. This hypothesis is strengthened by other research based on the rate of dental caries, analysis of the trace elements, historical documents and archaeozoology. Lastly, we highlighted within this sample a difference in dietary habits, which could be related to social status.

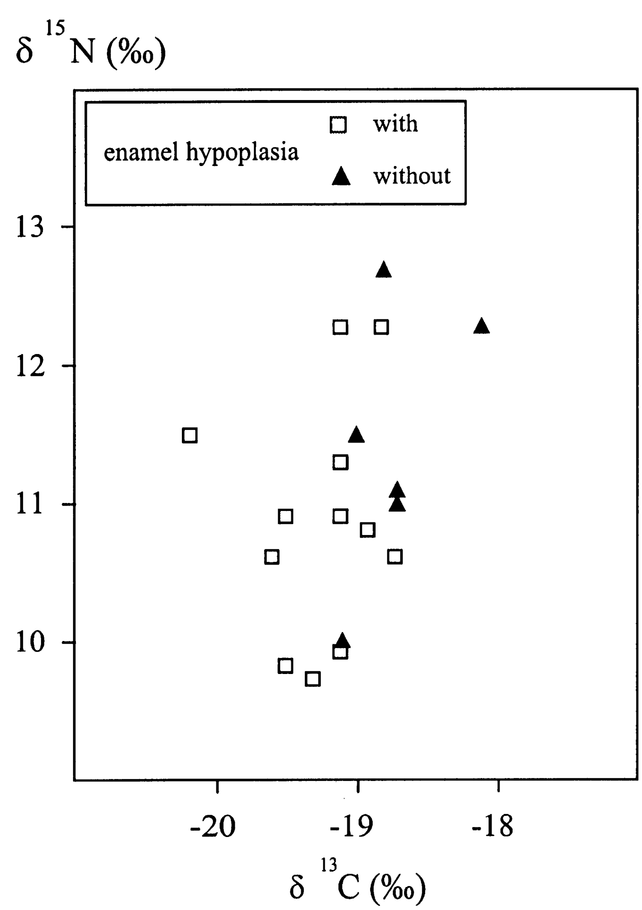

Fig. 4. Plots of the δ^{13}C and δ^{15}N values for the individuals of Koksijde with and without enamel hypoplasia.

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