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Stable isotope evidence for palaeodiets in southern Turkmenistan during Historical period and Iron Age

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Abstract

The subsistence patterns of Iron Age and Historical period humans from south-western Turkmenistan have been reconstructed using the carbon and nitrogen isotopic compositions of archaeological faunal and human bones. A qualitative comparison of the isotopic signatures points to a small proportion of ruminant meat and dairy in human diet for both periods. The ranges of proportions of dietary items yielded by a quantitative approach based on concentration dependent mixing models confirm the high proportions of plant food in the average diet, and show little change in the reconstructed diet for both periods. A comparison of results from zooarchaeological and isotopic approaches illustrates their complementarity in subsistence patterns reconstruction.

Keywords: Iron Age; Historical period; Subsistence; Turkmenistan; Collagen; Stable isotopes; $\delta^{13}C$; $\delta^{15}N$

1. Introduction

The determination of ancient human diet is always a difficult task. Humans can potentially consume a large variety of animal and plant food items, in almost any relative proportions. Due to differential preservation, plant material does not survive as frequently as animal bone in the archaeological record, thus biasing the diet reconstructed from archaeological organic remains towards meat intake. Moreover, even when archaeobotanical data are present, they may be difficult to interpret as remnants of food or fuel (e.g. [32,50]). The last two decades have witnessed the development of palaeodietary reconstruction through bone collagen carbon and nitrogen stable isotopic composition (e.g. see reviews in [2,6,20,25,68]). This approach provides individual dietary reconstruction for the last years before death, however biased in favour of protein-rich food items.

The combination of zooarchaeological and isotopic studies allows to define directly the isotopic signatures of the animal dietary resources, and to compare them with the observed isotopic signatures of humans from the same archaeological layers. A discrepancy between the conclusions of both investigating methods will point to the contribution of dietary resources other than the

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animal proteins inferred from the bones. Such foodstuffs that are not recorded in the archaeological material can be tentatively identified by the knowledge of the ecological variability in the study area.

When an ecosystem yields dietary resources with distinct isotopic signatures, it is possible to evaluate the relative amount of different protein resources used by ancient populations through the isotopic signatures of bone collagen (e.g. [1,37,38,61]). Indeed, bone collagen emphasises the isotopic signature of the protein fractions of the diet [3,67]. Using mixing models with $n+1$ dietary resources when n isotopes are used, it has been possible to attempt quantification of the relative contributions of these different dietary resources. The first attempts of modelling used linear mixing models (e.g. [44,63]). The most recent advances incorporate uncertainties and concentration dependence in the mixing models (e.g. [56,57]). So far, most studies using the advanced versions of such models have aimed at reconstructing the diet of modern omnivorous animals, such as bears (e.g. [40,57,58]). The extension of such modelling approaches to archaeological contexts provides an opportunity to quantify the relative contributions of different dietary resources for humans in ancient societies (e.g. [12,22,23,52,54]). The goal of the present work is to reconstruct the diet of ancient people from south-western Turkmenistan, an area still unexplored with stable isotope biogeochemistry, using qualitative and quantitative (mixing models) approaches.

The present study has been performed on archaeological material from the Dehistan Plain, located in the extreme south-western Turkmenistan adjacent to the Caspian Sea which is today an arid and flat region (Fig. 1). Archaeological evidence shows that this area has been densely occupied since the Iron Age, around 1300 BC. The plain is arid and the only water sources are the Atrek and Sumbar rivers south and east, respectively. It is, therefore, likely that agricultural practises had to rely on intensive irrigation systems [41]. It is usually considered that demographic pressure in the Sumbar valley led to a westward movement of people with necessary knowledge about irrigation techniques [41]. Indeed, traces of ancient irrigation webs are still visible on the surface of the plain, suggesting an intense agricultural activity in the past. In more eastern parts of southern Turkmenistan, at Geoksyur in the Tedzen valley, irrigation is linked to the cultivation of cereals such as wheat and barley [43]. Recent excavations in south-western Turkmenistan have yielded relatively abundant faunal remains, which indicate the occurrence of pastoral activities mostly based on caprine and bovine husbandry, with very few remains of hunted animals [46]. For reconstructing the ancient subsistence pattern in this region, it is necessary to assess the relative importance of agricultural and pastoral practises, since both have been evidenced, indirectly for agriculture and directly for pastoralism.

2. Isotopic signatures in the ecological context of southern Turkmenistan

2.1. Carbon-13

Carbon isotopic compositions (expressed as $\delta^{13}C$[2] values) in ecosystems reflect primarily the photosynthetic pathways and environmental parameters of the plants on the basis of the food webs. In terrestrial plants, the two major photosynthetic pathways, i.e. the so-called "C_3" and "C_4" pathways, lead to clearly different isotopic discriminations. Both types of plants are ^{13}C-depleted relative to their source of inorganic carbon, atmospheric CO_2 with a $\delta^{13}C$ value around $-8‰$, but C_4-plants are much less depleted than C_3-plants ($\delta^{13}C = -27.1 \pm 2.0‰$ and $\delta^{13}C = -13.1 \pm 1.2‰$ for C_3- and C_4-plants, respectively [53]). On a world-wide scale, most C_4-plants are grasses from warm areas, and they are distributed in regions where the growing season is the warm one (monsoon system), whereas C_3-plants are all the trees growing under any climatic conditions, as well as herbaceous plants from temperate and cold areas, where the growing season is cool. Southern Turkmenistan is located at the border between the Euro-Siberian and the Irano-Turanian phytogeographic zones [39], in a desertic climatic context [5]. In the Euro-Siberian region, C_4-plants are extremely scarce [48]. In the Irano-Turanian region, most plants are C_3 with locally significant amounts of C_4 species which are halophytes adapted to saline environments [70]. Among C_3-plants, some environmental conditions lead to different carbon isotopic compositions (e.g. [30,66]). In closed forested environments, where the CO_2 available to understorey plants is ^{13}C-depleted relative to the general atmosphere due to the contribution of CO_2 generated by respiration and organic matter decomposition and where light intensity is lower, plants exhibit $\delta^{13}C$ values as low as or lower than $-28‰$ (e.g. [13,14,49,69]). On the other hand, water and saline stress environments lead to less isotopic fractionation of carbon in C_3-plants, which thus have $\delta^{13}C$ values as high as $-20‰$ (e.g. [29]).

The carbon isotopic compositions of the plants are reflected in the tissues of their consumers, with an isotopic shift which is mainly linked to the analysed tissue (e.g. [17,21]). The average $\delta^{13}C$ value of an organism body is similar to that of the average diet, but its different biochemical fractions present consistently different carbon isotopic compositions, due to fractionation during the metabolic pathways [18]. For instance, carbohydrates

[2] Isotopic abundances are expressed as δ (delta) values, as follows: $\delta^{E}X = (R_{sample}/R_{standard} - 1)1000$ (‰), where X stands for C or N, E stands for 13 or 15 respectively, and R stands for the isotopic ratios $^{13}C/^{12}C$ and $^{15}N/^{14}N$, respectively. The standard, internationally defined, is a marine carbonate (PDB) for carbon and atmospheric nitrogen (AIR) for nitrogen.

Fig. 1. Map of south-west Turkmenistan and north-east Iran showing the location of Geoktchik Depe. The dotted lines indicate the approximate borders of ancient Hyrcania.

present globally a similar δ^{13}C value than the whole body, whereas lipids are depleted (around 4‰) and proteins are enriched (around 2‰) relative to the whole body [21]. The tissue of interest for the zooarchaeologist is mostly collagen, in bone and dentine, due to its potential for long-term preservation (e.g. [9,10,35]). The actual value of the isotopic shift between the carbon isotopic composition of diet and that of collagen is crucial for interpreting the measured values. It has been investigated through laboratory experiments (e.g. [3,21,33,34,67]) as well as in the field (e.g. [2,42,59,68,69]). Recently some very well controlled dietary experiments on rodents have obtained key results regarding the relationship between dietary and measured carbon isotopic compositions [3,67]. Both studies have clearly demonstrated that collagen presents δ^{13}C values directly linked to those of the protein fraction of the diet. In the case where all the biochemical fractions, i.e. lipids, carbohydrates and proteins, come from an isotopically homogeneous source, collagen is enriched around 5‰ relative to the average diet. Controlled diet experiments have provided difference values between δ^{13}C of collagen and muscle of +2.7 and +3.6‰ (e.g. [26,67]). In the field, differences measured between the δ^{13}C values of collagen from preys and of collagen from their predators range from 1.0 to 2.4‰ [7].

2.2. Nitrogen-15

Contrarily to carbon, a significant enrichment occurs between an organism's diet and its body, leading to δ^{15}N values 3–5‰ higher in the body than in the average diet [7,51,60,62]. This trophic isotopic effect leads to higher $\delta^{15}N$ values in carnivore collagen relative to that of their preys. Independently of dietary factors, a relationship has been found between herbivore $\delta^{15}N$ values and annual rainfall: collagen $\delta^{15}N$ values increase with aridity [28,31,64,65]. Thus collagen $\delta^{15}N$ cannot be used as an absolute proxy for diet. Local conditions, such as soil acidity or salinity, can also change plant $\delta^{15}N$ values [45,55], thus shifting isotopically the whole food web [59]. Arid environments such as Turkmenistan are likely to lead to a rather large range of $\delta^{13}C$ and $\delta^{15}N$ values in plants and herbivore tissues, similar to what has been observed in northern Iran [11]. Such variability will complicate the palaeodietary reconstruction of ancient human populations, since a given dietary item will not be characterised by a stable and recognisable range of isotopic signature.

3. Material and methods

The studied bones are yielded from Geoktchik Depe with two chronological periods, Iron Age, locally known as Archaic Dehistan (1300 BC) and Historical period (Sasanian and beginning of Islamic period, 6–7th century AD) and Misrijan, with archaeological remains from Historical period (Ilkhanid period, 11–12th century AD), 15 km distant from each other in the Dehistan Plain (Fig. 1). The bone material consists of human and animal specimens from a large suite of species since the isotopic background in Turkmenistan is almost nonexistent. Both human remains from Geoktchik Depe have been recovered alongside the animal bones during the excavation, whereas the juvenile human from Misrijan has been excavated from a grave. In addition, animal bones of domestic herbivores (caprine, cattle, camelid, donkey), wild herbivores (red deer, gazella, saiga), wild carnivores (Felidae indet.), and omnivores (domestic pigs and wild boars, dogs) have been investigated (Table 1). Collagen extraction and isotopic analysis has been performed at the Laboratoire de Biogéochimie Isotopique, University of Paris 6, using the routine protocol described elsewhere [9]. The analytical precisions are 0.1‰ for $\delta^{13}C$ values and 0.2‰ for $\delta^{15}N$ values.

4. Results

The chemical quality of the collagen is excellent. Extraction yields are high, ranging from 16.5 to 182.8 mg g^{-1}. Almost all collagen exhibit %C above 40% and %N above 14%, and all C/N are within the same range than modern collagen, 2.9–3.6 (Table 1), showing no clue of significant alteration of in vivo isotopic signatures [19].

The specimens from all archaeological contexts have been combined, since the number of samples available for each archaeological levels in the Dehistan Plain is small and the climatic conditions are relatively stable during the studied period [15]. The specimens have been sorted into six trophic/environmental categories, namely domestic herbivores (DH), wild herbivores (WH), wild carnivores (WC), dogs (D), suids (S) and humans (H) (Table 1). The $\delta^{13}C$ and $\delta^{15}N$ of domestic herbivores exhibit a large range of variations, ranging from −19.8 to −11.9‰ and from 5.4 to 15.1‰ for $\delta^{13}C$ and $\delta^{15}N$ values, respectively. Wild herbivores present $\delta^{13}C$ values ranging from −20.7 to −15.2‰, whereas their $\delta^{15}N$ values range from 5.0 to 12.9‰. One wild felid exhibits a $\delta^{13}C$ value of −16.5‰ and a $\delta^{15}N$ value of 16.4‰, clearly higher than those of wild herbivores (Table 1). One dog exhibits a $\delta^{13}C$ value of −18.3‰ and a $\delta^{15}N$ value of 13.7‰, whereas suids present $\delta^{13}C$ values ranging from −20.7 to −19.8‰ and $\delta^{15}N$ values ranging from 12.4 to 13.2‰. Human collagen $\delta^{13}C$ values are among the lowest measured in this study, ranging from −20.2 to −19.5‰, whereas their $\delta^{15}N$ range from 13.6 to 14.8‰.

5. Discussion

Only species consumed by humans are taken into account for the dietary study. No skeletal part of red deer was found in the archaeological excavation except the analysed shed antler, which is most likely corresponding to a trophy or some raw material for handicraft, and was most probably collected in a more humid area. The red deer specimen was thus excluded from the dietary discussion. Cut marks are absent on the recovered bones of donkeys, showing no evidence that this species was consumed; therefore, these specimens were ignored in the dietary discussion. Meat intake of ruminants, i.e. caprine, cattle and camel is documented through cut marks on bones from these species and through kill-off patterns. In addition, consumption of dairy products is expected from kill-off patterns for caprine and cattle, and the traditional consumption of fermented camel milk (tchal) in Central Asia strongly suggests that camel milk was most probably consumed in the past.

5.1. Qualitative dietary reconstruction

It is possible to infer the relative amounts of different foodstuff that have been consumed by ancient human beings knowing the isotopic differences between a consumer and its dietary items, and knowing the isotopic compositions of the possibly consumed dietary items. A rough estimate can be deduced by comparing the isotopic signatures of the humans and those of different

Table 1
List of material and isotopic results

# Excavation	Age	Period		# Lab	Taxon	Skeletal element	Trophic attribution	Yield (mg g^{-1})	%C	%N	C/N	δ^{13}C (‰)	δ^{15}N (‰)
MS 110 bottom	11–12th c.	Historical	Misrijan	MS100	Caprine	Mandible	DH	71.7	43.9	16.1	3.2	−19.4	7.1
MS 101	11–12th c.	Historical	Misrijan	MS800	Caprine	Tibia	DH	163.2	44.8	16.4	3.2	−17.9	8.8
MS 101	11–12th c.	Historical	Misrijan	MS300	Cattle	Mandible	DH	168.4	45.2	16.4	3.2	−16.9	10.8
GD 96/125	6–7th c.	Historical	Geoktchik Depe	GD2000	Cattle	Molar	DH	49.6	39.8	14.6	3.2	−13.9	13.2
GD 95/441	6–7th c.	Historical	Geoktchik Depe	GD9000	Cattle	Calcaneus	DH	181.2	43.4	16.0	3.2	−17.1	15.1
MS 110	11–12th c.	Historical	Misrijan	MS700	Camelid	Phalanx II	DH	139.3	44.7	16.4	3.2	−16.3	8.9
GD 96/121	6–7th c.	Historical	Geoktchik Depe	GD1000	Camelid	Metacarpal	DH	132.2	43.8	15.6	3.3	−17.8	8.2
MS 118	11–12th c.	Historical	Misrijan	MS600	Donkey	Humerus	DH	138.0	45.0	16.2	3.2	−19.8	5.4
GD 96/121	6–7th c.	Historical	Geoktchik Depe	GD400	Donkey	Phalanx II	DH	157.7	43.5	15.8	3.2	−19.0	12.4
MS	11–12th c.	Historical	Misrijan	MS900	Red deer	Antler	WH	40.5	44.1	16.1	3.2	−20.7	5.0
MS 118	11–12th c.	Historical	Misrijan	MS500	Gazella	Metatarsal	WH	114.8	44.9	16.1	3.2	−17.2	12.9
GD 96/126	6–7th c.	Historical	Geoktchik Depe	GD3000	Gazella	Humerus	WH	127.0	43.8	15.9	3.2	−15.2	12.5
GD 96/121	6–7th c.	Historical	Geoktchik Depe	GD100000	Gazella	Mandible	WH	111.8	43.0	15.7	3.2	−17.0	11.3
MS 110 #144	11–12th c.	Historical	Misrijan	MS1100	Saiga	Horncore	WH	116.8	45.2	16.6	3.2	−16.9	8.0
GD 96/121	6–7th c.	Historical	Geoktchik Depe	GD600	Suid (boar?)	Mandible	S	54.2	39.8	14.4	3.2	−19.8	13.2
GD 96/125	6–7th c.	Historical	Geoktchik Depe	GD6000	Suid (boar?)	Mandible	S	107.0	43.0	15.7	3.2	−20.3	13.1
GD 96/126	6–7th c.	Historical	Geoktchik Depe	GD4000	Felidae indet.	Humerus	WC	133.2	43.8	15.8	3.2	−16.5	16.4
MS	11–12th c.	Historical	Misrijan	MS1200	Dog	Mandible	D	136.4	45.1	16.3	3.2	−18.3	13.7
MS 101	11–12th c.	Historical	Misrijan	MS200	Human (6/7 yr)	Mandible	H	143.5	45.0	16.5	3.2	−19.5	14.8
GD 95/434	ca. 13th bc	Iron Age	Geoktchik Depe	GD800	Caprine	Mandible	DH	125.9	43.7	15.8	3.2	−16.5	8.4
GD 95/454	ca. 13th bc	Iron Age	Geoktchik Depe	GD10000	Camelid	Radius	DH	156.9	42.7	15.7	3.2	−11.9	10.6
GD 95/454	ca. 13th bc	Iron Age	Geoktchik Depe	GD7000	Donkey	Phalanx I	DH	182.8	42.5	15.6	3.2	−18.6	11.4
GD 95/454	ca. 13th bc	Iron Age	Geoktchik Depe	GD90000	Donkey	Mandible	DH	57.0	41.8	15.3	3.2	−18.3	11.5
GD 96/720	ca. 13th bc	Iron Age	Geoktchik Depe	GD50000	Gazella	Talus	WH	28.1	41.4	15.2	3.2	−17.2	11.1
GD 96/466	ca. 13th bc	Iron Age	Geoktchik Depe	GD8000	Suid (boar?)	Metatarsal	S	61.7	42.9	15.7	3.2	−20.6	12.4
GD 94/8,25-8,80	ca. 13th bc	Iron Age	Geoktchik Depe	GD500	Pig	Mandible	S	103.5	40.7	14.9	3.2	−20.7	13.1
GD 94/303	ca. 13th bc	Iron Age	Geoktchik Depe	GD5000	Human	Mandible	H	16.5	25.9	9.3	3.2	−20.1	14.2
GD 95/433	ca. 13th bc	Iron Age	Geoktchik Depe	GD20000	Human	Talus	H	61.2	39.4	14.3	3.2	−20.2	13.6

Species names are the following: Sheep = *Ovis aries*, cattle = *Bos taurus*, dromedary = *Camelus dromedarius*, donkey = *Equus asinus*, red deer = *Cervus elaphus*, gazella = *Gazella subgutturosa*, saiga = *Saiga tatarica*, dog = *Canis familiaris*, human = *Homo sapiens*, suid = *Sus scrofa*. Abbreviation keys for trophic attributions are the following: D = dog, DH = domestic herbivore, H = human, S = suid, WH = wild herbivore, WC = wild carnivore.

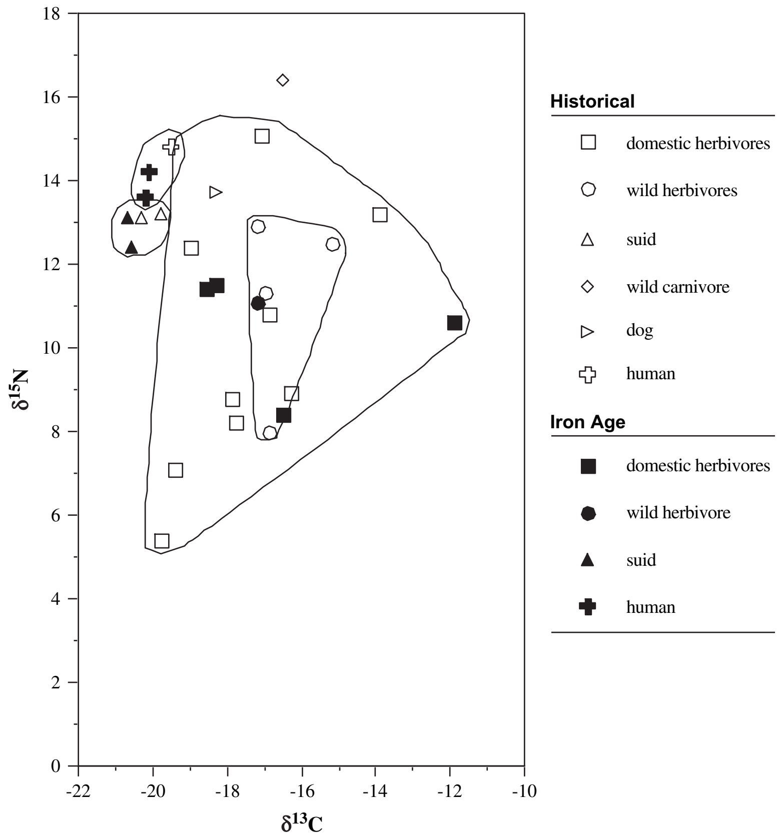

Fig. 2. Collagen $\delta^{13}C$ and $\delta^{15}N$ values of fauna and human specimens from south-western Turkmenistan.

animal species from the same environment. In the present study, human collagen $\delta^{13}C$ values are among the most negative measured in all the analysed specimens, ranging from −20.2 to −19.5‰, whereas their $\delta^{15}N$ range from 13.6 to 14.8‰ (Fig. 2). These isotopic values are too negative to indicate a high proportion of herbivore meat or dairy protein in their diet. The $\delta^{13}C$ values of humans are very similar to those of the analysed suids, wild or domestic pigs of the genus *Sus*, and their $\delta^{15}N$ values are slightly higher. Pigs are able to eat various dietary items, but they prefer C_3-plants, i.e. fruits, seeds, tubers and other fleshy parts. In the studied area, much of cultivated plants are C_3-plants, including cereals such as wheat and barley, legumes and vegetables. Only millet, reported from the Bronze Age of Bactriane [4], could be cultivated and provide C_4 proteins. There is no need to put forward fish in the diet, since the addition of freshwater and marine fish in human diet would have at least increased the $\delta^{15}N$ values, and possibly shifted the $\delta^{13}C$ values as well [6]. This result is in agreement with the absence of fish remains in the site [46], although Caspian Sea is 80 km away. Finally, humans seemed to rely mostly on cultivated C_3 plants, with a limited addition of herbivore proteins such as meat or dairy.

5.2. Quantitative dietary reconstruction

A more quantitative approach has been attempted, using the mixing models developed by Phillips and collaborators [40,56,57]. Such models allow the calculation

Table 2
Average isotopic signatures of ruminant meat during the Historical period using two modes of calculation, one based on NISP, the other based on percent meat weight

Taxa	NISP	%NISP	$\delta^{13}C$	$\delta^{15}N$	Weight	%Weight	$\delta^{13}C$	$\delta^{15}N$
Cattle (*Bos taurus*)	479	28.7	−16.0	13.0	18 533	52.7	−16.0	13.0
Domestic caprines (*Ovis* or *Capra*)	1074	64.4	−18.7	8.0	13 159	37.4	−18.7	8.0
Camel (*Camelus dromedarius*)	31	1.9	−17.0	8.6	1350	3.8	−17.0	8.6
Wild herbivores	84	5.0	−16.5	12.2	2137	6.1	−16.5	12.2
Total ruminants (average collagen)	1668	100	−17.8	9.7	35 179	100	−17.1	10.9
Total ruminants (average meat)			−20.8	9.7			−20.1	10.9

Table 3
Average isotopic signatures of ruminant meat during the Iron Age period using two modes of calculation, one based on NISP, the other based on percent meat weight

Taxa	NISP	%NISP	$\delta^{13}C$	$\delta^{15}N$	Weight	%Weight	$\delta^{13}C$	$\delta^{15}N$
Cattle (*Bos taurus*)	128	29.5	−16.0	13.0	3398	54.1	−16.0	13.0
Domestic caprines (*Ovis* or *Capra*)	275	63.4	−16.5	8.4	2431	38.7	−16.5	8.4
Camel (*Camelus dromedarius*)	2	0.4	−11.9	10.6	242	3.9	−11.9	10.6
Wild herbivores	29	6.7	−17.2	11.1	210	3.3	−17.2	11.1
Total ruminants (average collagen)	434	100	−16.4	9.9	6281	100	−16.1	11.1
Total ruminants (average meat)			−19.4	9.9			−19.1	11.1

of the percentage of three dietary items when the isotopic compositions of two chemical elements are available, as it is the case in the present study. This approach has primarily been developed to deal with modern food webs, where the isotopic signatures of different food resources are directly available (e.g. [24,27,36]). Although the isotopic signatures of food resources may be more difficult to determine accurately in archaeological contexts, this approach may be used for ancient food webs (e.g. [12,22,23,52,54]). In the present case, the archaeological context and the preliminary interpretation of the isotopic results leads us to consider the following three dietary items with different carbon and nitrogen isotopic compositions: ruminant proteins (dairy and meat = pole A), suid meat (pole B), and plant food (pole C). The calculation of the relative contribution of these food resources has been performed using the spreadsheet available at http://www.epa.gov/wed.pages/models.htm [57]. Three kinds of parameters have to be settled in order to be able to use such models. The first one is the isotopic composition of the different food resources, i.e. ruminant dairy and meat (A), suid meat (B) and plant food (C), for the different considered time periods. No direct measurement is possible for such values. Previous archaeological studies using such mixing models to reconstruct palaeodiets used collagen isotopic signatures as proxies of meat for the same animals (e.g. [23,54]). They used either direct measurement on fossil plant remains [54] or they deduced the isotopic values of plants from those of selected herbivores [52]. First of all, the data from both historical levels, sasanian and islamic, have been gathered to have enough measurements before attempting the quantitative palaeodietary reconstruction. Several ruminant species have been consumed: cattle, sheep, goat and camel. The isotopic compositions of several specimens from these species have been measured in the present study, and differences appear between species and within species (Table 1). It is thus necessary to aggregate the data to obtain one average value for this dietary item. For a given species an average isotopic value has been calculated when several bones from this species have been analysed in a given archaeological context. Averaging the isotopic data from different ruminant species has been performed in two ways: one way is based on the percentage of remnants (%NISP) for each species. However this way of quantification is biased due to fragmentation. An other way of averaging is based on the weight of bones from each species, which is a satisfactory proxy for weight of meat [16]. Both modes of calculation have been used in order to generate two different isotopic values for the dietary pole corresponding to ruminants (Tables 2 and 3). The main difference between both modes of calculation is a higher percentage for cattle using the meat weight, due to the larger size of cattle relatively to sheep and goats. Since cattle exhibit more positive $\delta^{15}N$ values than caprines, the $\delta^{15}N$ value of ruminant proteins is higher when using meat weight rather than NISP (Tables 2 and 3). Once an average isotopic composition has been calculated for collagen, a value for meat and dairy has been deduced, using the known isotopic shifts between collagen and muscle, on average 3‰ (review in Ref. [8]). For dairy products, milk presents a similar isotopic composition than the bulk proteins, and there is no evidence that fermentation leads to changes in the isotopic composition of cheese (I. Moussa, unpublished data). An average value has been calculated for suid collagen for each period, and then converted into a meat isotopic value using the same isotopic shift than between collagen and muscle of ruminants, i.e. 3‰ and 0‰ for

Table 4
Average isotopic signatures of the three dietary poles used in the linear mixing models during the Historical period

Calculation mode	I ($\delta^{13}C$, $\delta^{15}N$)	II ($\delta^{13}C$, $\delta^{15}N$)	III ($\delta^{13}C$, $\delta^{15}N$)	IV ($\delta^{13}C$, $\delta^{15}N$)
A: ruminant meat	(−20.8, 9.7)	(−20.8, 9.7)	(−20.1, 10.9)	(−20.1, 10.9)
B: pig meat	(−23.1, 13.2)	(−23.1, 13.2)	(−23.1, 13.2)	(−23.1, 13.2)
C: plant food	(−25.1, 10.2)	(−25.1, 8.2)	(−25.1, 10.2)	(−25.1, 8.2)

For calculation modes I and II, %NISP was used for ruminant meat, a fractionation factor of 3‰ and 5‰ were used between pig and plant $\delta^{15}N$ values for mode I and mode II, respectively. For calculation modes III and IV, %bone weight was used for ruminant meat, a fractionation factor of 3‰ and 5‰ were used between pig and plant $\delta^{15}N$ values for mode III and mode IV, respectively.

Table 5
Average isotopic signatures of the three dietary poles used in the linear mixing models during the Iron Age

Calculation mode	I (δ^{13}C, δ^{15}N)	II (δ^{13}C, δ^{15}N)	III (δ^{13}C, δ^{15}N)	IV (δ^{13}C, δ^{15}N)
A: ruminant meat	(−19.4, 9.9)	(−19.4, 9.9)	(−19.1, 11.1)	(−19.1, 11.1)
B: pig meat	(−23.6, 12.7)	(−23.6, 12.7)	(−23.6, 12.7)	(−23.6, 12.7)
C: plant food	(−25.6, 9.7)	(−25.6, 7.7)	(−25.6, 9.7)	(−25.6, 7.7)

For calculation modes, see legend of Table 4.

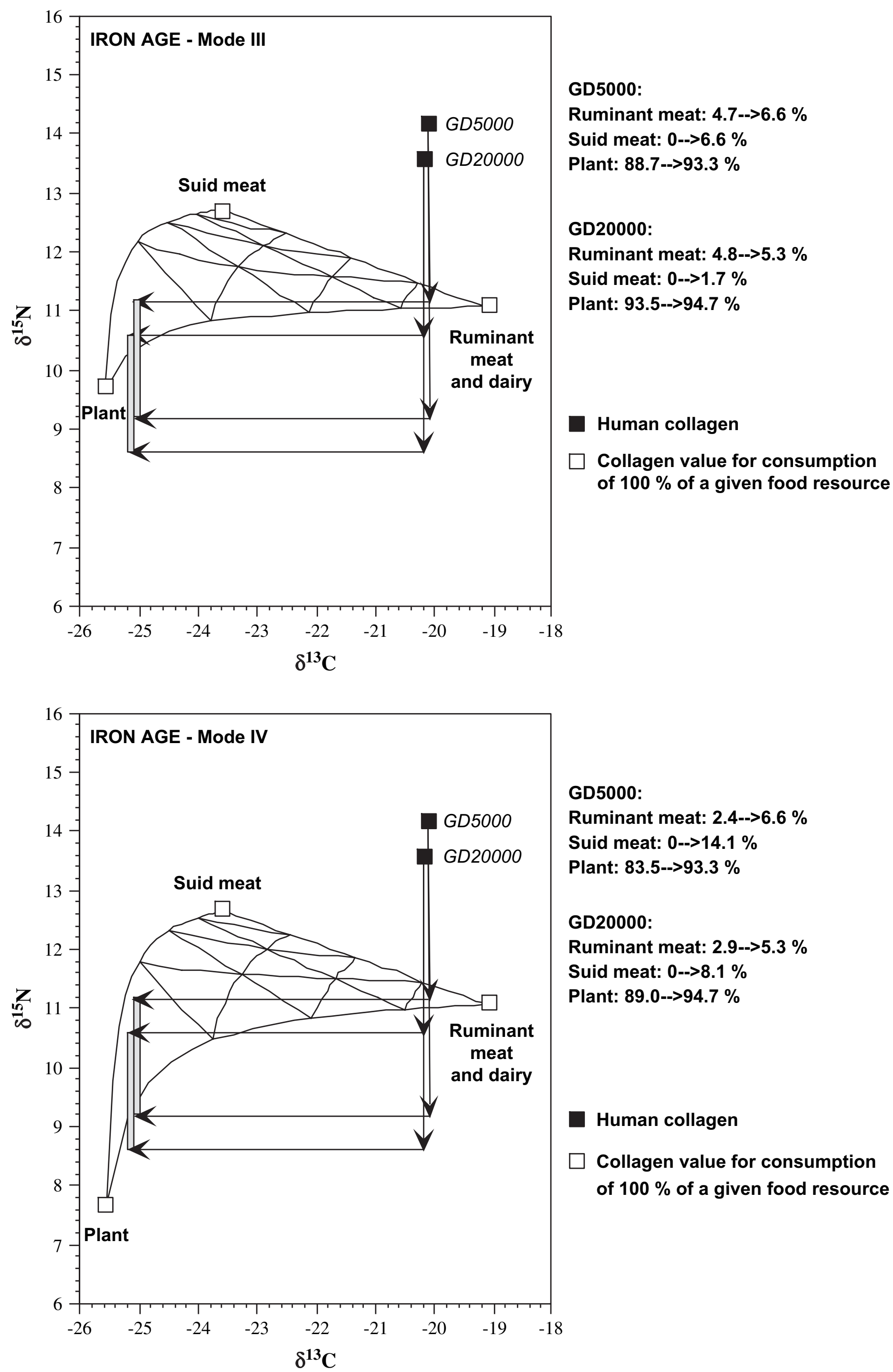

Fig. 3. Examples of concentration dependent mixing models using calculation modes III and IV for Iron Age humans. The grey rectangles correspond to the possible isotopic signatures of the average diet deduced from the isotopic compositions of human bone collagen. The possible range of proportions corresponds to the intersection between those rectangles and the concentration-weighted mixing triangle. The carbon and nitrogen concentrations for terrestrial meat and terrestrial plants presented in Table 1 by Phillips and Koch [57] have been used.

Table 6
Range of proportions of different dietary poles in the different humans according to the mode of calculation

	I (%)	II (%)	III (%)	IV (%)
Human MS200 (historical)	A: 5.5 → **12.2** B: **0** → 14.7 C: 79.8 → **87.8**	A: **3.4** → 10.7 B: 3.2 → **19.3** C: **77.3** → 86.1	A: 6.2 → **10.5** B: **0** → 10.8 C: 83.0 → **89.7**	A: **3.8** → 10.4 B: 0 → **17.0** C: **79.2** → 89.6
Human GD5000 (Iron Age)	A: 4.0 → **7.0** B: **0** → 9.6 C: 86.4 → **93.0**	A: **2.1** → 6.5 B: 1.5 → **15.5** C: **82.4** → 92.0	A: 4.7 → **6.6** B: **0** → 6.6 C: 88.7 → **93.3**	A: **2.4** → 6.6 B: 0 → **14.1** C: **83.5** → 93.3
Human GD20000 (Iron Age)	A: 4.2 → **5.6** B: **0** → 4.2 C: 91.6 → **94.4**	A: **2.6** → 5.6 B: 0 → **9.5** C: **87.9** → 94.4	A: 4.8 → **5.3** B: **0** → 1.7 C: 93.5 → **94.7**	A: **2.9** → 5.3 B: 0 → **8.1** C: **89.0** → 94.7

Figures in bold correspond to the possible extreme proportions using %NISP (modes I and II) or bone weight (modes III and IV) for ruminant meat (dietary pole A).

$\delta^{13}C$ and $\delta^{15}N$ values, respectively. The determination of plant food isotopic composition is more complicated. Contrarily to the Neolithic sites from Slovenia [54], it is not possible to use isotopic measurements performed on fossil plants from the same site in the case of Dehistan Plain. Using modern plants from the same area might be misleading, since plant species different than the modern ones might have been cultivated during ancient times. Moreover, since the nitrogen isotopic composition of plants is affected by local conditions, they are unpredictable for plants from the past. Following Newsome and collaborators [52], we used the isotopic signatures of the collagen of an animal eating the same type of plants than the humans in order to calculate the average isotopic composition of consumed plants. The animal that provides the closest estimate in this study is domestic or wild pig. Indeed, its diet is mainly based on C_3 plants such as seeds, fruits, rhizomes, most probably similar to those consumed by humans. We consider that grazers would not be a good choice, since these herbivores consume wild herbaceous plants that do not enter directly into the human diet. Finally, it is necessary to calculate the average food resource using the average isotopic composition of human bone collagen. The isotopic shift is 5‰ for $\delta^{13}C$ values, but the isotopic shift for $\delta^{15}N$ values varies according to different authors, ranging from 3 to 5‰ (review in [7]). These extreme enrichment values for $\delta^{15}N$ values have been tested in this study, in a similar way than other palaeodietary studies using mixing models [12,23]. Finally, due to the different calculation methods used for the ruminant food products and the plant food material, 4 different isotopic averages are presented for each period (Tables 4 and 5). An example of this approach is graphically presented in Fig. 3.

Using the quantitative model developed by Phillips and collaborators [56,57] for each of the 12 cases (4 cases for each 3 humans), the extreme percent of each dietary

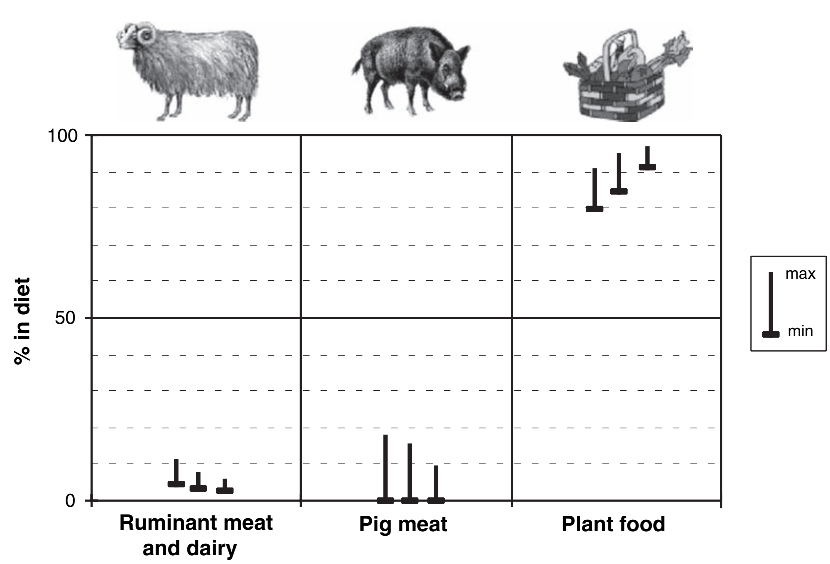

Fig. 4. Summary of the possible range of proportions for three dietary poles in the diet of archaeological humans for south-western Turkmenistan.

Table 7
Relative proportions of ruminants and suids during Historical period and Iron Age, based on NISP and meat weight

	Ruminant	Suid	% Ruminant	% Suid
Historical period (NISP)	1668	69	96.0	4.0
Historical period (estimated meat weight)	35 179	976	97.3	2.7
Iron Age (NISP)	434	75	85.3	14.7
Iron Age (estimated meat weight)	6281	2363	72.7	27.3

pole that is consistent with the calculated average diet of the each human was calculated (Tables 5 and 6). We considered separately the extreme values considering the NISP and meat weight estimations. The last method is more realistic as long as animal proteins are consumed as meat but it is not possible to quantify in the same way the consumption of dairy products. However, choosing NISP instead of meat weight has little influence on the final results, probably due to the small proportion of ruminant in the global diet of humans in the studied case. The results are, therefore, considered significant in terms of palaeodiets. They clearly show that plant food is dominant in the three studied human individuals, for historical and Iron Age contexts. All three humans are relatively similar in spite of their chronological difference (Fig. 4). In all cases, plants are dominant, pig meat is optional but ruminant products need to be included in the diet in order to fit the isotopic results. It seems that the contribution of plants is slightly higher in the Iron Age specimens than in the historical one but it is premature to generalise based on so few individuals. Further studies with more human individuals in the region may find a meaningful link between this difference and the intensity of agricultural practises during Iron Age as documented by archaeological fieldwork.

Zooarchaeological and isotopic results can be compared through the relative abundance of pig versus ruminants in the faunal remain and in the reconstructed diet. The prevalence of ruminants in the faunal assemblages is more important for Historical periods than for Iron Age (Table 7). The minimum contribution of ruminant meat and dairy is higher in the human from Historical period than for both Iron Age individuals. The results from zooarchaeological analysis and isotopic dietary reconstruction are thus in accordance on this aspect of the dietary regimen in ancient Turkmenistan.

6. Conclusion

The kill-off patterns established for south-western Turkmenistan indicate that husbandry was mostly oriented towards meat production although the human individuals analysed in this study mostly rely on cultivated C_3 plants, with only a limited addition of proteins from ruminants. This study demonstrates the possible complementarity of zooarchaology and isotopic approaches for palaeodietary reconstruction, since each method reflects a different chronological and demographic scale. Kill-off patterns are established using bones accumulated for time periods that might cover many centuries and correspond to the dietary trends of a human population of unknown size, whereas isotopic data reflect the actual diet of approximately the last decade of life of the analysed individuals. Moreover zooarchaeological data provide quantitative information about meat (and dairy) diet without any clue about the relative importance of other dietary sources, especially plant material, for which preservation potential is low.

Mixed economies are sometimes suggested by the study of faunal remains. This has been clearly demonstrated in some prehistoric Middle Eastern sites [47]. Quantifying the contribution of different food categories is thus a critical issue for palaeoeconomic interpretations and the understanding of the role of different economic activities in past societies. This pioneer work in Central Asia advocates a systematic collection of human bones associated to animal remains in prehistoric archaeological sites for joint zooarchaeological and isotopic studies, when the question of palaeodietary reconstruction is posed.

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