Archaeological bone lipids as palaeodietary markers

Journal:	*Rapid Communications in Mass Spectrometry*
Manuscript ID:	RCM-14-0460.R1
Wiley - Manuscript type:	Research Article
Date Submitted by the Author:	n/a
Complete List of Authors:	Colonese, André Carlo; University of York, Department of Archaeology Farrell, Thomas; University of Groningen, Arctic Centre Lucquin, Alexandre; University of York, Department of Archaeology Firth, Daniel; University of York, Department of Archaeology Charlton, Sophy; University of York, Department of Archaeology Robson, Harry; University of York, Department of Archaeology Alexander, Michelle; University of York, Department of Archaeology Craig, Oliver; University of York, Department of Archaeology
Keywords:	Archaeology, bone lipid, palaeodiet, GC/MS, GC/C/IRMS, EA/IRMS
Abstract:	RATIONALE Stable isotope analysis of archaeological and fossil bone samples can provide important insights into past environments, ecologies and diets. Previous studies have focused on stable carbon and nitrogen isotopes in bone collagen, or carbon isotopes in bone mineral (bioapatite). Carbon isotope analysis of lipids from archaeological bone has received much less attention, partly due to the lack of suitable methodologies allowing sufficient recovery of compounds for structural and isotopic characterisation. Here we show that lipids can be easily and reliably recovered from archaeological bone using a modified protocol, and that these provide complementary dietary information to other bone components. METHODS Human and animal bones were obtained from a variety of archaeological contexts. Lipids were sequentially extracted using solvent extraction (dichloromethane/methanol), followed by acidified methanol extraction (methanol/H2SO4). Lipids were analysed by gas chromatography-mass spectrometry (GC/MS) and gas chromatography-combustion-isotope ratio mass spectrometry (GC/C/IRMS). RESULTS Our results show that appreciable amounts of endogenous lipid can be recovered from archaeological bone. Importantly, a comparison between compound specific and bulk collagen isotopic data shows that archaeological bone lipids reflect dietary input and can be used to distinguish between marine and terrestrial consumers, as well as between C3 and C4 plant consumers. Furthermore, the presence of essential fatty

	acids directly incorporated from diet to bone may provide additional palaeodietary information. CONCLUSION Our findings suggest that archaeological bone lipids are a hitherto untapped resource of dietary information that offer further insights in addition to those gained from other isotopic analyses of bone.

Title: **Archaeological bone lipids as palaeodietary markers**

Short title: lipids as dietary markers

Author names and affiliations

André C. Colonese[1], Thomas Farrell[1,2], Alexandre Lucquin[1], Daniel Firth[1], Sophy Charlton[1], Harry K. Robson[1], Michelle Alexander[1] and Oliver E. Craig[1]

[1]BioArCh, University of York, Biology S-Block, Wentworth Way, York YO10 5DD, UK.

[2]Arctic Centre, University of Groningen, PO Box 716, 9700 AS Groningen, Netherland

Corresponding author

Colonese, A.C., BioArCh, University of York, Biology S-Block, Wentworth Way, York YO10 5DD, UK. *andre.colonese@york.ac.uk*

RATIONALE

Stable isotope analysis of archaeological and fossil bone samples can provide important insights into past environments, ecologies and diets. Previous studies have focused on stable carbon and nitrogen isotopes in bone collagen, or carbon isotopes in bone mineral (bioapatite). Carbon isotope analysis of lipids from archaeological bone has received much less attention, partly due to the lack of suitable methodologies allowing sufficient recovery of compounds for structural and isotopic characterisation. Here we show that lipids can be easily and reliably recovered from archaeological bone using a modified protocol, and that these provide complementary dietary information to other bone components.

METHODS

Human and animal bones were obtained from a variety of archaeological contexts. Lipids were sequentially extracted using solvent extraction (dichloromethane/methanol), followed by acidified methanol extraction (methanol/H_2SO_4). Lipids were analysed by gas chromatography-mass spectrometry (GC/MS) and gas chromatography-combustion-isotope ratio mass spectrometry (GC/C/IRMS).

RESULTS

Our results show that appreciable amounts of endogenous lipid can be recovered from archaeological bone. Importantly, a comparison between compound specific and bulk collagen isotopic data shows that archaeological bone lipids reflect dietary input and can be used to distinguish between marine and terrestrial consumers, as well as between C_3 and C_4 plant consumers. Furthermore, the presence of essential fatty acids directly incorporated from diet to bone may provide additional palaeodietary information.

CONCLUSION

Our findings suggest that archaeological bone lipids are a hitherto untapped resource of dietary information that offer further insights in addition to those gained from other isotopic analyses of bone.

Keywords: Archaeology, bone lipid, palaeodiet, GC/MS, GC/C/IRMS, EA/IRMS

Introduction

Bone is an invaluable resource for the reconstruction of palaeodiets, with stable isotope analysis of bulk collagen, amino acids, and apatite providing important insights into different aspects of past diets of both animals and humans [1–5]. The distribution and isotopic composition of lipids in ancient skeletal tissues can theoretically provide additional complementary palaeodietary information [6–12], but so far lipids have been under-utilised in studies of past diet.

Lipid in modern bone originates from marrow adipose tissue (MAT), blood, and bone-forming cells (osteocytes) [13]. Dietary lipids are incorporated into a consumer's tissue in a predictable manner [14], and the distributions of tissue lipids, notably fatty acids, are widely used within food-web studies in modern settings [15]. In addition, analysis of the stable carbon isotopes present in lipids may provide complementary dietary information to that obtained from more widely studied organic molecules, such as collagen. Firstly, lipids turnover much faster compared to bone collagen and mineral, and therefore reflect diet over a shorter period [16–18]. Secondly, experiments have shown that collagen is preferentially synthesised from dietary protein, whereas lipids represent whole diet (i.e. a combination of protein, lipids and carbohydrates) or dietary lipids [19–21]. Thirdly, the stable carbon isotope ($\delta^{13}C$) values of lipids (notably mid-chain length *n*-alkanoic acids) extracted from archaeological artefacts have already been widely measured to investigate their use. Inferences are normally made by comparison with modern authentic reference fats [22]. Obtaining comparative isotope measurements of these compounds directly from associated archaeological faunal remains would allow for a more precise elucidation of artefact use.

Although lipids have long been recognised as a source of dietary information, there are doubts concerning their preservation and authenticity in bone samples that have been extensively exposed to the burial environment. Absorbed fat-rich marrow is likely to be susceptible to leaching by ground water, microbial degradation, and removal prior to burial through boiling or cooking. Indeed, fatty acids, one of the most abundant classes of lipids in modern tissues, are rarely recovered by solvent extraction in all but arid environments [7]. For this reason, research has generally focused on more hydrophobic compounds, such as steroids, which are more resistant to oxidation and ground water leaching [6]. Lipids present in bone cells are protected within the bone lamellae and are expected to be less diagentically altered, less prone to contamination with soil lipids and therefore more promising for palaeodietary studies. Nevertheless, these molecules are likely to be more difficult to extract with conventional solvent extraction. Additional endogenous polar lipids may also form strong electrostatic interactions with the bone mineral phase or be directly hydrogen bonded with the mineral surface. The removal of either cellular or such structurally-bound lipid from bone requires a re-evaluation of the extraction methods.

Here we evaluate a novel approach using acidified methanol to partly demineralise bone whilst simultaneously extracting and derivatising any fatty acyl components for analysis by gas chromatography mass spectrometry (GC/MS) and gas chromatography combustion mass spectrometry (GC/C/IRMS).

Experimental

Sample selection

Human (n=10) and faunal (n=11) bone samples, dating from ~6,000 to 500 calibrated years before present were obtained from a variety of coastal and inland sites from Europe and South America, in order to capture a range of environments and C3/C4 terrestrial, and marine subsistence strategies (Tab. 1).

Collagen extraction

For most of samples the bulk collagen stable isotope data was already available (Tab. 1) and details of the methods can be found in previous studies [23-27]. Briefly collagen was extracted using a modified Longin method [28]. Bone (0.5-1 g) was coarsely ground and demineralised (0.6 M HCl, 4°C, 3-12 days), samples were rinsed with distilled water and then gelatinised (pH3 [0.001M] HCl, 80°C, 48 h). The supernatant containing the collagen was filtered (30 kDa, Amicon® Ultra-4 Centrifugal Filter Units, Millipore, Billerica, MA, USA), frozen, and lyophilised.

Lipid extraction

Between 0.3 and 0.9 g of mechanically cleaned bone was ground to a coarse powder with a pestle and mortar. Lipids were then extracted from individual bone samples via one of two methods:

Method 1 – Acidified methanol extraction

Lipids from two human (ABM08 and GBM24/04) and two bovine (GBC2 and GBC4) bone samples were extracted with a one-step, direct extraction and methylation [22,29]. In short, after adding 4 mL of methanol, samples were ultra-sonicated for 15 minutes. Subsequently, 800 µL of H_2SO_4 was added and the samples were heated at 70°C for 4 hours. Samples were then centrifuged (850 x g) for 5 minutes. Supernatant was then extracted with hexane (3 x 2 mL) and neutralised with K_2CO_3. Extracts were then dried under a gentle stream of N_2. 10 µL of internal standard (0.2 µg μL^{-1} tetratriacontane or 1.0 µg μL^{-1} hexatriacontane) was added to each sample before further analysis by GC/MS and GC/C/IRMS.

Method 2 – Solvent extraction followed by acidified methanol extraction

Lipids from all 21 bone samples were solvent extracted with dichloromethane/methanol (2/1 vol/vol; 3 x 2 mL), by ultra-sonicating for 15 minutes and then centrifuging (850 x g) for 10 minutes. The supernatant was removed, discarded and the bone powder was dried completely under gentle stream of N_2. The same procedure, outlined in method 1 (acidified methanol extraction), was then applied to the remaining bone powder.

Instrumentation

Elemental Analysis – Isotope Ratio Mass Spectrometry (EA/IRMS)

Collagen samples (1 mg) were analysed in duplicate or triplicate by EA/IRMS in a Sercon GSL analyser coupled to a Sercon 20-22 Mass Spectrometer (Sercon, Crewe, UK) at the University of York, or a Roboprep Combustion Device coupled to a Europa 20-20 Mass Spectrometer (PDZ-Europa, Crewe, UK) at the University of Bradford. For all these instruments the analytical error, calculated from repeated measurements of each sample and measurements of the bovine control from multiple extracts, was <0.2‰ (1σ). The results from the analysis are reported per mil (‰) relative to an international standard (V-PDB). Collagen standards were exchanged between laboratories to ensure instrument consistency.

Gas Chromatography – Mass Spectrometry (GC/MS)

GC/MS was carried out on all samples using an Agilent 7890A Series chromatograph attached to an Agilent 5975 C Inert XL mass-selective detector with a quadrupole mass analyser (Agilent technologies, Cheadle, Cheshire, UK). A splitless injector was used and maintained at 300°C. The carrier gas used was helium, and inlet/column head-pressure was constant. The GC column was inserted directly into the ion source of the mass spectrometer. The ionisation energy of the mass spectrometer was 70 eV and spectra were obtained by scanning between *m/z* 50 and 800. Two different columns phases were used. General screening was performed using a DB-5ms (5%-phenyl)-methylpolysiloxane column (30 m x 0.250 mm x 0.25 µm; J&W Scientific, Folsom, CA, USA). The temperature for this column was set at 50°C for 2 minutes, then raised by 10°C min^{-1} until 325°C was reached, where it was held for 15 minutes. A second more polar column (DB-23, (50%-Cyanopropyl)-methylpolysiloxane column, 60 m x 0.25 mm x 0.25 µm; J&W Scientific, Folsom, CA, USA), was used for a better resolution of isoprenoid fatty acids. The temperature was set at 50°C for 2 minutes, then raised by 10°C min^{-1} until 100°C, then raised at 4°C min^{-1} until reaching 250°C where it was held for 20 minutes.

Gas Chromatography – Combustion – Isotope Ratio Mass Spectrometry (GC/C/IRMS)

A procedure identical to that described by Craig et al. [30] was followed. Carbon stable isotopes were determined on two fatty acid methyl esters; methyl palmitate ($C_{16:0}$) and methyl stearate ($C_{18:0}$) in each extract using a Delta V Advantage IRMS Thermo Fisher linked to a Trace Ultra gas chromatograph Thermo Fisher with a ConFlo IV interface (Cu/Ni combustion reactor held at 1000°C; Thermo Fisher, Bremen, Germany). All samples were diluted with hexane and subsequently 1 µL of each sample was injected into a DB5 fused-silica column. The temperature was set for 1 minute at 45°C, and raised by 6°C min^{-1} until 295°C was reached, at which it stayed for 15 minutes. The carrier gas was ultra-high purity grade helium with a flow rate of 1.4 mL min^{-1}. Eluted products were combusted to CO_2 and ionized in the mass spectrometer by electron impact. Ion intensities of *m/z* 44, 45, and 46 were monitored in order to automatically compute the $^{13}C/^{12}C$ ratio of each peak in the extracts. Computations were made with Isodat 3.0 Gas Isotope Ratio MS Software (version 3.0; ThermoFisher Scientific) and were based on comparisons with a standard reference gas (CO_2) of known isotopic composition that was repeatedly measured. The results from the analysis are reported in parts per mil (‰) relative to an international standard (V-PDB). Replicate measurements of each sample and a mixture of fames fatty acid methyl esters (FAMEs) with $\delta^{13}C$ values traceable to international standards were used to determine instrument precision (<0.3‰) and accuracy (<0.5‰). Values were also corrected subsequent to analysis to account for the methylation of the carboxyl group that occurs during acid extraction. Corrections were based on comparisons with a standard mixture of $C_{16:0}$ and $C_{18:0}$ fatty acids of known isotopic composition processed in each batch as a sample.

Results and discussion

Stable carbon and nitrogen isotopic composition of bulk collagen

Based on the isotope values of the bulk collagen and other archaeological data, humans were assigned to a variety of dietary categories including marine, terrestrial C_3, terrestrial C_4, and terrestrial C_3/marine mixed (Fig. 1). Human remains with a marine protein diet exhibited average $\delta^{13}C$ and $\delta^{15}N$ values of -11.3‰ and +16.6‰. Individuals with a terrestrial diet based on C_3 plants and C_3 plant fed animals provided average $\delta^{13}C$ and $\delta^{15}N$ values of -20.2‰ and +11.2‰. One individual had $\delta^{13}C$ and $\delta^{15}N$ values of -16.4‰ and +11.0‰, which is attributable to C_4 plant-derived carbon in the diet [24]. Humans with a mixed diet including terrestrial based C_3 plants and marine resources had average $\delta^{13}C$ and $\delta^{15}N$ values of -17.5‰ and +12.1‰ respectively.

The $\delta^{13}C$ and $\delta^{15}N$ of marine fish (*Pogonias cromis*) and sea mammals (Pinnipedia, Cetacea) had values ranging from -9.8‰ to -11.8‰ and +12.6‰ to +19.5‰ respectively. The $\delta^{13}C$ and $\delta^{15}N$ of terrestrial faunal remains from C_3 plant ecosystems, including ruminants (*Bos taurus, Capreolus capreolus*), monogastric herbivores (*Agouti paca*, *Alouatta* sp.), and omnivores (*Sus scrofa*), had values ranging from -20.1‰ to -22.9‰ and +3.5‰ to +7.9‰. Finally, the $\delta^{13}C$ and $\delta^{15}N$ of one bovine sample (GBC4) had values of -14.3‰ and +7.4‰ respectively, with the relatively elevated $\delta^{13}C$ value attributed to C_4 plants in its diet [24].

Comparison of lipid extraction methods

Two human (ABM08 and GBM24/04) and two bovine (*Bos taurus*) bone samples (GBC2 and GBC4) were extracted using both acidified methanol (method 1) and sequential solvent-acidified methanol extraction (method 2). There were major differences observed in the distribution, quantity and isotopic composition of lipids extracted with the two methods (Tab. 1, SI1).

Lipid extracts of the two bovine bones obtained via method 1 were very similar in nature, mainly containing saturated fatty acids with even carbon numbers (between $C_{12:0}$-$C_{24:0}$), cholesterol derivatives, lesser concentrations of monounsaturated fatty acids with even carbon numbers (between $C_{16:1}$-$C_{24:1}$), and linoleic acid ($C_{18:2}$) (Fig. 2A). Numerous phthalates (plasticizer contaminants; P) were present in the method 1 extracts. The extracts of bovine bone obtained via method 2 were also similar to each other and similar to the extracts of method 1. Both contained saturated fatty acids with even carbon numbers (between $C_{14:0}$-$C_{24:0}$), cholesterol derivatives, monounsaturated fatty acids with even carbon numbers (between $C_{18:1}$ and $C_{24:1}$), and linoleic acid ($C_{18:2}$) (Fig. 2B). The major difference between method 1 and method 2 extracts was the lack of plastic contaminants in the latter, therefore these contaminants were efficiently removed by solvent wash prior to acid-extraction.

Human bone lipids extracted via method 1 were also similar in nature, containing saturated fatty acids with even carbon numbers ($C_{12:0}$-$C_{24:0}$), monounsaturated fatty acids ($C_{18:1}$, $C_{22:1}$, $C_{24:1}$), linoleic acid ($C_{18:2}$), and cholesterol derivatives. Like the bovine bones extracted with method 1, phthalate were also present in the human bones extracted with method, most likely reflecting their conservational history. The same samples extracted with method 2 had similar lipid profiles, containing saturated fatty acids ($C_{16:0}$-$C_{24:0}$), monounsaturated fatty acids ($C_{18:1}$

and $C_{24:1}$), linoleic acid ($C_{18:2}$), and cholesterol derivatives. Similar to the cattle bone samples, plastic contamination was absent in the human bone lipid extracts obtained via method 2.

The GC/MS results presented here demonstrate that method 2 removed contaminants from archaeological bone samples, whilst extracting a similar range of lipids to method 1. However, much lower overall lipid concentrations were obtained with method 2. For example, the total lipid yield of GBC2 was 82 $\mu g.g^{-1}$ with method 1, and only 31 $\mu g.g^{-1}$ for method 2. Additionally, yields of $C_{16:0}$ and $C_{18:0}$ dropped from 20 and 18 $\mu g.g^{-1}$ to 5 and 4 $\mu g.g^{-1}$respectively.

GC/C/IRMS analysis showed that isotopic values of $C_{16:0}$ and $C_{18:0}$ were greatly affected by the method used for lipid extraction (Fig. 3A-B). Based on bulk collagen isotope data, GBC2 bovine sample was assigned to the 'C_3 diet' category, and had a $\delta^{13}C$ value that was lower by ~6‰ relative to the C_4 bovine sample (GBC4). Additionally, the $\delta^{13}C$ value of human bulk collagen from ABM08 (C_3 diet) was ~2‰ lower relative to the GBM2404 value, attributed to a greater C_4 diet in the latter. The $\delta^{13}C$ values of $C_{16:0}$ and $C_{18:0}$ obtained from method 1 did not reflect bulk collagen data; the two bovine samples (GBC2, GBC4) had nearly identical $\delta^{13}C$ values, as did the two human extracts (ABM08, GBM24/04). In contrast, using method 2 the $\delta^{13}C$ value of GBC4 was higher by ~6‰ compared to GBC2. Similarly, the $\delta^{13}C$ value of GBM2404 was higher by ~2‰ compared to ABM08. These differences are consistent with the offset observed in bulk collagen $\delta^{13}C$ values.

These results highlight the efficiency of sequential extraction (method 2) for obtaining reliable archaeological bone lipid extracts. It is likely that exogenous lipids were removed by extraction with organic solvents leaving endogenous lipids present in bone cells (osteocytes) or bound to the mineral matrix. Although solvent extraction probably also removed some endogenous lipid, an adequate amount remained for subsequent biomolecular and isotopic analyses. Another, albeit less likely, explanation is that lipids soluble in organic solvents were derived from either a different fraction of diet or foods consumed over a different period of time to both collagen and the cellular/bound lipid fraction.

Based on these results, the remainder of the samples analysed in this study were extracted with method 2.

The distribution of lipids in archaeological bone

The lipid extracts from all archaeological bones analysed in this study were similar in composition (Fig. 4, SI1). In general, the extracts contained saturated fatty acids (primarily $C_{14:0}$, $C_{16:0}$, and $C_{18:0}$), lesser concentrations of monounsaturated fatty acids (primarily $C_{18:1}$), and some products of cholesterol oxidation (primarily cholesta-3,5-diene). In some samples, linoleic acid ($C_{18:2}$) was present in low quantities, and in one case hexadecadienoic acid ($C_{16:2}$) was present.

Traces of phytanic and/or pristanic acid were present in all of the samples analysed. The synthesis of phytanic acid from phytol occurs in abundance in ruminant animals and marine ecosystems, as phytol is made bioavailable by gut-bacteria in the former, and by zooplankton in the latter [31–33]. As other animals cannot separate phytol from chlorophyll, the presence of phytanic and pristanic acid is normally attributed to direct incorporation from the consumption of meat and/or fish and/or dairy products [31,33,34].

Although these isoprenoid fatty acids may be present at low abundance in the burial environment, their persistence in the bone samples following solvent extraction indicates that they are most likely endogenous and directly derived from diet, as previously reported in other studies of exceptionally well preserved soft and skeletal tissues [8]. The presence of isoprenoid fatty acids in bone up to 6,000 years old is encouraging and warrants further study.

Fatty acids stable carbon isotope values

All of the lipid extracts obtained via method 2 yielded sufficient amounts of $C_{16:0}$ and $C_{18:0}$ for GC/C/IRMS analysis (Tab. 1).

The $\delta^{13}C$ values of $C_{16:0}$ and $C_{18:0}$ across all samples ranged from -20.1‰ to -29.4‰, and -21.2‰ to -31.5‰ respectively, with clear separation between marine and terrestrial fauna, and between terrestrial C_3 and C_4 consumers. Similar isotopic differences were identified in humans according to their bulk collagen isotope values (Fig. 5).

Importantly, the humans with mixed terrestrial C_3/marine diets plot towards the middle of the range of isotopic values obtained here, and fall between humans with dominant marine and C_3 terrestrial diets.

Nevertheless, two seals had $C_{16:0}$ and $C_{18:0}$ depleted in ^{13}C relative to the other marine organisms, plotting among the C_3 consumers, and did not correlate with the bulk collagen isotope data (Tab. 1). This is unlikely to be the result of contamination, since both seals come from a marine shell midden site (Oronsay, Western Scotland) where contamination with lipids from the depositional matrix would be expected to elevate $\delta^{13}C$ values. While the seal values appear to be outliers in the data presented here, similar $\delta^{13}C$ values of bulk lipids from modern seals have been reported previously [35,36].

As expected, the fatty acids were consistently depleted in ^{13}C relative to bulk collagen values from the same samples (Fig. 6). Such ^{13}C depletion reflects fundamental differences between the biosynthesis of collagen and fatty acids. Both $C_{16:0}$ and $C_{18:0}$ fatty acids can either be directly routed from diet or biosynthesised *de novo* from all dietary macronutrients. However, a major kinetic isotope effect in lipid biosynthesis occurs through the oxidative decarboxylation of pyruvate to acetyl Co-A resulting in a depletion in ^{13}C [37].

Interestingly, the offset between collagen and lipids ($\Delta^{13}C_{FA\text{-}COLL}$) is not consistent and ranges from ~6‰ to ~18‰. This variation may reflect isotopic differences in dietary macronutrients, however $\Delta^{13}C_{FA\text{-}COLL}$ offset in marine fauna is consistently larger than in terrestrial animals. The offset in terrestrial C_3 animals (6.0‰ to 11.4‰) was consistent with the expected value for individuals with diets high in carbohydrates [19,20], where non-essential amino acids and fatty acids are at least in part *de novo* synthesised from this source. The larger $\Delta^{13}C_{FA\text{-}COLL}$ observed in the marine organisms (i.e. >13‰) may be due to the fact that the pool of dietary carbon in fish and marine mammals is derived from a greater amount of lipid compared to terrestrial herbivores, which then becomes further depleted in ^{13}C during subsequent lipogenesis. More work to determine the isotopic differences between essential and non-essential fatty and amino acids is needed to understand the degree of routing versus biosynthesis of macronutrients in marine organisms.

Conclusions

By using a modified two-step protocol, we show that a greater range of lipids than previously encountered can be reliably recovered from archaeological bone. The extraction of appreciable amounts of endogenous fatty acids from bone buried even in temperate environments is particularly promising since these compounds can be traced isotopically to dietary macronutrients or directly incorporated from known dietary sources. In addition, $\delta^{13}C$ values of fatty acids associated with artefacts have been widely measured in ancient contexts providing the opportunity to compare data. New avenues for research on bone fatty acids include the comparison with bulk collagen and single amino acids to identify the source and relative contribution of dietary protein, lipids and carbohydrates with more accuracy. Furthermore, as lipids turn-over much faster in bone in comparison to collagen, changes in diet through life may also be studied using this approach.

Acknowledgments

The authors want to thank Paulo DeBlasis, Levy Figuti, Veronica Wesolowski, Sabine Eggers, Claudia Regina Plens, Alison Sheridan, Søren H. Andersen, Kurt Gron, Antonio Hernández Pardos, Joan Cardona, the Museu Arqueològic de Gandía, the National Museum of Scotland and the Instituto de Patrimônio Histórico e Artístico Nacional (IPHAN) for providing materials and permissions for analysis. This research was partially funded by the EU Marie-Curie Action: ''Intra-European fellowships for career development'' (Coastal resources and South American hunter-gatherers: biochemical perspectives from Brazilian sambaquis - COREBRAS, Ref. 273734); FAPESP (Sambaquis e Paisagem, Ref. 11038-0); AHRC (Changing Scientific and Cultural Perspectives on Human-Chicken Interactions, Ref. AH/L006979/1); NERC (Finding the Mesolithic: Accessing Biomolecular Information from Bone Fragments, Ref.NE/K500987/1). The authors thank the anonymous reviewers for their comments on the manuscript.

References

[1] L. T. Corr, J. C. Sealy, M. C. Horton, R. P. Evershed. A novel marine dietary indicator utilising compound-specific bone collagen amino acid $\delta^{13}C$ values. *J. Archaeol. Sci.* **2005**, *32*, 321.

[2] M. L. Fogel, N. Tuross. Extending the limits of palaeodietary studies of humans with compound specific carbon isotope analysis of amino acids. *J. Archaeol. Sci.* **2003**, *30*, 535.

[3] R. G. Harrison, M. A. Katzenberg. Paleodiet studies using stable carbon isotopes from bone apatite and collagen: examples from Southern Ontario and San Nicolas Island, California. *J. Anthropol. Archaeol.* **2003**, *22*, 227.

[4] M. A. Katzenberg, H. G. McKenzie, R. J. Losey, O. I. Goriunova, A. Weber. Prehistoric dietary adaptations among hunter-fisher-gatherers from the Little Sea of Lake Baikal, Siberia, Russian Federation. *J. Archaeol. Sci.* **2012**, *39*, 2612.

[5] M. P. Richards and R. E. M. Hedges. Stable isotope evidence for similarities in the types of marine foods used by Late Mesolithic humans at sites along the Atlantic coast of Europe. *J. Archaeol. Sci.* **1999**, *26*, 717.

[6] R. P. Evershed, G. Turner-Walker, R. E. M. Hedges, N. Tuross, A. Leyden. Preliminary results for the analysis of lipids in ancient bone. *J. Archaeol. Sci.* **1995**, *22*, 277.

[7] M. S. Copley, S. Jim, V. Jones, P. Rose, A. Clapham, D. N. Edwards, M. Horton, P. Rowley-Conwy, R. P. Evershed. Short- and long-term foraging and foddering strategies of domesticated animals from Qasr Ibrim, Egypt. *J. Archaeol. Sci.* **2004**, *31*, 1273.

[8] L. T. Corr, M. P. Richards, S. Jim, S. H. Ambrose, A. Mackie, O. Beattie, R. P. Evershed. Probing dietary change of the Kwädąy Dän Ts'inchį individual, an ancient glacier body from British Columbia: I. Complementary use of marine lipid biomarker and carbon isotope signatures as novel indicators of a marine diet. *J. Archaeol. Sci.* **2008**, *35*, 2102.

[9] J. E. Spangenberg, M. Ferrer, S. Jacomet, N. Bleicher, J. Schibler. Molecular and isotopic characterization of lipids staining bone and antler tools in the Late Neolithic settlement, Zurich Opera Parking, Switzerland. *Org. Geochem.* **2014**, *69*, 11.

[10] A. W. Stott, R. P. Evershed. $\delta^{13}C$ analysis of cholesterol preserved in archaeological bones and teeth. *J. Anal. Chem.* **1996**, *68*, 4402.

[11] A. W. Stott, R. P. Evershed, N. Tuross. Compound-specific approach to the $\delta^{13}C$ analysis of cholesterol in fossil bones. *Org. Geochem.* **1997**, *26*, 99.

[12] A. W. Stott, R. P. Evershed, S. Jim, V. Jones, J. M. Rogers, N. Tuross, S. Ambrose. Cholesterol as a new source of palaeodietary information: experimental approaches and archaeological applications. *J. Archaeol. Sci.* **1999**, *26*, 705.

[13] R. P. Evershed, I. D. Bull, L. T. Corr, Z. M. Crossman, B. E. Van Dongen, C. J. Evans, S. Jim, H. R. Mottram, A. J. Mukherjee, R. D. Pancost, in *Stable Isotopes in Ecology and Environmental Science*, (Eds: R. Michener, K. Lajtha). Blackwell Publishing Ltd, Malden, **2007**, pp. 480-540.

[14] L. Hodson, C. M. Skeaff, B. A. Fielding. Fatty acid composition of adipose tissue and blood in humans and its use as a biomarker of dietary intake. *Prog. Lipid Res.* **2008**, *47*, 348.

[15] S. M. Budge, M. J. Wooller, A. M. Springer, S. J. Iverson, C. P. McRoy, G. J. Divoky. Tracing carbon flow in an arctic marine food web using fatty acid-stable isotope analysis. *Oecologia* **2008**, *157*, 117.

[16] L. L. Tieszen, T. W. Boutton, K. G. Tesdahl, N. A. Slade. Fractionation and turnover of stable carbon isotopes in animal tissues: implications for $\delta^{13}C$ analysis of diet. *Oecologia* **1983**, *57*, 32.

[17] A. Strawford, F. Antelo, M. Christiansen, M. K. Hellerstein. Adipose tissue triglyceride turnover, de novo lipogenesis, and cell proliferation in humans measured with ^2H_2O. *Am. J. Physiol.* **2004**, *286*, 577.

[18] P. Arner, S. Bernard, M. Salehpour, G. Possnert, J, Liebl, P. Steier, B. A. Bucholz, M. Eriksson, E. Arner, H. Hauner, T. Skurk, M. Ryden, K. N. Frayn, K. L. Spalding. Dynamics of human adipose lipid turnover in health and metabolic disease. *Nature*. **2011**, *478*, 110.

[19] A. W. Stott, E. Davies, R. P. Evershed, N. Tuross. Monitoring the routing of dietary and biosynthesized lipids through compound-specific stable isotope ($\delta^{13}C$) measurements at natural abundance. *Naturwissenschaften* **1997**, *84*, 82.

[20] M. R. Howland, L. T. Corr, S. M. M. Young, V. Jones, S. Jim, N. J. Van Der Merwe, A. D. Mitchell, R. P. Evershed. Expression of the dietary isotope signal in the compound-specific $\delta^{13}C$ values of pig bone lipids and amino acids. *Int. J. Osteoarchaeol.* **2003**, *13*, 54.

[21] S. Jim, S. H. Ambrose, R. P. Evershed. Stable carbon isotopic evidence for differences in the dietary origin of bone cholesterol, collagen and apatite: implications for their use in palaeodietary reconstruction. *Geochemica et Cosmochimica Acta* **2004**, *68*, 61.

[22] O. E. Craig, H. Saul, A. Lucquin, Y. Nishida, K. Taché, L. Clarke, A. Thompson, D. T. Altoft, J. Uchiyama, M. Ajimoto, K. Gibbs, S. Isaksson, C. P. Heron, P. Jordan. Earliest evidence for the use of pottery. *Nature* **2013**, *496*, 351.

[23] A. C. Colonese, M. Collins, A. Lucquin, M. Eustace, Y. Hancock, R. A. R. Ponzoni, A. Mora, C. Smith, P. DeBlasis, L. Figuti, V. Wesolowski, C. R. Plens, S. Eggers, D. S. E. de Farias, A. Gledhill, O. E. Craig. Long-term resilience of Late Holocene coastal subsistence system in southeastern South America. *PLOS ONE*, **2014**, 9, e93854, DOI: 10.1371/journal.pone.0093854.

[24] M. M. Alexander, C. M. Gerrard, A. Gutiérrez, and A. R. Millard. Diet, society, and economy in late medieval Spain: Stable isotope evidence from Muslims and Christians from Gandía, Valencia. *Am. J. Phys. Anthropol. Online advance view,* DOI: 10.1002/ajpa.22647

[25] O. E. Craig, R. Ross, S. H. Andersen, N. Milner, G. N. Bailey. Focus: sulphur isotope variation in archaeological marine fauna from northern Europe. *J. Archaeol. Sci.* **2006**, *33*, 1642.

[26] K. J. Gron. The Ertebølle faunal economy and the transition to agriculture in southern Scandinavia. PhD thesis, the University of Wisconsin, **2013**.

[27] M. Mundee. Exploring Diet and Society in medieval Spain: new approaches using stable isotope analysis. PhD thesis, Durham University, **2010**.

[28] T. A. Brown, D. E. Nelson, J. S. Vogel, J. R. Southon. Improved collagen extraction by modified Longin method. *Radiocarbon*, **1988**, *30*, 171.

[29] M. Correa-Ascencio, R. P. Evershed. High throughput screening of organic residues in archaeological potsherds using direct acidified methanol extraction. *Anal. Methods* **2014**, *6*, 1330.

[30] O. E. Craig, R. B. Allen, A. Thompson, R. E. Stevens, V. J. Steele, C. Heron. Distinguishing wild ruminant lipids by gas chromatography/combustion/isotope ratio mass spectrometry. Rapid Commun. Mass Sp. 2012, 26, 2359.

[31] P. J. Brown, G. Mei, F. B. Gibberd, D. Burston, P. D. Mayne, J. E. McClinchy, M. Sidey. Diet and Refsum's disease. The determination of phytanic acid and phytol in certain foods and the application of this knowledge to the choice of suitable convenience foods for patients with Refsum's disease. *J. Hum. Nutr. Diet* **1993**, *6*, 295.

[32] D. M. van den Brink, R. J. A. Wanders. Phytanic acid: production from phytol, its breakdown and role in human disease. *Cell. Mol. Life. Sci.* **2006**, *63*, 1752.

[33] R. J. A. Wanders, J. Komen, S. Ferdinandusse. Phytanic acid metabolism in health and disease. *BBA-Mol. Cell Biol. L.* **2011**, *1811*, 498.

[34] W. Vetter, M. Schröder. Phytanic acid – a tetramethyl-branched fatty acid in food. *Lipid Tech.* **2011**, *23*, 175.

[35] T. McConnaughey and C. P. McRoy. Food-web structure and the fractionation of carbon isotopes in the Bering Sea. *Mar. Biol.* **1979**, *53*, 257

[36] M. A. Ramsay, K. A. Hobson. Polar bears make little use of terrestrial food webs: evidence from stable-carbon isotope analysis. *Oecologia* **1991**, *86*, 598.

[37] M. J. DeNiro, S. Epstein. Mechanism of carbon isotope fractionation associated with lipid synthesis. *Science* **1977**, *197*, 261.

Table 1. Stable carbon isotope values of extracted lipids (palmitic and stearic acid) using method 1(*) and method 2. Bulk collagen stable carbon and nitrogen isotopic composition of human and faunal remains.

Samples	Country	Site	Aprox. Age	Taxa	Inferred diet	Lipid conc. (ug/g^{-1})	$\delta^{13}C_{16:0}$	$\delta^{13}C_{18:0}$	$\delta^{13}C_{COLL}$‰	$\delta^{15}N_{COLL}$‰	Reference
CC10502	UK	Cnoc Coig	5500 cal BP	Pinnipedia	Marine	24.9	-28.1	-29.7	-11.6	+18.8	This study
CC10420	UK	Cnoc Coig	5500 cal BP	Pinnipedia	Marine	35.9	-27.5	-29.2	-11.8	+19.5	This study
CRB 21	Brazil	Jabuticabeira II	3000 cal BP	*Pogonias cromis*	Marine	4.9	-24.1	-24.7	-9.8	+12.6	Colonese et al.[23]
CRB 26	Brazil	Jabuticabeira II	3000 cal BP	Cetacea	Marine	7.7	-24.2	-25.9	-10.8	+16.1	Colonese et al.[23]
104A–L1.85	Brazil	Jabuticabeira II	3000 cal BP	*Homo sapiens*	Marine	9.2	-23.5	-23.3	-11.2	+18.8	Colonese et al.[23]
1.1/2–T10	Brazil	Jabuticabeira II	3000 cal BP	*Homo sapiens*	Marine	24.3	-20.1	-21.2	-11.2	+17.6	Colonese et al.[23]
OTD	Denmark	Havnø	5600 cal BP	*Homo sapiens*	Marine	8.3	-25.2	-25.5	-11.5	+13.3	This study
AEEE/OL1	Denmark	Bjørnsholm	4000 cal BP	*Halichoerus grypus*	Marine	20.6	-24.1	-24.2	-10.4	+13.8	Craig et al.[25]
CRB 34	Brazil	Moraes	6000 cal BP	*Agouti paca*	Terrestrial C_3	16.8	-27.9	-29.7	-20.8	+7.9	Colonese et al.[23]
CRB 36	Brazil	Moraes	6000 cal BP	*Alouatta* sp.	Terrestrial C_3	9.2	-27.5	-28.4	-21.5	+7.9	Colonese et al.[23]
37A	Brazil	Moraes	6000 cal BP	*Homo sapiens*	Terrestrial C_3	16.9	-27.3	-28.9	-21.0	+10.3	Colonese et al.[23]
9A	Brazil	Moraes	6000 cal BP	*Homo sapiens*	Terrestrial C_3	19.6	-27.6	-28.9	-20.8	+11.4	Colonese et al.[23]
HSU	Denmark	Havnø	Mesolithic/Neolithic	*Capreolus capreolus*	Terrestrial C_3	13.3	-29.2	-29.7	-22.9	+3.5	Gron[26]
ABM08*	Spain	Almacabra de Albarracín	10^{th}-12^{th}	*Homo sapiens*	Terrestrial C_3	52.9	-26.6	-27.0	-18.9	+11.9	Mundee[27]
ABM08	Spain	Almacabra de Albarracín	10^{th}-12^{th}	*Homo sapiens*	Terrestrial C_3	26.4	-25.6	-27.3	-18.9	+11.9	Mundee[27]
CC17050	UK	Cnoc Coig	5500	*Sus scrofa*	Terrestrial C_3	24.5	-28.0	-28.3	-21.0	+4.6	This study
GBC2*	Spain	Benipeixcar	15^{th}-16^{th}	*Bos taurus*	Terrestrial C_3	81.7	-27.7	-28.5	-20.1	+5.8	Alexander et al.[24]
GBC2	Spain	Benipeixcar	15^{th}-16^{th}	*Bos taurus*	Terrestrial C_3	31.3	-29.4	-31.5	-20.1	+5.8	Alexander et al.[24]
XPG	Denmark	Havnø	4000 cal BP	*Homo sapiens*	Terrestrial C_3/marine	7.0	-26.0	-26.7	-17.9	+12.5	This study
24A – L2	Brazil	Jabuticabeira II	3000 cal BP	*Homo sapiens*	Terrestrial C_3/marine	24.1	-24.8	-26.6	-16.2	+12.7	Colonese et al.[23]
17C – L2	Brazil	Jabuticabeira II	3000 cal BP	*Homo sapiens*	Terrestrial C_3/marine	59.8	-23.8	-27.1	-18.4	+11.1	Colonese et al.[23]
GBC4*	Spain	Benipeixcar	15^{th}-16^{th}	*Bos taurus*	Terrestrial C_4	201.1	-28.7	-28.9	-14.3	+7.4	Alexander et al.[24]
GBC4	Spain	Benipeixcar	15^{th}-16^{th}	*Bos taurus*	Terrestrial C_4	11.5	-25.3	-27.4	-14.3	+7.4	Alexander et al.[24]
GBM2404*	Spain	Benipeixcar	15^{th}-16^{th}	*Homo sapiens*	Terrestrial C_4	110.4	-26.7	-26.3	-16.4	+11.0	Alexander et al.[24]
GBM2404	Spain	Benipeixcar	15^{th}-16^{th}	*Homo sapiens*	Terrestrial C_4	30.9	-22.9	-25.1	-16.4	+11.0	Alexander et al.[24]

Supporting information 1 (SI1) - Composition of lipid extracts. Abbreviations: SFA, saturated fatty acid; MUFA, monounsaturated fatty acid; DUFA, diunsaturated fatty acid; br, branched fatty acid. Method 1 (*).

Samples	Taxa	Site	Lipids extracted
CC10502	Pinnipedia	Cnoc Coig, Oronsay	SFA(C14:0-18:0, C20:0, C22:0, C24:0, C26:0), MUFA(C16:1, C18:1, C20:1, C22:1), DUFA(C18:2), br (C15-17), cholesta-3,5-diene, phytanic, pristanic
CC10420	Pinnipedia	Cnoc Coig, Oronsay	SFA(C14:0-18:0, C20:0, C22:0-C24:0), MUFA(C16:1, C18:1, C24:1), DUFA(C16:2, C18:2), br (C15-17), cholesta-3,5-diene, pristanic
CRB21	*Pogonias cromis*	Jabuticabeira II	SFA(C14:0-18:0, C20:0, C22:0, C24:0), MUFA(C18:1, C24:1), br (C15-17), phytanic, pristanic
CRB26	Cetacea	Jabuticabeira II	SFA(C14:0-18:0, C20:0, C22:0-C24:0), MUFA(C18:1), br (C15-18), phytanic, pristanic
104A–L1.85	*Homo sapiens*	Jabuticabeira II	SFA(C14:0-18:0, C20:0, C22:0, C24:0), br (C15-17), phytanic, pristanic
1.1/2–T10	*Homo sapiens*	Jabuticabeira II	SFA(C12:0-20:0, C22:0-C24:0), MUFA(C16:1, C18:1), br (C15-17), cholesta-3,5-diene, phytanic, pristanic
OTD	*Homo sapiens*	Havnø	SFA(C14:0-18:0, C20:0, C22:0-C24:0), MUFA(C16:1, C18:1, C24:1), br (C15-17), cholesta-3,5-diene, phytanic, pristanic
AEEE/OL1	Bjørnsholm	Bjørnsholm	SFA(C14:0-24:0, C26:0), MUFA(C16:1, C18:1, C24:1), DUFA(C18:2), br (C15-18), cholesta-3,5-diene, cholest-5-ene- (3-methoxy), pristanic
CRB34	*Agouti paca*	Moraes	SFA(C14:0-18:0, C20:0, C22:0, C24:0), MUFA(C16:1, C18:1, C24:1), br (C15-17), phytanic, pristanic
CRB36	*Alouatta* sp.	Moraes	SFA(C14:0-18:0, C20:0, C22:0-C24:0), MUFA(C16:1, C18:1, C24:1), br (C15-18), pristanic
37A	*Homo sapiens*	Moraes	SFA(C12:0-18:0, C20:0, C22:0,C24:0), MUFA(C16:1, C18:1, C22:1), br (C15-17), DA(C13), phytanic, pristanic
9A	*Homo sapiens*	Moraes	SFA(C12:0-18:0, C20:0, C22:0,C24:0), MUFA(C16:1, C18:1, C22:1, C24:1), br (C15, 16), DA(C9), cholesta-3,5-diene, phytanic, pristanic
HSU	*Capreolus capreolus*	Havnø	SFA(C14:0-18:0, C20:0, C22:0-C24:0), MUFA(C16:1, C18:1, C24:1), DUFA(C18:2), br (C15-18), cholesta-3,5-diene, cholest-5-ene- (3-methoxy), phytanic, pristanic
ABM08*	*Homo sapiens*	Almacabra	SFA(C14:0-18:0, C20:0, C22:0-C24:0), MUFA(C16:1, C18:1, C22:1, C24:1), DUFA(C18:2), br (C15-17), cholesta-3,5-diene, cholest-5-ene- (3-methoxy), cholesterol, phytanic
ABM08	*Homo sapiens*	Almacabra	SFA(C14:0-18:0, C20:0, C22:0-C24:0), MUFA(C16:1, C18:1, C22:1, C24:1), DUFA(C18:2), br (C15-17), cholesta-3,5-diene, cholest-5-ene- (3-methoxy), cholesterol, phytanic
CC17050	*Sus scrofa*	Cnoc Coig, Oronsay	SFA(C14:0-18:0, C20:0, C22:0-C24:0), MUFA(C16:1, C18:1), DUFA(C18:2), br br (C15-17), cholesta-3,5-diene, phytanic, pristanic
GBC2*	*Bos taurus*	Alquería de Benipeixcar	SFA(C12:0, C14:0-18:0, C20:0, C22:0-C24:0), MUFA(C16:1, C18:1, C22:1, C24:1), DUFA(C18:2), br (C15-18), cholesta-3,5-diene, cholest-5-ene- (3-methoxy), cholesterol, phytanic, pristanic
GBC2	*Bos taurus*	Alquería de Benipeixcar	SFA(C14:0-18:0, C20:0, C22:0-C24:0), MUFA(C16:1, C18:1, C22:1, C24:1), DUFA(C18:2), br (C15-18), cholesta-3,5-diene, cholest-5-ene- (3-methoxy), cholesterol, phytanic, pristanic
XPG	*Homo sapiens*	Havnø	SFA(C14:0-18:0, C20:0, C22:0-C24:0), MUFA(C16:1, C18:1, C24:1), br (C15-17),), cholesta-3,5-diene
24A-L2	*Homo sapiens*	Jabuticabeira II	SFA(C14:0-18:0, C20:0, C22:0-C24:0), MUFA(C16:1, C18:1, C24:1), DUFA(C18:2), br (C15-17), cholesta-3,5-diene, cholest-5-ene- (3-methoxy), phytanic, pristanic
17C-L2	*Homo sapiens*	Jabuticabeira II	SFA(C14:0-18:0, C20:0, C22:0-C24:0), MUFA(C16:1, C18:1, C24:1), br (C15-17),), cholesta-3,5-diene, cholest-5-ene- (3-methoxy)
GBC4*	*Bos taurus*	Alquería de Benipeixcar	SFA(C14:0-18:0, C20:0, C22:0,C24:0), MUFA(C16:1, C18:1, C24:1), DUFA(C18:2), br (C15-18), cholesta-3,5-diene, cholest-5-ene- (3-methoxy), cholesterol, phytanic, pristanic
GBC4	*Bos taurus*	Alquería de Benipeixcar	SFA(C15:0-18:0, C20:0, C22:0,C24:0), MUFA(C16:1, C18:1, C24:1), DUFA(C18:2), br (C15-18), cholesta-3,5-diene, cholest-5-ene- (3-methoxy), cholesterol, phytanic, pristanic
GBM24/04	*Homo sapiens*	Benipeixcar	SFA(C12:0, C14:0-18:0, C20:0, C22:0, C24:0), MUFA(C18:1, C20:1, C22:1, C24:1), DUFA(C18:2), br (C15, 16), cholesta-3,5-diene, cholest-5-ene- (3-methoxy), cholesterol, pristanic
GBM2404*	*Homo sapiens*	Benipeixcar	SFA(C12:0, C14:0-18:0, C20:0, C22:0, C24:0), MUFA(C18:1, C20:1, C22:1, C24:1), DUFA(C18:2), br (C15, 16), cholesta-3,5-diene, cholest-5-ene- (3-methoxy), cholesterol, pristanic

Figure captions

Fig. 1. Bulk collagen $\delta^{13}C$ and $\delta^{15}N$ values for the humans and faunal samples in this study. For details on assigning the samples by diet see Table 1 and references therein.

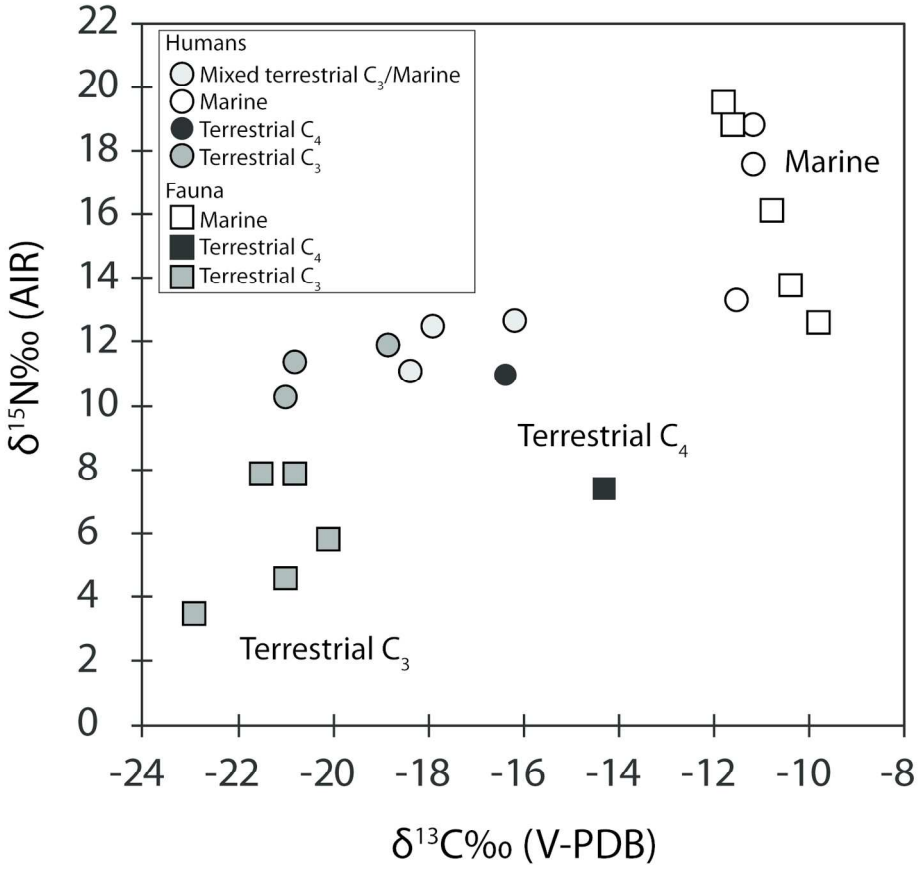
Fig. 2. Comparison of partial gas chromatogram of a bovine (GBC2) bone lipid extract using method 1 (A) and 2 (B). Abbreviations: $C_{n:x}$ indicates a fatty acid with n carbon atoms and x double bond; P indicates contaminant phthalate; IS indicates internal standard.

Fig. 3. Comparison of stable carbon isotope composition of palmitic and stearic fatty acid from acidified methanol (method 1; A) and sequential solvent- acidified methanol extraction (method 2; B) of bovine (GBC2, GBC4) and human (ABM08, GBM24/04) bones.

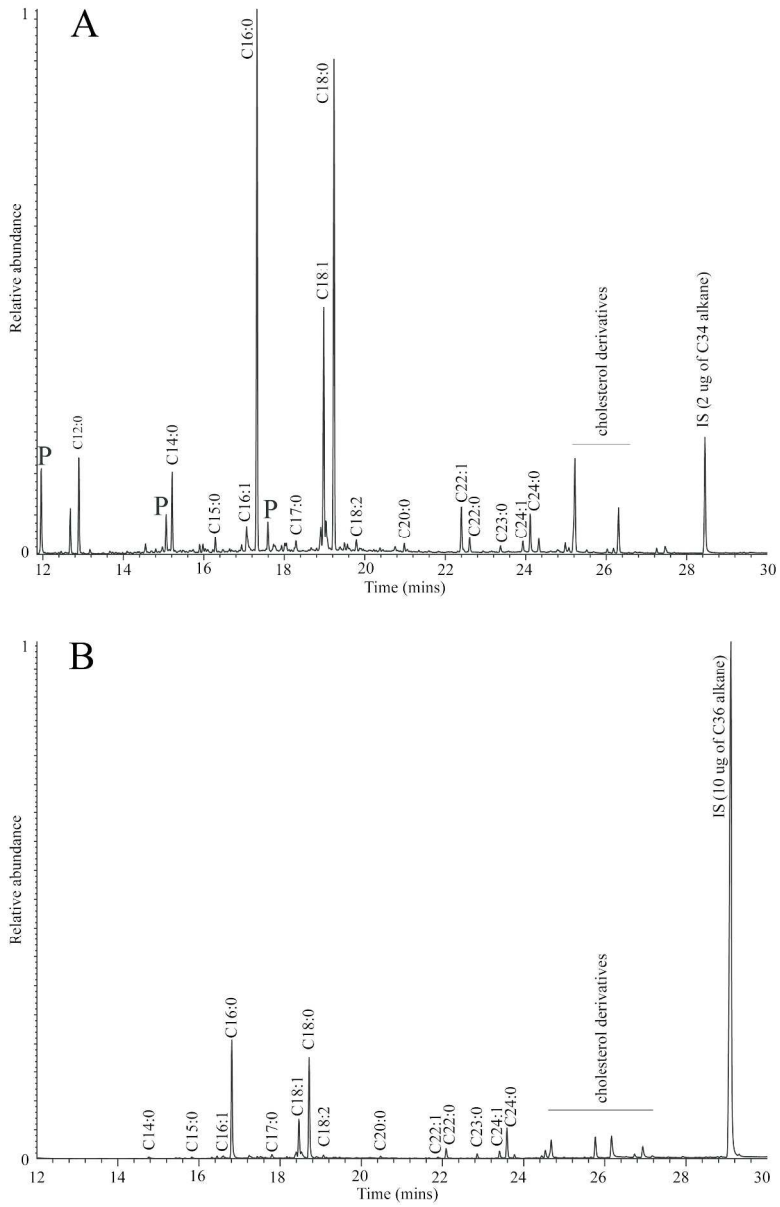
Fig. 4. Partial gas chromatogram of a human (1.1/2-T10) bone lipid extract. Inset shows partial mass spectrum of phytanic acid characterized by *m/z* ions 101, 171, and 326. Abbreviations: $C_{n:x}$ indicates fatty acid with n carbon atoms and x double bonds; br represents branched fatty acid with n carbon atoms; IS indicates internal standard (2 µg of tetratriacontane).

Fig. 5. Plot of $\delta^{13}C$ values of $C_{16:0}$ and $C_{18:0}$ fatty acids from all samples analysed in this study extracted with method 2.

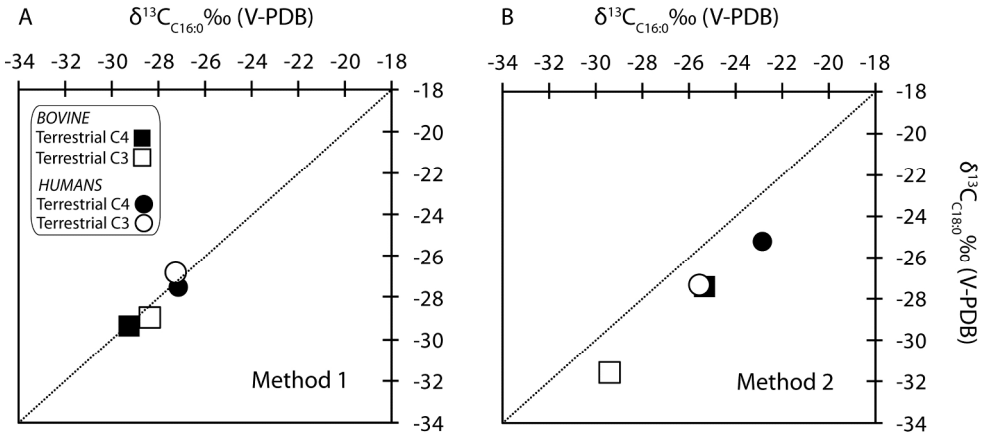
Fig. 6. Offset between $\delta^{13}C$ values of $C_{16:0}$ and $C_{18:0}$ fatty acids and collagen ($\Delta^{13}C_{FA\text{-}Coll}$).



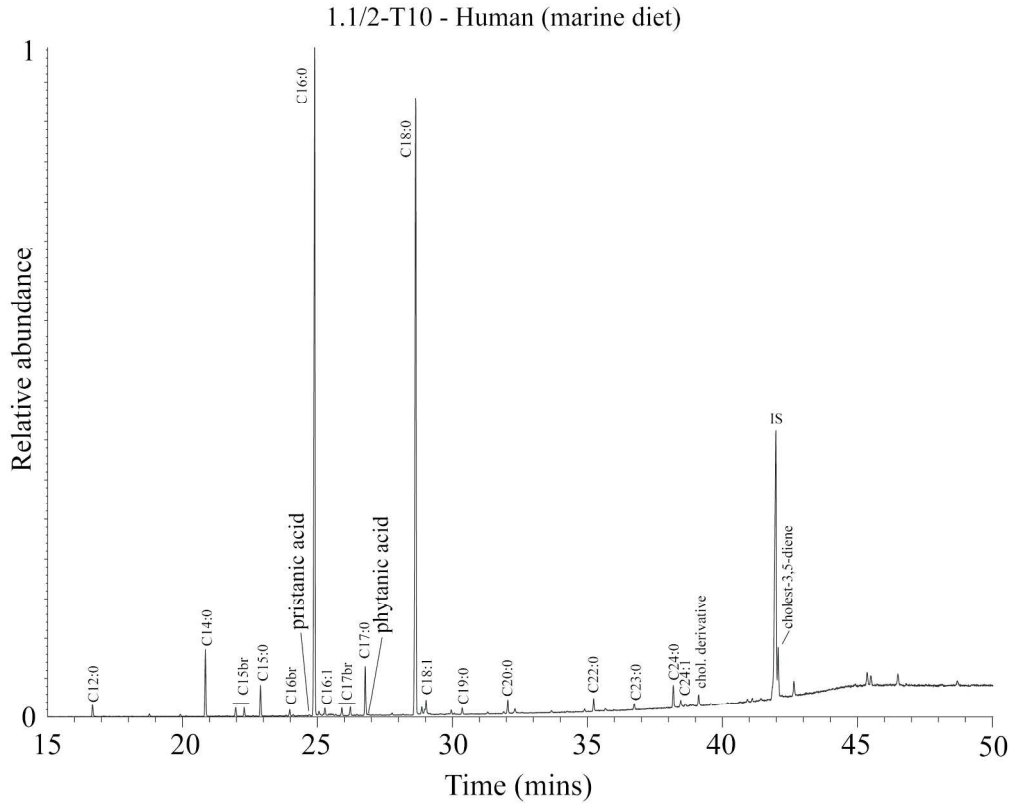
149x131mm (300 x 300 DPI)



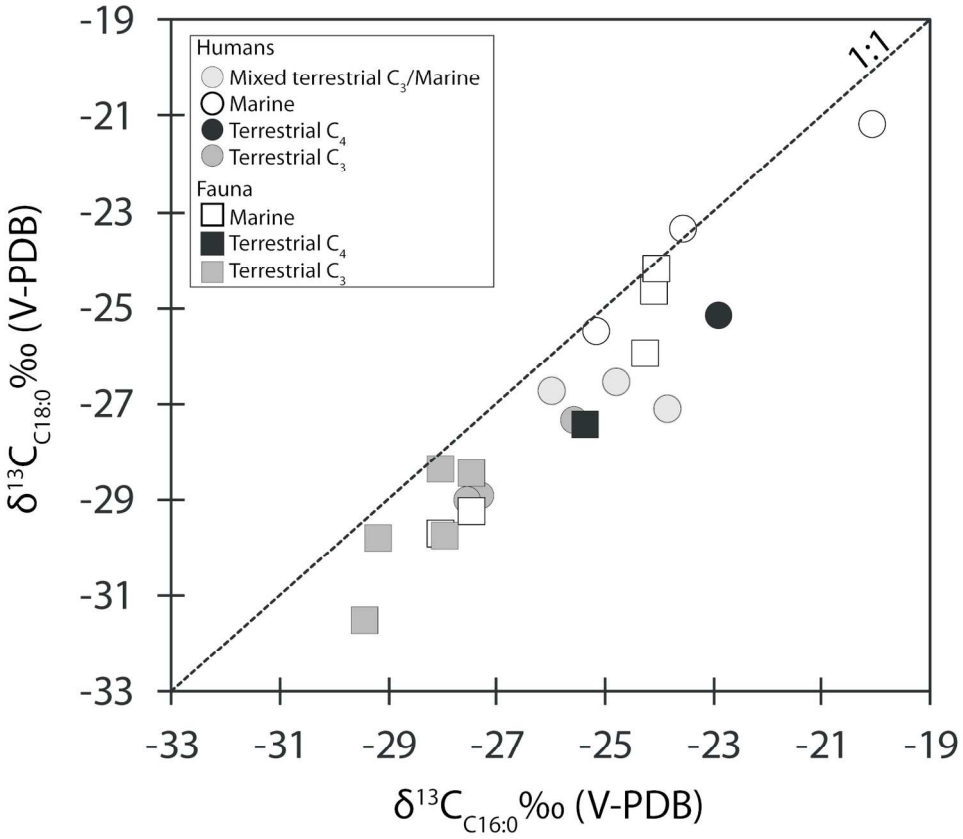
197x307mm (300 x 300 DPI)



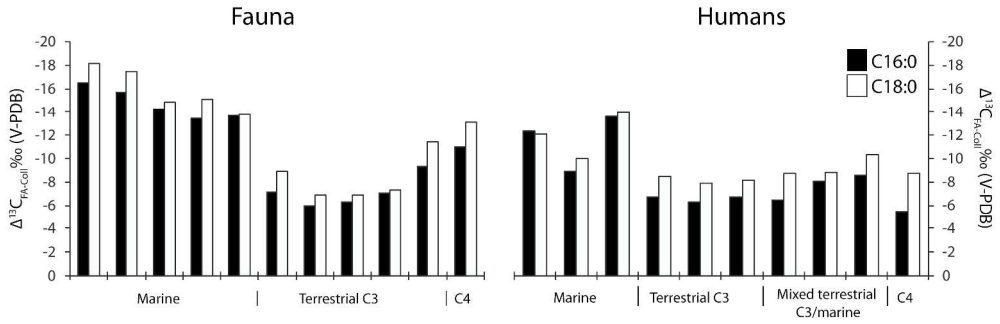
204x94mm (300 x 300 DPI)



209x167mm (300 x 300 DPI)



156x134mm (300 x 300 DPI)



358x113mm (300 x 300 DPI)