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δ^{13}C and δ^{15}N studies of prehistoric diet
Recent applications and developments

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The analysis of stable carbon and nitrogen isotopes in studies of prehistoric diet is described and some recent applications and developments reviewed. It is concluded that this has now become an established method, and a very powerful tool when studying several aspects of prehistoric society, such as mobility, dietary transitions, gender relations, social complexity, geographical adaptations, etc. Future prospects include the combined use of molecular sex determinations and stable isotopes to study gender differences within and between populations.

Introduction

Prehistoric diet can be inferred from several different kinds of archaeological evidence, including artefacts, structures such as hearths, faunal and botanical remains, art, impressions in pottery, food residues in vessels, coproliths, etc. These remains produce either qualitative information on what was (probably) eaten – in which case the inclusion of e.g. plant foods or fish, tends to be underestimated – or evidence of single meals – which says little about the diet on a long-term perspective. Furthermore, some remains are preserved only under special conditions. There is, however, one category of remains that goes beyond these limitations, namely human bone, which is often present and relatively well preserved, and which can produce quantitative information on the long-term diet of individuals and populations with the use of bone chemistry.

This paper will review some recently published studies which employ a particular bone chemistry method, viz. stable carbon and nitrogen isotope analysis, in investigations of prehistoric diet. After a brief introduction to the method, the main focus will be on what kinds of archaeological issues have been addressed, and on some methodological issues, concluding with some future prospects.

Method

Carbon and nitrogen each have two naturally occuring stable isotopes: ^{12}C and ^{14}N – which make up some 99% – and ^{13}C and ^{15}N. In contrast to radioisotopes, such as ^{14}C, stable isotopes do not decay. They do, on the other hand, fractionate during physical, geological and biological processes, i.e. the composition of isotopes is changed (Boutton 1991b). The resulting isotope ratios differ between e.g. terrestrial and marine resources (carbon), and between trophic levels (nitrogen).

The portion of ^{13}C or ^{15}N is expressed as a ratio relative to a standard, since the absolute amount, and therefore the variation between samples, is so minute. This ratio, expressed as δ^{13}C or δ^{15}N, is calculated as

$$\frac{R_{\text{sample}}-R_{\text{standard}}}{R_{\text{standard}}} \times 1000\ (‰)$$

where R is the ^{13}C/^{12}C or ^{15}N/^{14}N ratio respectively. Positive values of a sample imply a higher ratio than the standard, whereas negative values imply a lower ratio (Boutton 1991b). The standard for carbon, PDB (Pee Dee Belemnite), is a marine limestone fossil very rich in ^{13}C, which results in all measured values on e.g. bone collagen being negative. The standard for nitrogen is AIR (Ambient Inhalable Reservoire), corresponding to N_2 in the atmosphere.

Bone consists of inorganic components, i.e. hydroxyapatite and carbonate, and of organic components, of which some 90% is collagen, a protein (Hedges 1992). The earliest measurements of carbon isotopes on bone were ^{14}C-measurements performed on whole bone, including the inorganic fraction, which resulted in erroneous dates and a long-lasting distrust in isotope analyses of bone (Taylor 1992). The inorganic constituents of bone could incorporate carbonates from the surrounding soil and could therefore produce dates of both younger and older age than the bone itself. This kind of contamination confuses analysis of stable isotopes as well, and therefore is the organic fraction, of which c. 90% is collagen, in most cases preferred for isotope analyses of bone (but see below; for a discussion on the general applicability of the method, see e.g. Parkington 1991; Sealy & van der Merwe 1992). Cremation destroys, or irreversably alters, the collagen, so only unburned bones should be used for analysis (DeNiro et al. 1985).

Before analysis can take place, the sampled bone must be ground, and collagen isolated from the bone matrix (DeNiro & Weiner 1988; Boutton 1991; Hedges 1992). Its carbon and nitrogen content is thereafter converted into CO_2 and N_2, and isotopic composition measured by means of mass spectrometry. In order to estimate the quality of the extracted collagen, to detect any diagenetic change or alteration due to extraction procedures, and to assess reliability of the produced value, collagen yield and the C/N (carbon/nitrogen) ratio is always recorded, and samples with unacceptable deviations excluded (DeNiro 1985; DeNiro et al. 1985). The amino-acid composition could also be determined to dectect alterations (DeNiro & Weiner 1988).

The δ^{13}C and δ^{15}N of collagen mainly reflects protein intake. This is not surprising regarding nitrogen, where the amino acids of protein are the only source of nitrogen. As for carbon, experiments have shown that carbon from the ingested protein is routed to collagen, whereas δ^{13}C of carbonate reflects the whole diet (i.e. carbohydrates, lipids, proteins) (Gearing 1991; Ambrose & Norr 1993). The collagen δ^{13}C value is enriched by some 5‰ compared to ingested protein δ^{13}C (DeNiro 1985). This enrichment factor varies for different tissues and even for different compounds in the tissue; consequently it is very important that any lipids or carbonates are removed from the collagen prior to analysis, since they will otherwise distort δ^{13}C values. Lidén et al. (1995), showed that the use of NaOH (cf. (Ambrose & Norr 1993) is not sufficient to remove lipids and, furthermore, it alters the amino-acid composition. The authors therefore suggested an alternative method, including chloroform treatment to remove lipids, and ultrafiltration of the sample.

A basic d^{13}C difference exploited in archaeological dietary studies is that between terrestrial and marine food sources. A 100% marine food intake will produce a certain δ^{13}C signature, referred to as the marine end-value. This δ^{13}C value is less negative than the terrestrial end-value, indicating a higher frequency of ^{13}C. The range between end-values differs somewhat for different regions, but can be measured and estimated (see e.g. (van Klinken et al. 1994; Lidén & Nelson 1994; Lõugas et al. in press). Another important δ^{13}C difference is that between C_3 and C_4 plants. C_3 plants, which constitute most terrestrial plant species, and C_4 plants, species such as maize, millet, and sorghum (which grow in warm and arid environments), have different photosynthetic pathways and because of this incorporate different ratios of ^{13}C/^{12}C from the atmosphere (Boutton 1991a).

The δ^{15}N value increases c. 3‰ per trophic level. This enrichment factor can be used to establish position in the food web, e.g. to distinguish between plant foods and herbivores. Since marine food chains are generally longer than terrestrial chains, marine top predators have higher δ^{15}N values than terrestrial ones.

Stable isotope analysis of a population produces information not only on portions of different food classes in the diet, but also gives a measure of how homogeneous diet is throughout the population. For a population with homogeneous diet, the expected standard deviation of δ^{13}C is around 0.3 (Lovell et al. 1986). A higher standard deviation thus indicates differential food intake, in which case it is interesting to study individuals and try to correlate δ^{13}C with parameters such as age, sex, rank, etc. Bone growth, and accordingly turnover rates, varies for different parts of the skeleton, which should also be taken into account.

Applications

The earliest study of prehistoric diet employing stable isotope analysis, was published in 1977 (DeNiro 1985). Margaret Schoeninger and Katherine Moore made a comprehensive study of stable isotope studies in archaeology in 1992 (Schoeninger & Moore 1992), covering some 200 studies, published basically up to 1991. Since then, an increased interest in the potential of stable-istope studies can be traced in the archaeological community, reflecting the improved methods and enhanced knowledge of the mechanisms of stable-isotope fractionation.

Recent archaeological diet studies using stable isotope analyses have seen a number of applications, focusing on mobility (e.g. Pate 1995), dietary change (e.g. Larsen et al. 1992; White & Schwarcz 1994), social complexity (e.g. Lidén 1995a; Ubelaker et al. 1995), gender (e.g. Hastorf 1991; Sealy et al. 1992), geographical adaptation (e.g. Aufderheide et al. 1993; McGovern-Wilson & Quinn 1996), etc. Many methodological issues have also been addressed in that connection, e.g. diagenetic alteration (e.g. Bocherens et al. 1995), extraction problems (e.g. Lidén et al. 1995; Tuross et al. 1994), non-collagenous samples (e.g. Quade et al. 1995), reliability (e.g. Parkington 1991; Sealy & van der Merwe 1992), etc.

Food consumption

An obvious question to pose in connection with stable isotope analysis is whether a population utilized a specific food resource, and if they did, to what extent. This kind of interpretation is of course dependent on what food resources were available in the region, and the possibility for stable isotopes to distinguish between them (e.g. maize vs. other plants; marine vs. terrestrial prey). In this connection it is crucial to perform baseline studies, i.e. to determine the isotope signatures of accesible prey and plant resources, and particularly to establish isotopic end-values.

McGovern-Wilson and Quinn (1996) have recently published a dietary analysis of ten individuals found on an island in the Pacific, addressing issues of relative dependence on terrestrial, lagoonal, reef, and open-sea resources, compared to indications in the archaeological record, and of differences according to age, sex, or status. To some extent also temporal consistency in dietary proportions was studied. The $\delta^{13}C$ and $\delta^{15}N$ values indicated a more significant marine, in particular open-sea, contribution to diet than suggested by faunal analysis.

Lagoonal contribution to the diet was also studied by Lidén (1996), where $\delta^{13}C$, $\delta^{15}N$, copper, and zinc values indicated a specialized utilization of lagoonal resources among Neolithic and Mesolithic populations on Öland in the Baltic Sea, and in Scania, southern Sweden. Stable isotope analyses alone indicated a mixture of terrestrial and marine protein, but trace element analyses, producing very high copper values, pointed to a high intake of crustaceans or insects. Taking into account the geographical location at lagoons, Lidén suggested that a specific lagoon utilization was practised, which might have included deliberate fertilizing by garbage disposal in the water to increase productivity (cf. Arrhenius 1987; 1990).

Dietary patterns among three Neolithic cultures of the Baikal region were studied by Lam (1994). Earlier research had regarded the cultures as roughly contemporaneous, but radiocarbon dating proved one of the cultures, Kitoi, to be considerably older than the others. Lam therefore wanted to investigate whether the generally accepted view of subsistence and diet of the different cultures also had to be revised. Lake Baikal is a closed freshwater ecosystem with only C3 plants, thus making it difficult to assess dietary patterns from $\delta^{13}C$ analyses alone. Bones from the Kitoi culture showed slightly higher $\delta^{15}N$ values, and somewhat less negative $\delta^{13}C$ values as compared to the other cultures, but because of lack of sufficient food-resource data, Lam failed to explain the differences in terms of e.g. aquatic/terrestrial diet. Lam did not specify what fraction of the bone was used for analysis, and referred only to an unpublished manuscript for method description. Analyses were performed on different parts of the skeleton, which might explain the relatively high standard deviations, since different bones have different turnover rates (Ambrose & Norr 1993).

The Baltic Sea has a complex natural history, where salinity, and thus $\delta^{13}C$, has varied considerably over time. Lõugas et al. (in press) analysed human bones and seal bones from eight Neolithic and Mesolithic sites at the Estonian coast in the northeastern Baltic. Seal is a top predator, feeding exclusively on marine prey, which is why its $\delta^{13}C$ is used to set the isotopic marine end-value of a site. Radiocarbon dating and faunal analysis was also performed. Results from the analysis indicated that the Mesolithic people were dependent mainly on terrestrial resources, but a shift towards utilization of more marine resources on the islands during the Neolithic could be traced. The authors interpret the Mesolithic/Early Neolithic subsistence strategy in Estonia as an alternative, rather than a predecessor, to the traditional Neolithic agro-pastoralism.

Diet transitions

Several authors have studied diet transitions, particularly with emphasis on *why* dietary change takes place. Lidén (1995b), focusing on the Mesolithic–Neolithic transition in the Baltic area, listed a number of factors considered to induce dietary change, e.g. new technology, introduction of new species, environmental or genetic change, social competition, population growth, etc. Based on evidence from stable carbon and nitrogen isotope, and trace element analyses of several populations, Lidén concluded that diet was geographically, rather than temporally, or culturally determined. She was able to demonstrate that, contrary to what has earlier been suggested, the contribution of cereals to Neolithic diet was hardly detectable. To the extent one could talk of agriculture, pastoralism would be a more relevant term. No overall picture of the Neolithic could be traced; rather different populations adjusted to the available resources, involving continued extensive utilization of marine resource in some parts of the Baltic region.

Quite contrary conclusions were drawn when stable carbon and nitrogen isotope analyses were applied to bone collagen from individuals of the Portuguese Mesolithic and Neolithic by Lubell et al. (1994). Results indicated a marked change of diet at the Mesolithic–Neolithic transition, c. 7000 BP, supported by dental tooth analyses of wear and pathology. Twenty-three samples from three Mesolithic and seven Neolithic sites were subject to analyses. Neolithic individuals exhibited uniform, low values of both $\delta^{13}C$ and $\delta^{15}N$, whereas Mesolithic values were a little more dispersed and relatively higher ($\delta^{13}C$ less negative, $\delta^{15}N$ more positive). Lubell et al. concluded that Mesolithic people consumed a mixture of marine and terrestrial foods, while the Neolithic diet consisted of only terrestrial foods. The lack of dispersal of $\delta^{15}N$ values among the Mesolithic individuals was interpreted as dietary conservatism. According to Lubell et al. the introduction of a Neolithic economy in Portugal originated in the Mesolithic, as an "adjustment to problems of food supply", i.e. nutritional stress.

The hypothesis that nutritional stress induced the Neolithic transition was also investigated by Lidén et al. (in press) on an Ålandic population of the (subneolithic) Pitted Ware Culture. This sedentary population, living in the Baltic archipelago, was subject to osteological and stable carbon isotope analyses, determining diet and detecting any pathological traits indicative of nutritional stress. Isotope values showed that the protein of the diet was of almost entirely marine origin, and, judging by the standard deviation, the diet was homogeneous throughout the population. Palaeopathological results indicated that a few slightly nutritionally stressed individuals did occur, though not to such an extent as to explain a transition to farming practices instead of utilization of the abundant marine resources.

Pleistocene or older bone

Some recent articles/papers are dedicated to Pleistocene or even older fossil bones. Among those are Fizet et al. (1995), and Bocherens et al. (1991), who analysed bones and teeth of 40,000–45,000 year-old mammals, including Neanderthal humans, from a cave in France, concluding after extensive testing that isotopic signals from the collagen were reliable, and that the collagen was not subject to diagenesis, despite its age. Stable isotope composition of bones from large herbivores as well as carnivores found in the cave were analysed, showing how ^{13}C and ^{15}N content differ according to position in the food web. The diet of Neanderthal man was thereby inferred, appearing to be mainly carnivorous. This stresses the importance of performing analyses on accessible prey for comparison with values of humans. Teeth from reindeers proved to have higher δ^{15}N values than bone of the same species, as a result of lactation during tooth growth; this enrichment is commonly referred to as the nursing effect.

The method has also been applied to 15 million-year-old archaeological remains from Turkey. Quade et al. (1995) performed stable carbon (and oxygen) isotope analyses of mammal herbivores, using the inorganic fraction (apatite) of fossil tooth enamel in order to reconstruct palaeodiet and environment. Results proved reliable and showed a wide span of signatures within the C_3-plant range, varying according to species. Variation in δ^{13}C signatures was interpreted as reflecting different ecological settings for the plants consumed, i.e. open country, deep forest, etc.

Earlier studies of the reliability of carbon isotope values from tooth enamel apatite, as compared to bone apatite, have been carried out by e.g. Paul Koch (Craig 1992), who showed that while bone apatite values are notoriously unreliable, tooth enamel apatite could preserve its isotopic signal over many millions of years.

The nursing effect

The nursing effect, the fact that breastfeeding babies (who "prey" on their mothers) get enriched in δ^{15}N by some three per mil in relation to their mothers, has been studied by Noreen Tuross and Marilyn Fogel (Craig 1992; Fogel et al. 1989). When babies are weaned, i.e. given alternate food, a drop in the δ^{15}N value can be traced. Tuross and Fogel, in collaboration with physical anthropologist Douglas Owsley, were thereby able to tell at what age babies in two native American archaeological populations were weaned. In their study, no distinction in weaning age between the hunter-gatherer and horticultural populations could be traced (Fogel et al. 1989).

Also Katzenberg et al. (Katzenberg 1993; Katzenberg et al. 1993) found evidence of the nursing effect in a protohistoric Amerindian population of maize horticulturalists. Nitrogen values were 2–3 % higher for infants, with the exceptions of two neonatals. The latter may have died prior to, or near, the time of birth, before the shift in nitrogen values took place, or maybe could not be breastfed. Carbon values decreased significantly with age. According to ethnographical sources, infants were weaned on maize gruel, which could account for the high δ^{13}C values. Because of the deviating signatures of infants, Katzenberg et al. (1993) warn against using those bones to characterize the diet of the whole population.

Material other than bone

Hair is usually not very abundant in the archaeological record, but where present it could be used for stable isotope analysis to study short-term diet. Hair grows some 1–1.5 cm per month and thus represents a fairly recent food intake; the closer to the scalp, the more recent. Hair consists of keratin, a protein, and has proved resistant to remodeling/diagenetic change. In studies on contemporary populations bone is, for obvious reasons, not available, but hair (or nails) is a viable alternative material for stable isotope analysis. Because of the short-term perspective, hair analysis is suitable for investigating e.g. seasonal crop rotation, or mobility patterns (inland–coast or vice versa).

Aufderheide et al. (1994) analysed eleven spontaneously mummified individuals of the Alto Ramirez Culture in northern Chile, dating to c. 1000 BC. This cultural group, originating in the highlands, is traditionally characterized by agriculture (i.e. horticulturalism and pastoralism), but the cemetery was situated on the coast, and it was therefore interesting to determine diet and thereby subsistence. Isotopic analyses of bone, muscle, and hair revealed an almost purely marine diet. Hair produced the most reliable values, since both bone and muscle seemed to have undergone diagenesis. Dental analyses, as well as artefacts associated with marine subsistence, corroborated this interpretation, demonstrating that this adaptation was geographically, rather than culturally, induced.

Modern populations in sudanese Nubia practise seasonal crop scheduling, cultivating C_3 plants (wheat, barley, and most fruits and vegetables) in the winter, and C_4 plants (sorghum and millet) in the summer. To investigate whether this was the case also in the first century AD, White (1993) performed δ^{13}C analyses on hair from 14 Nubian mummies, representing two subsequent time periods, thus benefitting from the fact that different segments of a hair strand reflect different times of growth. The study demonstrated how δ^{13}C values shifted according to season, indicating a considerable rise in C_4 plant consumption during the summer. The season of death was also established, exposing a mortality pattern similar to those of modern populations in this area, with a peak in July/August, because of extremely high temperatures and nutritional stress.

An investigation of hair isotope values ($\delta^{13}C$, $\delta^{15}N$) as compared to documented and estimated diet, was performed by Yoshinaga et al. (1996) on a contemporary population at Papua New Guinea. The authors tested the reliability of isotope anlaysis on hair, particularly comparing isotopic composition of hair and of actual food items (hair–diet enrichment), and examined the relationship between ecological setting vs. food and nutrition. Samples from adult males from four villages, representing four ecological settings, were analysed. The fractionation factor, i.e. the enrichment of ^{13}C and ^{15}N in hair as compared with diet, varied between villages and also deviated somewhat from previously reported values. According to Yoshinaga et al. this could be explained by the methods of estimating diet, and by seasonal variation, since neither diet, nor time of formation of hair, was sufficiently controlled. Deviating values from one village could not be accounted for by these or other known factors, and remained unexplained.

Differences within populations

Pate (1995) used stable carbon isotope signals to study mobility in a prehistoric Aboriginal population from an inland riverine site in southern Australia. Non-local marine and/or C_4-based terrestrial components in the diet, as revealed by $\delta^{13}C$, would imply mobility and utilization of adjacent coastal and/or interior zones. Four individuals in a population of 45 showed signs of mixed diet, but Pate was not able to distinguish between marine and C_4-based diets, and will therefore employ $\delta^{15}N$ analyses in a future study.

In an investigation of two Swedish megalith populations, Lidén (1995a) studied the supposed connection between social complexity and subsistence. If the erection of megaliths, implying a greater social complexity, conincided with the introduction of horticulturalism, one would expect that to show in the stable isotope values.

Although $\delta^{13}C$ values were mainly terrestrial, $\delta^{15}N$ values were much higher than expected for people relying heavily on plant foods. Instead, they indicated the keeping of cattle and sheep/goat, as supported by faunal remains. Based on these results, the author questioned the view that social complexity in the Neolithic originated from cereal production. Rather, she put forward sedentism as a more important determining factor.

The recovery of six shaft tombs from the fourth century in highland Ecuador, comprising the remains of nine high-status individuals accompanied by human sacrifices, offered the opportunity for Ubelaker et al. (1995) to study status differences in diet. The age and, where possible, the sex of the nine high-status and twenty-three low-status individuals were morphologically determined, and stable carbon and nitrogen isotope values of collagen measured. Sixteenth century ethnological sources had indicated that access to *meat* might have been differentiated, but no such evidence was produced by isotopic data. On the contrary, there were no significant differences in $\delta^{15}N$ between the two status groups (i.e. no difference in trophic level). $\delta^{13}C$ on the other hand, differed significantly, suggesting a greater maize intake by the high-status group, possibly in the form of beer (*chica*). No correlation between age and diet was found, neither any gender differences, although not all individuals could be sexed.

As opposed to this, Hastorf (1991) found clear gender differences in another Andean population, dating some 1000 years later, living during Inka control. From carbon and nitrogen isotope data it was evident that women and men had differential access to certain foodstuffs, expecially maize. Moreover, nitrogen values were higher for men, suggesting higher meat consumption. A population from the period immediately preceding the Inka hegemony, exhibited no such difference, although conclusions were somewhat uncertain because of the limited number of individuals. Hastorf interprets the gender differences as a result of the change in political organization induced by the Inka.

Sealy et al. (1992) found marked $\delta^{13}C$ differences between males and females in 74 Stone Age individuals buried in shell middens and sand dunes at the south-western Cape coast in South Africa. The skeletons, which were not recovered under controlled circumstances, ranged from c. 6000 BP to around 1000 BP, and can hardly be considered one population in a regular sense. Most individuals, however, dated to the third and second millennia BP – an important period in this region, since pastoralism first appeared at c. 2000 BP.

Skeletons pre-dating 2000 BP accordingly had more enriched $\delta^{13}C$ signatures, revealing a high consumption of marine foodstuffs, whereas those post-dating 2000 BP were more depleted in $\delta^{13}C$, indicating a larger portion of terrestrial protein sources. Food waste at contemporaneous settlement sites in this region confirm this pattern, with shell middens in the former period, and bones of terrestrial animals in the latter.

What was interesting was that while male signatures followed this trend, there was no such trend for females. Men, in general, had more marine signatures than women, moving towards more terrestrial signatures over time. Women's signatures, on the other hand, seemed to have changed less during the course of time. A further study including $\delta^{15}N$ analyses would reveal more about these gender-related differences.

Conclusion

To conclude, 20 years of archaeological $\delta^{13}C$ and $\delta^{15}N$ analyses have proved the usefulness of this well-founded, independent, and reliable method, which adds substantially to our knowledge of prehistoric diet and society.

I have here been trying to demonstrate the potential and wide field of application for stable isotope analyses in archaeology. The increased use and continuous development of the method promises many new interesting studies in the future, with approaches covering very wide areas of archaeological issues.

As demonstrated by the above review, questions of mere diet are not the only issues that can be addressed using stable isotope analysis. Since diet is such an important aspect of society, the method is also a means of investigating social complexity and mobility patterns, for example.

It is clear that combined $\delta^{13}C$ and $\delta^{15}N$ analyses produce much more information than either of them separately, but to interpret correctly the stable isotope data, it is crucial to perform baseline studies and establish endvalues. The method is particularly powerful in detecting dietary differences, exposed as variation of isotopic signatures within and between populations, as well as geographical, cultural, and temporal variation. Lack of variation within a population demonstrates a homogeneous diet.

From a Scandinavian point of view, the Neolithic Funnel-Beaker, Battle-Axe, and Pitted-Ware Cultures offer great opportunities to apply the stable isotope technique. There are many hypotheses regarding the social organizations of these "cultures" (e.g. Malmer 1975; Knutsson 1995), many of which can be tested isotopically. These hypotheses include questions of mobility/sedentism, hereditary/achieved rank, and weaning age. Furthermore, gender differences, exposed as differential access to certain protein sources, are easily detected, provided reliable sex identifications can be performed.

The use of molecular sex identification opens up new possibilities for future isotopic studies of gender. The presence of specific skeletal parts for morphological sex identification is no longer crucial, and even children can be reliably sexed. Furthermore, a recent study employing molecular sex identifications on individuals from the Gotlandic Pitted-Ware site Ajvide, Sweden (Götherström et al. in press) indicates that some Neolithic "males" may in fact be females, which have been erroneously identified because of their robustness.

A broad investigation employing stable isotope analyses, trace-element analyses, and molecular sex identifications, covering populations representing several sites from all three Neolithic "cultures", would reveal differences within populations, between sites of the same "culture", and between "cultures", contributing substantially to our knowledge of the Neolithic.

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