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Finding Britain's last hunter-gatherers: A new biomolecular approach to 'unidentifiable' bone fragments utilising bone collagen

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Abstract

In the last decade, our knowledge of the transition from foraging, fishing, and hunting to agricultural food production has been transformed through the molecular analysis of human remains. In Britain, however, the lack of Late Mesolithic human remains has limited our understanding of this dietary transition. Here, we report the use of a novel strategy to analyse otherwise overlooked material to identify additional human remains from this period. ZooMS, a method which uses bone collagen sequences to determine species, was applied to unidentifiable bone fragments from 5th millennium deposits from the Late Mesolithic site of Cnoc Coig (Oronsay, Inner Hebrides) using an innovative new methodology. All samples bar one produced ZooMS results, with 14/20 bone fragments identified as human, and the remainder a mixture of pig and seal. 70% of bone fragments had sufficient collagen for stable isotope analyses, however none of three human bone fragments analysed had sufficient endogenous DNA. By conducting AMS dating and stable isotope analysis on this identified collagen, we provide new data that supports the view that the exploitation of marine resources partially overlapped with the earliest agricultural communities in Britain, and thus argues against the idea that forager lifeways in Britain were immediately replaced by agriculture c.4000 cal. BC. Unfortunately, we were unable to explore the genetic relationship between contemporaneous farmers and foragers. However, the more persistent bone protein could be used to identify species, determine date, and assess diet. This novel approach is widely applicable to other early prehistoric sites with fragmentary skeletal material.

1. Introduction

Archaeology, according to Kristiansen (2014), is experiencing its third scientific revolution, driven by the application of new biomolecular methods. One of the most demonstrable signs of this revolution has been to transform our understanding the transition from foraging, fishing and hunting to agricultural food production. Previously, stable isotope analysis of human bone collagen has been used to assess the degree of dietary change associated with the shift to farming, AMS dating of bone collagen has been used to determine the speed and trajectory of this shift, whilst ancient DNA analysis has provided new insights regarding the extent of demographic change. In many parts of Europe, these methods have been applied with spectacular success (e.g. Bramanti et al., 2009; Haak et al., 2010; Lidén et al., 2004; Lightfoot et al., 2015; Michael P. Richards et al., 2003; Rasteiro and Chikhi, 2013; Shennan and Edinborough, 2007) triggering new and better informed debates regarding this key phase in human history (e.g. Richards, 2003; Rowley-Conwy, 2011; Rowley-Conwy, 2004; Tresset and Vigne, 2011). However, in Britain their application has been hampered by the near absence of human remains dating to the period immediately preceding the arrival of farming c.4,000 cal. BC, i.e. the Late Mesolithic. Remarkably, the only directly dated sites from the whole of the 5th millennium BC with human remains are from the small Inner Hebridean island of Oronsay (Meiklejohn et al., 2011), severely restricting meaningful comparisons with more abundant Neolithic remains found across Britain.

The paucity of human remains from the Late Mesolithic of Britain is puzzling. Although the British Isles may have been less densely populated during this period compared to the Neolithic (Collard et al., 2010), many bone bearing sites have been identified. One possibility is that human remains became disarticulated and highly fragmented through cultural practices (Gray Jones, 2011) that rendered them unidentifiable using conventional osteological methods. Here, we revisit the site of Cnoc Coig, Oronsay, one of the few Late Mesolithic sites with human remains known in Britain. Despite the identification of only six individuals at the site (Meiklejohn et al., 2011, 2005), it has previously been pivotal to the argument for a rapid dietary change with the arrival of agriculture in Britain (Richards et al., 2003; Schulting and Richards, 2002). We apply an innovative method (ZooMS), which uses bone collagen sequences to determine species, to investigate whether additional human remains can be identified amongst 5th millennium deposits of small, fragmentary 'loose' bone. The study also aimed to utilise this collagen to conduct AMS dating and stable isotope analysis on any identified bone samples, to enhance our understanding of the diet of Britain's last forager groups and their chronological relationship to the earliest evidence for agriculture, thereby contributing to larger debates regarding the transition in Britain.

1.1. Cnoc Coig

The site of Cnoc Coig is one of five Mesolithic shell middens on the island of Oronsay, Inner Hebrides. Cnoc Coig was first excavated in 1911-1912 (Wickham-Jones et al., 1982), and then more extensively in 1973-1979 (Mellars, 1987). During the latter excavations, 49 pieces of human bone were recovered, predominantly from the hands and feet, thought to represent at up to six individuals (Meiklejohn et al., 2011, 2005; Meiklejohn and Denston, 1987).

Spatial analysis has suggested these human remains fall largely into seven circumscribed bone groups, although none are indicative of primary inhumation (Meiklejohn et al., 2005). Critically, AMS dating of the samples revealed that they date to the late 5th millennium BC, immediately prior to the emergence of agriculture in Britain; although slightly earlier dates (4300 cal. BC) have been proposed for both Neolithic monuments and pottery on the West Coast of Scotland (Sheridan, 2010). Although small and fragmented, the Oronsay remains represent one of the only Late Mesolithic human skeletal assemblages in Britain and, as such, have been subjected to a range of analyses aimed at establishing their date, circumstances of deposition, and diet (e.g. Meiklejohn et al., 2011, 2005; Mellars et al., 1980; Richards and Mellars, 1998; Richards and Sheridan, 2000; Wicks et al., 2014).

In particular, stable isotope analysis of the human bones from Cnoc Coig has shown a strongly marine isotopic signature, in contrast to the terrestrial signatures observed for humans from early 4th millennium sites along the west coast of Scotland and elsewhere in Britain (e.g. Schulting and Richards, 2002; Hedges et al., 2008; Milner and Craig, 2009). In the absence of other Late Mesolithic human remains, the Oronsay material has been pivotal to the argument for a rapid dietary change with the arrival of agriculture in Britain (Richards et al., 2003; Schulting and Richards, 2002), despite being based on a very small number of individuals. However, from recent recalibration of the dates, it has been suggested the human remains may instead date to the early 4th millennium BC (Milner and Craig, 2009) and are therefore coeval with the earliest evidence for domestic crops and animals in Scotland and other parts of Britain (Brown, 2007; Rowley-Conwy, 2004). Therefore, further identification of human remains for dating and dietary analysis from Cnoc Coig has the potential to greatly clarify our understanding of the transition in Western Scotland and more generally across Britain.

2. Materials and Methods

2.1. Samples

New biomolecular techniques have opened up the possibility of the identification of bone fragments to genera using collagen peptide mass fingerprinting (ZooMS; Welker et al., 2015). Twenty fragments of disarticulated and heavily fragmented bone from the 1973-9 excavations, originally classified as ‘unidentifiable’ or ‘?human’, and which had therefore remained unstudied, were utilised within this research (Fig. 1). Although the trench number of the remains is known, little other contextual information is available. The majority of fragments (n=15) derive not from the main midden structure, but instead lie just outside in a single outlying trench (Fig. 2). The remaining five ‘unidentifiable’ bones were selected from other areas within the main midden structure. This research was undertaken with permission from National Museums Scotland, to whom the Oronsay assemblage has been allocated.

Figure 1: Selection of bone fragments from the Cnoc Coig assemblage used within this research; highlighting the range of sizes, elements and preservation. From top, L-R, ZooMS IDs: seal, pig, remainder human

Figure 2: Plan of excavated areas of Cnoc Coig (adapted from Mellars 1987, 215), indicating the extent of the midden as defined by Mellars. Trench U, where the human remains identified in this study were found, is highlighted in red

2.2. A Combined Biomolecular Approach

A multi-methodological approach was adopted in the study of these bone fragments, combining ZooMS, stable isotope analysis and AMS dating (Fig. S1). Collagen was extracted and isotopically analysed using published protocols (Richards and Hedges, 1999; Colonese et al., 2015). ZooMS, a qualitative analytical technique for taxonomic identification of archaeological materials (Buckley et al., 2009; 2010), was undertaken on a sub-sample of the extracted collagen (<1mg), using a novel methodology, as outlined below. Four samples with adequate collagen preservation were submitted for AMS dating at the NERC radiocarbon facility (Oxford) and calibrated using the procedure detailed below. Three samples identified as human using ZooMS were also submitted for aDNA analysis. Protocols for each of the methodologies employed in this study are provided in the Supplementary Information.

3. Results and Discussion

Initially, collagen was prepared and extracted from all 20 bone fragments using previously published protocols (Richards and Hedges, 1999; Colonese et al., 2015), but yields varied, with only fourteen having sufficient collagen for $\delta^{13}C$ and $\delta^{15}N$ isotopic analysis (Fig. 3). The range of $\delta^{13}C$ and $\delta^{15}N$ values obtained however indicated samples with both fully marine and fully terrestrial diets. van Doorn et al. (2011) have previously shown that it is possible to undertake ZooMS on samples soaked in ammonium bicarbonate buffer (AmBic), utilising macroscopic amounts of bone collagen. Due to this, we speculated that the emptied 15ml Falcon tubes previously utilised for lyophilisation following collagen extraction would have absorbed sufficient collagen to their surface to allow for ZooMS identification to be undertaken. Lyophilised collagen samples were therefore removed from Falcon tubes, and 75µl 50mM AmBic was added to each 'empty' tube used during ultrafiltration and digested with 1µl trypsin. Identification was based upon peptide matching as outlined in Welker et al. (2015). Nineteen of the twenty samples yielded identification information, including six that had insufficient collagen to undertake stable isotope analyses. Two fragments identified as *Pinnipedia* (seal) using ZooMS had $\delta^{13}C$ and $\delta^{15}N$ isotopic values indicative of a typical marine based diet expected of these animals. Indeed, all the seal bones analysed from Oronsay (Richards and Mellars, 1998; this study) are within analytical error (Pestle et al., 2014) and could therefore even be from the same skeleton.

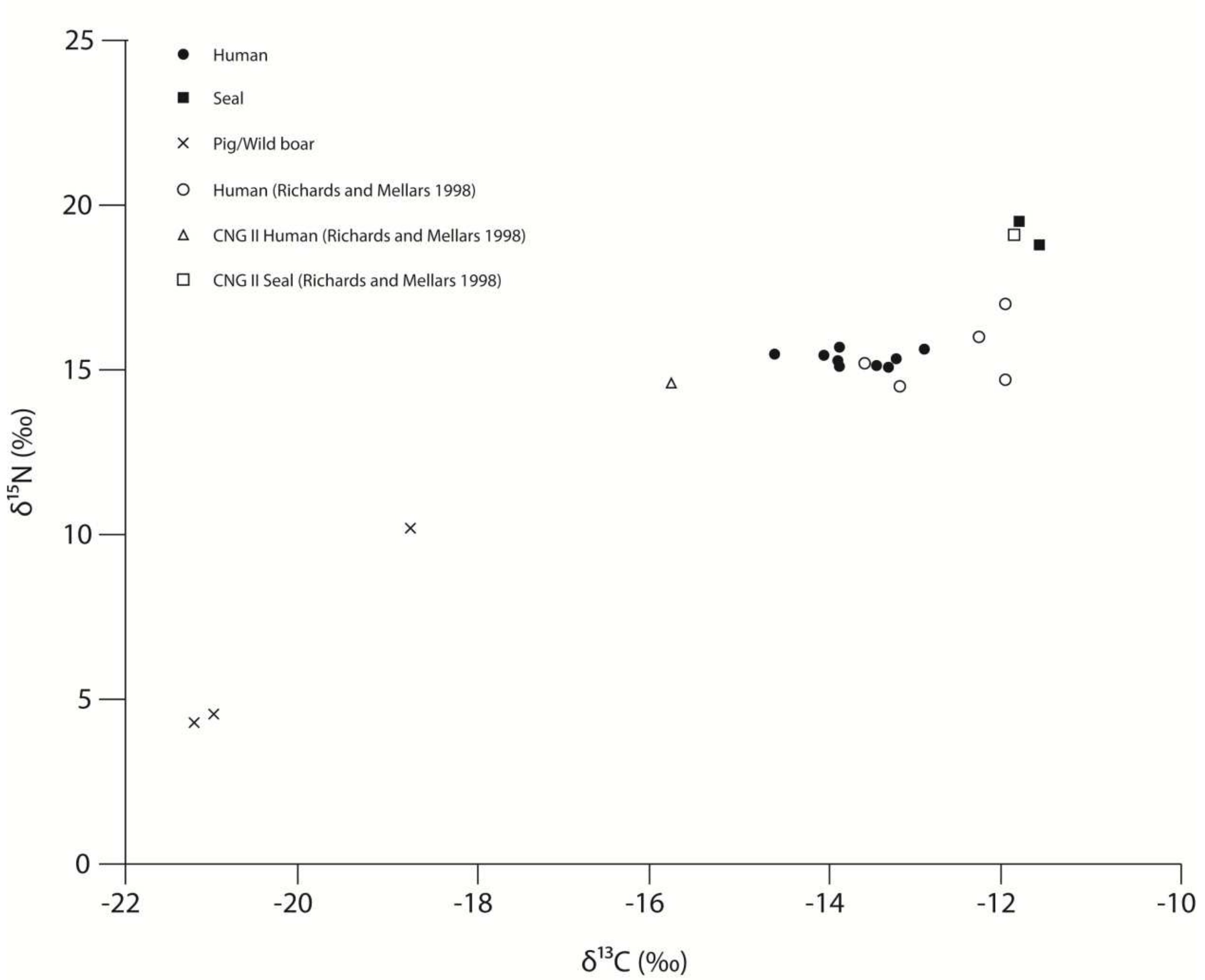

Figure 3: Stable carbon and nitrogen isotope values from Cnoc Coig and Caisteal nan Gillean human and fauna. The analytical error on data obtained in this study was <0.2‰ (1σ) for both $\delta^{13}C$ and $\delta^{15}N$. Data from this study and(Richards and Mellars, 1998)

Of the three bone fragments identified as *Sus scrofa* using ZooMS, two samples (at least one individual) showed $\delta^{13}C$ and $\delta^{15}N$ values indicative of a terrestrial herbivorous diet, whilst the third had isotope values consistent with a more marine/omnivorous diet, possibly deriving from the consumption of refuse from the shell midden, or being purposively fed marine foods by humans. Biometrically identified as wild boar (Grigson and Mellars, 1987), these animals are likely to have been purposively brought to Oronsay from the mainland or larger surrounding islands. As they had differential diets prior to death, we may hypothesise that they inhabited different areas, derived from two (geographically) distinct populations, or were managed differently prior to their death, mirroring interpretations of deer at the site (Grigson and Mellars, 1987).

Remarkably, fourteen of the fragments were identified as human, increasing the number of known human bone fragments from all five Oronsay middens from 55 (Meiklejohn et al., 2005) to 74 (including five fragments recently recovered at NMS) (Sheridan, *pers. comm.*). Of the fourteen bone fragments identified as human, nine yielded sufficient amounts of collagen for $\delta^{13}C$ and δ^{15} N isotopic analysis (Fig. 3). Generally, the isotope values of the human samples are similar to those from previous study, confirming marine protein rich diets (Fig. 3; Table S1). However, variation in the $\delta^{13}C$ and $\delta^{15}N$ values indicates that the human bone samples are unlikely to be from the same individuals as previously analysed. At least two of the new human samples are outside the error expected by replicate analysis of a single individual (Pestle et al., 2014). Conservatively, if we use these errors, combining this new human isotopic data with previous analysis (Richards and Mellars, 1998) suggests a potential minimum of seven human individuals are represented isotopically, from thirteen pieces of bone (Fig. 3).

Given the scarcity of British Late Mesolithic human remains and the unique nature of these samples, aDNA analysis was attempted at two independent laboratories on three fragments of bone identified as human here using ZooMS. Unfortunately, this was unsuccessful due to low endogenous DNA content and inhibition of the samples (Barnes & Brace, *pers. comm.*; Reich & Harney, *pers. comm*; see Supplementary Information). However, this does highlight that in sites which do not yield DNA, the bone protein collagen can still provide useful biomolecular information, through identifying species, determining date, and assessing diet.

Finally, importantly, all the human remains identified here originate from outside the main midden structure (Fig. 2) and may represent a different depositional event. This raises interesting questions as to whether deposition in this location was intentional, or is a product of taphonomic processes – and can perhaps contribute to discussions surrounding the deposition of human remains in the late 5th-early 4th millennium BC in Britain. Given the ubiquitous nature of disarticulated human remains with the Mesolithic burial record, potential degrees of intentionality with regards to these kinds of deposits have previously been discussed. Gray Jones (2011), for example, has suggested that ‘loose bone’ or disarticulated remains may in fact be the result of deliberate acts, and thus a part of, rather than separate from, other types of mortuary practice. Additionally, only one of the bone fragments identified here as human appears to originate from the hands or feet, which have previously been noted to be the dominant element types within the midden deposits, and have led to suggestions of excarnation at the site (Meiklejohn et al., 2005).

3.1. Re-dating human remains at Cnoc Coig

Previous AMS dates on human remains dated Cnoc Coig to 4300-3800 cal. BC (Milner and Craig, 2009; Richards and Sheridan, 2000). However, the marine carbon isotope signatures of the human remains mean they are subject to uncertainties associated with the marine reservoir effect (MRE). Additional ^{14}C dates previously obtained from bulk charcoal (Switsur and Mellars, 1987) could have derived from ‘old wood’ (Schiffer, 1986), adding to the uncertainty regarding the dating of the site. The first dates on short-lived terrestrial mammals, as identified by ZooMS, were therefore undertaken here, along with dates on the newly identified human remains (Table 1).

Sample Number	Trench	ZooMS ID	Lab Ref. No.	^{14}C Date BP	Date cal. BC (95.4%)
8257	U III	Human	OxA-29939	5391 ± 30	3991-3702
8267	U III	Human	OxA-29938	5379 ± 29	3944-3649
10494	P (E)	Pig	OxA-29937	5122 ± 30	3982-3803
17050	H/ 13	Pig	OxA-29936	5117 ± 29	3977-3803

Table 1: AMS dates obtained within this study from newly identified humans and fauna. A ΔR value of 47 ±52 was used to calibrate samples 8257 and 8267

Calibration of all dates was undertaken using OxCal v.4.2 (Bronk Ramsey, 2009). As the human samples had marine isotopic signatures however, they were calibrated using a mixed marine-terrestrial curve (Marine13/IntCal13, Reimer et al., 2103) in a proportion determined by marine/terrestrial carbon contribution to collagen (as in Barrett and Richards 2004; following best practice outlined in Cook et al. 2015). The latter was estimated for each individual from their δ^{13}C values following linear interpolation from the observed marine and terrestrial endpoints after Schulting and Richards (2002) (-12‰ and -21‰ respectively; Table S1). We placed a 10% error on this value following Hedges (2004). Calibration of AMS dates from Cnoc Coig using this approach has previously been successfully undertaken by Gordon Cook (Milner and Craig 2009). MRE and ΔR values are known to vary both temporally and geographically, caused by palaeoclimatic, environmental and oceanographic changes (Ascough et al., 2007, 2004). As the MRE has not been assessed at Oronsay itself, a calculated mean ΔR value for Scotland was utilised (ΔR= 47 ±52 14 C yr) (Russell et al., 2015) following best practices (Cook et al., 2015). Although this value is calculated for the west coast of Scotland 3500 BC onwards, it is at present the most conservative and suitable ΔR offset to utilise for these samples (Ascough, pers. comm.). The two pig samples dated were calibrated using only the terrestrial (IntCal13) calibration curve.

Intriguingly, the dates on two pig bone samples with purely terrestrial diets fall within the 4th millennium BC at 95% confidence (Table 1). After calibration of both new dates presented here and those previously obtained from Oronsay using the approach outlined above, it is clear that all the humans overlap with the terrestrial fauna and fall within the early part of the 4th millennium BC (Tables 1 and S1; Fig. 4). This is a significant result as the Oronsay human dates, with marine isotope signatures, overlap with humans from other parts of Western Scotland with fully terrestrial isotope signatures (Fig. 4) and with the earliest evidence for domesticated animals and plants in Britain. We suggest that there was considerable heterogeneity in human diets in the early part of the Neolithic reflecting specialisation in subsistence practices across the landscape, and the continuity of foraging, hunting and fishing into the period traditionally associated with agriculture and pastoralism. Sheridan (2010) argues for the arrival of a ‘Breton Neolithic’ in this region from around 4300-4200 cal. BC, and Collard et al. (2010) suggest that farming emerged in western Scotland c.6100 cal. BP. These dates, combined with the data obtained here, would imply that both hunter-gatherer-fisher and farming lifestyles potentially co-existed on the West Coast of Scotland for several hundred years. However, it should be noted that we have very little isotopic evidence for human subsistence practices in 5th millennium Britain.

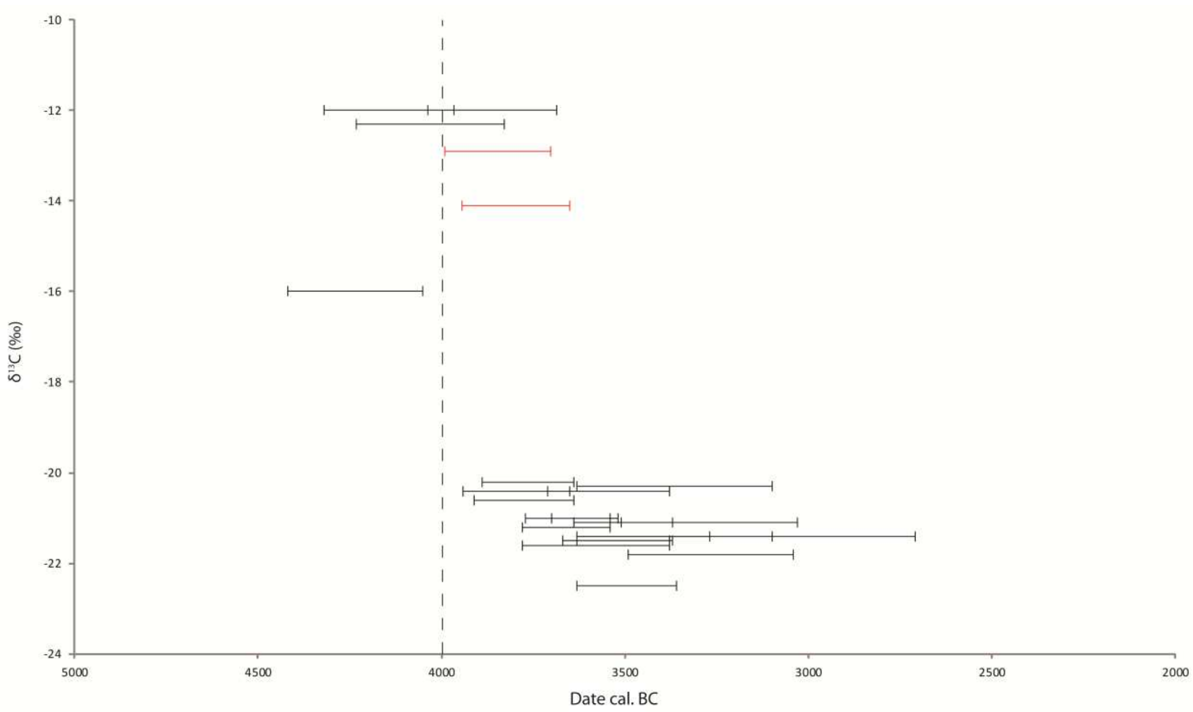

Figure 4: Plot of δ^{13}C values against radiocarbon dates for humans from Scottish West Coast sites, c.4500-3000 cal. BC (data from this study (Tables 1 and S1); Richards and Sheridan, 2000; Schulting and Richards, 2002). New human data obtained for Cnoc Coig within this study is highlighted in red

4. Conclusions

This study adopted an innovative biomolecular approach to bone fragments from the site of Cnoc Coig, and highlights the archaeological information which can be obtained from bone protein alone. By combining a variety of scientific techniques (all of which target bone collagen) and applying them in tandem to the same samples, this research has aimed to illustrate the information which can be obtained from previously overlooked fragmented material. As such, this study importantly highlights the research potential currently dormant within osteologically unidentifiable bone fragments from prehistoric contexts. There is consequently significant potential for future application of the method to other prehistoric sites with fragmentary or loose bone, such as caves and middens. We therefore call for widespread application of ZooMS to similar Mesolithic assemblages across Britain.

As demonstrated here for the first time, the ability to be able to obtain taxonomic information from ‘empty’ tubes previously utilised within the collagen extraction process also appears to hold great future potential - particularly as it does not require the use of collagen reserved for isotopic analysis or AMS dating. It also presents a potential opportunity to retrospectively analyse empty tubes previously utilised within collagen extractions to gain taxonomic information. This may be of particular use with samples which produce AMS dates or isotopic values that are distinctly different from what is anticipated.

Overall, this research has detected extremely rare human bones from the Mesolithic-Neolithic transition which can be used to further elucidate issues surrounding the period. In total, fourteen new fragments of human bone have been identified, increasing the number of known human bone fragments from the five Oronsay middens from 55 (Meiklejohn et al., 2005) to 74 (including five fragments recently recovered at NMS) (Sheridan, *pers. comm.*). The human remains identified here provide additional data comparable to isotopic analyses undertaken previously at Cnoc Coig. The isotopic results also provide additional evidence of a high marine protein diet along the west coast of Scotland – but AMS dates obtained from these samples suggest that this marine diet may have extended into the 4th millennium BC and the 'Neolithic' period. However, the presence of a marine isotopic signature within one *Sus scrofa* sample suggests the need for better characterisation of faunal baselines within the British Mesolithic, in particular when considering interpretations of marine resource consumption by humans.

Finally, unfortunately, insufficient endogenous DNA content within the samples analysed here meant that it was not possible to explore the genetic relationship between the Cnoc Coig humans and the earliest known agricultural communities in Britain. In future, analysis of the single human petrous bone known from Cnoc Coig may be worth exploration, as this element is known to provide significantly higher endogenous DNA yields (Pinhasi et al., 2015).

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References

Ascough, P.L., Cook, G.T., Dugmore, A.J., Barber, J., Higney, E., Scott, E.M., 2004. Holocene variations in the Scottish marine radiocarbon reservoir effect. Radiocarbon 46, 611–620.

Ascough, P.L., Cook, G.T., Dugmore, A.J., Scott, E.M., 2007. The North Atlantic marine reservoir effect in the Early Holocene: Implications for defining and understanding MRE values. Nucl. Instrum. Methods Phys. Res. B 259, 438–447.

Barrett, J.H., Richards, M.P., 2004. Identity, Gender, Religion and Economy: New Isotope and Radiocarbon Evidence for Marine Resource Intensification in Early Historic Orkney, Scotland, UK. European Journal of Archaeology 7, 249–271.

Bramanti, B., Thomas, M.G., Haak, W., Unterlaender, M., Jores, P., Tambets, K., Antanaitis-Jacobs, I., Haidle, M.N., Jankauskas, R., Kind, C.-J., Lueth, F., Terberger, T., Hiller, J., Matsumura, S., Forster, P., Burger, J., 2009. Genetic discontinuity between local hunter-gatherers and central Europe's first farmers. Science 326, 137–140.

Bronk Ramsey, C., 2009. Bayesian analysis of radiocarbon dates. Radiocarbon 51, 337–360.

Brown, A., 2007. Dating the onset of cereal cultivation in Britain and Ireland: the evidence from charred cereal grains. Antiquity 81, 1042–1052.

Brown, T.A., Nelson, D.E., Vogel, J.S., Southon, J.R., 1988. Improved collagen extraction by modified Longin method. Radiocarbon 30, 171–177.

Buckley, M., Collins, M., Thomas-Oates, J., Wilson, J.C., 2009. Species identification by analysis of bone collagen using matrix-assisted laser desorption/ionisation time-of-flight mass spectrometry. Rapid Commun. Mass Spectrom. 23, 3843–3854.

Buckley, M., Whitcher Kansa, S., Howard, S., Campbell, S., Thomas-Oates, J., Collins, M. 2010. Distinguishing between archaeological sheep and goat bones using a single collagen peptide. J. Archaeol. Sci. 37, 13-20.

Collard, M., Edinborough, K., Shennan, S., Thomas, M.G., 2010. Radiocarbon evidence indicates that migrants introduced farming to Britain. J. Archaeol. Sci. 37, 866–870.

Colonese, A.C., Farrell, T., Lucquin, A., Firth, D., Charlton, S., Robson, H.K., Alexander, M., Craig, O.E., 2015. Archaeological bone lipids as palaeodietary markers. Rapid Commun. Mass Spectrom. 29, 611–618.

Cook, G.T., Ascough, P.L., Bonsall, C., Hamilton, W.D., Russell, N., Sayle, K.L., Scott, E.M., Bownes, J.M., 2015. Best practice methodology for 14C calibration of marine and mixed terrestrial/marine samples. Quat. Geochronol. 27, 164–171.

CR Wickham-Jones, MM Brown, TG Cowie, DB Gallager, JNG Ritchie, 1982. Excavations at Druim Arstail, Oronsay, 1911-12. Glasgow Archaeological Journal 9, 18–30.

Dabney, J., Knapp, M., Glocke, I., Gansauge, M.-T., Weihmann, A., Nickel, B., Valdiosera, C., García, N., Pääbo, S., Arsuaga, J.-L., Meyer, M., 2013. Complete mitochondrial genome sequence of a Middle Pleistocene cave bear reconstructed from ultrashort DNA fragments. Proc. Natl. Acad. Sci. U. S. A. 110, 15758–15763.

DeNiro, M.J., 1985. Postmortem preservation and alteration of in vivo bone collagen isotope ratios in relation to palaeodietary reconstruction. Nature 317, 806–809.

Gray Jones, A., 2011. Dealing with the Dead: Manipulation of the Body in the Mortuary Practices of Mesolithic North West Europe. School of Arts, Histories and Cultures; University of Manchester.

Grigson, C., Mellars, P., 1987. The mammalian remains from the middens. Excavations on Oronsay: Prehistoric Human Ecology on a Small Island. Edinburgh University Press, Edinburgh 24.

Haak, W., Balanovsky, O., Sanchez, J.J., Koshel, S., Zaporozhchenko, V., Adler, C.J., Der Sarkissian, C.S.I., Brandt, G., Schwarz, C., Nicklisch, N., Dresely, V., Fritsch, B., Balanovska, E., Villems, R., Meller, H., Alt, K.W., Cooper, A., Members of the Genographic Consortium, 2010. Ancient DNA from European early neolithic farmers reveals their near eastern affinities. PLoS Biol. 8, e1000536.

Haak, W., Lazaridis, I., Patterson, N., Rohland, N., Mallick, S., Llamas, B., Brandt, G., Nordenfelt, S., Harney, E., Stewardson, K., Fu, Q., Mittnik, A., Bánffy, E., Economou, C., Francken, M., Friederich, S., Pena, R.G., Hallgren, F., Khartanovich, V., Khokhlov, A., Kunst, M., Kuznetsov, P., Meller, H., Mochalov, O., Moiseyev, V., Nicklisch, N., Pichler, S.L., Risch, R., Rojo Guerra, M.A., Roth, C., Szécsényi-Nagy, A., Wahl, J.,

Meyer, M., Krause, J., Brown, D., Anthony, D., Cooper, A., Alt, K.W., Reich, D., 2015. Massive migration from the steppe was a source for Indo-European languages in Europe. Nature 522, 207–211.
Hedges, R.E.M., 2004. Isotopes and red herrings: comments on Milner *et al.* and Lidén *et al.* Antiquity 78, 34–37.
Hedges, R., Saville, A., O'Connell, T., 2008. Characterizing the Diet of Individuals at the Neolithic Chambered Tomb of Hazleton North, Gloucestershire, England, Using Stable Isotopic Analysis. Archaeometry 50, 114–128.
Jardine, W.G., 1978. Radiocarbon ages of raised-beach shells from Oronsay, Inner Hebrides, Scotland: a lesson in interpretation and deduction. Boreas 7, 183–196.
Kristiansen, K., 2014. Towards a New Paradigm: The Third Science Revolution and its Possible Consequences in Archaeology. Current Swedish Archaeology 22, 11–34.
Lidén, K., Eriksson, G., Nordqvist, B., Götherström, A., Bendixen, E., 2004. "The wet and the wild followed by the dry and the tame" – or did they occur at the same time? Diet in Mesolithic – Neolithic southern Sweden. Antiquity 78, 23–33.
Lightfoot, E., Boneva, B., Miracle, P.T., Šlaus, M., O'Connell, T.C., 2015. Exploring the Mesolithic and Neolithic transition in Croatia through isotopic investigations. Antiquity 85, 73–86.
Li, H., Durbin, R., 2009. Fast and accurate short read alignment with Burrows–Wheeler transform. Bioinformatics 25, 1754–1760.
Li, H., Handsaker, B., Wysoker, A., Fennell, T., Ruan, J., Homer, N., Marth, G., Abecasis, G., Durbin, R., 1000 Genome Project Data Processing Subgroup, 2009. The Sequence Alignment/Map format and SAMtools. Bioinformatics 25, 2078–2079.
Lindgreen, S., 2012. AdapterRemoval: easy cleaning of next-generation sequencing reads. BMC Res. Notes 5, 337.
Meiklejohn, C., Chamberlain, A.T., Schulting, R.J., 2011. Radiocarbon dating of Mesolithic human remains in Great Britain. Mesolithic Miscellany 21, 20–58.
Meiklejohn, C., Denston, B., 1987. The Human Skeletal Material: Inventory and Initial Interpretation, in: Mellars, P. (Ed.), Excavations on Oronsay: Prehistoric Human Ecology on a Small Island. Edinburgh University Press, Edinburgh, pp. 290–300.
Meiklejohn, C., Merrett, D.C., Nolan, R.W., Richards, M.P., Mellars, P.A., 2005. Spatial relationships, dating and taphonomy of the human bone from the Mesolithic site of Cnoc Coig, Oronsay, Argyll, Scotland, in: Proceedings of the Prehistoric Society. Cambridge Univ Press, pp. 85–105.
Mellars, P., 1987. Excavations on Oronsay: Prehistoric Human Ecology on a Small Island. Edinburgh University Press, Edinburgh.
Mellars, P.A., Wilkinson, M.R., Fieller, N.R.J., 1980. Fish Otoliths as Indicators of Seasonality in Prehistoric Shell Middens: the Evidence from Oronsay (Inner Hebrides). Proceedings of the Prehistoric Society 46, 19–44.
Meyer, M., Kircher, M., 2010. Illumina sequencing library preparation for highly multiplexed target capture and sequencing. Cold Spring Harb. Protoc. 2010, db.prot5448.
Michael P. Richards, T. Douglas Price, Eva Koch, 2003. Mesolithic and Neolithic Subsistence in Denmark: New Stable Isotope Data. Curr. Anthropol. 44, 288–295.
Milner, N., Craig, O.E., 2009. Mysteries of the middens: change and continuity across the Mesolithic Neolithic Transition, in: Land and People: Papers in Memory of John G. Evans. Oxbow Books Oxford, pp. 169–180.
Pestle, W.J., Crowley, B.E., Weirauch, M.T., 2014. Quantifying inter-laboratory variability in stable isotope analysis of ancient skeletal remains. PLoS One 9, e102844.
Pinhasi, R., Fernandes, D., Sirak, K., Novak, M., Connell, S., Alpaslan-Roodenberg, S., Gerritsen, F., Moiseyev, V., Gromov, A., Raczky, P., Anders, A., Pietrusewsky, M.,

Rollefson, G., Jovanovic, M., Trinhhoang, H., Bar-Oz, G., Oxenham, M., Matsumura, H., Hofreiter, M., 2015. Optimal Ancient DNA Yields from the Inner Ear Part of the Human Petrous Bone. PLoS One 10, e0129102.

Rasteiro, R., Chikhi, L., 2013. Female and male perspectives on the neolithic transition in Europe: clues from ancient and modern genetic data. PLoS One 8, e60944.

Reimer, P.J., Bard, E., Bayliss, A., Beck, W.J., Blackwell, P.G., Bronk Ramsey, C., Buck, C.E., Cheng, H., Edwards, L.R., Friedrich, M., Haflidason, H., Heaton, T.J., Hoffmann, D.L., Reimer, R.W., Richards, D.A., Scott, E.M., Southon, J.R., Staff, R.A., Turney, C.S.M., van der Plicht, J., 2013. IntCal13 and Marine13 Radiocarbon Age Calibration Curves. Radiocarbon 55, 1869–1887.

Richards, M., 2003. The Neolithic transition in Europe: archaeological models and genetic evidence. Documenta Praehistorica 30, 159–167.

Richards, M.P., Hedges, R.E.M., 1999. 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. 26, 717–722.

Richards, M.P., Mellars, P.A., 1998. Stable isotopes and the seasonality of the Oronsay middens. Antiquity 72, 178–184.

Richards, M.P., Schulting, R.J., Hedges, R.E.M., 2003. Archaeology: sharp shift in diet at onset of Neolithic. Nature 425, 366.

Richards, M.P., Sheridan, J.A., 2000. New AMS dates on human bone from Mesolithic Oronsay. Antiquity 74, 313–315.

Rohland, N., Harney, E., Mallick, S., Nordenfelt, S., Reich, D., 2015. Partial uracil–DNA–glycosylase treatment for screening of ancient DNA. Philos. Trans. R. Soc. Lond. B Biol. Sci. 370, 20130624.

Rowley-Conwy, P., 2011. Westward Ho! The Spread of Agriculturalism from Central Europe to the Atlantic. Curr. Anthropol. 52, S431–S451.

Rowley-Conwy, P., 2004. How the West Was Lost: A Reconsideration of Agricultural Origins in Britain, Ireland, and Southern Scandinavia. Curr. Anthropol. 45, S83–S113.

Russell, N., Cook, G.T., Ascough, P.L., Scott, M. 2015. A period of calm in Scottish seas: A comprehensive study of ΔR values for the northern British Isles coast and the consequent implications for archaeology and oceanography. Quat. Geochronol. 30, 34–41.

Schiffer, M.B., 1986. Radiocarbon dating and the “old wood” problem: The case of the Hohokam chronology. J. Archaeol. Sci. 13, 13–30.

Schulting, R.J., Richards, M.P., 2002. The wet, the wild and the domesticated: the Mesolithic–Neolithic transition on the west coast of Scotland. European Journal of Archaeology 5, 147–189.

Sealy, J., Johnson, M., Richards, M., Nehlich, O., 2014. Comparison of two methods of extracting bone collagen for stable carbon and nitrogen isotope analysis: comparing whole bone demineralization with gelatinization and ultrafiltration. J. Archaeol. Sci. 47, 64–69.

Shennan, S., Edinborough, K., 2007. Prehistoric population history: from the Late Glacial to the Late Neolithic in Central and Northern Europe. J. Archaeol. Sci. 34, 1339–1345.

Sheridan, A., 2010. The Neolithization of Britain and Ireland: The “Big Picture,” in: Finlayson, B., Warren, G. (Eds.), Landscapes in Transition. Oxbow, Oxford, pp. 89–105.

Strohalm, M., Kavan, D., Novák, P., Volný, M., Havlícek, V., 2010. mMass 3: a cross-platform software environment for precise analysis of mass spectrometric data. Anal. Chem. 82, 4648–4651.

Switsur, V.R., Mellars, P.A., 1987. Radiocarbon dating of the shell midden sites. Excavations on Oronsay 139–149.

Tresset, A., Vigne, J.-D., 2011. Last hunter-gatherers and first farmers of Europe. C. R. Biol. 334, 182–189.

van Doorn, N.L., Hollund, H., Collins, M.J., 2011. A novel and non-destructive approach for ZooMS analysis: ammonium bicarbonate buffer extraction. Archaeol. Anthropol. Sci. 3, 281–289.

van Klinken, G.J., 1999. Bone Collagen Quality Indicators for Palaeodietary and Radiocarbon Measurements. J. Archaeol. Sci. 26, 687–695.

Welker, F., Soressi, M., Rendu, W., Hublin, J.-J., Collins, M., 2015. Using ZooMS to identify fragmentary bone from the Late Middle/Early Upper Palaeolithic sequence of Les Cottés, France. J. Archaeol. Sci. 54, 279–286.

Wicks, K., Pirie, A., Mithen, S.J., 2014. Settlement patterns in the late Mesolithic of western Scotland: the implications of Bayesian analysis of radiocarbon dates and inter-site technological comparisons. J. Archaeol. Sci. 41, 406–422.

Supporting Information

SI Materials and Methods

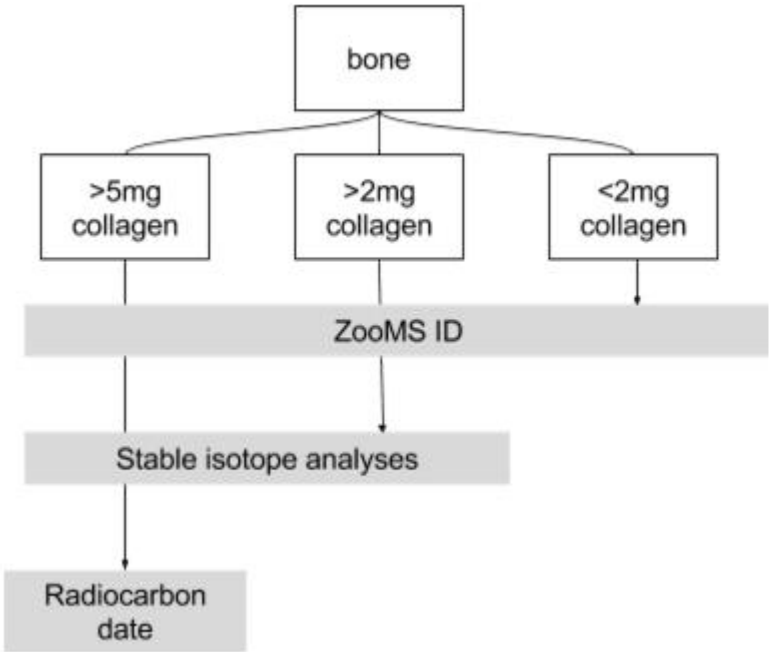

Figure S1: Schematic of analyses

ZooMS Analysis

The ZooMS methodology utilised involved a standard collagen extraction from *c.*500mg of bone (see below), followed by ZooMS analysis (as in Welker et al., 2015) being undertaken on the 'empty' tubes used for the lyophilisation of collagen – thereby utilising the macroscopically invisible amounts of collagen left adhering to the tube. The benefit of this novel ZooMS methodology lies in the fact that it can determine species identification from samples without the utilisation of collagen reserved for isotopic analyses. In effect, taxonomic information is being obtained from 'empty' tubes previously used within the collagen extraction process of these samples.

Briefly, lyophilised collagen samples (see below) were removed from falcon tubes and transferred into eppendorfs. 75µl 50mM AmBic (ammonium bicarbonate buffer, pH8.0) was added to each 'empty' tube used during ultrafiltration, vortexed and then centrifuged. 1µl trypsin (Promega) was then added to each sample, and digested for 16h at 37°C. Following this, samples were centrifuged at 13k RPM for 1 min and then 1µl 5% TFA was added to stop enzymatic digestion. Peptides were then extracted using C_{18} ZipTips (Agilent), which were eluted using 50µl 50% ACN in 0.5% TFA.

MALDI-TOF-MS analysis, using 1µl eluted peptides and 1µl α-cyano-4-hydroxycinnamic acid matrix solution (Buckley et al., 2009; Welker et al., 2015) spotted onto a ground steel plate, was undertaken in triplicate for each sample on a Bruker Ultraflex III MALDI-TOF/TOF at the University of York. Spectral analysis was performed using the open-source cross-platform software mMass (Strohalm et al., 2010). Replicates were averaged for each sample and manually analysed for peptide markers following the protocol detailed in (Welker et al., 2015).

All samples bar one provided sufficient taxonomic information using this modified ZooMS protocol to allow for species identification (Table S1). Two samples (17050 and GEN1) however required the initial ZooMS identification obtained from the empty tubes to be clarified via secondary ZooMS analysis using the standard protocol(Welker et al., 2015) on 0.5mg of extracted collagen.

Isotopic Analysis

Isotopic analyses of $\delta^{13}C$ and $\delta^{15}N$ were undertaken following a modified Longin collagen extraction protocol using ultrafiltration on *c*.500mg of bone (Brown et al., 1988; Colonese et al., 2015; Richards and Hedges, 1999). Briefly, samples were initially cleaned manually using a scalpel, and then were demineralised in 0.6M aq. HCl solution at 4°C, and the resulting insoluble fraction gelatinised in pH3 HCl for 48h at 80°C. The supernatant solution was then ultrafiltered (30kDa MWCO, Amicon) to isolate the high molecular weight fraction, which was then lyophilised. Purified collagen samples (1mg) were analysed in triplicate by EA-IRMS on a Sercon GSL analyser coupled to a Sercon 20-22 Mass Spectrometer at the University of York. The analytical error, calculated from repeated measurements of each sample, a bovine control, and international standards, was <0.2‰ (1σ) for both $\delta^{13}C$ and $\delta^{15}N$. Stable isotope values are presented here relative to the internationally defined standards of VPDB for $\delta^{13}C$ and AIR for $\delta^{15}N$.

Collagen quality fell within prescribed quality ranges (DeNiro, 1985; van Klinken, 1999). However, some variability was seen in the yields obtained from the samples, generally ranging from over 1% to over 3.5%. Only two samples fell below the 1% collagen yield from the retentate sample alone (samples 8260 and 8266), but both samples showed acceptable C:N ratios and so were still included within this study (Table S1). Furthermore, it has previously been noted that collagen yields calculated from retentate samples following ultrafiltration, as was undertaken here, contain only high molecular weight fractions and therefore quality criteria are actually more important than yields(Sealy et al., 2014). All samples with reported $\delta^{13}C$ and $\delta^{15}N$ values in this work have atomic C:N ratios of between 3.3-3.6 (Table S1).

Sample Number	ZooMS ID	Possible Element	δ13C (‰)	δ15N (‰)	Atomic C:N Ratio	% Collagen Yield	Estimated % contribution of marine C to collagen
8254	Human	Cranial frag?	-13.8	15.1	3.4	2.4	79%
8255	Human	Long bone?	-13.4	15.1	3.4	3.2	84%
8256	Human	Radius?	-13.3	15.0	3.3	2.1	85%
8257	Human	Cranial frag?	-14.1	15.4	3.3	3.6	77%
8258	Human	Cranial frag	-13.9	15.3	3.3	1.2	79%
8260	Human	Vertebrae	-14.6	15.5	3.6	0.9	71%
8266	Human	Vertebrae	-13.9	15.7	3.6	0.6	70%
8267	Human	Unknown	-12.9	15.6	3.3	1.4	90%
General Find 1 (GEN1)	Human	Metacarpal?	-13.2	15.3	3.2	3.7	86%
10420	Seal	Unknown	-11.8	19.5	3.5	1.2	-
10494	Pig	Long bone?	-21.2	4.3	3.4	2.9	-
10502	Seal	Long bone?	-11.6	18.8	3.3	2.9	-
17050	Pig	Long bone?	-21.0	4.6	3.3	2.3	-
'Unknown' (General find)	Pig	Unknown	-18.8	10.2	3.4	2.7	-
8259	Human	Rib	-	-	-	0.5	-
8261	Human	Vertebrae	-	-	-	0.8	-
8262	Unidentifiable	Unknown	-	-	-	0.5	-
8263	Human	Vertebrae	-	-	-	0.1	-
8265	Human	Rib	-	-	-	0.2	-
8268	Human	Vertebrae	-	-	-	0.8	-

Table S1: ZooMS species ID and collagen stable isotope values obtained. Estimated % marine carbon contribution to collagen for humans calculated from isotopic data after

Schulting and Richards (2002) using marine and terrestrial carbon end-points of -12‰ and -21‰ respectively, with an error ±10%

AMS Dating

AMS dating of four bone fragments identified using ZooMS and with associated isotopic information was also undertaken in an attempt to elucidate information about the chronology of the skeletal remains at Cnoc Coig. Dating of terrestrial faunal samples was undertaken to provide valuable reference points to evaluate the overall date of the site, which is currently based on marine and charcoal samples (Table S2), and to identify if the fauna studied were contemporaneous to the human remains. There have previously been no dates (or isotopic values) for terrestrial fauna from Cnoc Coig.

All AMS data were generated by the NERC radiocarbon facility based in the Oxford Radiocarbon Acceleration Unit. Calibration of dates (both those undertaken in this study, and dates previously obtained) was undertaken using OxCal v.4.2. As many of the bone fragments utilised in this study showed high marine isotopic values however (Table S1), this suggested the need for calibration of radiocarbon dates adjusted for a marine reservoir correction, with the appropriate ΔR offset. To do this, mixed marine/atmospheric calibration curves (Marine13/IntCal13, Reimer et al., 2103) were used in a proportion determined by marine/terrestrial carbon contribution to collagen (as in Barrett and Richards, 2004); following best practice as outlined in Cook et al. (2015). The latter was estimated for each individual from their $\delta^{13}C$ values following linear interpolation from the observed marine and terrestrial endpoints (Table S1), with an error ±10%. A ΔR value of 47 ±52 was also applied to human samples with marine isotopic signatures (Tables S1 and S2). This is a mean ΔR value calculated for the entirety of Scotland (Russell et al., 2105; Ascough, *pers. comm.*).

Material Dated	**Lab Ref. No.**	**^{14}C Date BP**	**Original Published Date cal. BC**	**New Date cal. BC (with MRO) (95.4%)**	**Reference**
Arctica islandica shell	Birm-326Z	7240 ±200	6400-5100	6144-5354	(Jardine, 1978; Mellars, 1987)
Arctica islandica shell	Birm-326Y	7290 ±120	6200-5450	6011-5527	(Jardine, 1978; Mellars, 1987)
Arctica islandica shell	Birm-326X	7610 ±150	6500-5650	6399-5760	(Jardine, 1978; Mellars, 1987)
Bulk charcoal	Q-1352	5430 ±130	4520-3970	-	(Switsur and Mellars, 1987)
Bulk charcoal	Q-1351	5495 ±75	4510-4070	-	(Switsur and Mellars, 1987)

Bulk charcoal	Q-1354	5535 ±140	4690-4040	-	(Switsur and Mellars, 1987)
Bulk charcoal	Q-1353	5645 ±80	4690-4340	-	(Switsur and Mellars, 1987)
Bulk charcoal	Q-3006	5675 ±60	4690-4360	-	(Switsur and Mellars, 1987)
Bulk charcoal	Q-3005	5650 ±60	4660-4350	-	(Switsur and Mellars, 1987)
Human bone (sample no. 17203)	OxA-8014	5495 ±55	4000-3800	4036-3686	(Richards and Sheridan, 2000)
Human bone (sample no. 17157)	OxA-8019	5615 ±45	4200-4000	4232-3830	(Richards and Sheridan, 2000)
Human bone (sample no. 18284)	OxA-8004	5740 ±65	4300-4000	4320-3966	(Richards and Sheridan, 2000)

Table S2: Radiocarbon dates previously obtained for Cnoc Coig. It is important to note that the previous dates on human bone were undertaken on collagen which had not been ultrafiltered. Also note the large standard deviations on both previous shell and charcoal BP dates. New calibration of dates was undertaken using mixed marine/atmospheric calibration curves (Marine13/IntCal13, Reimer et al., 2103), in a proportion determined by marine/terrestrial carbon contribution to collagen following linear interpolation from the observed marine and terrestrial endpoints, with an error ±10%. A ΔR value of 47 ±52 was also applied

DNA analysis

<u>Sample 8256:</u>

DNA extraction and library preparation were carried out in a dedicated ancient DNA laboratory at The Natural History Museum, London. 50mg of finely drilled bone powder was utilised, and DNA extracted following Dabney et al. (2013), but with the the Zymo-Spin V column binding apparatus replaced with a high pure extender assembly from the High Pure Viral Nucleic Acid Large Volume Kit (Roche). Library preparations followed a modified version of the Meyer and Kircher (2010) protocol: the initial DNA fragmentation step was not required; all clean-up steps used MinElute PCR purification kits (Qiagen). The index PCR step used AmpliTaq Gold DNA polymerase and the addition of 0.4mg/mL BSA. The index PCR was set for 20 cycles with three PCR reactions conducted per library. The library was sequenced on an Illumina NextSeq platform (The Natural History Museum, London) using a NextSeq 500/550 Mid-Output v2 Kit (150 cycles).

Bioinformatics
AdapterRemoval (Lindgreen, 2012) was used to trim residual Illumina adapter sequences and low quality bases, with paired end reads longer than 25 bases merged with a minimum overlap of 11 bases. Quality trimmed, merged only reads were then aligned to a human reference genome (hg19) using BWA (Li and Durbin, 2009), with minimum base quality set to phred scale 15. SAMtools (Li et al., 2009) was used to further filter the mapped reads by map quality value 30 and remove all duplicates. Endogenous DNA content was determined through the number of filtered, quality (30), non-duplicate reads aligning to the human genome divided by the total number of reads. The endogenous DNA content of sample 8256 was found to be 0.02% (Barnes and Brace, *pers. comm.*).

<u>Samples 8257 and 8267:</u>
DNA extraction and library preparation were carried out in dedicated ancient DNA facilities at Harvard Medical School, Boston, following a standard screening process previously reported (Haak et al., 2015). Samples were cleaned by removing the outer layer of bone using a Dremel sanding disk, followed by overnight exposure to UV light. Powder was produced by crushing the cleaned bone using a mortar and pestle. 75mg of powder was utilised, and DNA extracted following Dabney et al. (2013) but with the the Zymo-Spin V column binding apparatus replaced with a high pure extender assembly from the High Pure Viral Nucleic Acid Large Volume Kit (Roche). Library preparations were performed following Rohland et al. (2015), using a partial UDG treatment. This treatment repairs C->U damage in the interior of the DNA molecule, while leaving a fraction of damage intact at the terminal nucleotides of the molecule in order to enable tests of ancient DNA authenticity.

Following amplification, libraries were evaluated on a BioAnalyzer to assess library preparation success. Both samples exhibited signs of inhibition during library preparation, demonstrated by flat BioAnalyzer traces. The libraries were therefore not brought forward in the ancient DNA screening process, as inhibition of the library prevents the acquisition of useful DNA sequences from samples. Thus, no informative genetic data could be obtained from either sample (Reich and Harney, *pers. comm.*).