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BONE PRE-TREATMENT BY ULTRAFILTRATION
A REPORT ON UNINTENDED RADIOCARBON AGE OFFSETS INTRODUCED BY THE METHOD

SCIENTIFIC DATING REPORT

Christopher Bronk Ramsey, Thomas F G Higham, and Jessica A Pearson

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SUMMARY

Bone samples for radiocarbon dating undergo pre-treatment to extract original proteins from the bone and to exclude contaminants. Ultrafiltration is an extra stage in this process which further purifies the proteins and was first developed in 1988 (Brown *et al* 1988). In 2000 the Oxford Radiocarbon Accelerator Unit (ORAU) adopted this method for the pre-treatment of bone in order to improve the accuracy of its dating. Diagnostics of protein purity, including CN ratio, and background measurements all indicated that the method was working well. However, in 2002 it became apparent that the accuracy of dates, particularly those younger than 10,000 years old, was in some instances, being affected by the technique because of traces of contaminants from the filters themselves. A new method of preparing and testing the filters was developed (Bronk Ramsey *et al* 2004) and a programme of re-dating started.

Despite the purity of protein resulting from the original method, the remaining filter-derived contaminants (averaging 1.5%) were very different in age from the samples and this produced age offsets averaging 120 years. The effect was size dependent and greatest for samples yielding <10mg collagen. However, even samples >10mg collagen had an average age offset of 100 years and only above about 30mg does the average offset fall to 55 years. The effect is also seen to be very variable.

The original ultrafiltration method used between 2000 and 2002 represented a regressive step in terms of the accuracy in dating bones < 10,000 years old. The method did, probably, produce accurate results in comparison to other methods for bones between 10,000 and 15,000 years old, although producing slightly older rather than slightly younger dates. The only significant improvement was apparent in bones in excess of 15,000 years old.

The implementation of new cleaning protocols (Bronk Ramsey *et al* 2004; Brock *et al* 2007) has resulted in a significant improvement in the routine application of the technique at ORAU.

CONTRIBUTORS

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We would like to thank the all the archaeologists who submitted the samples considered in this study, both for their forebearance and patience whilst we traced and resolved the flaws in the original ultrafiltration protocol and for providing additional material that allowed us to re-date so many specimens from new bone samples. We also thank Johannes van der Plicht for providing the measurements reported in Appendix II so swiftly. We are also very grateful to the technical staff at ORAU who worked so hard to help resolve the issues and undertake repeat analyses.

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INTRODUCTION

A method of pre-treatment is necessary when dating bone by radiocarbon to remove the mineral components of the bone (since they are susceptible to exchange with CO_2 in groundwater and air), and other contaminants (for example humic acids from the soil). Basic pre-treatment involves the use of acid and alkali rinses to remove these major components. Gelatinisation of the bone (Law and Hedges 1989) is a process that then puts the remaining collagen proteins into solution, which can be freeze-dried prior to radiocarbon dating. This method has been used in most radiocarbon laboratories including the Oxford Radiocarbon Accelerator Unit (ORAU) where it is given the method code "AG".

Ultrafiltration was first used for radiocarbon bone pre-treatment in 1988 (Brown *et al* 1988) and has subsequently been adopted by a small number of laboratories around the world. In this technique, after gelatinisation, the solution is filtered so that only the large molecular components remain. This allows the separation of well-preserved collagen from other soluble components with smaller molecular weight (typically degraded collagen and other proteins, which may include contaminants). ORAU, in consultation with the originators of this technique, adopted the method in 2000 (see Bronk Ramsey *et al* 2000). This method is given the laboratory code "AF".

The benefit of the ultrafiltration method is most apparent with older bones where the removal of small amounts of more recent contamination makes a significant difference to the age (see Jacobi *et al* 2006; Higham *et al* 2006a, –b). However, in 2002 it became apparent that the method as originally implemented also had disadvantages in that older contamination (low radiocarbon content, of geological origin) was introduced. Although the quantity of contamination was small (on average 1–2% of the total) it significantly affected the ages. It may be that this older contamination was only present in filters produced in this period, as subsequent measurements (Brock *et al* 2007) have found that the filters sometimes have humectant which is modern (of organic origin).

PROBLEMS WITH DATES PERFORMED BY ULTRAFILTRATION

Eight measurements were performed in 2002 for English Heritage by ORAU on known-age bone as part of a blind test to look at the reliability of bone measurements. Most dates showed a significant bias to older ages. This obviously raised the possibility that other dates might have been in error in a similar way.

Subsequent investigations at ORAU found that there was a systematic pattern indicating that bones dated with low collagen yields often seemed to give older dates than higher yield samples from the same contexts. Since the known-age bones also had low yields it was suspected that this was also the problem in this case. All other bones with low yields (typically less than 10mg collagen) were reassessed in the light of this evidence and dating using this method was stopped. At that time, repeat measurements on the English

Heritage and other known-age samples confirmed that when the collagen yield was high (>40mg collagen) the results were in agreement with the expected age. The original assessment was that there was a fairly constant 25–30µg of carbon introduced by the method giving an offset in age of 60 years for samples with a collagen content of 10mg, and in inverse proportion to the collagen quantity (for example, 30 years for 20mg of collagen and 120 years of 5mg collagen).

Investigation of the problem revealed that the reason for these offsets was that humectants (glycerol) present in the ultrafilters were not removed by following the manufacturer's instructions, or the methods employed by the researchers who first introduced this method (Brown *et al* 1988) and adopted by ORAU in 2000. A new method of preparation and testing the filters was therefore developed and tested on known-age bone at a whole range of possible collagen yields.

Following these developments ORAU started a program of re-dating for English Heritage and other submitters, concentrating on the samples with the lowest collagen yield that were likely to be most affected. These measurements showed the offsets to be present in a high proportion of samples. The scale of the effect was on average higher than had been estimated from the initial results, and was also found to be highly variable. Additionally it seemed that samples with an 'intermediate' collagen-yield (*c* 10–35mg) were also likely to be significantly affected.

The details of the new method and the nature of the problem with the original method were reported in September 2003 at the 18th International Radiocarbon Conference (Bronk Ramsey *el al* 2004). From the first stages of the re-dating exercise it was concluded that the average offset might be as high as 100 years until the collagen yield was above 40mg. Consequently, it was decided to conduct a more extensive re-dating exercise on all of the English Heritage samples dated using the original method to get an extensive data-set with which we could assess the inaccuracies due to the method. Small biases in the reported results was particularly important for many of the sites funded by English Heritage because a large proportion of measurements were included in large-scale Bayesian models that produced high-resolution chronologies. This report covers the result of that re-dating process.

DATING METHODOLOGIES

For the re-dating, two main methods were employed at ORAU. These are the revised ultrafiltration method and the re-ultrafiltration of collagen generated using the original methodology.

The original ultrafiltration method

This original ultrafiltration method is documented in Bronk Ramsey *et al* (2000) and was applied to all bone samples with the AF, or AF* pre-treatment codes with results in the range OxA-9361–11851 and OxA-12214–36. The AF* pre-treatment code indicates that a solvent extraction has also been applied to the sample, often to remove particular contaminants.

Revised ultrafiltration method

Details of the revised ultrafiltration method are published in Bronk Ramsey *et al* (2004). The main changes from the original method are:

- A considerably extended cleaning protocol for the filters.
- Monitoring of the residual carbon content of the filters.
- Routine tests on low and high collagen content samples of recent known age (in addition to background tests already routinely undertaken).

The results of the diagnostic tests and quality assurance data from this method are available in Brock *et al* (2007). The revised ultrafiltration method has been applied to all bones with the AF or AF* pre-treatment codes and with OxA numbers in the range OxA-11852–12213 and after OxA-12236.

Re-ultrafiltration

Given that the glycerol contaminant is highly soluble, and a small molecule, it is possible to remove it from prepared collagen by ultrafiltration using the new cleaning protocol. This approach means that re-sampling is not required for samples where there is sufficient pre-treated collagen (P-excess) remaining from when the original method was applied.

This approach was tested in two ways. One was to look at the material from Abingdon Spring Road Cemetery (Allen and Kamash 2008), where the most extreme age offsets had been initially observed; the other was to test the method on samples of known-age bone.

Four of the samples from Abingdon Spring Road Cemetery (P12847–50) were re-ultrafiltered and dated. During this process the eluent from the filter was examined and traces of glycerol could be seen suggesting high levels of the contaminant were indeed present. These highly contaminated samples provide an effective test of the re-ultrafiltration method. New bone samples were obtained from the same specimens, and re-dated from scratch, using the revised ultrafiltration protocol (Bronk Ramsey *et al* 2004).

Table 1: Measurements from the re-ultrafiltration of severely contaminated samples from Abingdon Spring Road Cemetery

	Original Measurement		Repeat measurement from new bone		Re-ultrafiltration of original P-excess	
Sample	Radiocarbon Age (BP)	Error	Radiocarbon Age (BP)	Error	Radiocarbon Age (BP)	Error
P12847	4073	39	3861	29	3901	31
P12848	2686	39	2286	26	2281	38
P12849	2600	45	2253	27	2357	26
P12850	2660	40	2301	27	2279	28

The results of these measurements are given in Table 1. All but the results on P12849 are within acceptable error limits. P12849 fails a χ^2 test when comparing the two repeat measurements (T′=7.7; ν=1; T′(5%)=3.8). Taken as a whole the six new dates on P12848–50, which are all expected to be of similar age, do easily pass a χ^2 test (T′=8.8; ν=5; T′(5%)=11.1) suggesting that P12849 may just be an outlier. However, taking the average of the re-ultrafiltered dates they are systematically 29 years older than the measurements on the samples which had been reprocessed from new bone, which is just significant at the 95% level. The average offset from the original measurements is 330 years, and so the re-ultrafiltration has removed about 91% of the contaminant. This makes sense, as 100% removal of the contaminant would be unlikely.

We have also tried to re-ultrafilter stored collagen, from pig bones recovered from the wreck of the *Mary Rose*, which has already been ultrafiltered (by the new method – so it should contain no glycerol) to see if this gives rise to any significant offsets. We performed the test on three aliquots. The results are (from wheel 2044):

Table 2: Results from re-ultrafiltration of collagen from known-age pig bones from the Mary Rose

Collagen used (mg)	Collagen extracted (mg)	Radiocarbon Age (BP)	Error
7.1	6.15	327	25
10.3	8.9	312	26
13.9	11.6	335	24

These tests are all on samples which yielded collagen towards the lower limit of what we consider acceptable (Bronk Ramsey *et al* 2004). Despite this the results are in good agreement with each other and with the expected radiocarbon age (311 BP), the average offset from the calibration curve value being 14 radiocarbon years which is not significant.

The re-ultrafiltration method in this form has been applied to bone samples with the NRC (non-routine-chemistry) pre-treatment code and with special OxA-X numbers (X denoting experimental).

These results suggested that to provide the best estimate for the age of a sample the following be undertaken:

1. Calculate the shift from the original measurement and add an extra 10% shift (using the 91% result from above)
2. Add in an additional error term of 20 years in quadrature to take account of any variation.

Applied to the results for Abingdon Spring Road Cemetery, this entirely removes any bias between the re-measurement and the re-ultrafiltration and it brings all pairs into agreement at the 95% confidence level. Most of the repeat measurements have offsets significantly less than 300 years and so the corrections are, in those cases, relatively small. Such corrections have been applied where bone samples have the NRC pre-treatment code and normal OxA numbers (without the –X suffix).

If the original measurement is ro ± σo, the repeat measurement is rn ± σn, then the corrected date is given by:

$$r_c = r_n - 0.1(r_o - r_n)$$

$$\sigma_c = \sqrt{(\sigma_n^2 + 20^2)}$$

The effectiveness of this approach will be discussed further in light of the re-dating exercise.

RESULTS

The results of the re-dating exercise are given in Appendix I. In most instances the measurements were repeated at ORAU, but for some samples duplicate measurements were obtained from the Centrum voor Isotopen Onderzoek, Rijksuniversiteit Groningen. These samples dated at Groningen were pre-treated to collagen using the Longin method (see van der Plicht *et al* 2000 for a summary of laboratory procedures) and without ultrafiltration. In some instances results are available from both laboratories and these provide a further inter-comparison test. The results of these inter-comparisons are shown in Appendix II.

DISCUSSION

This dataset is very useful in providing a comprehensive characterisation of the effect of the contaminants on the measurements obtained. It is particularly useful to look at the results in relation to sample size and age.

Overall there are 216 samples that have results obtained using both the original ultrafiltration method, and the methods described above. On average, the offset observed is 120±121 radiocarbon years. The large variation is problematic as 121 years corresponds to about 1.5% contamination from carbon free of radiocarbon.

Scale of offset versus sample size

The first analysis that we consider in relation to these results is the effect of the offset in relation to sample size. Figure 1 shows a plot of the offset versus sample size and a marked relationship is clearly apparent. When the effect was first observed in 2002 it was thought that this might be a mass-dependent effect with an inverse relationship against the weight of collagen. Based on the offsets of some of the lowest collagen yielding samples this was estimated to be 120 years at 5mg, 60 years at 10mg, and only 30 years at 15mg. This estimate is shown as a dotted line in Figure 1. Although the very lowest collagen samples do lie on this line, the effect is, on average, higher for intermediate size samples than originally estimated. Overall, the effect of the offset in relation to sample size shows a roughly logarithmic dependence (Figure 1; solid trend-line).

We can also characterise the results in terms of ranges of sample size where there are enough samples to do this. These results are shown in Table 1 and Figure 1. It can be clearly seen that the largest effect is indeed in the samples with the lowest collagen yield. However, it is not until the collagen yield rises above 30mg that the average effect becomes comparable to the error term given for the radiocarbon ages (which is on average 40 BP).

Effect of offsets versus sample age

Figure 2 shows a plot of the results reported here against radiocarbon age. There is no discernable trend. This is not surprising; the addition of a proportion of radiocarbon-free contaminant should theoretically produce the same age offset regardless of the age of the samples and so we would expect the average size of the effect to be 120 years at any point on the radiocarbon time-scale.

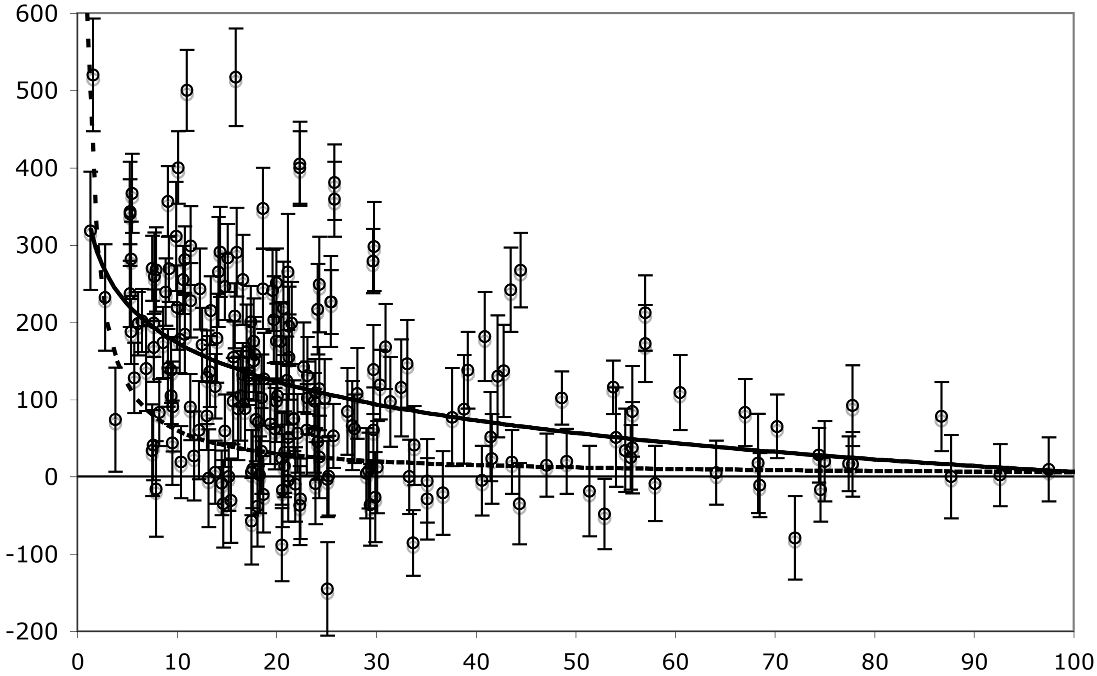

Figure 1: Plot of offsets in the ages (radiocarbon years) as a function of collagen yield (mg); the dotted trend line shows the original estimate of the scale of the offset based on the smallest samples in 2002; the solid logarithmic trend line gives a better indication of the average effect

Table 3: Analysis of offsets caused by the original ultrafiltration method as a function of collagen yield

Yield ranges				Yields greater than				Summary			
Range (mg)	Offset (BP)	σ	n	Range (mg)	Offset (BP)	σ	n	Range (mg)	Offset (BP)	σ	n
0–10	204	117	33	>10	105	116	183	All	120	121	216
10–20	146	125	65	>20	82	104	118				
20–30	108	121	60	>30	55	121	58	<10	204	117	33
30–40	57	76	15	>40	54	76	43	>10	105	116	183
40–50	88	97	13	>50	39	61	30				
50–60	60	80	11	>60	28	44	19				
								10–40	120	121	140
								<40	136	125	173
								>40	54	76	43

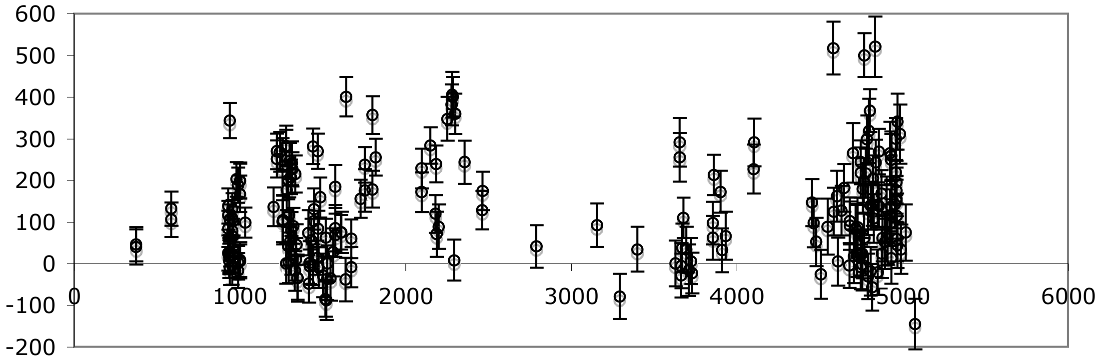

Figure 2: Plot of the offsets as a function of radiocarbon age

Although the size of the offset remains constant with time, the significance does not. This is mostly because the quoted uncertainty increases with age. For this period the average error (σ) estimate quoted by ORAU follows an approximately exponential dependency on radiocarbon age (r):

$$\sigma < \exp(0.00008\ r)$$

In addition, it is important to realise that this method must be compared to others available at that time. The most recent radiocarbon inter-comparison exercise (phase II of VIRI) indicates that for well-preserved bone of approximate radiocarbon age 40,000 BP, the inter-quartile range of AMS measurements (using principally the Longin (1971) method) is 4000 years. This represents the equivalent of about 0.4% modern contamination that has not been removed by the methods employed. It should be pointed out that this bone is much better preserved than many archaeological bones and so the remaining contamination may be much greater in some cases. Although the offset is given in terms of 'modern' contamination, in practice this is more likely to be due to a larger proportion of older contamination present in the samples. Ultra-filtration, on the other hand gave a much tighter range of measurements in the VIRI inter-comparison.

If we consider the effect of 0.4% of modern contamination on bones, this will have an effect that is much greater for older samples than for young ones and indeed this is why most of the development work on ultrafiltration concentrated on the dating of old bones (ie older than 15,000 years). Figure 3 attempts to put this information into context. The grey lines show the approximate error terms for samples of increasing age. The black solid line shows the average offset to older ages that seems to be present in samples measured using the original ultra-filtration method. The dotted black line shows the effect of 0.4% modern contamination on a bone sample.

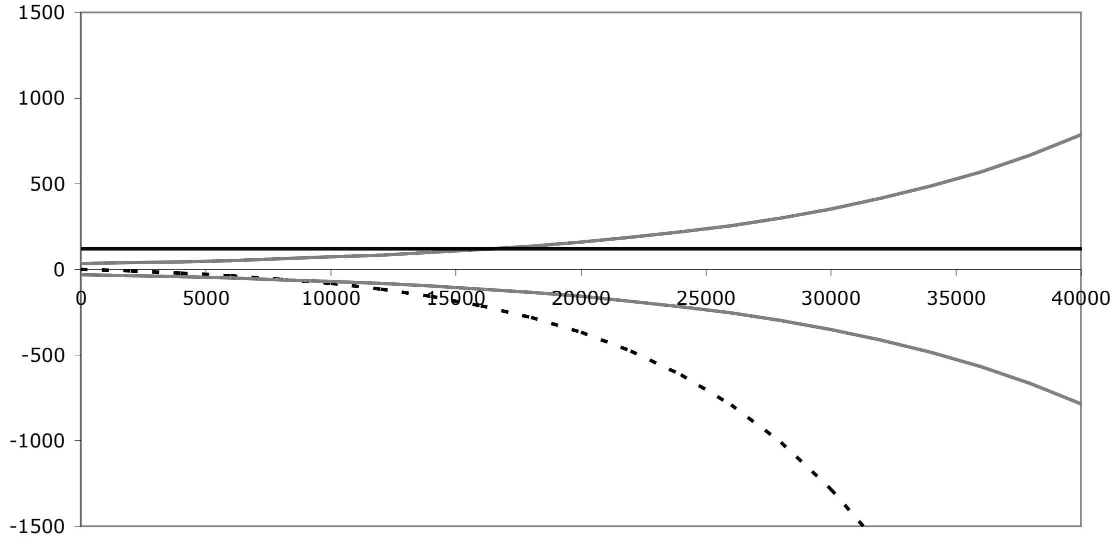

Figure 3: Plot showing (in solid black) the average expected offset from the original ultrafiltration method, (in grey) the typical error limits on radiocarbon dates measured by the method and (in dotted black) the effect of 0.4% of modern contamination on a bone sample

Figure 3 shows what we have already seen above. For recent samples, despite its ability to remove contaminants, the original ultrafiltration method is expected to be much less accurate for recent bones than other methods. For samples older than 10,000 years ago the limitations of different methods probably become more comparable, although the ultrafiltration method will tend to give dates that are slightly too old rather than being too young, at least in these intermediate age ranges. For samples that are in excess of 20,000 years old the offset becomes small in comparison to the quoted error term and the benefits of the method almost certainly outweigh the disadvantages, even of the original ultrafiltration method.

Ability of diagnostic tests to distinguish offset

There are diagnostic tests that are routinely used in radiocarbon laboratories to look for contamination of samples (see van Klinken 1999). These include the CN ratio and, to a lesser extent, stable isotope values. However, in this instance these measures give no indication of contamination. Comparison of the CN ratio of the samples undergoing the original ultrafiltration method (3.20±0.09), and those repeated using the newer methods, or by re-ultrafiltration (3.28±0.09), show there is a very slight difference but not one that could be used for individual samples to suggest the presence of contamination. Figure 4 shows the relationship between the original CN ratios and the observed offsets; there is no clear trend in the data, other than samples with very high CN ratios are slightly more offset. Likewise, the carbon isotopic values shift by only –0.1±0.4‰ with the repeat measurements.

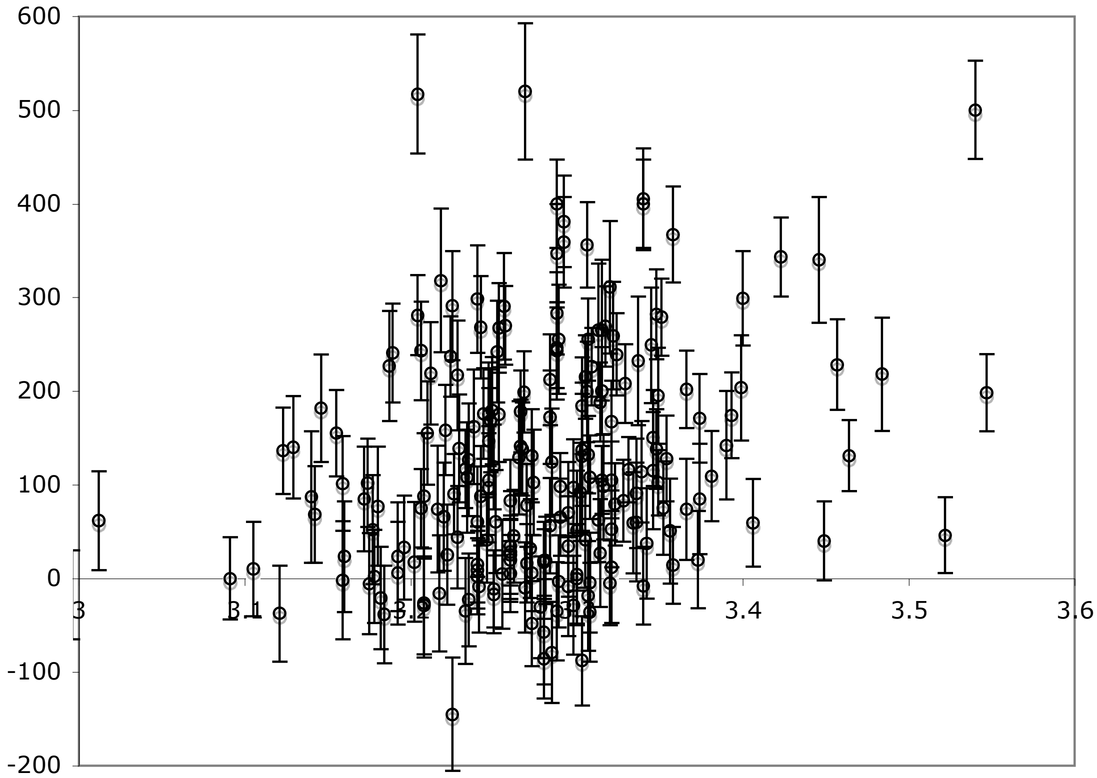

Figure 4: Plot of offset in original dates against the CN ratio of the collagen

Such an interpretation makes sense as the levels of contamination are low in proportional terms. For example, the effect of a collagen contaminant with no nitrogen and a stable isotope value 10‰ different from that of the sample. A 1.5% addition of such a contaminant to a sample would only be expected to shift the CN ratio by about 0.05 and the stable isotope ratio by 0.15‰.

These measures are useful for seeing contaminants at the 5% level and above but not low-level contaminants of radically different age. Paradoxically in this case the collagen is probably very pure (98%); it is the difference in age of the remaining low-level contaminants that is the problem.

Effectiveness of the re-ultrafiltration method

When repeating the radiocarbon measurement, it is clearly preferable if the original object does not have to be re-sampled. In many of the repeat measurements reported here re-ultrafiltration of collagen generated by the first pre-treatment has been used instead. For a number of samples independent measurements have been obtained, using the Longin (1971) method at Groningen, or from samples dated from new bone samples using the revised ultrafiltration method.

There are ten examples, in Appendix II, where samples have been re-ultrafiltered and also measured at other laboratories. The error weighted average offset between these two datasets is –1±18 BP (that is the re-ultrafiltered ages are 1 year younger on average) and the offsets pass a χ^2 test (T'=9.7; ν=9; T'(5%)=16.9).

In addition there are samples submitted to the laboratory that are in fact duplicates. These can be used as further checks of the method. The results from the duplicate samples are shown in Table 4. There are five further comparisons to be added to those from the inter-laboratory comparison above. The overall error weighted offset of the NRC method, compared to measurements performed from new bone is –9±13 BP (that is the re-ultrafiltered ages are 9 years younger on average) and the offsets pass a χ^2 test (T'=10.4; ν=14; T'(5%)=23.7).

Table 4: Samples that are duplicates and have therefore given results that can be directly compared

Equivalence	Comparison 1				Comparison 2			
	OxA	Method	Age (BP)	±	OxA	Method	Age (BP)	±
P11156=P12264	13146	NRC	1305	33	13247	AF	1325	23
P12266=P11159	13248	NRC	1284	31	13234	AF	1310	24
P12266=P11160	13248	NRC	1284	31	13235	AF	1299	23
P11155=P12270	13163	NRC	1614	34	12276	AF*	1641	26
P11155=P11155	13163	NRC	1614	34	13177	AF	1610	24
P11152=P12267	13161	NRC	1576	37	13249	NRC	1487	31
P11154=P12269	13162	NRC	1640	37	13249	NRC	1575	40

The final two pairs of measurements in Table 4 are duplicates and pass χ^2 tests (T'=3.4 and T'=1.4 respectively; ν=1; T'(5%)=3.8 for both).

Other intercomparisons

There are another eight results listed in Appendix II where there are measurements from other laboratories that can be used for direct comparison. The error weighted offset of these is –15±16 BP (that is the ultrafiltered ages are 15 years younger on average) and the offsets pass a χ^2 test (T'=13.6; ν=7; T'(5%)=14.1). Within the error limits there are no discernible differences, and the newly ultrafiltered results are comparable with results measured using the Longin method.

CONCLUSIONS

This re-dating exercise has essentially confirmed the findings reported in Bronk Ramsey *et al* (2004) where it was suggested that the average offset due to the original ultrafiltration method in use at ORAU between 2000 and 2002 might well have been as high as a 100 years, to the old side, until the yield rose above 40mg collagen. In practice the offsets for samples yielding less than 10mg collagen averaged about 200 years but even those greater than 10mg had an average offset of about 100 years, only reducing to an average of 55 years above about 30mg collagen. The overall average offset seems to have been about 120 years, however, it is also very variable with some shifts being much greater than the average and some very minimal. This precludes a precise correction factor.

With hindsight the introduction of this method in its original form, although yielding high purity collagen reduced the accuracy of the ages significantly and was retrograde, certainly for samples less than 10,000 years old. For older samples the advantages of the removal of traces of modern contamination, and the average 120 year offset becomes much less significant in relation to the quoted error terms. Thus, for samples > 10,000 year old the method was probably at least as good as other available methods, and a marked improvement in the case of older samples (>15,000 years old). Only with the revision of the method after 2002 (Bronk Ramsey *et al* 2004), was the ultrafiltration method properly suited to the accurate AMS dating of samples of all ages.

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APPENDIX I: RESULTS OF THE REDATING PROGRAMME

In this table we show all of the measurements made for English Heritage using the original ultrafiltration method (all have been withdrawn, except those marked *, which have been retained since they are either statistically consistent with replicate measurements or with other measurements from the same archaeological feature or, in a few cases, were published before re-analysis could be undertaken), and the results of their re-measurement either using the revised ultrafiltration method, or from re-ultrafiltered excess collagen, or other independent methods at other radiocarbon laboratories.

Pno.	Site	Original result (withdrawn)*						New result						
		OxA	Yield	CN	$\delta^{13}C$	Age	±	OxA	Method	Yield	CN	$\delta^{13}C$	Age	±
12845	Abingdon Spring Road Cemetery	11221	72.0	3.3	-21.6	3215	45	12376	AF	34.3	3.2	-21.8	3294	30
12846	Abingdon Spring Road Cemetery	11222	77.8	3.3	-22.1	3248	34	12377	AF	86.0	3.2	-20.9	3156	40
12847	Abingdon Spring Road Cemetery	11119	57.0	3.3	-21.7	4073	39	12100	AF	41.0	3.2	-21.8	3861	29
12847	Abingdon Spring Road Cemetery	11119	57.0	3.3	-21.7	4073	39	X-2037-15	NRC1	10.0	3.3	-21.3	3901	31
12848	Abingdon Spring Road Cemetery	11120	22.3	3.3	-19.9	2686	39	12101	AF	28.3	3.1	-20.0	2286	26
12848	Abingdon Spring Road Cemetery	11120	22.3	3.3	-19.9	2686	39	X-2037-16	NRC1	13.3	3.3	-19.4	2281	38
12849	Abingdon Spring Road Cemetery	11121	18.6	3.3	-20.0	2600	45	12102	AF	27.3	3.1	-20.2	2253	27
12849	Abingdon Spring Road Cemetery	11121	18.6	3.3	-20.0	2600	45	X-2037-17	NRC1	10.4	3.3	-19.6	2357	26
12850	Abingdon Spring Road Cemetery	11122	25.8	3.3	-20.1	2660	40	12103	AF	37.0	3.1	-20.3	2301	27
12850	Abingdon Spring Road Cemetery	11122	25.8	3.3	-20.1	2660	40	X-2037-18	NRC1	16.0	3.3	-19.6	2279	28
12342	Antler Macehead-Attenborough	10744	31.4	3.2	-21.7	4560	45	13208	NRC	21.3	3.2	-21.9	4463	37
12338	Antler Macehead-Duggleby Howe	10743	21.0	3.3	-22.0	4710	40	13327	NRC	8.9	3.1	-22.2	4586	40
12337	Antler Macehead-Liffs Low	10742	8.1	3.3	-22.2	4445	45	Withdrawn but not repeated						
12335	Antler Macehead-Windmill Lane	10740	29.0	3.3	-21.8	4615	45	13207	NRC	19.1	3.1	-21.9	4611	37
12336	Antler Macehead-Windmill Lane	10741	9.6	3.3	-21.8	4775	45	13440	AF	6.3	3.6	-22.2	4684	37
13499	Barnetby le Wold	11648*	10.2	3.3	-19.7	2072	37	Not repeated, probably slightly too old						
12288	Barton-upon-Humber/St Peter's	10624	53.8	3.3	-19.7	1046	23	12373	AF	31.6	3.2	-19.4	930	26
12289	Barton-upon-Humber/St Peter's	10625	23.8	3.3	-19.5	1130	24	12374	AF	24.0	3.2	-18.5	1032	27
12290	Barton-upon-Humber/St Peter's	10626	48.6	3.3	-19.0	1062	24	12375	AF	31.5	3.2	-19.6	960	25
12291	Barton-upon-Humber/St Peter's	10670	17.2	3.5	-19.9	1086	23	12247	AF	37.9	3.2	-19.7	955	30
12292	Barton-upon-Humber/St Peter's	10627	7.7	3.3	-19.8	1202	35	12248	AF	67.6	3.1	-19.8	1003	26
12292	Barton-upon-Humber/St Peter's	10627	6.1	3.5	-20.6	1201	32	12248	AF	67.6	3.1	-19.8	1003	26
11370	Berwick Castle Terrace	9952	20.1	3.3	-18.7	692	32	15176	AF	46.6	3.2	-18.4	587	26

Pno.	Site	Original result (withdrawn)*						New result						
		OxA	Yield	CN	$\delta^{13}C$	Age	±	OxA	Method	Yield	CN	$\delta^{13}C$	Age	±
11370	Berwick Castle Terrace	9952	16.6	3.3	-18.7	719	32	15176	AF	46.6	3.2	-18.4	587	26
10993	Binchester Roman Fort	9532*	44.4	3.3	-19.9	1315	34	7639	AG	25.6	3.5	-21.7	1350	40
10993	Binchester Roman Fort	9667*	14.6	3.2	-20.3	1315	40	7639	AG	25.6	3.5	-21.7	1350	40
13068	Chambers Wharf	11142*	252.0	3.4	-16.7	415	33	X-2204-36	NRC	4.9	3.1	-17.7	372	25
11094	Eton Rowing Lake	9857	5.3	3.4	-22.1	5310	50	GrA-22561	Longin				4970	45
11096	Eton Rowing Lake	9858*	12.2	3.3	-20.0	4970	45	GrA-22560	Longin				4910	45
11092	Eton Rowing Lake	9670*	3.5	3.4	-21.8	5295	70	Not repeated, probably slightly too old						
12273	Fussell's Lodge	10689	36.7	3.2	-23.1	4830	40	13205	NRC	26.3	3.2	-22.8	4851	37
12274	Fussell's Lodge	10600	10.5	3.2	-21.2	4975	45	Withdrawn but not repeated						
12275	Fussell's Lodge	10601	37.6	3.2	-21.9	4805	40	13173	NRC	29.9	3.2	-21.7	4728	49
12275	Fussell's Lodge	10601	38.8	3.1	-21.7	4815	50	13173	NRC	29.9	3.2	-21.7	4728	49
12276	Fussell's Lodge	10603	41.6	3.2	-21.2	4900	45	13206	NRC	30.6	3.2	-20.8	4877	37
12277	Fussell's Lodge	10604	20.5	3.2	-22.3	4780	45	13326	NRC	19.9	3.1	-21.7	4757	39
12277	Fussell's Lodge	10604	13.2	3.2	-22.2	4755	50	13326	NRC	19.9	3.1	-21.7	4757	39
12278	Fussell's Lodge	10606	9.5	3.2	-20.3	5015	45	12277	AF*	21.1	3.2	-20.6	4971	31
12279	Fussell's Lodge	10607	25.1	3.2	-20.3	4930	45	13174	NRC	17.6	3.3	-20.7	5075	40
12280	Fussell's Lodge	10667	3.8	3.2	-20.1	5095	60	12278	AF*	22.9	3.2	-20.6	5021	31
12281	Fussell's Lodge	10608	11.2	3.3	-20.8	5200	40	Withdrawn but not repeated						
12282	Fussell's Lodge	10609	7.9	3.2	-21.0	5125	45	12279	AF*	29.3	3.2	-20.8	4857	31
12283	Fussell's Lodge	10610	6.7	3.2	-20.6	4940	50	Withdrawn but not repeated						
12284	Fussell's Lodge	10611	7.5	3.3	-20.5	5025	50	12280	AF*	13.0	3.1	-20.4	4991	32
12285	Fussell's Lodge	10668	3.0	3.4	-21.1	5345	60	Withdrawn but not repeated						
12286	Fussell's Lodge	10669	2.2	3.3	-21.1	5130	55	Withdrawn but not repeated						
12287	Fussell's Lodge	10612	6.9	3.1	-21.1	4990	45	12281	AF*	19.2	3.2	-20.7	4850	31
13209	Fussell's Lodge, Long Barrow	11376	22.7	3.4	-20.1	5097	40	13185	NRC	13.7	3.2	-20.6	4955	42
13210	Fussell's Lodge, Long Barrow	11377	19.7	3.4	-20.0	5027	40	13186	NRC	9.4	3.4	-20.4	4824	39
13211	Fussell's Lodge, Long Barrow	11425	21.2	3.4	-20.2	4945	40	13329	NRC	14.2	3.2	-20.3	4894	39
13212	Fussell's Lodge, Long Barrow	11426	15.6	3.3	-20.2	5030	45	13187	NRC	8.6	3.4	-20.6	4932	34
13213	Fussell's Lodge, Long Barrow	11427	11.4	3.4	-20.5	4990	45	Withdrawn but not repeated						
13214	Fussell's Lodge, Long Barrow	11428	14.8	3.3	-20.0	4840	45	Withdrawn but not repeated						
13215	Fussell's Lodge, Long Barrow	11429	20.8	3.3	-20.2	4940	40	Withdrawn but not repeated						

Pno	Site	Original result (withdrawn)						New result						
		OxA	Yield	CN	$\delta^{13}C$	Age	±	OxA	Method	Yield	CN	$\delta^{13}C$	Age	±
10984	Helicon Mosaic Aldborough	9981	58.0	3.2	-19.6	1666	37	15796	NRC	14.8	3.2	-20.0	1675	32
10984	Helicon Mosaic Aldborough	9981	14.8	3.4	-19.9	1734	34	15796	NRC	14.8	3.2	-20.0	1675	32
11694	Higham Ferrers, Northants	10125	13.2	3.3	-18.9	1095	45	Withdrawn but not repeated						
11747	Hillside Farm, Bryher	10185	12.5	3.4	-18.9	2269	39	12095	AF	18.3	3.2	-19.0	2098	27
11747	Hillside Farm, Bryher	10185	11.4	3.5	-19.1	2326	40	12095	AF	18.3	3.2	-19.0	2098	27
11027	Huntsmans Quarry	9742	3.6	3.3	-20.7	2990	60	Withdrawn but not repeated						
13243	Known-Age Bone	11520	5.4	3.3	-19.4	1177	34	16165	AF*	56.0	3.2	-19.6	989	25
13243	Known-Age Bone	11520	74.6	3.3	-19.6	972	33	16165	AF*	56.0	3.2	-19.6	989	25
13243	Known-Age Bone	11520	92.6	3.2	-19.6	991	32	16165	AF*	56.0	3.2	-19.6	989	25
13244	Known-Age Bone	11521	5.3	3.4	-19.4	1284	33	16166	AF*	68.4	3.2	-19.4	941	26
13244	Known-Age Bone	11521	77.8	3.3	-19.5	957	33	16166	AF*	68.4	3.2	-19.4	941	26
13244	Known-Age Bone	11521	68.5	3.3	-19.5	930	32	16166	AF*	68.4	3.2	-19.4	941	26
13245	Known-Age Bone	11522	7.7	3.3	-19.6	1168	36	16167	AF*	16.3	3.2	-19.7	1001	25
13245	Known-Age Bone	11522	64.1	3.3	-19.5	1006	33	16167	AF*	16.3	3.2	-19.7	1001	25
13245	Known-Age Bone	11522	97.5	3.2	-19.7	1010	33	16167	AF*	16.3	3.2	-19.7	1001	25
13246	Known-Age Bone	11523	6.5	3.4	-18.7	1182	32	16168	AF*	36.6	3.2	-18.8	980	26
13246	Known-Age Bone	12223	49.1	3.3	-18.7	977	33	16169	AF*	61.6	3.1	-18.8	957	26
13246	Known-Age Bone	12223	70.2	3.3	-18.5	1022	32	16169	AF*	61.6	3.1	0.0	957	26
13247	Known-Age Bone	11524	9.4	3.3	-19.2	1067	33	16170	AF*	32.9	3.2	-19.3	929	27
13247	Known-Age Bone	11524	67.0	3.3	-19.7	1012	34	16170	AF*	32.9	3.2	-19.3	929	27
13247	Known-Age Bone	11524	55.5	3.3	-19.6	954	32	16170	AF*	32.9	3.2	-19.3	929	27
13248	Known-Age Bone	11525	9.4	3.3	-19.1	1045	34	mean of replicates				940	13	
13248	Known-Age Bone	11525	74.4	3.3	-19.4	968	33	mean of replicates				940	13	
13248	Known-Age Bone	11525	77.4	3.3	-19.6	957	33	mean of replicates				940	13	
13249	Known-Age Bone	11526	23.9	3.3	-18.7	1063	33	16171	AF*	64.0	3.2	-18.8	955	30
13249	Known-Age Bone	11526	86.7	3.3	-19.0	1033	33	16171	AF*	64.0	3.2	-18.8	955	30
13249	Known-Age Bone	11526	40.6	3.3	-19.0	950	34	16171	AF*	64.0	3.2	-18.8	955	30
13250	Known-Age Bone	11527	13.8	3.3	-19.2	944	32	16172	AF*	38.0	3.2	-19.4	938	25
13250	Known-Age Bone	11527	43.6	3.3	-19.7	957	33	16172	AF*	38.0	3.2	-19.4	938	25
13250	Known-Age Bone	11527	47.1	3.2	-19.6	953	32	16172	AF*	38.0	3.2	-19.4	938	25

Pno.	Site	Original result (withdrawn)						New result						
		OxA	Yield	CN	$\delta^{13}C$	Age	±	OxA	Method	Yield	CN	$\delta^{13}C$	Age	±
	Silbury Hill	11970	87.7	3.3	-23.3	3634	30	GrA-27355					3630	45
12573	Silbury Hill	10818	20.0	3.3	-22.4	3953	34	13328	NRC	11.1	3.1	-22.6	3856	39
12573	Silbury Hill	10818	19.8	3.0	-22.3	3918	36	13328	NRC	11.1	3.1	-22.6	3856	39
12844	Silbury Hill	11187	14.3	3.2	-22.9	3946	37	GrA-27331	Longin				3655	45
12844	Silbury Hill	11188	16.6	3.3	-23.0	3910	37	GrA-27331	Longin				3655	45
13309	Silbury Hill	11490	55.0	3.3	-22.0	3435	40	13210	NRC	47.1	3.2	-22.1	3401	36
13311	Silbury Hill	11491	33.8	3.3	-20.2	2833	38	13211	NRC	20.4	3.2	-20.5	2792	34
13312	Silbury Hill	11492	20.8	3.3	-20.6	3945	40	13333	NRC	12.5	3.2	-20.8	3913	34
10969	Stonehenge	9361	24.8	3.2	-19.7	1359	38	13193	NRC	18.3	3.2	-19.5	1258	34
10969	Stonehenge	9361	2.8	3.3	-19.5	1490	60	13193	NRC	18.3	3.2	-19.5	1258	34
12494	Tarrant Hinton	10865	29.2	2.9	-19.6	2302	36	13209	NRC	13.3	3.1	-19.8	2294	34
12494	Tarrant Hinton	10864	17.7	3.1	-19.3	2270	36	Withdrawn but not repeated						
10124	Wardy Hill ringwork	10735*	11.1	3.3	-21.5	2370	29	Not repeated, probably slightly too old						
12250	Wayland's Smithy	10586	16.1	3.2	-21.9	4635	40	13168	NRC	8.8	3.3	-22.6	4547	54
12260	Wayland's Smithy	10597	23.0	3.2	-20.7	4830	45	13245	NRC	15.3	3.1	-20.8	4770	38
13216	Wayland's Smithy	11378	7.1	3.3	-20.6	4985	40	Withdrawn but not repeated						
13217	Wayland's Smithy	11379	55.7	3.4	-20.6	4802	38	13175	NRC	45.2	3.2	-20.7	4717	45
13218	Wayland's Smithy	11380	17.5	3.3	-20.6	4760	40	13330	NRC	10.7	3.2	-20.8	4817	39
13219	Wayland's Smithy	11381	51.4	3.3	-20.7	4790	39	13176	NRC	45.6	3.2	-20.8	4809	44
12253	Wayland's Smithy 1	10589	24.3	3.2	-20.5	4774	38	13203	NRC	16.8	3.2	-20.8	4749	38
12254	Wayland's Smithy 1	10590	4.4	3.4	-21.0	5260	45	Withdrawn but not repeated						
12255	Wayland's Smithy 1	10591	12.0	3.3	-21.1	4835	40	Withdrawn but not repeated						
12256	Wayland's Smithy 1	10592	4.6	3.3	-21.0	5055	45	Withdrawn but not repeated						
12257	Wayland's Smithy 1	10593	13.0	3.3	-20.6	4920	45	13170	NRC	5.6	3.4	-20.4	4791	40
12258	Wayland's Smithy 1	10594	17.4	3.3	-20.7	4890	45	Withdrawn but not repeated						
12248	Wayland's Smithy 1 + 2	10565	40.9	3.1	-20.7	4830	40	13167	NRC	9.0	3.4	-21.2	4649	41
12249	Wayland's Smithy 1 + 2	10566	18.5	3.3	-20.0	4785	40	13244	NRC	11.3	3.1	-20.5	4683	39
12251	Wayland's Smithy 1 + 2	10587	8.2	3.3	-21.0	4520	40	Withdrawn but not repeated						
12252	Wayland's Smithy 1 + 2	10588	18.7	3.2	-21.3	4760	40	13169	NRC	9.7	3.3	-21.6	4634	45
12259	Wayland's Smithy 2	10596	14.0	3.2	-20.7	4940	40	13171	NRC	7.5	3.3	-20.9	4761	41
12261	Wayland's Smithy 2	10598	17.0	3.2	-21.1	4765	50	13246	NRC	10.7	3.1	-21.2	4603	35
12262	Wayland's Smithy 2	10599	68.3	3.2	-20.7	4725	50	13325	NRC	56.5	3.1	-20.4	4707	40
11001	West Heslerton	10365	18.7	3.2	-19.9	3708	34	13194	AF	22.9	3.2	-20.3	3731	36

Pno.	Site	Original result (withdrawn)						New result						
		OxA	Yield	CN	δ13C	Age	±	OxA	Method	Yield	CN	δ13C	Age	±
11002	West Heslerton	10366	18.4	3.2	-19.9	3730	40	13148	NRC	4.8	3.3	-20.5	3697	39
11003	West Heslerton	10367	17.5	3.2	-19.5	3730	40	13149	NRC	5.0	3.3	-20.1	3725	38
11004	West Heslerton	9418	35.1	3.3	-20.6	3636	36	13150	NRC	22.3	3.2	-20.9	3665	39
11004	West Heslerton	9418	35.1	3.2	-20.3	3659	38	13150	NRC	22.3	3.2	-20.9	3665	39
11005	West Heslerton	10477	7.9	3.2	-21.1	3695	55	12132	AF	32.9	3.1	-21.4	3711	28
11051	West Heslerton	9419	29.4	3.3	-20.8	1512	33	13142	NRC	20.5	3.3	-21.1	1548	41
11052	West Heslerton	9420	17.9	3.4	-20.9	1487	33	13151	NRC	11.2	3.3	-21.6	1413	43
11053	West Heslerton	9421	14.5	3.3	-20.8	1414	34	13231	AF	50.5	3.2	-21.3	1422	24
11054	West Heslerton	9422	20.8	3.4	-20.3	1482	33	13232	AF	10.5	3.2	-20.7	1468	24
11055	West Heslerton	9436	8.2	3.3	-21.7	1556	36	12136	AF	24.6	3.1	-20.7	1473	25
11056	West Heslerton	9423	21.9	3.3	-20.8	1466	33	13152	NRC	15.3	3.3	-21.1	1476	35
11132	West Heslerton	9749	52.9	3.3	-20.9	1370	29	13153	NRC	22.3	3.3	-21.1	1418	35
11133	West Heslerton	9439	33.7	3.3	-21.3	1432	26	13195	NRC	20.8	3.2	-21.4	1518	34
11134	West Heslerton	9562	23.1	3.3	-20.9	1579	36	13143	NRC	9.3	3.1	-20.9	1448	34
11134	West Heslerton	9562	23.1	3.2	-21.0	1550	32	13143	NRC	9.3	3.1	-20.9	1448	34
11135	West Heslerton	9563	22.1	3.3	-21.1	1490	35	13154	NRC	14.6	3.3	-21.3	1434	37
11136	West Heslerton	9564	20.5	3.3	-21.6	1434	33	13155	NRC	13.0	3.3	-22.1	1522	34
11137	West Heslerton	9565	25.1	3.3	-21.6	1440	35	13144	NRC	14.1	3.2	-22.0	1443	34
11138	West Heslerton	9440	22.4	3.2	-21.4	1474	36	13156	NRC	14.1	3.2	-21.3	1503	38
11139	West Heslerton	9441	22.3	3.1	-21.9	1489	38	13157	NRC	14.3	3.3	-21.6	1526	34
11140	West Heslerton	9442	10.4	3.3	-21.9	1331	38	12239	AF	33.9	3.2	-22.0	1312	27
11141	West Heslerton	9443	17.6	3.1	-22.2	1348	36	13158	NRC	8.4	3.3	-21.7	1338	35
11142	West Heslerton	9444	18.3	3.2	-22.3	1297	36	13159	NRC	10.6	3.5	-21.9	1295	34
11143	West Heslerton	9445	7.6	3.2	-21.9	1334	36	12240	AF	11.4	3.2	-21.7	1293	28
11145	West Heslerton	9446	20.6	3.0	-22.0	1315	34	13160	NRC	12.6	3.3	-21.6	1333	34
11148	West Heslerton	9447	25.2	3.0	-22.2	1420	38	13145	NRC	15.0	3.2	-21.4	1419	35
11149	West Heslerton	9628	27.8	3.3	-21.4	1583	36	12275	AF*	33.2	3.2	-21.5	1521	26
11150	West Heslerton	9448	11.7	3.3	-21.3	1592	36	GrA-22822	Longin				1565	45
11151	West Heslerton	9449	15.2	3.1	-22.0	1531	36	13233	AF	7.4	3.2	-20.7	1531	25
11152	West Heslerton	9450	19.4	3.1	-21.2	1644	36	13161	NRC	12.8	3.3	-21.0	1576	37
11152	West Heslerton	9450	10.8	3.3	-22.0	1760	36	13161	NRC	12.8	3.3	-21.0	1576	37
11153	West Heslerton	10381	10.8	3.2	-22.3	1722	34	12090	AF	47.5	3.1	-22.1	1441	26
11154	West Heslerton	9452	18.1	3.2	-21.3	1601	37	13162	NRC	10.5	3.3	-21.3	1640	37

Pno.	Site	Original result (withdrawn)						New result						
		OxA	Yield	CN	$\delta^{13}C$	Age	±	OxA	Method	Yield	CN	$\delta^{13}C$	Age	±
11155	West Heslerton	9453	21.7	3.4	-21.4	1689	36	13163	NRC	7.0	3.4	-21.7	1614	34
11155	West Heslerton	10382	21.7	3.2	-21.6	1685	34	13177	AF	28.9	3.4	-21.5	1610	24
11156	West Heslerton	9454	25.7	3.3	-21.2	1358	25	13146	NRC	7.7	3.3	-21.3	1305	33
11157	West Heslerton	9455	33.3	3.3	-21.2	1280	35	13147	NRC	18.4	3.2	-21.2	1280	33
11157	West Heslerton	9455	5.4	3.3	-21.3	1562	35	13147	NRC	18.4	3.2	-21.2	1280	33
11158	West Heslerton	10851	15.8	3.3	-21.1	1517	33	12091	AF	28.0	3.2	-21.6	1309	26
11159	West Heslerton	10852	13.0	3.3	-22.2	1389	37	13234	AF	22.4	3.3	-21.8	1310	24
11160	West Heslerton	10383	13.8	3.2	-22.1	1416	35	13235	AF	33.1	3.1	-21.8	1299	23
11614	West Heslerton	9913	13.3	3.1	-20.0	1341	35	13178	AF	34.6	3.3	-20.0	1205	30
11617	West Heslerton	9914	5.3	3.2	-21.7	1992	34	12241	AF	29.0	3.2	-21.7	1755	26
11618	West Heslerton	9915	15.7	3.2	-21.3	1883	35	13196	AF	29.9	3.4	-21.5	1728	30
11619	West Heslerton	9916	10.3	3.3	-22.0	1980	36	12242	AF	22.4	3.2	-21.9	1802	25
11620	West Heslerton	9958	10.6	3.3	-20.8	2076	36	12243	AF	35.3	3.2	-21.2	1821	25
11621	West Heslerton	9959	9.1	3.3	-20.3	2158	36	12244	AF	38.8	3.2	-20.9	1802	28
11622	West Heslerton	9960	17.4	3.3	-18.9	1492	34	13273	NRC	8.3	3.1	-19.9	1292	32
11623	West Heslerton	9961	19.6	3.2	-20.9	1555	40	13164	NRC	10.8	3.3	-21.4	1314	34
11625	West Heslerton	9962	25.5	3.3	-21.4	1542	33	13236	AF	31.9	3.2	-20.8	1316	25
11626	West Heslerton	9963	20.4	3.3	-21.1	1928	38	13237	NRC	13.4	3.1	-20.8	1753	34
11627	West Heslerton	9964	13.4	3.3	-21.4	1551	34	13197	AF	11.9	3.4	-21.7	1336	29
11628	West Heslerton	9965	14.8	3.3	-20.8	1548	35	12245	AF	28.4	3.2	-20.6	1302	25
11629	West Heslerton	9966	44.5	3.3	-20.6	1511	35	13238	NRC	13.4	3.1	-20.5	1244	33
11630	West Heslerton	9967	16.4	3.2	-20.5	1365	37	13166	NRC	10.2	3.2	-20.7	1261	45
11631	West Heslerton	9968	9.2	3.3	-22.1	1493	33	12246	AF	47.9	3.1	-22.3	1224	27
11631	West Heslerton	9968	20.0	3.0	-21.2	1475	35	12246	AF	47.9	3.1	-22.3	1224	27
12263	West Heslerton	10853	29.7	3.4	-21.6	1558	33	12097	AF	31.8	3.1	-21.6	1279	25
12264	West Heslerton	10413	11.3	3.2	-20.9	1415	36	13247	AF	54.0	3.1	-20.7	1325	23
12265	West Heslerton	10414	24.1	3.3	-21.5	1387	37	13204	NRC	16.4	3.2	-22.1	1342	33
12266	West Heslerton	10415	20.0	3.2	-21.6	1460	37	13248	NRC	12.8	3.1	-22.1	1284	31
12267	West Heslerton	10416	17.8	3.2	-20.7	1645	37	13249	NRC	10.5	3.1	-21.1	1487	31
12268	West Heslerton	10417	7.5	3.3	-21.6	1739	34	12098	AF	43.1	3.2	-22.5	1469	25
12269	West Heslerton	10418	27.1	3.2	-20.9	1660	39	13172	NRC	20.2	3.3	-21.4	1575	40
12270	West Heslerton	10419	10.1	3.3	-21.3	2041	39	12276	AF*	65.5	3.1	-21.5	1641	26
13318	West Heslerton	11517	8.6	3.4	-20.9	2641	37	12285	AF	10.8	3.2	-21.1	2467	27

Pno.	Site	Original result (withdrawn)						New result						
		OxA	Yield	CN	$\delta^{13}C$	Age	±	OxA	Method	Yield	CN	$\delta^{13}C$	Age	±
13319	West Heslerton	11518	5.7	3.4	-20.6	2590	37	12286	AF	16.3	3.2	-21.0	2462	27
13220	West Kennet	11382	9.1	3.3	-20.3	4960	40	12282	AF*	45.3	3.1	-20.2	4819	30
13221	West Kennet	11389	1.6	3.3	-20.7	5355	65	12283	AF*	28.4	3.1	-19.9	4835	33
13222	West Kennet	11383	21.5	3.3	-20.7	4966	38	13188	NRC	15.8	3.3	-20.4	4767	38
13223	West Kennet	11384	23.9	3.3	-21.1	4738	38	13331	NRC	16.1	3.1	-21.1	4747	37
13224	West Kennet	11390	1.3	3.2	-21.1	5115	70	12284	AF*	32.1	3.1	-20.5	4797	31
13225	West Kennet	11385	15.4	3.3	-20.8	4760	40	13332	NRC	9.7	3.1	-21.1	4791	37
13226	West Kennet	11386	21.2	3.3	-20.9	4676	37	13190	NRC	14.5	3.3	-21.0	4680	39
12046	West Kennet Chambered Tomb	10399	24.1	3.2	-20.7	4995	45	13179	NRC	17.1	3.3	-20.8	4778	38
12047	West Kennet Chambered Tomb	10400	29.7	3.2	-20.4	4945	45	13241	NRC	21.9	3.1	-21.7	4806	36
12048	West Kennet Chambered Tomb	10401	29.8	3.2	-20.5	5085	40	13180	NRC	21.7	3.3	-21.1	4787	41
12049	West Kennet Chambered Tomb	10402	16.0	3.3	-20.0	4395	45	13181	NRC	9.1	3.3	-20.5	4105	35
12050	West Kennet Chambered Tomb	10403	33.1	3.2	-19.0	4600	45	13182	NRC	23.9	3.4	-19.4	4454	34
12051	West Kennet Chambered Tomb	10490	29.9	3.2	-20.0	4480	45	13242	NRC	20.6	3.1	-20.1	4506	37
12052	West Kennet Chambered Tomb	10404	25.4	3.2	-20.6	4330	45	13183	NRC	18.8	3.4	-20.6	4103	38
12053	West Kennet Chambered Tomb	10405	41.5	3.2	-21.2	4530	45	13184	NRC	33.9	3.3	-21.2	4478	37
12054	West Kennet Chambered Tomb	10406	15.9	3.2	-21.1	5100	45	13243	NRC	9.0	3.1	-21.0	4583	45
12055	West Kennet Chambered Tomb	10463	43.5	3.3	-20.2	5080	40	13198	NRC	35.0	3.1	-20.5	4838	37
12056	West Kennet Chambered Tomb	10464	39.2	3.3	-20.3	4994	39	12652	AF	24.1	3.1	-20.6	4856	31
12057	West Kennet Chambered Tomb	10465	29.7	3.3	-20.0	4940	40	13199	NRC	22.4	3.2	-20.4	4880	38
12058	West Kennet Chambered Tomb	10466	30.9	3.2	-20.2	5040	40	13200	NRC	23.6	3.1	-20.6	4872	38

Pno.	Site	Original result (withdrawn)						New result						
		OxA	Yield	CN	$\delta^{13}C$	Age	±	OxA	Method	Yield	CN	$\delta^{13}C$	Age	±
12059	West Kennet Chambered Tomb	10467	28.1	3.2	-19.9	4935	45	13201	NRC	20.2	3.1	-20.6	4827	38
12060	West Kennet Chambered Tomb	10468	5.5	3.4	-19.6	5170	40	12653	AF	34.5	3.0	-19.6	4803	32
12061	West Kennet Chambered Tomb	10491	27.6	3.2	-23.0	4000	45	13202	NRC	16.2	3.1	-23.3	3934	36
13200	Whitegates Farm, Bleadon	11423*	16.8	3.2	-20.4	2290	40	14989	NRC	8.3	3.2	-20.6	2202	35
13201	Whitegates Farm, Bleadon	11424*	18.2	3.3	-20.4	2260	40	14990	NRC	10.2	3.2	-20.7	2190	36
13202	Whitegates Farm, Bleadon	11447	15.1	3.3	-20.3	2435	32	12378	AF	22.5	3.3	-20.8	2152	30
13203	Whitegates Farm, Bleadon	11448	8.9	3.3	-20.1	2424	32	12379	AF	18.9	3.2	-20.8	2185	30
13204	Whitegates Farm, Bleadon	11449	30.4	3.3	-19.4	2301	33	12380	AF	24.5	3.2	-20.1	2182	31
11035	Whitwell Quarry Long Cairn	9701	60.5	3.4	-20.8	3786	37	12758	AF	36.7	3.2	-20.9	3677	31
11036	Whitwell Quarry Long Cairn	9487	55.7	3.3	-19.5	3710	45	12759	NRC	37.6	3.2	-19.4	3673	38
11037	Whitwell Quarry Long Cairn	9768	75.0	3.4	-20.5	4745	40	12760	AF*	30.0	3.2	-20.7	4725	33
11038	Whitwell Quarry Long Cairn	9702	11.0	3.5	-20.9	5270	45	12133	AF*	42.4	3.2	-21.0	4770	27
11039	Whitwell Quarry Long Cairn	9650	14.2	3.3	-21.1	4965	55	GrA-22551	Longin				4700	45
11040	Whitwell Quarry Long Cairn	9651	30.1	3.3	-20.2	4945	50	12761	AF*	65.3	3.2	-20.8	4933	33
11040	Whitwell Quarry Long Cairn	9651	42.8	3.3	-20.3	5070	50	12761	AF*	65.3	3.2	-20.8	4933	33
11041	Whitwell Quarry Long Cairn	9653	54.0	3.3	-20.2	4945	55	12762	AF*	72.1	3.2	-20.8	4894	33
11042	Whitwell Quarry Long Cairn	9654	24.3	3.3	-20.2	5180	55	12134	AF	15.1	3.1	-21.1	4931	28
11042	Whitwell Quarry Long Cairn	9654	7.7	3.3	-20.5	5190	50	12134	AF	15.1	3.1	-21.1	4931	28
11043	Whitwell Quarry Long Cairn	9656	9.9	3.3	-20.6	5295	65	12135	AF*	33.0	3.2	-21.0	4984	28
11044	Whitwell Quarry Long Cairn	9657	21.1	3.3	-20.3	5190	65	12763	NRC	22.9	3.1	-20.4	4925	38
11044	Whitwell Quarry Long Cairn	9657	32.5	3.3	-20.2	5040	50	12763	NRC	22.9	3.1	-20.4	4925	38
11045	Whitwell Quarry Long Cairn	9659	42.2	3.3	-20.8	5035	65	GrA-22564	Longin				4905	45
11046	Whitwell Quarry Long Cairn	10217	23.8	3.3	-21.8	5025	45	12764	AF*	33.3	3.1	-21.0	4966	30
11046	Whitwell Quarry Long Cairn	10217	24.3	3.3	-21.2	5080	45	12764	AF*	33.3	3.1	-21.0	4966	30
11047	Whitwell Quarry Long Cairn	10371	11.4	3.4	-20.7	5260	40	12765	AF*	27.7	3.2	-20.6	4961	31
11047	Whitwell Quarry Long Cairn	10371	10.0	3.2	-20.7	5180	45	12765	AF*	27.7	3.2	-20.6	4961	31
11048	Whitwell Quarry Long Cairn	9888	12.3	3.2	-21.0	4990	40	12766	AF*	40.5	3.1	-20.9	4747	34
11048	*Whitwell Quarry Long Cairn*	*9888*	*20.7*	*3.5*	*-20.6*	*4965*	*50*	*12766*	*AF**	*40.5*	*3.1*	*-20.9*	*4747*	*34*
11049	*Whitwell Quarry Long Cairn*	*9705*	*17.7*	*3.3*	*-20.6*	*5115*	*40*	*12767*	*AF**	*30.5*	*3.2*	*-20.6*	*4965*	*32*
11049	*Whitwell Quarry Long Cairn*	*9705*	*21.2*	*3.3*	*-20.4*	*5160*	*40*	*12767*	*AF**	*30.5*	*3.2*	*-20.6*	*4965*	*32*

11049	*Whitwell Quarry Long Cairn*	*9705*	*17.7*	*3.2*	*-20.5*	*5140*	*45*	*12767*	*AF**	*30.5*	*3.2*	*-20.6*	*4965*	*32*
11049	*Whitwell Quarry Long Cairn*	*9705*	*21.2*	*3.2*	*-20.6*	*5120*	*45*	*12767*	*AF**	*30.5*	*3.2*	*-20.6*	*4965*	*32*

Pno Lab accession code for the sample
Site Name of site

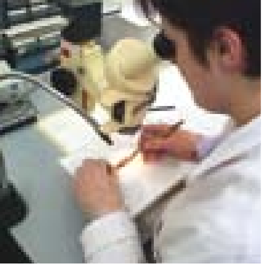
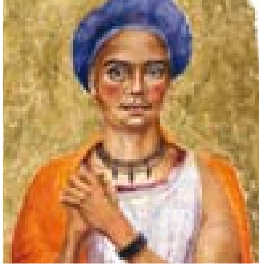
Original dates
OxA Original OxA number (now withdrawn)
Yield Collagen yield from pre-treatment (mg)
CN Carbon:Nitrogen atomic ratio
Age Radiocarbon Age (BP)
± Uncertainty in Age (yr)

New dates
OxA New OxA number or other lab code with prefix
Method Method pre-treatment code
Yield Collagen yield (mg)
CN Carbon:Nitrogen atomic ratio
Age Radiocarbon Age (BP)
± Uncertainty in Age (yr)

APPENDIX II: OTHER INTERCOMPARISONS

Here we show the results of other radiocarbon dates that can be used to compare to the results of the re-dating exercise.

New OxA	Method	Yield	CN	$\delta^{13}C$	Date	Error	Intercomparison 1			Intercomparison 2			Average intercomparison	
							Lab ref	Date	Error	Lab ref	Date	Error	Date	Error
12095	AF	18.3	3.2	-19.0	2098	27	GrA-22411	2100	35				2100	35
12090	AF	47.5	3.1	-22.1	1441	26	GrA-22562	1535	40				1535	40
12091	AF	28.0	3.2	-21.6	1309	26	GrA-22412	1285	30				1285	30
12097	AF	31.8	3.1	-21.6	1279	25	UB-4565	1280	17	GrA-22416	1260	30	1270	17
12098	AF	43.1	3.2	-22.5	1469	25	GrA-22550	1455	40				1455	40
12652	AF	24.1	3.1	-20.6	4856	31	GrA-23180	4790	50				4790	50
12653	AF	34.5	3.0	-19.6	4803	32	GrA-23181	4950	50				4950	50
12281	AF*	19.2	3.2	-20.7	4850	31	GrA-23183	4950	50				4950	50
13205	NRC	26.3	3.2	-22.8	4851	37	GrA-28199	4880	50	GrA-28218	4880	50	4880	35
13185	NRC	13.7	3.2	-20.6	4955	42	GrA-23195	4955	45				4955	45
13210	NRC	47.1	3.2	-22.1	3401	36	GrA-27336	3390	40				3390	40
13333	NRC	12.5	3.2	-20.8	3913	34	GrA-27332	4015	45				4015	45
13153	NRC	22.3	3.3	-21.1	1418	35	GrA-22624	1345	40				1345	40
13195	NRC	20.8	3.2	-21.4	1518	34	GrA-22821	1460	40				1460	40
13237	NRC	13.4	3.1	-20.8	1753	34	GrA-22606	1745	40				1745	40
13179	NRC	17.1	3.3	-20.8	4778	38	GrA-23178	4835	45				4835	45
13180	NRC	21.7	3.3	-21.1	4787	41	GrA-23179	4855	45				4855	45
12763	NRC	22.9	3.1	-20.4	4925	38	GrA-27513	4875	40				4875	40



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