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VALIDATING AND IMPROVING ARCHAEOLOGICAL PHASING AT ST. MARY SPITAL, LONDON

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ABSTRACT. This paper outlines the radiocarbon program applied to the excavation and skeletal assemblage from the cemetery of the medieval Priory and Hospital of St. Mary Spital in London. Problems encountered in dating medieval cemeteries are outlined. The problems were addressed through the application of Bayesian modeling to validate and refine conventional approaches to constructing phases of archaeological activity. It should be noted that this project was solely funded by the developer of the land; such projects rarely undertake even modest programs of ^{14}C dating. We aim to show how the investment of a proportionally small sum, compared to the overall project costs, may reap significant benefits.

ST. MARY SPITAL

The Priory and Hospital of St. Mary Spital was an Augustinian monastery that looked after the sick and poor on the outskirts of the medieval City of London (Figure 1). It was founded around AD 1197 and became London's largest medieval hospital, looking after 180 people (Stow 1908:151). The hospital was refounded in 1235 on a much larger scale (Thomas et al. 1997). The public infirmaries lay north of the entrance yard and the lay sisters who looked after the sick lived in a house next to the infirmary. The church lay at right angles to the infirmary and to its north lay the monastic cloister surrounded by possible guest quarters, a refectory with an adjacent kitchen and a dormitory over cellars, and a chapter house. To the east lay a kitchen, the canon's infirmary, and a number of other structures, which underwent intensive alterations in the 15th and early 16th centuries, including one that may be the infirmarer's workshop—a rare example of a medieval pharmacy.

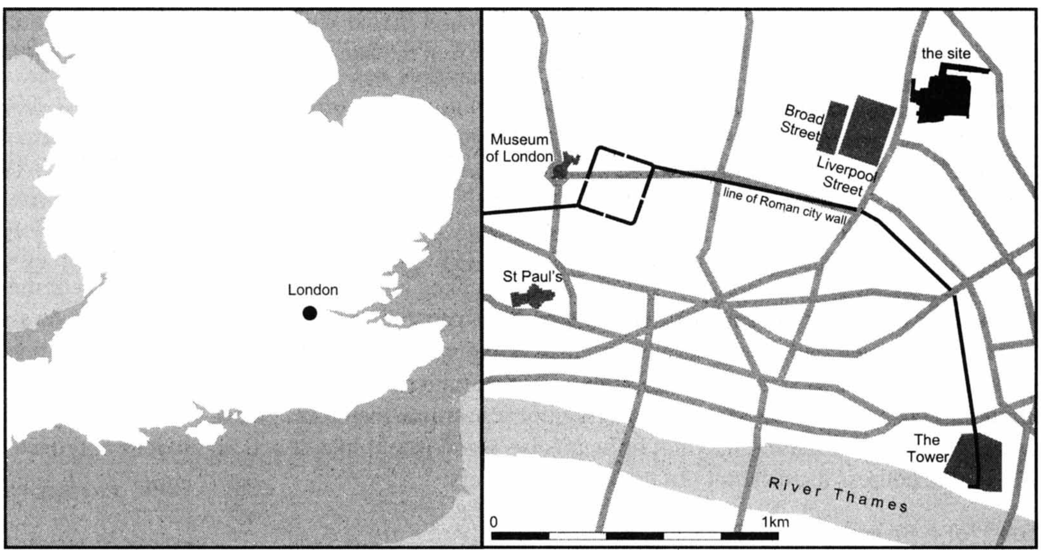

Figure 1 Site location map. © Museum of London Archaeology Service.

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To the south lay the medieval cemetery from which approximately 10,500 skeletons were excavated. The cemetery covered an area of ~5500 m^2, although its eastern half was much disturbed by the construction of Spitalfields Market in 1926–8. This represents the largest archaeologically excavated sample of medieval burials from Europe and is thus of international importance for the understanding of medieval demographics, health, and medicine. At least 1 period of catastrophic burial occurred when many corpses were interred in mass burial pits. In the center of the cemetery lay the foundations of an open-air pulpit, and to its south, the well-preserved remains of a charnel house. A gallery for watching sermons at the pulpit was added onto the north side of the charnel house in the late 15th century.

St. Mary Spital relied on the charity of the people of London and was an important part of its social fabric, but the Priory could not survive Henry VIII's desire for reform (and the wealth) of the church. It was dissolved on 1 January 1539.

The Fieldwork

Archaeologists have investigated the site since the mid-1980s with observations also recorded from the 1930s. Since 1991, the Museum of London Archaeology Service (MoLAS) has carried out a series of excavations in advance of redevelopment covering an area of approximately 10 acres.

Although much of the site is legally protected, intense pressure to redevelop the area led to consent being granted to excavate the entire site. The new building avoided the well-preserved remains of the east end of the church, which were protected and preserved in situ. The remarkably well-preserved remains of the 14th-century charnel house were also protected during construction, the basements redesigned, and the monument is now publicly displayed. Discoveries other than those from the Medieval period include a major Roman cemetery and houses dating from the late 16th century through to the widespread redevelopment of the area from the late 17th century to the 19th century.

Need for Radiocarbon Dating

While radiocarbon dating is more usually undertaken on prehistoric sites, or historic aceramic sites, there are certain types of archaeological sites that present difficulties in creating chronological frameworks. Medieval cemeteries are one such case. Although such cemeteries naturally produce a great deal of stratigraphic data—in particular, the relative chronology seen through intercutting articulated skeletons—the bodies generally lack associated artifacts with the rare exception of dress accessories, undatable shroud pins, and exceptionally, papal bullae. It is, however, crucial to be able to divide chronologically the human population; without this ability, it is not possible to track developments in, for instance, demographic change and variations in health. Studying the bodies from a single long period provides disappointingly poor resolution; therefore, precision in phasing is fundamental. While ^{14}C dating may not be as precise as we would like, it was an obvious approach in this case to address the difficulty of dating the cemetery.

Need for a Bayesian Model

There were several reasons for employing Bayesian modeling (Buck et al. 1996) instead of simple calibrated ^{14}C dates for this application. Firstly, applying the Bayesian approach would be more cost effective because fewer samples would be needed to achieve the required precision (Bayliss and Bronk Ramsey 2004). Secondly, there is an important ethical issue to take into consideration when sampling human remains. The Bayesian approach allows the use of AMS dating for this application, instead of conventional high-precision dating, thus requiring smaller samples and reducing destruction of human remains.

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The principal reason, however, for employing this approach was to test the accuracy of the archaeological phasing. Excavations are generally phased using a combination of methods. Central to this is the work of the stratigrapher who analyzes the interrelationship of the features, layers, structures, and deposits in the ground, and produces a model of their chronological succession (Harris 1979). This model is composed of sequences of archaeological events, e.g. burials. Each group of stratigraphically related burials is independent and has to be related to other groups by a variety of archaeological interpretations. This is usually accomplished by analyzing 3-dimensional patterning, such as rows of graves, which is supported by typologically datable material obtained from the graves, primarily pottery. Cemetery-wide stratigraphy, such as soil dumped to raise the ground surface between episodes of burial, is exceptional and not present at St. Mary Spital. Archaeological phasing is thus based on combining a range of archaeological evidence, most of which is more open to multiple interpretations than the simple relative sequence provided by stratigraphic relationships between articulated skeletons.

Surprisingly, models constructed in this manner are rarely tested independently, although they are heavily relied upon. At St. Mary Spital, there were significant difficulties in creating a securely dated phasing model because of the paucity of artifacts. This situation is not, however, unusual in the analysis of medieval cemeteries; sadly, rarely do archaeologists try to remedy this problem.

METHODS

Radiocarbon Dating

All the samples taken for ^{14}C analysis were human long bones, mostly femora, from articulated inhumations. No bone which exhibited significant pathological or degenerative conditions was sampled in order to preserve them for future osteological research.

In total, 63 samples were dated. Ten samples were dated by the Queen's University, Belfast, in 2000–1, using methods described in Longin (1971) and dated by liquid scintillation spectrometry (Pearson 1984). Twenty-three samples were pretreated and converted to graphite targets at the Scottish Universities Research and Reactor Centre, East Kilbride, in 2002 using methods described by Stenhouse and Baxter (1983) and Slota et al. (1987), and measured using accelerator mass spectrometry (AMS) at the University of Arizona (Donahue et al. 1997). Finally, 30 samples were dated by the Leibniz Labor für Altersbestimmung und Isotopenforschung, Christian-Albrechts Universität, Kiel, in 2005. The powdered bone samples were first treated with acetone, rinsed with demineralized water, and subsequently demineralized in hydrochloric acid (1%) (Grootes et al. 2004). To remove mobile humic acids, the demineralized bone was treated with sodium hydroxide (1% at 20 °C for 1 hr), and again with hydrochloric acid (1% at 20 °C for 1 hr). Bone gelatin was dissolved overnight in water (at 85 °C and pH 3), filtered through a precombusted 0.45-µm pore silver filter, and freeze-dried. Combustion, graphitization, and measurement procedures were those described by Nadeau et al. (1997, 1998).

Bayesian Modeling

The Bayesian approach to the interpretation of archaeological chronologies has been described by Buck et al. (1996). It is based on the principle that although the calibrated age ranges of ^{14}C measurements accurately estimate the calendar ages of the samples themselves, it is the dates of archaeological events associated with those samples that are important. Bayesian techniques can provide realistic estimates of the dates of such events by combining absolute dating evidence, such as ^{14}C results, with relative dating evidence, such as stratigraphic relationships between ^{14}C samples.

These "posterior density estimates" (which, by convention, are always expressed *in italics*) are not absolute. They are interpretative estimates that will change as additional data become available or as the existing data are modeled from different perspectives. This approach addresses formally the statistical scatter on a group of ^{14}C dates (Buck et al. 1992; Steier and Rom 2000; Bronk Ramsey 2000), which is often ignored or misinterpreted by archaeologists (Bayliss et al. 2007).

The technique used is a form of Markov Chain Monte Carlo sampling, which has been applied using the program OxCal v 3.10 (Bronk Ramsey 1995, 1998, 2001). At St. Mary Spital, we assumed that the archaeological phases of burial defined by the stratigraphers were chronologically successive. This is common archaeological practice based on fundamental stratigraphic rules, for instance the law of superposition (Lowe and Walker 1990:276). Firstly, direct stratigraphic relationships between dated skeletons were incorporated into the model (e.g. UB-4598, KIA-28398-9, and KIA-28394; Figure 4). Then, the phasing sequence was incorporated into the model. This highlighted particular burials, which through their low individual indices of agreement appeared to have been misphased. The criteria for allocating these individuals to particular phases were reexamined. This led not only to the rephasing of these skeletons, but also to a refinement of our overall criteria for phase allocation. A series of models were constructed as the methodology for archaeological phasing developed (see below).

Sampling

To assess the potential for accurately dividing the skeletal population into chronologically successive phases, a series of simulations were constructed using the R_Simulate function of OxCal v 3.10 (Bronk Ramsey 1995, 1998, 2001, http://rlaha.ox.ac.uk/), with the aim of testing the chronological validity of the proposed phasing scheme from a pilot area within the cemetery. This simulation included some existing ^{14}C determinations, the stratigraphic sequence of proposed samples, and documentary evidence that suggests that the Priory was founded in AD 1197 and dissolved in AD 1539. A small, random selection of burials phased to each period was submitted for dating.

The results were then modeled, and the criteria for allocating burials to phases refined. A second series of samples was then submitted, to test the accuracy of this revised phasing scheme. It is this model that is presented in Figures 2–7.

Research Questions

The dating program was explicitly tied to a series of archaeological research questions. This was focused on examining the potential for dating the cemetery via stratigraphic phasing, and confirming (or refuting) the documented dates for the establishment and abandonment of the cemetery. A pilot study focused on one area of the site that was phased using the limited artifactual dating evidence available, the stratigraphic sequence, and spatial distribution of burials. Twenty-three ^{14}C samples were submitted to assess the chronological validity of this preliminary phasing scheme. The results demonstrated that the phasing was approximately 80% accurate in relation to the ^{14}C dates. The pilot study suggested one significant methodological change; in the case of 2 of the 5 suggested amendments, the dated burials were at the base of a stratigraphic sequence. They had not originally been assigned to the earliest phase because, spatially, they seemed to belong in a slightly later phase. However, the ^{14}C dating suggested that they should be placed in the earliest medieval phase, Period 14. By retrospectively applying this principle, the accuracy of the phasing increased to approximately 90%. With regard to the time span of cemetery use, the ^{14}C dates supported the suggestion that burial continued on site until the dissolution of the Priory in AD 1539 (Caley and Hunter 1810), while burial appeared to begin prior to the documented founding date of AD 1197 (Dugdale 1830; Stow 1908).

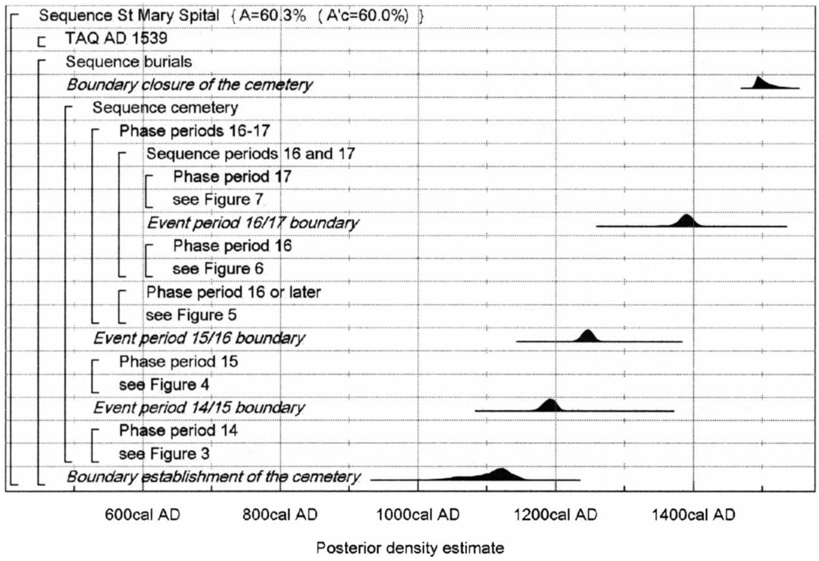

Figure 2 Overall structure of the chronological model for the medieval cemetery. The component sections of this model are shown in details in Figures 3–7. Each distribution represents the relative probability that an event occurred at a particular time, and corresponds to an aspect of the model. For example, the distribution *establishment of the cemetery* is the estimated date when the medieval burial started on the site. The large square brackets down the left-hand side of Figures 2–7, along with the OxCal keywords, define the overall model exactly.

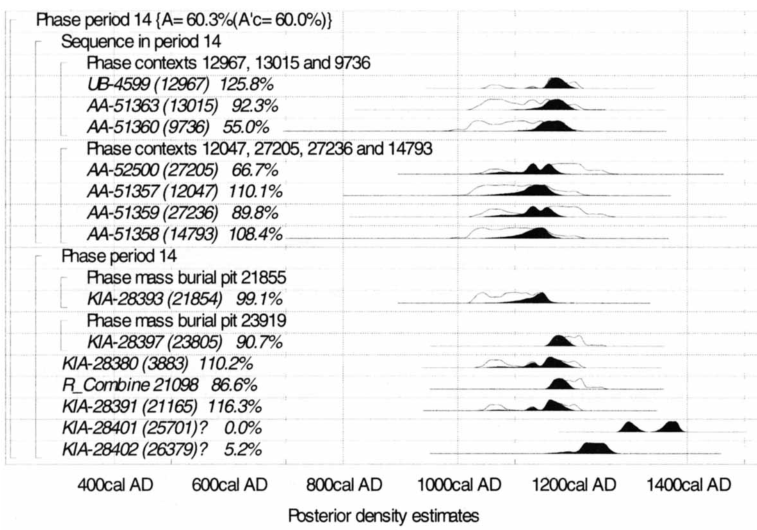

Figure 3 Probability distributions of dates from period 14. For each of the dates, 2 distributions have been plotted, one in outline that is the result produced by the scientific evidence alone, and a solid one that is based on the chronological model used. The other distributions correspond to aspects of the model. Dates followed by a question mark have been calibrated (Stuiver and Reimer 1993), but not included in the chronological model for reasons explained in the text. The large square brackets down the left-hand side of Figures 2–7, along with the OxCal keywords, define the overall model exactly.

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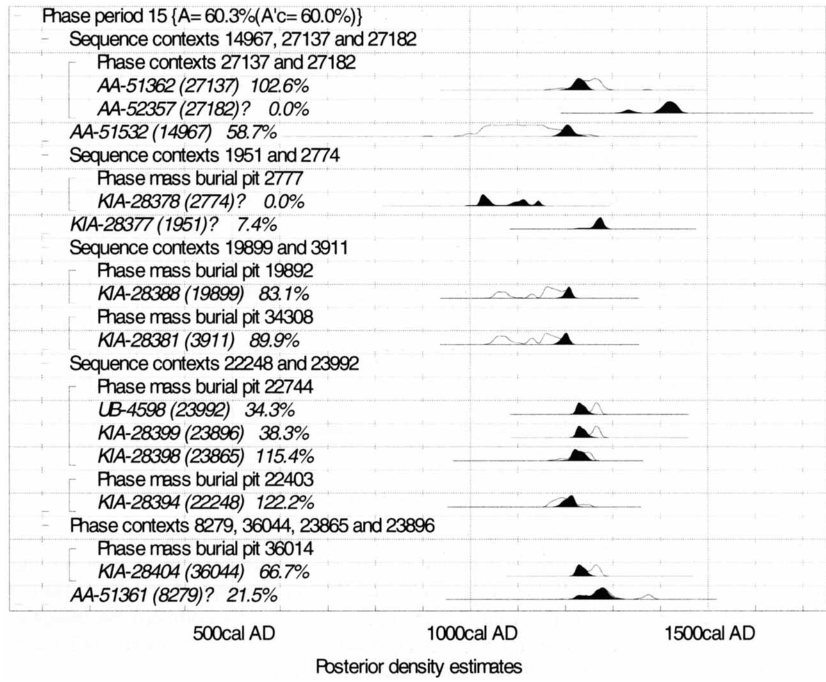

Figure 4 Probability distributions of dates from period 15. The format is identical to that of Figure 3. The large square brackets down the left-hand side of Figures 2–7, along with the OxCal keywords, define the overall model exactly.

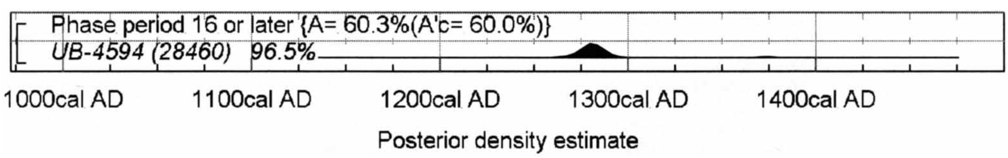

Figure 5 Probability distributions of dates from period 16 or later. The format is identical to that of Figure 3. The large square brackets down the left-hand side of Figures 2–7, along with the OxCal keywords, define the overall model exactly.

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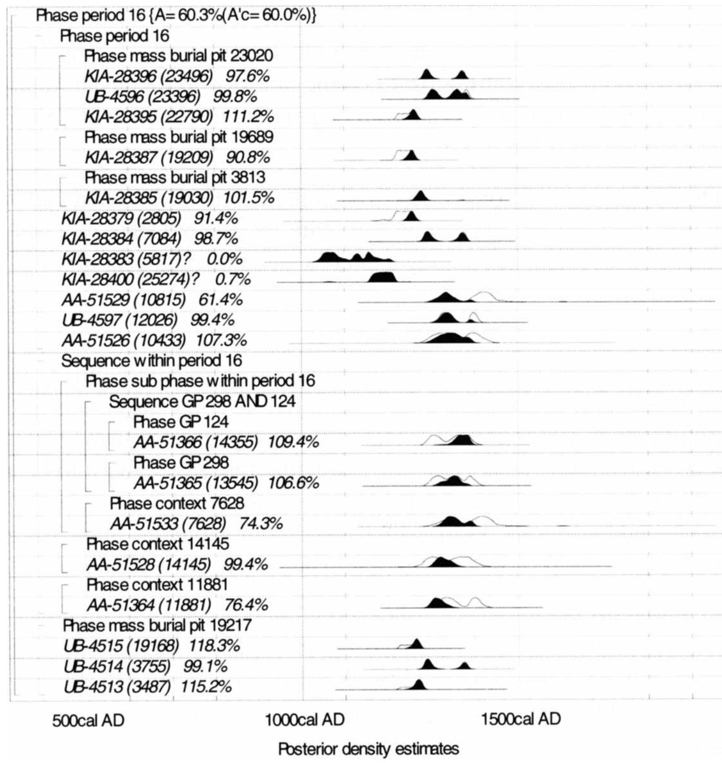

Figure 6 Probability distributions of dates from period 16. The format is identical to that of Figure 3. The large square brackets down the left-hand side of Figures 2–7, along with the OxCal keywords, define the overall model exactly.

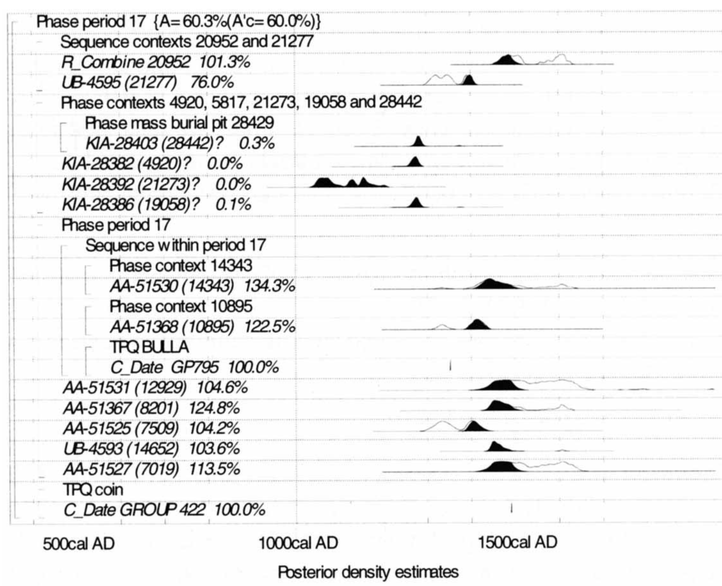

Figure 7 Probability distributions of dates from period 17. The format is identical to that of Figure 3. The large square brackets down the left-hand side of Figures 2–7, along with the OxCal keywords, define the overall model exactly.

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Once the cemetery had been divided into broad periods, the final set of samples was submitted to validate the chronological accuracy of the stratigraphic phasing, to tie the stratigraphically defined periods to calendar dates, to establish when burial began, and to examine the potential for chronological variation within the mass burial pits.

A series of secondary research questions were also included in the project and included examination of the probability that mass graves were associated with the Black Death of 1348, dating the construction of the charnel house, and also dating a child with congenital syphilis.

RESULTS

Details of the ^{14}C dates are given in Table 1 and are quoted in accordance with the international standard known as the Trondheim convention (Stuiver and Kra 1986). Dates are given as conventional ^{14}C ages (Stuiver and Polach 1977). All ^{14}C dates have been calibrated using OxCal v 3.10 (Bronk Ramsey 1995, 1998, 2001, http://rlaha.ox.ac.uk/), using the IntCal04 calibration curve of Reimer et al. (2004). The calibrated date ranges cited in the text are those for 95% confidence. They are quoted in the form recommended by Mook (1986), with the end points rounded outwards to 5 yr where the error on the determination is ±25 or less, or to 10 yr when the error is greater than this.

The chronological model for the cemetery of St. Mary Spital is shown in Figures 2–7. For both the chronological modeling and the stratigraphic phasing, it was assumed that burial on the site continued reasonably frequently until the cemetery closed, before or in AD 1539. Within this time frame, burials have been assigned to 4 consecutive, contiguous periods, relating to identifiable changes in cemetery use (Figure 2). For example, the boundary between periods 16 and 17 is defined by the construction of the pulpit when a substantial part of the cemetery appears to go out of use. These periods form the chronological framework against which changes in the human population may be measured.

Period 14

Fourteen burials assigned to period 14 by archaeological phasing have been ^{14}C dated (Figure 3). Within this period, 4 dated skeletons are contemporary on spatial and stratigraphic grounds (AA-51358, -51359, -51357, -52500). These are earlier than a further 3 skeletons (AA-51360, -51363, and UB-4599), on stratigraphic grounds. These 2 sets of burials are separated stratigraphically by a number of intervening burials. The other 7 dated burials in this period have no stratigraphic relationships with other dated burials in period 14, although 2 skeletons are from mass burial pits (KIA-28393 and -28397).

Two of the 14 dated individuals in this period have ^{14}C measurements that are in poor agreement with their inclusion in this period (KIA-28401-2; Figure 3). In neither case is there firm archaeological evidence to indicate that these burials cannot be later than initially suggested, so they have probably simply been misphased.

Period 15

Thirteen burials assigned to period 15 by archaeological phasing have been ^{14}C dated (Figure 4). Three dated skeletons are directly connected stratigraphically (AA-51532, -52357, and -51362). Another direct stratigraphic relationship, through a sequence of intervening burials, links 2 more dated burials (KIA-28377 and -28378). Two mass pits are linked, with 1 body from each dated (KIA-28381 and -28388). A further 2 linked pits have had 1 and 3 burials from them dated (KIA-28394, KIA-28398, KIA-28399, and UB-4598). Two further burials were dated (AA-51361 and KIA-28404), but have no stratigraphic relationships with the other dated burials in period 15.

Table 1 Radiocarbon measurements from the medieval cemetery of St. Mary Spital. $\delta^{13}C$ values marked * were measured by AMS, all other $\delta^{13}C$ values were measured by mass spectrometry.

Laboratory #	Context #	Period	W #	Material dated	^{14}C age (BP)	$\delta^{13}C$ (‰)*	Weighted mean (BP)	Calibrated date AD (95% confidence)	*Posterior density estimate (cal AD; 95% probability)*
AA-51357	12047	14	W3	indet long bone	925 ± 45	−18.4		1010–1220	*1070–1180*
AA-51358	14793	14	W3	right femur	940 ± 45	−18.9		1010–1220	*1070–1180*
AA-51360	9736	14	W3	indet long bone	955 ± 45	−18.6		990–1210	*1205–1210*
AA-51363	13015	14	W3	indet long bone	905 ± 35	−18.8		1020–1220	*1130–1210*
AA-52500	27205	14	W3	indet long bone	860 ± 40	−18.4		1040–1270	*1060–1180*
UB-4599	12967	14	W3	right femur or tibia	882 ± 16	−19.3		1050–1220	*1150–1200*
KIA-28401	25701	14	W11	left femur	648 ± 22	−18.7*		1280–1395	*1280–1320 (41.6%)* or *1345–1395 (53.8%)*
KIA-28402	26379	14	W11	left femur	804 ± 26	−17.8*		1180–1280	*1180–1280*
KIA-28393	21854	14	W27	left femur	940 ± 24	−16.8*		1020–1165	*1075–1170*
KIA-28397	23805	14	W27	left femur	848 ± 18	−19.6*		1155–1225	*1155–1200*
KIA-28380	3883	14	W31	right femur	890 ± 24	−17.5*		1040–1220	*1060–1090 (3.8%)* or *1115–1205 (91.6%)*
KIA-28390a	21098	14	W31	left femur	833 ± 29	−15.8*	843 ± 18; T' = 0.2; T' (5%) = 3.8; ν = 1	1165–1255	*1150–1200*
KIA-28390b	21098	14	W31	left femur	850 ± 24	−18.3*			
KIA-28391	21165	14	W67	right femur	887 ± 19	−19.8*		1045–1215	*1065–1080 (1.9%)* or *1115–1205 (93.5%)*
AA-51361	8279	15	W1	right femur	715 ± 45	−19.6		1220–1390	*1210–1310*
AA-51362	27137	15	W1	?right humerus or ulna	770 ± 45	−19.5		1180–1290	*1200–1260*
AA-51532	14967	15	W1	right femur	930 ± 65	−18.5		980–1250	*1180–1240*
AA-52357	27182	15	W1	right femur	510 ± 40	−18.9		1320–1450	*1310–1360 (14.5%)* or *1380–1450 (80.9%)*
AA-51359	27236	14	W3	left femur	875 ± 45	−18.7		1030–1260	*1060–1180*
KIA-28398	23865	15	W28	right femur	819 ± 18	−19.2*		1185–1265	*1205–1255*
KIA-28399	23896	15	W28	left femur	764 ± 18	−18.9*		1220–1280	*1215–1255*
UB-4598	23992	15	W28	right femur and tibia	764 ± 17	−19.2		1220–1280	*1215–1255*
KIA-28394	22248	15	W29	left tibia	843 ± 19	−19.6*		1160–1255	*1180–1225*
KIA-28381	3911	15	W36	left femur	890 ± 24	−18.0*		1040–1220	*1180–1215*

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Laboratory #	Context #	Period	W #	Material dated	^{14}C age (BP)	$\delta^{13}C$ (‰)*	Weighted mean (BP)	Calibrated date AD (95% confidence)	*Posterior density estimate (cal AD; 95% probability)*
KIA-28377	1951	15	W38	left femur	737 ± 24	–19.9*		1255–1290	*1225–1235 (1.7%)* or *1235–1290 (93.7%)*
KIA-28388	19899	15	W40	left femur	884 ± 22	–16.8*		1045–1220	*1185–1225*
KIA-28378	2774	15	W53	left femur	978 ± 23	–15.4*		1015–1155	*1010–1055 (47.5%)* or *1075–1155 (47.9%)*
KIA-28404	36044	15	W69	left tibia	768 ± 23	–18.9*		1215–1280	*1215–1255*
UB-4597	12026	16	W2	right humerus, radius and ulna	577 ± 20	–19.7		1305–1415	*1305–1365 (86.4%)* or *1385–1400 (9.0%)*
AA-51529	10815	16	W4	right femur	510 ± 60	–19.1		1300–1470	*1290–1400*
KIA-28384	7084	16	W4	right femur	665 ± 22	–17.9*		1275–1380	*1275–1315 (53.8%)* or *1350–1390 (41.6%)*
AA-51364	11881	16	W5	?right femur	575 ± 35	–19.3		1290–1430	*1280–1350*
AA-51528	14145	16	W5	right femur	640 ± 60	–18.6		1260–1420	*1290–1370*
AA-51533	7628	16	W5	right femur	525 ± 60	–18.9		1290–1460	*1315–1400*
AA-51365	13545	16	W9	indet long bone	610 ± 35	–18.8		1280–1420	*1310–1390*
AA-51366	14355	16	W9	left proximal humerus	630 ± 35	–19.0		1280–1410	*1330–1400*
KIA-28400	25274	16	W17	left femur	859 ± 19	–19.9*		1155–1225	*1055–1075 (1.6%)* or *1150–1225 (93.8%)*
KIA-28395	22790	16	W26	left femur	778 ± 18	–20.0*		1215–1280	*1240–1280*
KIA-28396	23496	16	W26	right femur	666 ± 18	–18.9*		1280–1390	*1280–1310 (54.9%)* or *1355–1390 (40.5%)*
UB-4596	23396	16	W26	left femur and tibia	626 ± 20	–19.9		1285–1400	*1290–1330 (42.2%)* or *1340–1395 (53.2%)*
KIA-28385	19030	16	W48	right femur	722 ± 27	–18.2*		1260–1300	*1250–1300 (93.9%)* or *1370–1380 (1.5%)*
KIA-28387	19209	16	W48	left femur	796 ± 17	–17.7*		1210–1270	*1240–1275*
UB-4513	3487	16	W48	right femur	755 ± 23	–18.8		1220–1285	*1245–1285*
UB-4514	3755	16	W48	right femur	676 ± 23	–18.6		1275–1390	*1275–1315 (62.7%)* or *1355–1390 (32.7%)*
UB-4515	19168	16	W48	left femur	771 ± 17	–18.7		1220–1280	*1240–1280*
KIA-28379	2805	16	W59	left femur	806 ± 23	–20.0*		1205–1270	*1240–1275*

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Laboratory #	Context #	Period	W #	Material dated	^{14}C age (BP)	$\delta^{13}C$ (‰)*	Weighted mean (BP)	Calibrated date AD (95% confidence)	*Posterior density estimate (cal AD; 95% probability)*
KIA-28383	5817	16	W80	left femur	903 ± 23	−17.3*		1035–1215	*1040–1110 (46.9%)* or *1115–1210 (48.5%)*
AA-51526	10433	16/17	W2	indet long bone	585 ± 60	−18.5		1280–1440	*1290–1400*
UB-4594	28460	16/17	W12	right femur and tibia	709 ± 19	−19.8		1265–1295	*1260–1300*
AA-51367	8201	17	W6	left femur	405 ± 35	−19.5		1430–1630	*1430–1510*
AA-51525	7509	17	W6	right femur	565 ± 40	−18.9		1290–1440	*1380–1440*
AA-51527	7019	17	W6	right femur	385 ± 60	−19.7		1420–1650	*1420–1510*
AA-51530	14343	17	W6	left femur	445 ± 60	−19.1		1400–1640	*1410–1500*
AA-51531	12929	17	W6	right femur	370 ± 70	−19.8		1410–1670	*1420–1520*
UB-4593	14652	17	W6	right femur or tibia	413 ± 21	−19.7		1435–1610	*1435–1490*
AA-51368	10895	17	W8	?left femur	530 ± 35	−18.9		1310–1450	*1390–1440*
KIA-28403	28442	17	W21	left femur	705 ± 18	−18.7*		1270–1295	*1265–1300*
KIA-28392	21273	17	W62	left femur	903 ± 19	−19.0*		1040–1210	*1040–1110 (49.1%)* or *1115–1195 (43.6%)* or *1195–1210 (2.8%)*
KIA-28386	19058	17	W65	left tibia	726 ± 23	−19.0*		1260–1290	*1250–1300*
KIA-28389a	20952	17	W74	right tibia	345 ± 24	−18.6*	359 ± 16; T' = 0.6; T' (5%) = 3.8; ν = 1	1455–1630	*1455–1510*
KIA-28389b	20952	17	W74	right tibia	371 ± 22	−19.6*			
UB-4595	21277	17	W74	left femur, tibia, and fibula	597 ± 20	−19.0		1295–1410	*1380–1415*
KIA-28382	4920	17	W84	left femur	734 ± 24	−17.6*		1255–1290	*1235–1250 (1.9%)* or *1250–1295 (93.5%)*

Four of the 13 dated individuals in this period have ^{14}C measurements that are in poor agreement with their inclusion in this period (Figure 4). On the basis of the stratigraphy, there is possibly a misfit (KIA-28378) since this measurement has poor agreement with another sample (KIA-28377), which it is stratigraphically above. There is no stratigraphic reason to suggest that the other ^{14}C measurements are incorrect (AA-51357, -51361, and KIA-28377), and cannot in fact belong to a later period.

Period 16/17

One burial (UB-4594) can only be assigned to period 16 or 17 on stratigraphic grounds, although from its ^{14}C date it clearly falls in period 16 (Figure 5). Twenty burials assigned to period 16 by archaeological phasing have been ^{14}C dated (Figure 6). The relative chronology of 5 of these burials has been established by direct stratigraphic relationships (AA-51364, -51528, -51533, -51365, and -51366). None of the other burials in this period have stratigraphic relationships with the other dated burials.

Two of the 20 dated individuals in period 16 have ^{14}C measurements that are in poor agreement with their inclusion in this period (Figure 6). One (KIA-28383) seems earlier than predicted and indeed the feature is truncated by a period 15 burial pit, and so its inclusion in this period at all was an archaeological error! (This sample has good agreement when included in period 14 [A = 96.9%].) Another (KIA-28400), on the basis of stratigraphy and pottery dating may be another misfit and the burial may actually date to the turn of the 14th century.

Period 17

Thirteen burials assigned to period 17 by archaeological phasing have been ^{14}C dated (Figure 7). Two dated skeletons were stratigraphically linked (UB-4595 and KIA-20952a and b); another pair (AA-51368 and -51530) were linked with each other and with a burial containing a papal bull of AD 1352–62 stratigraphically earlier than both. A terminus post quem for the end of period 17 is provided by a coin dated to AD 1490 or later from another burial. The other 9 dated skeletons in this period have no stratigraphic relationships with other dated burials in period 17.

Four of the 13 dated individuals in period 17 have ^{14}C measurements that are in poor agreement with their inclusion in this period (Figure 7). One (KIA-28382) dates to the late 13th century (period 16), a date not inconsistent with the stratigraphic and finds evidence. Two further skeletons appear to date to period 16 (KIA-28386 and -28403). In neither case is there firm archaeological evidence to indicate that these burials cannot be earlier than initially suggested. Another burial may have been incorrectly assigned to its stratigraphic group and could actually fall in period 14 as suggested by the ^{14}C determination (KIA-28392).

Interpretation

Following modeling, it may be suggested that burial started in *cal AD 1040–1155* (*95% probability; establishment of the cemetery*, Figure 2)[1], most probably in *cal AD 1090–1145* (*68% probability*), significantly earlier than the foundation date of AD 1197. It would seem the site was used for burial before the foundation of the Priory. The end of burial seems to have occurred in *cal AD 1485–1525* (*95% probability; closure of the cemetery*, Figure 2), most probably in *cal AD 1485–1510* (*68% probability*). This suggests that burial ceased sometime before the Dissolution of the Monasteries, although this may be a result of relatively few burials being dated from the top of the sequence.

[1]Ages are posterior density estimates, which are by convention given italicized.

In summary, 12 of the 61 dated individuals from St. Mary Spital have ^{14}C measurements that are in poor agreement with their suggested phasing. In 2 cases, however, there is strong archaeological evidence to suggest that the ^{14}C measurements may be misfits, and that the burials are actually of the date originally suggested. This is in line with the number of outlying measurements expected on statistical grounds. On this basis, we can suggest that 10 of 61 dated individuals may have been phased incorrectly (16%). This means that 84% of individuals assigned to periods by the phasing are likely to have died within the dates suggested for the period boundaries in this analysis.

In reality, burial at St. Mary Spital was probably on the one hand continuous, and on another, episodic, with more burial occurring during times of crisis. It is highly improbable that there really were absolutely successive phases of burial; it is extremely difficult to see individual events that occurred in the past imprinted in the ground we excavate today. Therefore, "phasing" is a modern construct that we impose upon the past in order to facilitate analysis by archaeologists and human osteologists by providing manageable data sets to enable the discussion of human development through time. In view of this, 84% accuracy for such an artificial scheme is impressive and suggests that the osteological analysis based upon it is not wholly without foundation.

Sensitivity Analyses

The calendrical chronology suggested by the model discussed above (Figures 2–7) at first sight does not fit with extant documentary records. In particular, burial appears not to have continued right up until the dissolution of the Priory, although given the small number of individuals from this late phase, this is perfectly plausible. On the other hand, a considerable number of individuals appear to have been buried before the known foundation date of AD 1197 (Figure 3). A model that constrains all burials from the site to be later than this date, however, has poor overall agreement ($A_{overall}$ = 18.0%).

In cases where potentially anomalously early ^{14}C dates have been obtained, the possible significance of dietary offsets must be considered (see Cook et al. 2001). This is an area that is incompletely understood (Bayliss et al. 2004), and so a range of possible offsets have been applied to explore the sensitivity of our results to this technical issue.

As part of a commercial excavation, $\delta^{13}C$ values have only been measured as part of the dating process. In common with most laboratories, those that were used for this application did not quote errors on these measurements. A further complication is provided by the methods used to produce these values. Those provided with the results from Belfast and Arizona were measured by mass spectrometry from a subsample of the carbon dioxide produced during the chemical preparation of the samples for dating. Those from Kiel were measured by AMS from the target graphite (denoted by * in Table 1). This means that these values include fractionation effects from the graphitization process as well as those from diet. We therefore hesitate to use them to infer diet.

Figure 8 illustrates the posterior density estimates for the establishment of the cemetery according to 3 alternative models. The first model (Figures 2–7) is based on terrestrial calibration (Reimer et al. 2004) and suggests that it is 100% probable that the cemetery began before the documented foundation date of AD 1197. The second model is identical to the first, but includes an arbitrary offset of 10 ± 5% marine carbon, mixing the marine calibration curve of Hughen et al. (2004), with the terrestrial curve using the methodology of Bronk Ramsey (1998) and ΔR value of 5 ± 40 BP for the coastal waters of England (Stuiver and Braziunas 1993). This model suggests that the cemetery was established in *cal AD 1120–1190* (*95% probability; 10 ± 5% marine*, Figure 8), probably in *cal AD 1140–1175* (*68% probability*). In this case, it is 99.9% probable that the cemetery began before 1197.

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A third model is identical but incorporates an offset of 20 ± 5% marine carbon. This suggests that the cemetery was established in *cal AD 1150–1215* (*95% probability; 20 ± 5% marine*, Figure 8), probably in *cal AD 1170–1205* (*68% probability*). In this case, it is 75.3% probable that the burial ground was initiated before 1197.

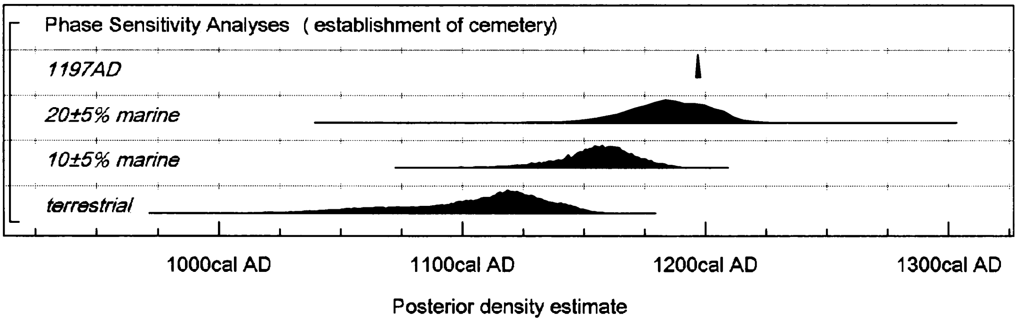

Figure 8 Probability distributions of dates for the establishment of the cemetery, derived from the model defined in Figures 2–7, and from the same model recalculated using arbitrary estimates of 10 ± 5% and 20 ± 5% marine carbon (see text). The format is identical to that of Figure 3.

The average $\delta^{13}C$ value for the individuals measured by AMS is –19.6‰. This does not suggest that marine resources formed a significant proportion of the diet, and indeed is borne out by the relatively low quantities of fish bone recovered from the site and historical sources that also point to significant trade in preserved marine fish occurring only later in the Medieval period (Unger 1980). We therefore believe that, although our estimate of the actual calendar date when burial on the site began may be affected by this factor, the model presented in Figures 2–7 is unlikely to be *importantly* wrong (see Bayliss et al. 2007). The archaeologically significant interpretation is that burial on the site started before the documented foundation of the Priory in 1197.

Secondary Questions

It was possible to estimate calendar ages for a range of the secondary questions. All dates stratigraphically related to the charnel house were modeled using the XREF function of OxCal v 3.10, the results of which suggest that it was constructed in *cal AD 1245–1345* (*95% probability*; distribution not shown), probably in *cal AD 1275–1330* (*68% probability*). While this confirmed what the molded stone experts had already suggested as the likely date for the building, it did not actually refine the date further. In this case, there were so few ^{14}C dates stratigraphically later than the building that a relatively imprecise estimate was produced.

A further secondary level question related to the presence of a child exhibiting pathological lesions (*caries sicca*) associated with congenital syphilis. Over the last few years, it has become apparent that congenital syphilis was present in the Old World, rather than having been contracted from the New World following contact by Christopher Columbus in 1492 (Mays et al. 2003; Gilchrist and Sloane 2005:212). A very few examples of pre-Columbian syphilis have been convincingly identified in Britain from York (Mays 1998:139), for example. The individual from Spitalfields was thought to be another such case. Dating the individual and including it in the Bayesian model produced a posterior density estimate of *cal AD 1260–1300* (*95% probability*; UB-4594; Figure 5).

One of the major unexpected finds on the site was evidence for a "catastrophe cemetery." The term is used to denote burial on a scale unprecedented within contemporary mortality profiles. At Spitalfields, the catastrophe cemetery manifested itself as several hundred burial pits, containing between 2 and 43 individuals (Figure 9). It was immediately considered that these might be "plague pits," usually considered to refer to the Black Death of 1348. In the few cases where Black Death cemeteries have been proven, e.g. East Smithfield (Gilchrist and Sloane 2005:74), the pits have tended to be long rectangular trenches; therefore, it was considered important to date the mass burial pits.

Figure 9 Mass burial pit from period 16. © Museum of London Archaeology Service.

Two mass burial pits from period 14 (pits 23919 and 21855) have been dated, 6 from period 15 (pits 36014, 22403, 22744, 34308, 19892, and 2777), 4 from period 16 (pits 19217, 3813, 19689, and 23020), and finally 1 from period 17 (pit 28429), although we are not convinced that this latter pit has been phased correctly. The results indicate a series of events and that the catastrophe cemetery is highly unlikely to result from the Black Death of 1348 (see Figure 10), with all but 1 pit predating the early 14th century.

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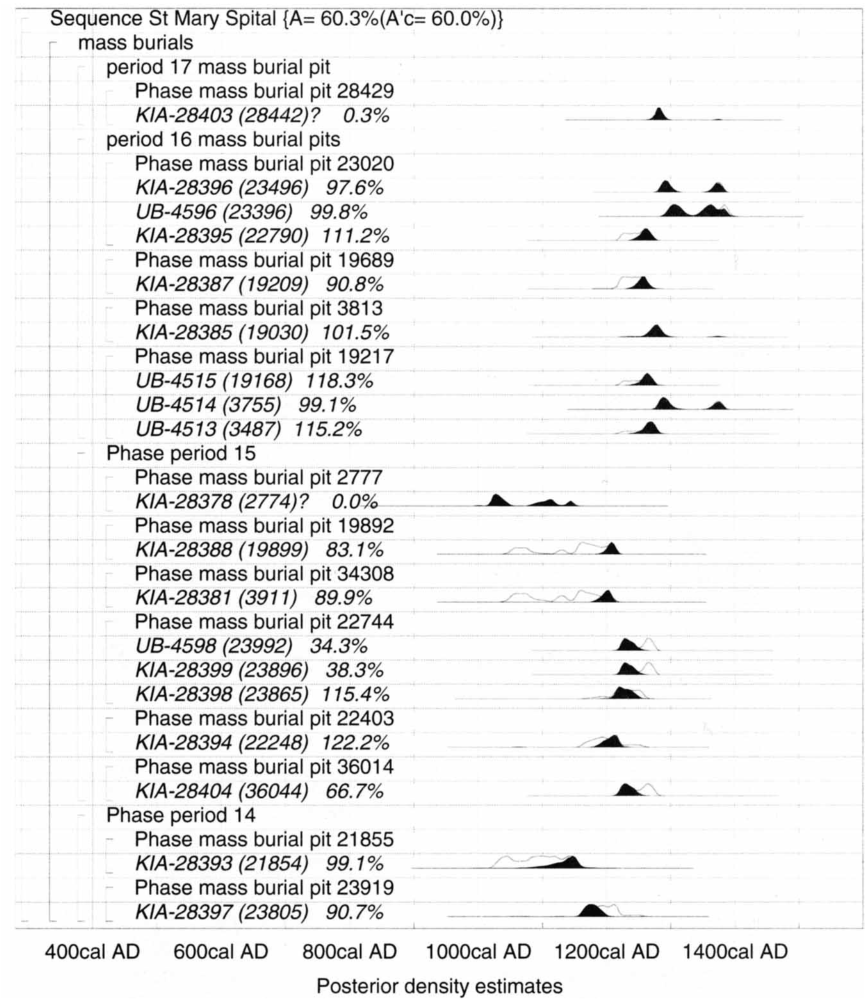

Figure 10 Probability distributions of dates from the mass burial pits. The format is identical to that of Figure 3. The distributions are derived from the model defined in Figures 2–7.

CONCLUSION

To most commercial archaeologists, 63 ^{14}C dates would appear to be a completely unjustifiable expenditure. Nevertheless, when the costs are considered in a broader context, they seem more reasonable. Cemeteries are exceptional sites; they can tell us more about past societies than any other form of archaeological find. The research justification is easy to make, but that will not convince commercial developers. But to look at the issue from another angle, what is the cost of ^{14}C dating in relative terms? On this site, ^{14}C dating required <0.5% of the total budget; an insignificant amount compared to the cost of lifting and analyzing the collection. Yet, the dating has dramatically increased the research potential by allowing the osteologists to create a significantly more detailed picture of the population that lived and died in this part of London.

The cemetery of St. Mary Spital now has 4 well-dated periods of cemetery use within which 84% of 10,516 bodies are expected to be in the right period. A case of pre-Columbian syphilis and mass burial pits predating the Black Death of 1348 have been confirmed. It may be suggested that there was a pre-Priory burial ground on the site and that the burial ground went out of use slightly before the Priory was dissolved. At the time of writing, the analysis of the human population is ongoing but promises to provide one of the most detailed examinations of any human population in the medieval world.

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REFERENCES

Bayliss A, Bronk Ramsey C. 2004. Pragmatic Bayesians: a decade integrating radiocarbon dates into chronological models. In: Buck CE, Millard AR, editors. *Tools for Constructing Chronologies: Tools for Crossing Disciplinary Boundaries*. Lecture Notes in Statistics, Volume 177. London: Springer. p 25–41.

Bayliss A, Sheperd Popescu E, Beavan-Athfield N, Bronk Ramsey C, Cook GT, Locker A. 2004. The potential significance of dietary offsets for the interpretation of radiocarbon dates; an archaeologically significant example from medieval Norwich. *Journal of Archaeological Science* 31(5):563–75.

Bayliss A, Bronk Ramsey C, van der Plicht J, Whittle A. 2007. Bradshaw and Bayes: towards a timetable for the Neolithic. *Cambridge Journal of Archaeology* 17(supplement S1):1–28.

Bronk Ramsey C. 1995. Radiocarbon calibration and analysis of stratigraphy: the OxCal program. *Radiocarbon* 37(2):425–30.

Bronk Ramsey C. 1998. Probability and dating. *Radiocarbon* 40(1):461–74.

Bronk Ramsey C. 2000. Comment on 'The use of Bayesian statistics for ^{14}C dates of chronologically ordered samples: a critical analysis.' *Radiocarbon* 42(2):199–202.

Bronk Ramsey C. 2001. Development of the radiocarbon program. *Radiocarbon* 43(2A):355–63.

Buck CE, Litton CD, Smith AFM. 1992. Calibration of radiocarbon results pertaining to related archaeological events. *Journal of Archaeological Science* 19(5): 497–512.

Buck CE, Cavanagh WG, Litton CD. 1996. *Bayesian Approach to Interpreting Archaeological Data*. Chichester: John Wiley & Sons. 402 p.

Caley J, Hunter J, editors. 1810. *Valor Ecclesiasticus, Tempore Henrici VIII, Auctoriate Regia Institus*. Volume 1. London: Record Commission. In Latin.

Cook GT, Bonsall C, Hedges REM, McSweeney K, Boroneant V, Pettitt PB. 2001 A freshwater diet-derived ^{14}C reservoir effect at the Stone Age sites in the Iron Gates Gorge. *Radiocarbon* 43(2A):453–60.

Donahue DJ, Beck JW, Biddulph D, Burr GS, Courtney C, Damon PE, Hatheway AL, Hewitt L, Jull AJT, Lange T, Lifton N, Maddock R, McHargue LR, O'Malley JM, Toolin LJ. 1997. Status of the NSF-Arizona AMS laboratory. *Nuclear Instruments and Methods in Physics Research B* 123(1–4):51–6.

Dugdale W. 1830. *Monasticon Anglicanum*, 6, London.

Gilchrist R, Sloane B. 2005. *Requiem: The Medieval Monastic Cemetery in Britain*. London: Museum of London Archaeology Service. 273 p.

Grootes PM, Nadeau M-J, Rieck A. 2004. ^{14}C-AMS at the Leibniz-labor: radiometric dating and isotope research. *Nuclear Instruments and Methods in Physics Research B* 223–4:55–61.

Harris EC. 1979. *The Principles of Archaeological Stratigraphy*. New York: Academic Press. 149 p.

Hughen KA, Baillie MGL, Bard E, Beck JW, Bertrand CJH, Blackwell PG, Buck CE, Burr GS, Cutler KB, Damon PE, Edwards RL, Fairbanks RG, Friedrich M, Guilderson TP, Kromer B, McCormac G, Manning S, Bronk Ramsey C, Reimer PJ, Reimer RW, Remmele S, Southon JR, Stuiver M, Talamo S, Taylor FW, van der Plicht J, Weyhenmeyer CE. 2004. Marine04 marine radiocarbon age calibration, 0–26 kyr BP. *Radiocarbon* 46(3):1059–86.

Longin R. 1971. New method of collagen extraction for radiocarbon dating. *Nature* 230(5291):241–2.

Lowe JJ, Walker MJC. 1990. *Reconstructing Quaternary Environments*. New York: John Wiley & Sons. 352 p.

Mays S. 1998. *The Archaeology of Human Bones*. London: Routledge. 242 p.

Mays S, Crane-Kramer G, Bayliss A. 2003. Two probable cases of treponemal disease of Medieval date from

England. *American Journal of Physical Anthropology* 120(2):133–48.

Mook WG. 1986. Business meeting: recommendations/resolutions adopted by the Twelfth International Radiocarbon Conference. *Radiocarbon* 28(2A):799.

Nadeau M-J, Schleicher M, Grootes PM, Erlenkeuser H, Gottdang A, Mous DJW, Sarnthein JM, Willkomm H. 1997. The Leibniz-Labor AMS facility at the Christian-Albrechts University, Kiel, Germany. *Nuclear Instruments and Physics Research B* 123(1–4):22–30.

Nadeau M-J, Grootes PM, Schleicher M, Hasselberg P, Rieck A, Bitterling M. 1998. Sample throughput and data quality at the Leibniz-Labor AMS facility. *Radiocarbon* 40(1):239–45.

Pearson GW. 1984. The development of high-precision ^{14}C measurements and its application to archaeological timescale problems [unpublished PhD thesis]. Belfast: Queen's University Belfast.

Reimer PJ, Baillie MGL, Bard E, Bayliss A, Beck JW, Bertrand CJH, Blackwell PG, Buck CE, Burr GS, Cutler KB, Damon PE, Edwards RL, Fairbanks RG, Friedrich M, Guilderson TP, Hogg AG, Hughen KA, Kromer B, McCormac G, Manning S, Bronk Ramsey C, Reimer RW, Remmele S, Southon JR, Stuiver M, Talamo S, Taylor FW, van der Plicht J, Weyhenmeyer CE. 2004. IntCal04 terrestrial radiocarbon age calibration, 0–26 cal kyr BP. *Radiocarbon* 46(3):1029–58.

Slota Jr PJ, Jull AJT, Linick TW, Toolin LJ. 1987. Preparation of small samples for ^{14}C accelerator targets by catalytic reduction of CO. *Radiocarbon* 29(2):303–6.

Steier P, Rom W. 2000. The use of Bayesian statistics for ^{14}C dates of chronologically ordered samples: a critical analysis. *Radiocarbon* 42(2):183–98.

Stenhouse M, Baxter MS. 1983. ^{14}C dating reproducibility: evidence from routine dating of archaeological samples. In: Waterbolk HT, Mook WG, editors International Symposium ^{14}C and Archaeology. *PACT* 8: 147–61.

Stow J. 1908. *The Survey of London*. Kingsford CL, editor. Oxford: Oxford University Press.

Stuiver M, Braziunas TF. 1993. Modeling atmospheric ^{14}C influences and ^{14}C ages of marine samples to 10,000 BC. *Radiocarbon* 35(1):137–89.

Stuiver M, Kra RS. 1986. Editorial comment. *Radiocarbon* 28(2B): ii.

Stuiver M, Polach HA. 1977. Discussion: reporting of ^{14}C data. *Radiocarbon* 19(3):355–63.

Stuiver M, Reimer PJ. 1993. Extended ^{14}C data base and revised CALIB 3.0 ^{14}C age calibration program. *Radiocarbon* 35(1):215–30.

Thomas C, Sloane B, Phillpotts C. 1997. *Excavations at the Priory and Hospital of St. Mary Spital, London.* London: Museum of London Archaeology Service. 267 p.

Unger RW. 1980. Dutch herring, technology, and international trade in the seventeenth century. *The Journal of Economic History* 40(2):253–80.