CROSSRAIL BROADGATE TICKET HALL AND ASSOCIATED WORKS
Liverpool Street Station
London EC2M
ARCHAEOLOGICAL POST-EXCAVATION ASSESSMENT

THE POST-MEDIEVAL OSTEOLOGY OF THE NEW CHURCHYARD
MOLA XSM10 PXA02a_REV.3.0
C257-MLA-T1-RGN-CRG03-50094 Rev.3.0

Site code XSM10
NGR 533050 181610
OASIS ID: molas1-241917

Post-excavation assessment and updated project design

Sign-off History:

Issue No.	Date:	Prepared by:	H&S signed off by:	Checked/ Approved by:	Reason for Issue:
rev0.0	03.11.15	NC, JH, MH, EK, DW	HSCM	Julian Hill	Draft for client review
rev0.0 reissue	12.11.15	NC, JH, MH, EK, DW	HSCM	Julian Hill	As above with edit to p.62 and fig 4
rev1.0	19.02.16	NC, JH, MH, EK, DW	HSCM	Julian Hill	As above, incorporating X-rail comment as per (Marit Leenstra) comment sheet **C257-MLA-T1-XCS-CRG03-50026** and (Jay Carver) comment in Adobe comment format. The latter has been translated to a comment sheet and serial no. will be added when available
Rev 2.0	10.03.16	NC, JH, MH, EK, DW	HSCM	Julian Hill	For acceptance (Incorporating rev 1.0 comment)
Rev 3.0	24.05.16	NC, JH, MH, EK, DW	HSCM	Julian Hill	Approved (Incorporating rev 2.0 comment – comment sheet C257-MLA-T1-XCS-CRG03-50030 rev.2.0)

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Executive summary

This report presents the results of the osteological assessment of burials excavated at the Crossrail Central Broadgate Ticket Hall site (sitecode XSM10). It details the scope of that assessment work and proposes a schedule of analysis tasks to take the osteological work forward towards publication.

The Crossrail Broadgate Ticket Hall site produced multi-period archaeology ranging from early Roman through to post-medieval. The largest component of the archaeological sequence was the post-medieval burial ground documented as the 'New Churchyard' (also known as the Bedlam burial ground). Because the osteological analysis of the human remains from this cemetery constitutes a substantial and discrete element of the post-excavation analysis programme and represents the longest time-line of proposed analysis work, this document (C257-MLA-T1-RGN-CRG03-50094 or **MOLA XSM10 PXA02a rev 3.0**) concentrates exclusively on these purely osteological tasks with a view to getting client authorisation for the proposed schedule of works at the earliest opportunity. It does not, therefore, include any assessment of the other archaeological aspects of the site. The Roman and medieval sequence up to *c* AD 1000 (from which human remains were also recovered) will be covered separately as MOLA XSM10 PXA 1. The remainder of the archaeological sequence postdating *c* AD 1000 and the documentary evidence relating to the New Churchyard will be assessed as MOLA XSM10 PXA2.

The 2015 excavations employed a methodology where burials were divided into different categories:

- **Category A** comprises all burials from Area 5, as well as burials from *c* 40% of the surface area of Area 1 and Area 2/3. Category A burials were retained by MOLA as having potential for further analysis.
- **Category C** represents the burials from the remaining 60% of Area 1 and Area 2/3, which were assessed on site by an osteologist and then sent for reburial.
- **Category B** is a subset of Category C, 118 burials of specific osteological interest selected on site for retention for further analysis.

In total this assessment reports on **3354** articulated human remains (Category A: 1971, Category B: 118, Category C: 1265): it also includes assessment of the disarticulated human bone recovered during excavation.

It is currently proposed that full analysis be carried out on **792** of these human remains from XSM10:

- Category A burials greater than 65% complete with sufficient survival to allow estimation of age in the case of subadults, and estimation of biological sex in the case of adults. Total 652 burials (or *c* 30% of 1971 Category A).
- Category B burials comprising 140 burials (118 burials identified on site and a further 22 selected at assessment). Total 140 burials.
- However, as the osteological assessment is being presented in advance of the completion of the full stratigraphic assessment of the site the full identification of archaeologically defined individuals of whom components may be present in more than one archaeological intervention has yet to be completed. As a result the statistics forming the basis of this report and the analysis task list and resource requirement derived from them may be subject to minor revision.

In addition *c* 300 individuals from that part of the cemetery recorded in 1985 (LSS85: unpublished) will be incorporated within the analysis level data, set, bringing the overall

analysis dataset total to *c* **1100** human remains. This will provide a rare and important opportunity to analyse the health and demography of a subset of London's population from the late 16th–early 18th centuries, a period poorly represented in comparable studies undertaken to date.

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1 Introduction

MOLA (Museum of London Archaeology) is a company limited by guarantee registered in England and Wales with company registration number 07751831 and charity registration number 1143574. Registered office: Mortimer Wheeler House, 46 Eagle Wharf Road, London N1 7ED.

All work carried out on this project at assessment level has been, and all proposed analysis tasks will be, is subject to the health and safety policy statement of MOLA as defined in the MOLA Health And Safety Policy. This document is available on request. It is MOLA policy to comply with the requirements of the Health and Safety at Work Act 1974, the Management of Health and Safety at Work Regulations 1992 and all Regulations and Codes of Practice made under the Act which affect MOLA operations.

All work has also been carried in accordance with the generic Crossrail Written Scheme of Investigation (WSI) (Document No. CR-XRL-T1-GST-CR001-0003) and the Site-Specific WSI (Document No. C138-MMD-T1-RST-C101-00001 Rev. 3.1 and addendum (Document No. C502-XRL-T1-RST-C101-50002 rev. 2). Specific site methodology was also iterated in the MOLA method statement for the watching brief and excavation of the Crossrail Broadgate Ticket Hall site Areas 1–6 (Document No. C257-MLA-T1-GMS-C101-50002; MOLA 2015).

1.1 Site background

The site is being developed by Crossrail Ltd in order to create a new, sub-surface ticket hall beneath Liverpool Street, City of London, EC2, to serve new platforms being inserted in tunnels beneath Liverpool Street station. The approximate site centre lies at Ordnance Survey NGR 533050 181610. The Museum of London sitecode is XSM10. Henceforth in this report the Broadgate Ticket Hall site is referred to as either 'the site', 'XSM10' or 'site A').

The site was occupied until recently by the road and pavement of Liverpool Street, to the east of Blomfield Street, and to the south and west of the disused former Broad Street ticket hall/sub-station

The report was commissioned from MOLA by Crossrail Project Archaeologist by Jay Carver on behalf of Crossrail Ltd.

1.2 Scope of the excavations and report

The archaeological excavations at the site produced a record of multi-period activity ranging from early Roman through to post-medieval. The largest component of the archaeological sequence was the post-medieval burial ground documented as the 'New Churchyard' (later also commonly known as the Bedlam burial ground because of its association with the medieval Bethlehem Hospital).

This burial ground, the first of the early modern non-parochial cemeteries, was established in 1569 by the City of London. The priory and hospital of St Mary (of) Bethlehem had been founded on the western side of Bishopsgate in 1247, on a site now beneath the present Great Eastern Hotel, and the burial ground was established on one acre of land belonging to the hospital. The site had not initially been intended for the exclusive use of the hospital, however, but as an 'overflow' area, relieving pressure on the increasingly crowded burial grounds within the City. In 1563, there was an outbreak of plague and, consequently, the City had sought to increase burial capacity in case of further epidemics. The extent of the

'New Churchyard' is shown on several historic maps including Ogilby and Morgan's of 1676 (Fig 3). The burial ground fell out of use in the mid 18th century and in the mid-19th century Liverpool Street was widened over its southern part. As a result, the site is located within the south-western part of the cemetery, in what is now the western half of Liverpool Street's carriageway and pavements.

There is a paucity of evidence from cemeteries of the date range covered by the use of the New Churchyard. As a result the excavated evidence will contribute significantly to an understanding of health and living conditions in London in the late 16th–early 18th centuries, a period characterised in London by a substantial and rapid population growth fed by inward migration. Initially at least, the New Churchyard accepted poor and non-conformist burials. Parish burial registers, examined as part of a Crossrail volunteer programme, resulted in a database of over 5000 Londoners buried at the site (http://www.crossrail.co.uk/sustainability/archaeology/bedlam-burial-ground-register). Documentary sources reveal that the New Churchyard was used as an emergency burial ground during plague epidemics; consequently the discovery of a probable 17th-century mass burial pit containing approximately 45 individuals may be direct evidence of such, perhaps specifically the Great Plague of 1665. This will allow us to address the paucity of previous studies of 17th-century plague victims, particularly in regard to the analysis of the pathogen DNA of *Yersinia pestis* (plague), with the potential to advance studies of the history and evolution of this major killer. This not only has implications for the study of plague but for future work on other emerging and re-emerging bacterial infectious diseases.

This report, Document No. C257-MLA-T1-RGN-CRG03-50094, represents one of three assessment documents (PXA's) to be produced to cover the site's archaeological sequence. This report precedes the completion of full stratigraphic assessment. It does not, therefore, include any assessment of the other archaeological aspects of the site. The Roman and medieval sequence up to *c* AD 1000 (from which human remains were also recovered) will be covered separately as MOLA XSM10 PXA01. The remainder of the archaeological sequence postdating *c* AD 1000 and the documentary evidence relating to the New Churchyard – including that deriving from the Crossrail volunteer programme – will be assessed as MOLA XSM10 PXA02. This report represents an assessment of a subset or component part of the post *c* AD1000 archaeological data: as such, even though it is the first of the three to be issued it effectively constitutes an appendix to MOLA XSM10 PXA02, and is therefore numbered as MOLA XSM10 PXA02a.

This report constitutes an assessment of the condition and disturbance of the burial contexts with notes on demography, pathological lesions and minimum numbers of individuals represented in the sample. Whilst bone preservation was generally good, the crowded nature of the burial ground led to a relatively high level of truncation and resulting variability in the completeness of burial contexts. Initial results suggest that approximately equal numbers of males and females were recovered, and that subadults were under-represented. Brief observations of pathological conditions highlighted potential for the study of health and disease in this period, including rare archaeological examples of metastatic cancer. At full analysis, the skeletal sample will provide important information on life and living conditions in London during a period of great change. Stable isotope analysis will help to reconstruct the extent and form of migration to the city, together with any changes in diet as people moved from a rural to an urban environment. Evidence of trauma, metabolic disorders and infectious diseases will enlighten us as to the consequences of such shifts in living conditions. Sampling of dental calculus will characterise the oral microbiome: the pathogens hosted in the mouths of individuals, whether they be symbiotic or malign. It will further aid in the identification of local environmental conditions affecting the population, whether domestic or occupational, by collecting evidence of dust, smoke and other particles trapped in dental tartar during life.

Because the osteological analysis of the human remains from this cemetery constitutes a substantial and discrete element of the post-excavation analysis programme and represents the longest time-line of proposed analysis work, this document (MOLA ref. **MOLA XSM10 PXA02a**) concentrates exclusively on these purely osteological tasks with a view to getting Crossrail authorisation for the proposed schedule of works at the earliest opportunity. The presentation of the osteological data as **MOLA XSM10 PXA02a** in advance of the completion of full stratigraphic assessment means that it has not yet been fully reconciled with the stratigraphic data. Stratigraphic subgrouping will unite individuals currently divided between separate archaeological interventions and the result will be that 'total subgroups' will equal 'total archaeologically identified individuals'. It is also the case that reconciliation of the osteological and stratigraphic datasets will reduce the osteologically defined burial population of **3354** by a small number (possibly *c* 50).

There will therefore be a discrepancy between the statistics currently defined in this **MOLA XSM10 PXA02a** and the final count of archaeologically defined individuals. Furthermore, the definition of archaeologically defined individuals may add to the subset of the population that meet the criteria of completeness for analysis by a small amount (probably < 5%). Some revision in the analysis resource may therefore become necessary and MOLA **XSM10 PXA02a** is submitted as **version 1** with this caveat.

The 3354 skeletal remains osteologically recorded at assessment constitute:

Category A	1971	(58.77%)
Category B	118	(3.52%)
Category *C*	1265	(37.73%)

All bar *c* 30 of these contexts relate to the post-medieval cemetery.

The schedule of proposed analysis tasks includes provision for the integration of analysis data relating to further human remains interred within the New Churchyard, which were excavated at a contiguous site (LSS85) as part of the Broadgate development and which remain unpublished. These burials are currently being recorded to analysis level by the Centre for Human Bioarchaeology of the Museum of London where these human remains are stored and do not form part of the XSM10 assessment assemblage covered by this document. It is likely that a minimum of *c* 30% (120) of these will match the criterion of 65% complete. The presence of several mass burial events within LSS85 will contribute a quantity of Category B remains. It is estimated that up to *c* 300 LSS85 individuals will be included in the overall analysis dataset total of *c* **1100** human remains.

1.3 Planning background

The legislative and planning framework within which the excavation took place has been set out previously elsewhere. In brief, the overall framework within which archaeological work is undertaken is set out in the Environmental Minimum Requirements (EMR) for Crossrail (Crossrail 2008b) under which the nominated undertaker or any contractors will be required to implement certain control measures in relation to archaeology before construction work begins.

Schedules 9, 10 and 15 of the Crossrail Act (2008) concern matters relating to archaeology and the built heritage and allows the dis-application by Crossrail of various planning and legislative provisions, including those related to listed building status, conservation areas and scheduled ancient monuments (Schedule 9). Schedule 10 allows certain rights of entry to English Heritage given that Schedule 9 effectively dis-applied their existing rights to the Crossrail project, and Schedule 15 allows Crossrail to bypass any ecclesiastical or other existing legislation relating to burial grounds.

Notwithstanding these dis-applications, it is intended that agreements setting out the detail of the works and requiring relevant consultations and approvals of detail and of mitigation arrangements will be entered into by the nominated undertaker with the relevant local planning authorities and English Heritage in relation to listed buildings and with the

Department of Culture, Media and Sport (DCMS) and English Heritage in relation to Scheduled Ancient Monuments.

1.4 Circumstances and dates of fieldwork

A fuller description of the circumstances and dates of fieldwork will be presented in MOLA XSM10 PXA01. In summary, archaeological interventions took place between February 2011 and September 2015 and involved excavation of archaeological contexts from pile alignments as well as reduction of the main site area. The individual zones of excavation are shown on Fig 2.

1.5 Organisation of the report

As per section 1.3 above: 'Notwithstanding these dis-applications, it is intended that agreements setting out the detail of the works and requiring relevant consultations and approvals of detail and of mitigation arrangements will be entered into by the nominated undertaker with the relevant local planning authorities …..'

Consequently, despite the statutory framework of the planning background, this report adopts the standard structure of a MOLA PXA/UPD submission for a site within the City of London which is the relevant planning authority for the site. The *Post-excavation Assessment and Updated Project Design report* is defined in the relevant English Heritage Greater London Archaeology Advisory Service (GLAAS) guidance paper (Paper VI) as intended to 'sum up what is already known and what further work will be required to reach the goal of a well-argued presentation of the results of recording and analysis' (VI/1). The principle underlying the concept of post-excavation assessment and updated project design were established by English Heritage in the *Management of Archaeological Projects 2* (MAP2), (1991). More recent Heritage England guidance, superseding MAP2 but embodying the same principles, is contained in Heritage England's (previously English Heritage) Management of Research Projects in the Historic Environment (MoRPHE) Project Planning Note (PPN) 3.

However, because this report focusses on a specific subset of tasks relating to osteological analysis and is a subset of the wider programme of analysis to be presented in MOLA XSM10 PXA02 it does not present a summary of the archaeological and historical background of the site which, for the medieval and post-medieval periods of use of the site will be covered by that document.

The updated project design and proposed publication outline have been formulated in response to the Crossrail Central Archaeology Post-Excavation Strategy (CRL Doc CR-XRL-T1-STP-CR001-50001) and proposed publication output (Crossrail workstream ref CRL11 'Roman and Medieval Broadgate and Blomfield Street'). The original research aims for the project are set out in Section 2. This is followed by the quantification and assessment of the osteological assemblage in Section 3. In Sections 4 and 5 the potential and significance of the findings are considered.

Within the report the archaeological data is broken down into specific numbered units. Context numbers are distinguished in the text by square brackets [1] and environmental samples by the use of curly brackets {1}. For example [145] refers to the specific context number allocated to a cut/coffin/skeleton/fill etc during the excavation. During the process of field assessment, these are amalgamated into larger units or subgroups (sgp 1). Conventionally, a cut, the coffin within it, the human remains and any associated fill will be treated as a subgroup. Distinctions within the burial population and the in the use of the cemetery over time will be made during fieldwork analysis through the mechanism of land-use entities (described as Open Areas (OA1) or structures (S1) and chronological periods, as defined by both stratigraphic and dating evidence.

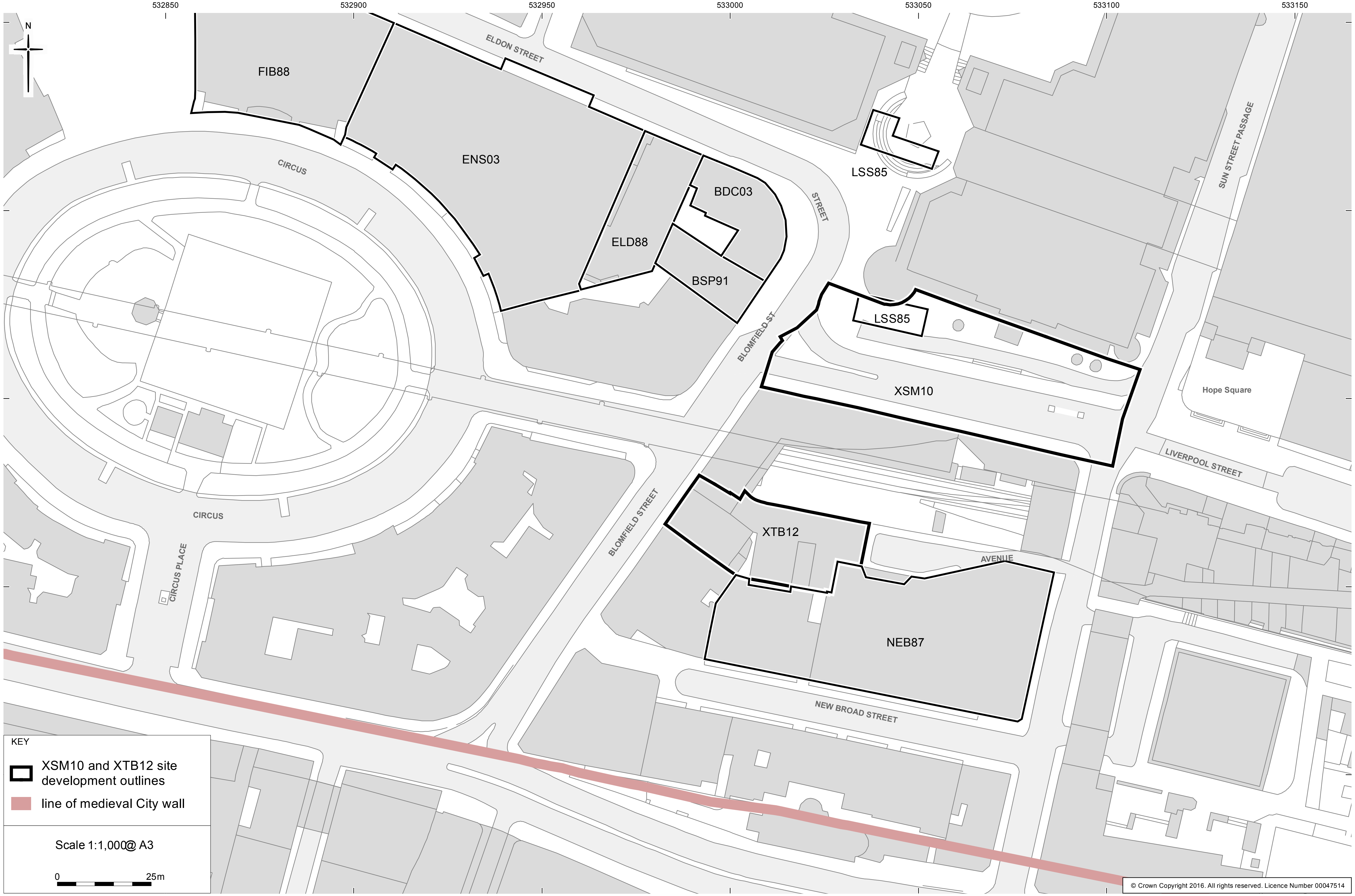

Fig 1 The study area with the modern street plan and other sites referred to in the text

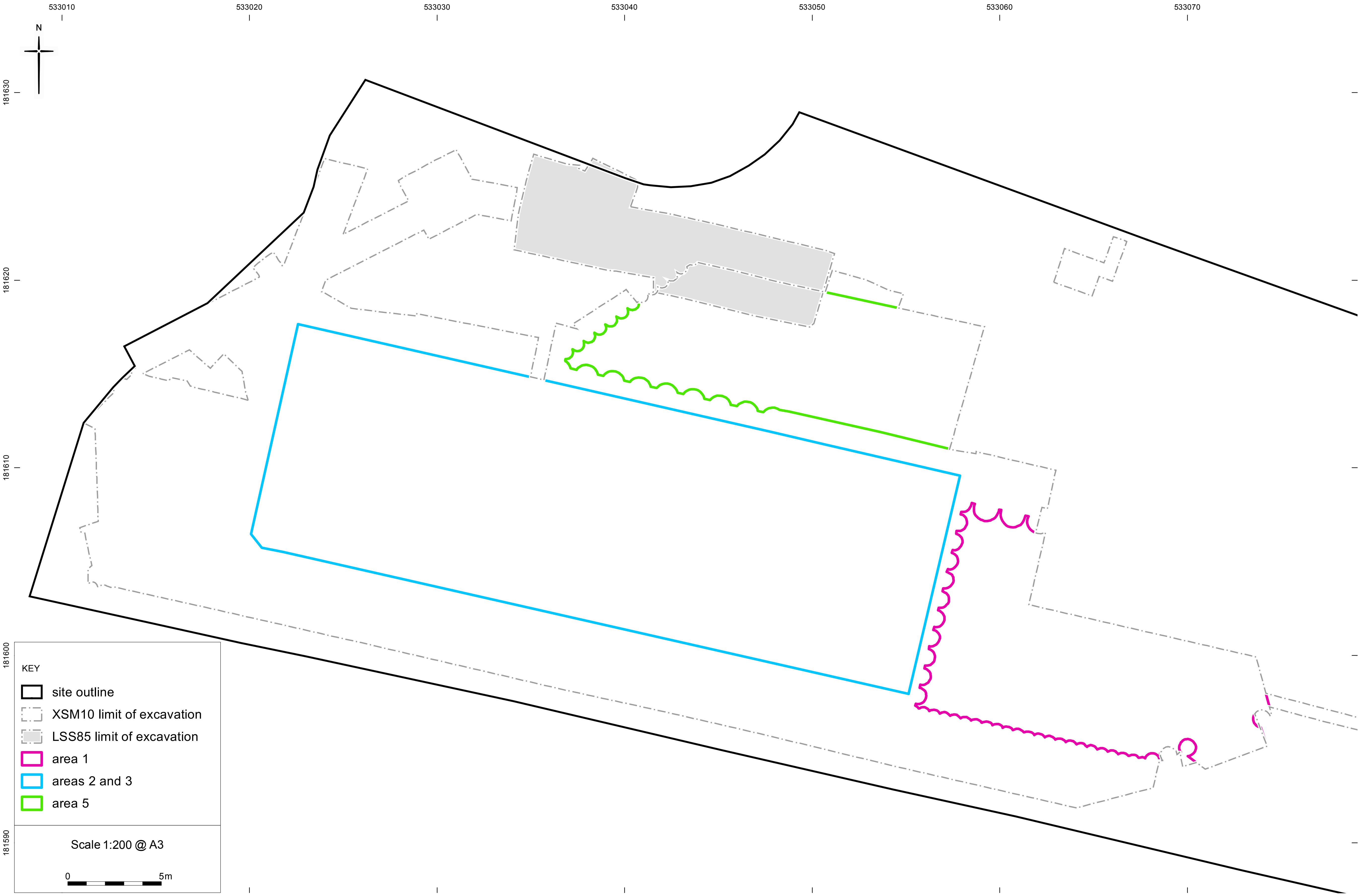

Fig 2 location of main excavation areas within the site

Fig 3 Ogilby and Morgan's map of 1676 with the areas of excavation and recorded inhumations superimposed

Fig 4 Multi-phase plan of burial ground features and structures

Fig 5 Excavation of mass pit [7482]

2 Original research aims

The Original Research aims (ORAs) relating to the New Churchyard/ Bedlam burial ground have been previously presented in document C502-XRL-T1-RST-C101-50002 rev. 2. In that document they are numbered as BB1 etc. Here, they are prefixed with ORA to distinguish them from revised research aims presented later in this document.

ORA-BB 1 *Characterise and date the sequence of late medieval and early post-medieval dumping and reclamation associated with the establishment of the cemetery. What evidence is there for the original boundary of the burial ground, its subsequent rebuilding and any intra site spatial organisation?*

ORA-BB 2 *Characterise and refine the sequence and dating of burials. How was the cemetery filled up? Is there evidence for intermittent import of other soils and hiatus referred to in historic documents? Does structural evidence for the alleged pulpit survive?*

ORA-BB 3 *Can different burial practices be defined? Use of shrouds, coffins, mass burial pits? How does it change spatially and chronologically? What indication is there for formal organisation/management and zoning? Can burial episodes be related to historic events such as documented plagues?*

ORA-BB 4 *Is there a zone of multiple or pit burials in the northern part of the site around Trenches 13 and 14, and the 1985 excavations?*

ORA-BB 5 *What date did the cemetery go out of use and how was the site prepared for subsequent re-use as gardens and then development? Can the gradual encroachment of Georgian buildings and plots in the 18th century be phased and dated?*

ORA-BB 6 *Can gravestones or marker/ledger slabs provide evidence which will identify individuals, and can these be correlated with documentary sources?*

ORA-BB 7 *What evidence is there for coffin use, construction type, furniture and coffin plates? Although preservation of these has been shown to be poor what use of specialist recovery methods and scientific testing could be applied?*

ORA-BB 8 *How can osteology studies be used to describe the population of the burial ground and what scientific samples should be taken to determine the role of various pathogens particularly in relation to potential plague victims?*

ORA-BB 9 *Can skeletal evidence, injury, or other indicators be correlated with biographic details derived from burial records?*

ORA-BB 10 *Can the skeletal evidence be correlated with burial records to build a picture of the population of the cemetery as a whole and establish chronological trends during the use of the cemetery relating to parish origin, age and cause of death, gender, social, occupation, and religious belief profiles etc.?*

ORA-BB 11 *(not numbered other than by paragraph in document C502-XRL-T1-RST-CR101-50002- Rev. 2.0) Can scientific sampling of soil samples be used to illuminate any of the other research objectives?*

The scope of this assessment document is purely osteological and consequently only ORA-BB 8–ORA-BB 11 are addressed by it. ORA-BB 1–ORA-BB 7 will be covered by MOLA XSM10 PXA 2.

3 Osteological quantification and assessment

3.1 Introduction

3.1.1 *Quantification*

Estimated no. of individuals	3354
No. of boxes:	916

Table 1 Contents of human bone archive

This assessment has been undertaken on the human skeletal remains recovered during archaeological interventions by Museum of London Archaeology (MOLA) at the Crossrail Central Broadgate Ticket Hall site. The significance and potential of the human remains as defined by this document provides the basis upon which the schedule of work is proposed for the study of the burials at full analysis.

The site is located within the southern half of the New Churchyard, also known as the Bedlam burial ground, in use from 1569–1730's. Recent excavations recovered more than 3300 individuals (Table 2; Fig 4). The burials were densely packed and predominantly orientated east to west, with heads to the west. The majority were contained within wooden coffins, mostly remaining as organic stains and corroded metal fittings. Extensive land use and inter-cutting of graves led to heavy truncation in some areas. This resulted in a large quantity of disarticulated bone and a number of partial burials remaining.

Trench/ Area	Category A burials	Category B burials	Category C burials
1	64	-	-
2	66	-	-
7	63	-	-
13	22	-	-
14	24	-	-
Pit 4	61	-	-
MHS1 and MHS2-100	72	-	-
Area 5	248 (57+191)*	-	-
Area 1	300	64	301
Area 2/3	1051	54	964
Totals by category	1971	118	1265
Grand total		**3354**	

*Table 2 Summary of assessed burials by area and category (*Area 5 includes 57 from 2014 phase, 191 from 2015 phase)*

This report contains a preliminary osteological assessment of **3354** post-medieval articulated human remains excavated under archaeological conditions. Because articulated parts of some individuals were excavated at different times in separate interventions this figure overstates the number of articulated individuals actually recovered.

During excavation the articulated remains of each individual were allocated to one of three categories, A, B or C, which defined the methodology applied to the generation of the archaeological record for that individual subsequent. These categories are defined in the section ('Methods') of this report immediately below.

This report also details the data gathered from examination of disarticulated bone.

Previous excavations in 1985 (LSS85) immediately north of the site, investigated burials which had survived the construction of the station within the development footprint of Broadgate. The excavation trench was located under what had been the taxi cab ramp, immediately in front of the station building itself. Within the main excavation trench, over 400 partial or complete burials were encountered at a density of up to 8 per m^3 of ground and 200 more came from further test-pits (Malt & White 1988).

3.1.2 Methodology and category definition

A site specific strategy was devised by Crossrail and MOLA to address both the large quantity of human remains encountered at excavation and the specific circumstances of the site. The methods employed are described in detail in the WSI Addendum (Crossrail 2014, 6.2.1 to 6.2.15).

<u>Category A</u>

Category A was applied to all phases of archaeological excavation undertaken at XSM10 prior to 2015 and to 40% of the area of Area 1 and Area 2/3 excavated in 2015. All skeletons within this category were retained.

All inhumations and disarticulated bone were examined by a MOLA Human Osteologist in accordance with English Heritage Centre for Archaeology Guidelines 2004 and MOLA standard practice (Powers *unpublished*). Each context representing an articulated skeleton was inspected visually and recorded onto an Excel spreadsheet. This process resulted in collated data for skeletal completeness and bone condition, and created a summary catalogue of each body area present. Overall completeness was then estimated in 5% increments from 5–95% based on the approximate percentage survival of bone (skull 20%, legs and feet 20%, arms and hands 20%, torso and pelvis 40%). Bone preservation was coded on a three point scale from good to poor (1–3) following Connell and Rauxloh (2003).

Biological sex and approximate age at death were estimated for each individual with appropriate surviving skeletal elements. Subadult age was estimated following observations of the eruption of the permanent teeth (Gustafson and Kock 1974) and stage of epiphyseal fusion (Scheuer and Black 2000). An adult age category was assigned to those individuals displaying erupted third molars and/or complete epiphyseal fusion. No attempt was made to define adult age ranges at the assessment stage. Adult biological sex was estimated through brief observations of cranial and pelvic morphology following (Buikstra and Ubelaker 1994), and recorded on a five point scale (Table 3).

Observations of pathological bone changes and dental disease were recorded by disease category following Connell and Rauxloh (2003) and supplemented by brief descriptions of location and type where appropriate. A note was made of any staining of bone surfaces. Intrusive human bone elements were noted and the <u>minimum number of individuals</u> (MNI) for each context calculated based on the age, sex and bone morphology of repeated elements. All assessment results should be considered preliminary and subject to the possibility of adjustment during detailed observation at full analysis.

Age
Foetal/neonatal
1 month to 6 years
7–12 years
13–16 years
Adult
Subadult (age unknown)
Sex
Male
Probable male
Intermediate
Probable female
Female
Undetermined
Subadult

Table 3 Demographic assessment categories

Category C burials

The remaining 60% of burials from Area 1 and Area 2/3 formed the Category C burials. They were assessed on site by an osteologist who recorded (where possible) age, biological sex, and obvious pathological lesions. Following assessment and lifting, the majority of these skeletons (see Category B below) were then passed to the C502 exhumation contractor for reburial, with no further osteological investigation.

Category B burials

Any burials within Category C which were determined by the MOLA osteologist to be a 'special case' formed the Category B burials. This sub-selection provided for burials of particular archaeological or osteological interest to be retained for further analysis by MOLA. The criteria for selection included skeletal remains within mass burial pits, well preserved or named coffins, tombs and those with grave goods and accessories, as well as individuals or groups with unusual pathological conditions or other characteristics informed by the research aims of the project. These were treated in the same way as Category A burials, and retained for further investigation.

Disarticulated bone

Disarticulated human bone from archaeological excavation areas in trenches 1, 2, 6, 7, 9 and 13 was examined. In Areas 1, 2/3 and 5, disarticulated human bone was only recorded when encountered as a discrete assemblage (reburied within a pit or structure for example) or where pathological lesions were observed. All disarticulated bone was scanned on site by the MOLA osteologist and a decision made about its potential for further investigation.

The disarticulated bone data was catalogued and recorded onto an Excel spreadsheet when elements or bone segments were at least 50% present. Long bones were recorded by shaft (proximal, medial and distal). This allowed for the calculation of an MNI based on the presence of repeated elements. A note was made of any intrusive animal bone, staining or observations of any pathological conditions. Age and sex was recorded where possible.

3.2 Assessment of the Category A burials (1971 no.)

3.2.1 Condition and disturbance

Preservation

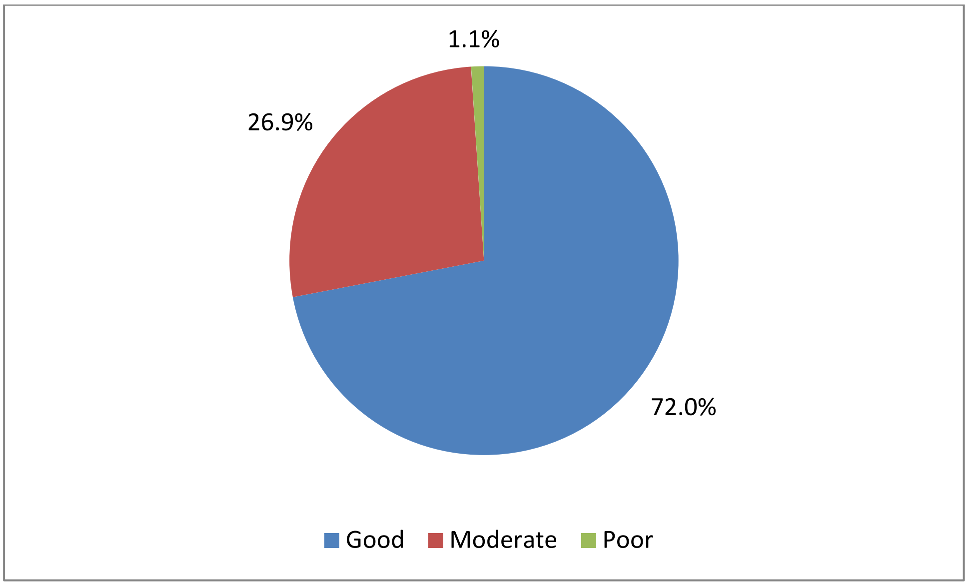

Fig 6 Preservation of Category A burials

The majority of the Category A assemblage exhibited good levels of bone preservation (1419/1971: 72.0%), over a quarter were moderately well preserved (531/1971: 26.9%) and only 1.1% were poorly preserved (21/1971: 1.1%) (Fig 6). The separation of the assemblage into adult and subadult age categories mirrored this pattern with 71.2% (1043/1465) of adults and 74.3% of subadults (376/506) displaying good bone preservation.

Hair survived in 0.2% (4/1971) of burials: three adults (3/1465: 0.2%) and one subadult (1/506: 0.2%). Adult [370] had an almost full head of wavy blonde/ light brown hair still attached to the skull. Numerous taphonomic factors can affect the preservation of hair, including burial depth, burial mode, body adornments and decomposition. Anaerobic conditions and well preserved coffins can protect the corpse from the surrounding soil and from keratinolytic fungi that would otherwise destroy the hair (Mant 1987; Haglund and Sorg 1997; Wilson and Gilbert 2007). Metal corrosion products can also cover and protect hair within the burial environment (Roberts 2009, 55–6; Walker 2012, 277). In the case of burial [370], the head end of the coffin was relatively well preserved, perhaps accounting for the level of hair survival.

Green staining, probably the result of contact with copper within the burial environment was present on bone surfaces in 14.2% of contexts (279/1971). Twenty-four individuals (24/1971: 1.2%) had fragments of iron adhering to bone elements, likely remnants of coffin fittings or furniture. Purple staining was observed in two contexts: [1182] and [1139], this may relate to the early stages of chemical diagenesis of the bone (Molleson and Cox 1993, 13) or manganese staining from the soil (Stermer et al 1996).

Twenty-seven contexts exhibited dark brown or black staining to multiple elements (27/1971: 1.4%), this was often observed in earlier burials that were cut into the medieval marsh deposits.

Completeness

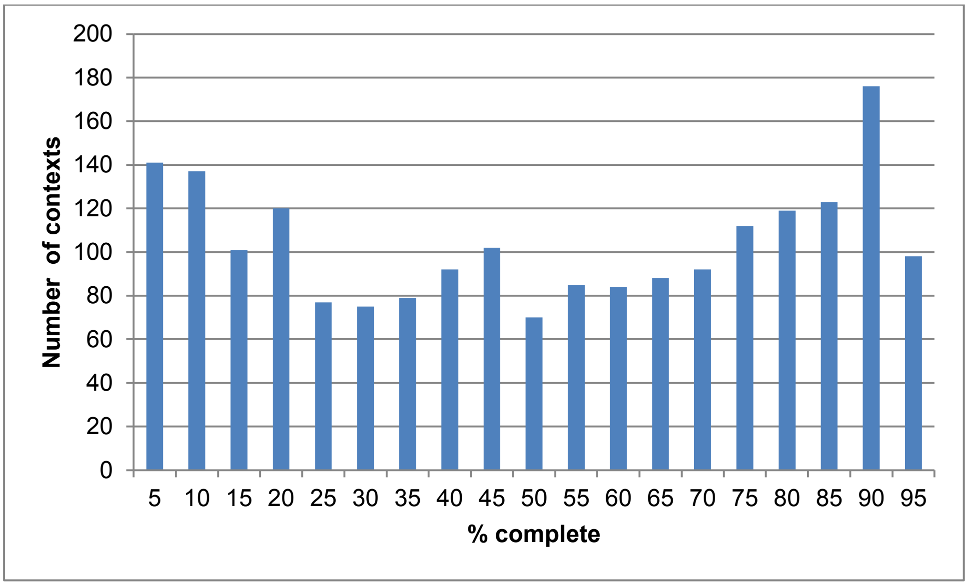

Fig 7 Completeness of Category A burials

The completeness of the Category A burials ranged from 5–95%, reflecting the variation in the degree of truncation and inter-cutting of burials.

More than half the burials were more than 50% complete (1047/1971: 53.1%) and 31.9% (628/1971) had 75% or more elements present. Ninety-eight burials were recorded as 95% complete. At the other end of the scale, 37.0% (730/1971) were less than 35% complete and 7.2% (141/1971) had only 5% of elements present (Fig 7).

Composite scores were compiled for elements in each context, combining those with one or two legs, arms, hands and feet. The bones of the torso were the most commonly observed elements present (1569/1971: 79.6%), followed by the arms (1543/1971: 78.3%) and legs (1524/1971: 77.3%). A complete, measurable crania was recorded in 149 individuals (/1971: 7.6, 134/1465: 9.1% of adults and 15/506: 3.0% of subadults). Dentition was present in 49.9% of burials (984/1971) (Fig 8). Intrusive animal bone was recorded in only four contexts (4/1971: 0.2%).

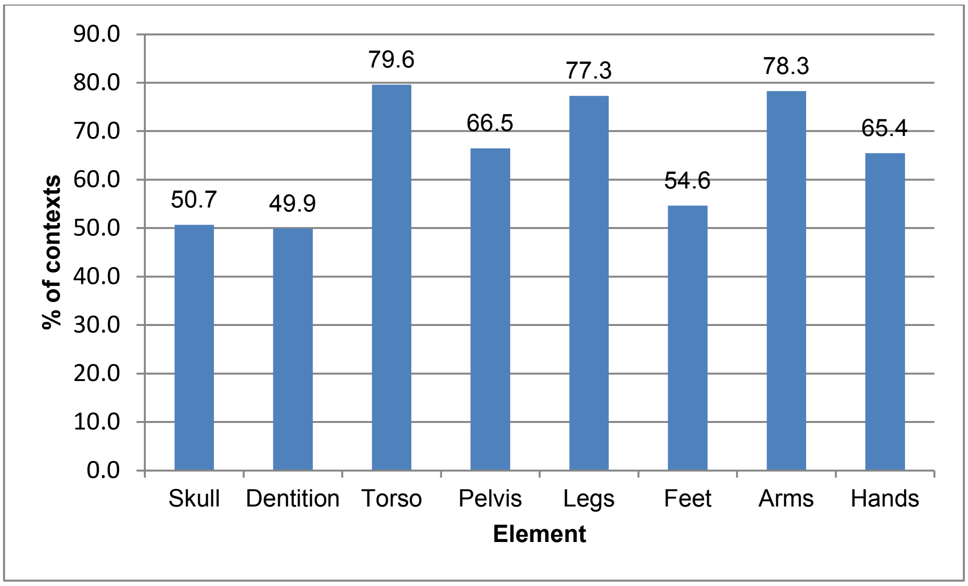

Fig 8 Percentage of identified elements present in Category A burials

Associated artefacts

Two individuals were found with associated artefactual remains: subadult [349] was found with a bead necklace and female [5265] had a pewter plate placed over the lower torso region of the skeleton.

3.2.2 Minimum number of individuals

A total of **1971** Category A articulated human skeletons were subject to osteological assessment. A single individual was present in 56.2% of burials (1108/1971), intrusive remains were present in 43.8% of the assemblage (863/1971) (Table 4). Examination of context records and stratigraphic data will permit re-association of some of these elements at analysis. There are also a number of duplicate and erroneous contexts. These will be cleaned from the dataset before analysis commences.

MNI	**1**		**2**		**3**		**4**		**5**	
	N	**%**	**n**	**%**	**n**	**%**	**n**	**%**	**n**	**%**
Adult	829	42.1	499	25.3	129	6.5	7	0.4	1	0.1
Subadult	279	14.2	188	9.5	36	1.8	2	0.1	1	0.1
Total	**1108**	**56.2**	**687**	**34.9**	**165**	**8.4**	**9**	**0.5**	**2**	**0.1**

Table 4 Category A minimum number of individuals

3.2.3 Demography

The demographic profile of the assemblage identified a higher number of adults (1465/1971: 74.3%) than subadults (506/1971: 25.7%) (Fig 9).

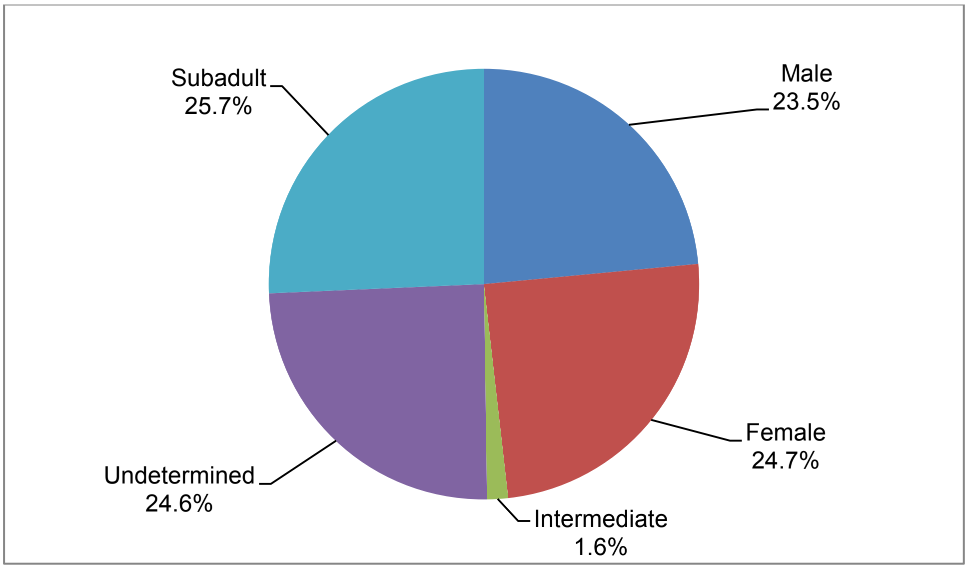

Fig 9 Demographic distribution of Category A burials

<u>Subadult age at death</u>

The majority of subadults were aged between one month and six years at death (159/506: 31.4%) while 26.9% (136/506) were aged between 13–17 years reflecting a high proportion of adolescent individuals. Neonate or foetal burials comprised 2.8% of the subadult population (14/506) and 17.2% (87/506) were aged 7–12 years. The incomplete nature of burials prevented the refining of age for 21.7% (110/506) of individuals assigned a general ‘subadult’ age category (Fig 10).

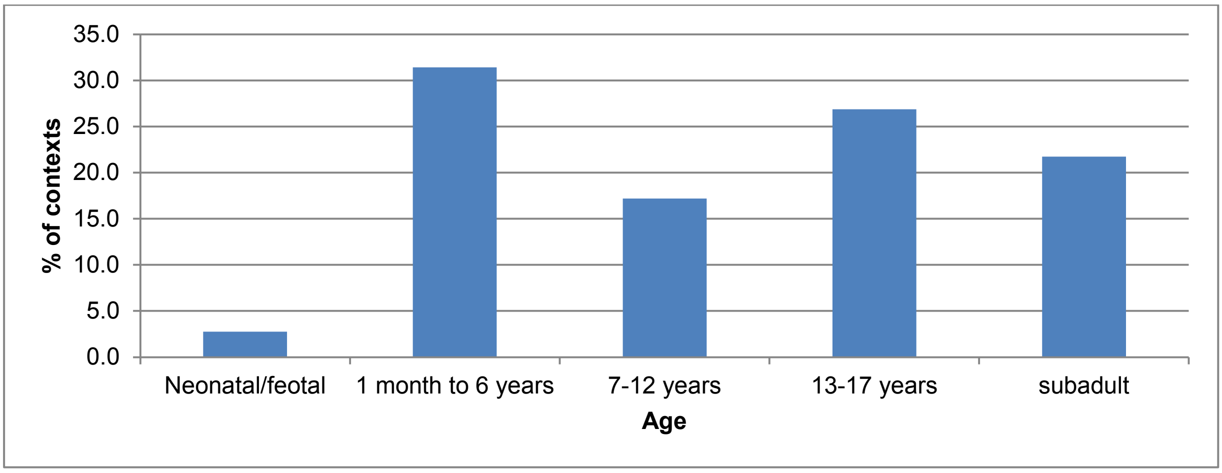

Fig 10 Category A subadult age at death distribution

<u>Adult sex</u>

	N	% adults
Male	251	17.1
Possible male	212	14.5
Intermediate	31	2.1
Possible female	257	17.5
Female	230	15.7
Undetermined	484	33.0
Total	**1465**	**100.0**

Table 5 Category A adult sex distribution

When definite and probable adult sexes were pooled there was an almost even proportion of males (463/1971: 23.5%) and females (487/1971: 24.7%) with a ratio of 0.96:1. Thirty-one adults displayed intermediate morphological traits (31/1971: 1.6%). It was not possible to determine the sex of 484 adults (/1971: 24.6%) due to insufficient survival of skeletal elements (Table 5).

Named Burials

Two Category A burials: female [5586] and subadult [5193], were found within coffins which had complete inscriptions (there were other incomplete examples) formed of upholstery studs.

The coffin lid of female [5586] had the inscription:

R + R
1·6·7·4

The coffin lid of subadult [5193] had the inscription:

P·W
1·6·7·6

While these inscriptions provide clear dating evidence, they also have potential as identification evidence. Further analysis of burial registers may provide a clear match to an individual, however, given how many parishes used the burial ground, it may only be possible to narrow down potential matches to a small number of individuals.

3.2.4 Paleopathology

The rates recorded stated below are calculated as crude prevalences, and thus represent only an indication of the potential for recovery of information at full analysis.

Dental health

Dentitions were observable in 987 individuals (/1971: 50.1%): 47.8% of adults (700/1465) and 56.1% of subadults (284/506). Evidence of dental disease was recorded in 39.5% of contexts (779/1971) (Table 6).

	Adult		Male		Female		Sub-adult		Total	
	1465		463		487		506		1971	
	N	%	n	%	n	%	n	%	n	%
Ante mortem tooth loss	422	28.8	162	35.0	215	44.1	17	3.4	439	22.3
Caries	444	30.3	196	42.3	203	41.7	79	15.6	522	26.5
Calculus	412	28.1	202	43.6	175	35.9	62	12.3	474	24.0
Enamel hypoplasia	150	10.2	68	14.7	62	12.7	36	7.1	186	9.4
Periodontal disease	177	12.1	83	17.9	77	15.8	1	0.2	178	9.0
Periapical lesions	106	7.2	53	11.4	44	9.0	7	1.4	113	5.7

Table 6 Dental disease crude prevalence rates for Category A burials

Ante-mortem tooth loss affected over a quarter of the adult population (422/1465: 28.8%) with a higher proportion of females (215/487: 44.1%) than males (162/463: 35.0%) losing teeth during life. Five adults (6/1465: 0.3%) had lost all of the teeth of the mandible and 0.1% (2/1465) had lost all the teeth of the maxilla. Adult female [248] was fully edentulous.

Dental caries (cavities) was the most frequently observed dental disease affecting 26.5% (522/1971) of individuals, 444 adults (444/1465: 30.3%) and 79 subadults (79/506: 15.6%). Calculus (mineralised plaque) was present on the tooth surfaces of 24.0% individuals (474/1971), with a higher rate amongst adult males compared to females.

Fourteen individuals had impacted teeth (/1971: 0.7%), dental crowding was present in seven contexts (/1971: 0.4%), three burials had evidence of a peg tooth (/1971: 0.2%) and abnormal dental wear affected the dentitions of four individuals (/1971: 0.2%). Four adults had dental tori (4/1465: 0.3%).

Circulatory disease

Thirteen individuals exhibited evidence of circulatory disorders (/1971: 0.7%, 12/1465: 0.8% of adults, 1/506: 0.2% of subadults) (Table 7). Eight adults, including five males (/463: 1.1%) and two females (/487: 0.4%) displayed circular lesions in the subchondral bone of joint surfaces (osteochondritis dissecans). Three adults (/1465: 0.2%) had defects in the vertebral bodies of the spine (Scheuermann's disease). Male [438] had pitted erosions to the femoral heads that were also flattened in shape, possibly a result of a disruption of the blood supply and death of bone tissue (necrosis). Female [3639] and subadult [5198] had a deformity to the shape of the femoral head diagnostic of a slipped femoral epiphysis.

	Adult		Male		Female		Subadult		Total	
	1465		463		487		506		1971	
	N	%	n	%	n	%	n	%	n	%
Osteochondritis dissecans	8	0.5	5	1.1	2	0.4	0	-	8	0.4
Scheuermann's disease	3	0.2	1	0.2	2	0.4	0	-	3	0.2
Femoral head necrosis	1	0.1	1	0.2	0	0.0	0	-	1	0.1
Slipped femoral epiphysis	1	0.1	0	-	1	0.2	1	0.2	2	0.1

Table 7 Circulatory disease crude prevalence rates for Category A burials

Neoplastic disease

Thirty-three burials (/1971: 1.7%, 31/1465: 2.1% of adults, 2/506: 0.4% of subadults) had evidence of neoplastic bone changes, the result of irregular tissue which develops beyond the normal range of growth, including cancerous tumours. Neoplasms comprise a range of both benign and malignant conditions (Table 8).

Fifteen individuals (/1471: 0.8%) exhibited smooth, circular masses of sclerotic bone on the outer surfaces of the skull (osteoma). Five adults (5/1465: 0.3%) had osseous outgrowths of bone on the surfaces of long bones reflecting ossified cartilage tissue or benign bone tumours (osteochondromas). Eight individuals (8/1971: 0.1%) had evidence of lytic cysts.

	Adult		Male		Female		Subadult		Total	
	1465		463		487		506		1971	
	n	%	n	%	n	%	n	%	n	%
Bone Tissue	4	0.3	2	0.4	2	0.4	0	-	4	0.2
Cartilage tissue	1	0.1	0	-	1	0.2	0	-	1	0.1
Osteoma	14	1.0	6	1.3	8	1.6	1	0.2	15	0.8
Bone cysts	7	0.5	2	0.4	3	0.6	2	0.4	8	0.4
Metastatic carcinoma (osteoblastic)	3	0.2	2	0.4	1	0.2	0	-	3	0.2
Metastatic carcinoma (osteoclastic)	1	0.1	0	-	1	0.2	0	-	1	0.1

Table 8 Neoplastic disease crude prevalence rates for Category A burials

Four adults (4/1465: 0.3%, 2/463: 0.4% of males and 2/487: 0.4% of females) presented distributions of bone lesions possibly representing metastatic carcinomas. Male [98] had regions of porosity and localised lytic erosions on the outer surface of the cranium. Female [3271] had erosive lesions on the mandible, frontals and parietals that penetrated both tables of the cranial vault. There were also plaques of porous bone in the orbits and thickening of multiple rib shafts with abnormal erosive lesions on the sternal ends. A fragment of pubis or ischium had severe erosions and thickening of the underlying trabecular bone structures. Female [5012] had extensive new bone growth with destructive lesions in the right pelvis. Male [3293] had extensive, florid new bone growth to the scapulae, clavicles, humeri, axis vertebrae and manubrium. The distribution and extensive nature of these bone changes suggested an osteoblastic metastatic carcinoma with a secondary spread; such a distribution is common in prostate cancer (Resnick 2002: 4285).

Congenital disease

Congenital disorders were recorded in 59 individuals (/1971: 3.0%), 3.7% of adults (54/1465), 5.0% of males (23/463), 5.5% of females (27/487) and 1.0% of subadults (5/506) (Table 9).

Seventeen individuals (/1971: 0.9%) had disorders of the spine. Five adults (5/1465: 0.3%) had sacralisation of the fifth lumbar vertebrae and seven individuals (/1971: 0.4%) had spina bifida occulta. Female [813] had a hemivertebrae between the eleventh and twelfth thoracic vertebrae. Female [5943] had Klippel-Feil syndrome and subadult [6089] had an occipitalised atlas.

Congenital curvature of the spine was recorded in 0.4% of contexts (8/1971), seven individuals had lateral curvature of the spine (scoliosis) (7/1971: 0.4%). Male [6485] displayed an anteroposterior curvature (kyphosis). Female [813] had two abnormally formed thoracic vertebrae resulting in a severe scoliosis of the mid-lower spine. There was also evidence of a malformation to the parietal bone of the right skull.

	Adult		Male		Female		Subadult		Total	
	1465		463		487		506		1971	
	N	%	n	%	n	%	n	%	n	%
Spinal disorders	14	1.0	4	0.9	10	2.1	3	0.6	17	0.9
Hallux valgus	8	0.5	2	0.4	4	0.8	0	-	8	0.4
Skull malformation	5	0.3	1	0.2	4	0.8	0	-	5	0.3
Scoliosis	5	0.3	1	0.2	2	0.4	2	0.4	7	0.4
Kyphosis	1	0.1	1	0.2	0	-	0	-	1	0.1
Other	2	0.1	2	0.4	0	-	0	-	2	0.1
Lower limb aplasia/ hypoplasia/ malformation	4	0.3	3	0.6	1	0.2	0	-	4	0.2
DDH	1	0.1	1	0.2	0	-	0	-	1	0.1
Spondlylolysis (bilateral)	14	1.0	8	1.7	6	1.2	0	-	14	0.7
Spondylolysis (unilateral L)	1	0.1	1	0.2	0	-	0	-	1	0.1
Spondylolysis (unilateral R)	2	0.1	0	-	2	0.4	0	-	2	0.1

Table 9 Congenital disease crude prevalence rates for Category A burials

Seventeen contexts (/1971: 0.9%) displayed partial or complete spondylolysis. This affected the fifth lumbar vertebrae in 14 cases, the fourth lumbar vertebrae in two instances and the first sacral element in one context. This was bilateral in 1.0% of adults (14/1465) and unilateral in 0.2% of adults (3/1465: 0.2%).

Three males (/463: 0.6%) had coxa vara deformity of the femoral neck. Adult male [438] had possible congenital dislocation of the right hip. Eight adults (/1465: 0.5%) had hallux valgus deformity of the first metatarsals.

Five adults (/1465: 0.3%) had developmental disorders to the bones of the skull. Male [4968] had deformities to the temporomandibular joints of the mandible. Large deposits of calculus on the tooth surfaces may have reflected an inability to masticate. Female [768] had an enlarged left parietal bone and pronounced occipital bun.

<u>Infectious disease</u>

Bone changes resulting from infectious disease were recorded in 11.4% of the assemblage (224/1971): 13.4% of adults (197/1465) and 5.3% of subadults (27/506) (Table 10).

Non-specific infection was recorded on 10.5% of burials (207/1971) comprising 182 adults (/1465: 12.4%), with an equal proportion of males (69/463: 14.9%) and females (67/487:13.8%) affected. Twenty-five subadults also displayed non-specific infectious changes (25/506: 4.9%).

Non-specific periostitis lesions affected 10.0% of individuals (198/1971). The majority of cases consisted of plaques of new bone on the surfaces of limb elements. Adult [470] had diffuse plaques of woven new bone on the left tibia, together with a large erosive lesion on the anteromedial surface, possibly reflecting an overlying soft tissue lesion such as a longstanding skin ulcer (Ortner 2003, 207). Observations of the internal cranium revealed inflammatory bone growth on the maxillary sinuses (sinusitis) in eighteen individuals (/1971: 0.9%), 1.1% of adults (16/1465) and 0.4% of subadults (2/506). Male [516] had a large bulbous ossified mass in the right maxillary sinus, suggesting longstanding infection.

	Adult		Male		Female		Subadult		Total	
	1465		463		487		506		1971	
	N	%	n	%	n	%	n	%	n	%
Non-specific infection (general)	2	0.1	1	0.2	1	0.2	0	-	2	0.1
Non-specific periostitis	173	11.8	63	13.6	103	21.1	25	4.9	198	10.0
Non-specific osteomyelitis	6	0.4	4	0.9	0	-	0	-	6	0.3
Non-specific osteitis	8	0.5	7	1.5	0	-	0	-	8	0.4
Tuberculosis	10	0.7	6	1.3	1	0.2	2	0.4	12	0.6
Treponemal disease	15	1.0	7	1.5	3	0.6	0	-	15	0.8

Table 10 Infectious disease crude prevalence rates for Category A burials

New bone on visceral rib surfaces was identified in eighteen individuals (/1971: 0.9%, 16/1465: 1.1% of adults and 2/506: 0.4% of subadults). Such changes may indicate an inflammatory reaction to thoracic disease, possibly tuberculosis (Roberts and Manchester 2005, 190).

Infection of the internal bone structures (osteomyelitis) was recorded in six individuals (/1971: 0.3%, /1465: 0.4% of adults). Expansive change to the bone diagnostic of inflammation of the bone cortex (osteitis) was observed in eight individuals (/1971: 0.4%, /1465: 0.5% of adults).

Twenty-six individuals displayed bone changes possibly resulting from a specific infection (/1971: 1.3%, 24/1465: 1.6% of adults, 12/463: 2.6% of males, 4/487: 0.8% of females and 2/506: 0.4% of subadults).
Tuberculosis was recorded in 12 individuals (/1971: 0.6%, 10/1465: 0.7% of adults, 6/463: 1.3% of males, 1/487: 0.2% of females and 2/506: 0.4% of subadults).

Bone changes in the form of treponemal disease, possibly venereal syphilis, were recorded in 15 adults (/1465: 1.0%; 7/463: 1.5% of males and 3/487: 0.6% of females). Males [3895], [7671] and [7740] exhibited characteristic lesions on the cranium (caries sicca) and expansive changes in the upper and lower limb bones with dense remodelled bone formation consistent with a diagnosis of venereal syphilis.

Joint disease

A quarter of the assemblage had evidence of degenerative joint disease (492/1971: 25.0%, 479/1465: 32.7% of adults, 239/463: 51.6% of males, 167/487: 34.3% of females and 13/506: 2.6% of subadults).
In the spine, disc herniation (Schmorl's nodes) was the most frequently observed joint disorder. This affected 18.5% of adults (271/1465) and with a higher prevalence amongst males (156/463: 33.7%) compared to females (84/487: 17.2%). Osteoarthritis, osteophytes (new bone growth), intervertebral disc disease and fusion of vertebral elements were also recorded (Table 11).

	Adult		Male		Female		Subadult		Total	
	1465		463		487		506		1971	
	N	%	n	%	n	%	n	%	n	%
Schmorl's nodes	271	18.5	156	33.7	84	17.2	12	2.4	283	14.4
Osteophytes	203	13.9	105	22.7	63	12.9	1	0.2	204	10.4
Osteoarthritis	89	6.1	39	8.4	37	7.6	0	-	89	4.5
Intervertebral disc disease	61	4.2	28	6.0	23	4.7	0	-	61	3.1
Fusion	31	2.1	17	3.7	11	2.3	0	-	31	1.6

Table 11 Spinal joint disease for Category A burials

Extra-spinal joint disease was recorded in 117 adult individuals (/1465: 8.0%, 52/463: 11.2% of males and 42/487: 8.6% of females) (Table 12).

Osteoarthritis affected 77 adults (/1465: 5.3%) with an equal distribution amongst males and females. In four adults (/1465: 0.3%), these changes were recorded as secondary to an injury. Male [741] had osteoarthritis related to a fracture of the right forefoot (second metatarsal). Females [1575] and [5609] suffered a Bennett's fractures of the hand (first metacarpal) with related joint degeneration and adult [781] had an injury in the left knee with secondary joint disease.

	Adult		Male		Female		Total	
	1465		463		487		1971	
	n	%	n	%	n	%	n	%
Osteoarthritis	77	5.3	31	6.7	33	6.8	77	3.9
Gout	4	0.3	2	0.4	0	-	4	0.2
Diffuse idiopathic skeletal hyperostosis (DISH)	10	0.7	7	1.5	1	0.2	10	0.5
Ankylosis	5	0.3	4	0.9	1	0.2	5	0.3
Rheumatoid arthritis	1	0.1	0	-	1	0.2	1	0.1
Other	1	0.1	1	0.2	0	-	1	0.1

Table 12 Extra spinal joint disease for Category A burials

Four adult males: [750], [600] and [1846] and [7065] had circular, punched out erosive lesions in the para-articular regions of the medial heads of the first metatarsals of the forefoot, characteristic of gout (Rogers and Waldron 1995, 78).

Ten adults (/1465: 0.7%, 7/463: 1.5% of males and 1/487: 0.2% of females) had fusion of several contiguous vertebrae with bone growth along the anterior ligament and preservation of intervertebral disk spaces diagnostic of diffuse idiopathic skeletal hyperostosis (DISH) (Aufderheide and Rodríguez-Martín 1998, 97).

Bony ankylosis of joints affected five adults (/1971: 0.3%). Males [142], [7458] and [1599] had fusion of the small joints of the hands. Female [7476] had fusion of the right sacroiliac joint. Male [1698] had bony union of the navicular and cuneiform bones of the right foot. Female [1553] displayed erosive lesions in the joint margins of the left hand, a diagnosis of rheumatoid arthritis should be considered.

<u>Trauma</u>

Traumatic injury was evident in 132 individuals (/1971: 6.7%, 125/1465: 8.5% of adults), with a greater frequency amongst males (69/463: 14.9%) when compared to females (30/487: 6.2%). Evidence of trauma was recorded in three subadults (7/506: 1.4%) (Table 13).

	Adult		Male		Female		Subadult		Total	
	1465		463		487		506		1971	
	N	%	n	%	n	%	n	%	n	%
Surgical Intervention	2	0.1	1	0.2	1	0.2	0	-	1	0.1
Amputation	2	0.1	1	0.2	1	0.2	0	-	2	0.1
Subluxation	5	0.3	1	0.2	3	0.6	0	-	5	0.3
Avulsion injury	8	0.5	7	1.5	1	0.2	0	-	8	0.4
Compression fracture (vertebrae)	14	1.0	11	2.4	2	0.4	0	-	14	0.7
Soft tissue trauma	29	2.0	16	3.5	4	0.8	3	0.6	32	1.6
Fracture with secondary infection	5	0.3	4	0.9	0	-	0	-	5	0.3
Pathological fracture	0	-	0	-	0	-	2	0.4	2	0.1
Fracture of a joint	2	0.1	2	0.4	0	-	0	-	2	0.1
Sharp force trauma healed	1	0.1	1	0.2	0	-	0	-	1	0.1
Sharp force trauma unhealed	1	0.1	0	-	1	0.2	0	-	1	0.1
Blunt force trauma healed	8	0.5	3	0.6	4	0.8	0	-	8	0.4
Healed fracture	62	4.2	30	6.5	18	3.7	2	0.4	64	3.2
Non-union of fracture (atrophic)	1	0.1	0	-	0	-	0	-	1	0.1
Non-union of fracture (hypertrophic)	2	0.1	2	0.4	0	-	0	-	2	0.1

Table 13 Trauma for Category A burials

Compression fractures of the vertebrae were noted in 14 adults (/1465: 1.0%), 11 males and two females. Eight individuals (/1971: 0.4%, 8/1465: 0.5% of adults) displayed avulsion injuries, the majority occurring in the spinal column and involving injuries to the vertebral endplates (Maat and Mastwijk 2000).

Five adults (/1465: 0.3%) suffered subluxation injuries at joint locations. Male [750] and female [4230] had dislocation injuries of the left elbow joint. Other soft tissue injuries were observed in 29 adults (/1465: 2.0%) and three subadults (/506: 0.6%). The majority of these cases consisted of isolated bony spurs at the site of muscle attachments. Female [3463] had a healed fracture in the left ilium with a large bone spur to the posterior sacroiliac joint. Male [6331] presented a large oval shaped ossified mass on the anterior left femoral midshaft, likely a case of myositis ossificans following a blow or injury to the leg.

Eight adults (/ 1465: 0.5%) had evidence of healed blunt force trauma on the cranium and two adults had possible sharp force injuries (/1465: 0.1%). The partial skull of a probable adult female [1256] displayed a large subcircular depression on the posterior left parietal suggesting a blunt force injury to the back of the head. The injury was well healed, although radiating fissures surrounded the lesion and a corresponding indentation was visible to the internal surface. The well preserved and intact cranium of adult female [1459] displayed two rounded depressions to the outer surface of the left parietal bone. One healed fracture may have resulted from blunt force trauma to the head. A second lesion penetrated the skull with inwardly displaced fragments of bone remaining attached to the outer surfaces. There was no evidence of healing or remodelling suggesting that this injury occurred at or around the time of death (peri-mortem). Male [608] had a healed sharp force or penetrating injury on the left frontal bone of the skull. Six adults (/1465: 0.4%) had healed injuries on the facial bones of the skull including four males (/463: 0.9%) with healed nasal fractures.

Sixty individuals (/1971: 3.0%) had healed fractures of the extra spinal skeleton (excluding the cranium). This included 33 fractures (/1971:1.7%) to the torso, mainly comprising rib injuries. Twenty-eight individuals (/1971: 1.4%) had fractures of the upper limbs, including the clavicle and hand elements. Twenty-seven skeletons (/1971: 1.4%) had fractures in the lower limbs including the pelvis and feet. There was a much higher prevalence of healed fractures amongst males (30/463: 6.5%) than females (18/487: 3.7%). Three adults (/1465: 0.2%) displayed evidence of non-united fractures.

Two subadults (/506: 0.4) had fractures that were likely secondary to an underlying illness. Subadult [428] had a healed greenstick fracture of the right distal femur, and [1671] had pathological fractures to the left femur, right humerus and ulna. Both individuals had bone changes diagnostic of rickets.

Evidence of post-mortem intervention was recorded in four contexts (/1971: 0.2%, 4/1465: 0.3% of adults). Male [5328] and female [5986] exhibited saw cuts on the cranium (craniotomy) suggesting they had undergone autopsy. Two adults (2/1465: 0.1%) had evidence of amputation. Female [4171] had a sawn right femoral midshaft with no evidence of healing. The femoral shaft and elements of the spine displayed bone lesions suggesting an underlying infection, possibly tuberculosis. Male [7004] had an unhealed amputation of the right distal femur. An intrusive right tibia and fibula also displayed saw cuts.

Metabolic disease

Metabolic disease was present in 67 individuals (/1971: 3.4%, 29/1465: 2.0% of adults, 38/506: 7.5% of subadults) (Table 14).

	Adult		Male		Female		Subadult		Total	
	1465		463		487		506		1971	
	n	%	n	%	n	%	n	%	n	%
Rickets	26	1.8	7	1.5	12	2.5	33	6.5	59	3.0
Scurvy	0	-	0	-	0	-	8	1.6	8	0.4
Osteoporosis	3	0.2	1	0.2	2	0.4	0	-	1	0.1

Table 14 Metabolic disease for Category A burials

Vitamin D deficiency resulting in rickets affected 3.0% of individuals (59/1971), 1.8% of adults (26/1465) and 6.5% of (33/506) subadults. Bowed deformities in the limb bones of adults, most commonly seen in the femora and tibiae indicated resolved rickets. Scurvy resulting from vitamin C deficiency was recorded in eight subadults (/506: 1.6). Four subadults ([777], [1671], [3798] and [4679]) had bone changes consistent with a diagnosis of active rickets.

Subadult [1671] aged 1 month to 6 years had diffuse bone changes throughout the skeleton affecting the limbs, pelvis and shoulder with flaring of the distal metaphyses and sternal rib ends. The lower limbs had bowing deformities and the distal femora were flared, with new bone formation along the shafts. There was a probable greenstick fracture on the left proximal femur with fractures also present on the right humerus. There was abnormal porosity was present in the cortical bone of the occipital, mandible, maxilla and scapulae and hypoplastic defects on the deciduous incisor tooth crowns.

Three adults (females [1730], [3788] and male [5235]) presented bone changes suggestive of possible osteoporosis. Radiography of these contexts will permit examination of the trabecular structure of the bones and measurements of cortical index may aid diagnosis at analysis.

<u>Miscellaneous conditions</u>

Sixty-two individuals (/1971: 3.1%) displayed pitted lesions to the roofs of the orbits diagnostic of cribra orbitalia. This affected 42 adults (/1465: 2.9%) and 20 subadults (/506: 4.0%). The fragmented nature of many crania allowed for observation of the internal (endocranial) surfaces of the skull. Endocranial lesions were recorded in nine adults (/1465: 0.6%) and three subadults (/506: 0.6%). Thickening and rounded, bulbous bone nodules on the internal surfaces of the frontal bones, diagnostic of hyperostosis frontalis interna were recorded in seven adults (/1465: 0.5%, 2/463: 0.4% of males and 5/487: 1.0% of females). Abnormal porosity on the outer cranial surfaces (porotic hyperostosis) was recorded in 0.5% of adults (33/1465) and 1.0% of subadults (5/506) (Table 15).

Two adults: male [3417] and female [5109] displayed thickening to the bones of the cranial vault indicating possibly Paget’s disease of bone.

	Adult		Male		Female		Subadult		Total	
	1465		463		487		506		1971	
	n	%	n	%	n	%	n	%	n	%
Rib deformation	5	0.3	0	-	5	1.0	0	-	5	0.3
Cribra orbitalia	42	2.9	15	3.2	24	4.9	20	4.0	62	3.1
Porotic hyperostosis	33	2.3	19	4.1	12	2.5	5	1.0	38	1.9
Hyperostosis frontalis interna	7	0.5	2	0.4	5	1.0	0	-	7	0.4
Endocranial lesions	9	0.6	1	0.2	7	1.4	3	0.6	12	0.6
Dental	62	4.2	37	8.0	19	3.9	3	0.6	65	3.3
Paget's disease of bone	2	0.1	1	0.2	1	0.2	0	-	2	0.1

Table 15 Miscellaneous conditions for Category A burials

Rib deformation resulting from possible corset/ stay wear was recorded in five adult females (5/487: 1.0%). Thirty-one adults (/1465: 2.1%, 18/463: 3.9% of males and 8/487: 1.6% of females) displayed rounded notches on the occlusal surfaces of the teeth suggesting habitual pipe smoking. Seven adults (7/1465: 0.5%) had black stains on the surfaces of teeth, and this was associated with a pipe notch in three males (3/463: 0.6%).

3.3 Assessment of the Category B burials (118 no.)

3.3.1 Condition and disturbance

<u>Preservation</u>

The majority of the Category B articulated assemblage showed good levels of bone preservation (103/118: 87.3%), only 12.7% were moderately well preserved and none were poorly preserved. The separation of the assemblage into adult and subadult categories revealed a continuation of this pattern with 85.5% (71/83) of adults and 91.4% of subadults (32/35) displaying good bone preservation (Fig 11).

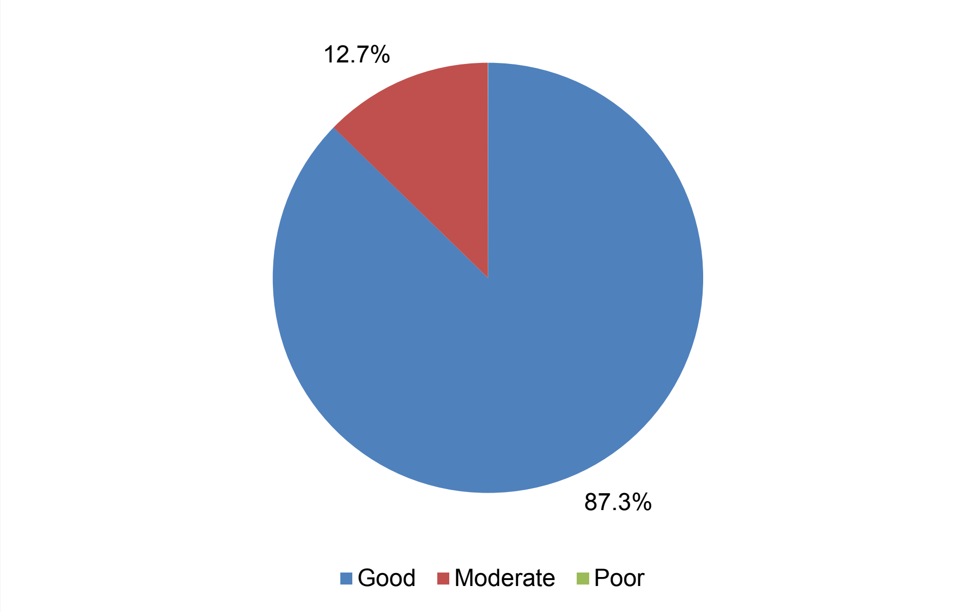

Fig 11 Preservation of Category B burials

Adult female [5613] had a substantial amount of head hair present. Green staining was present on bone surfaces in 13.6% of contexts (16/118). Thirteen individuals (13/118: 11%) had fragments of iron adhering to bone elements. Black staining was observed in one context: [8097].

<u>Completeness</u>

The completeness of the Category B burials ranged from 5–95%. Over half of burials were more than 50% complete (90/118: 53.1%) and 46.6% (55/118) had at least 75% of elements present (Fig 12).

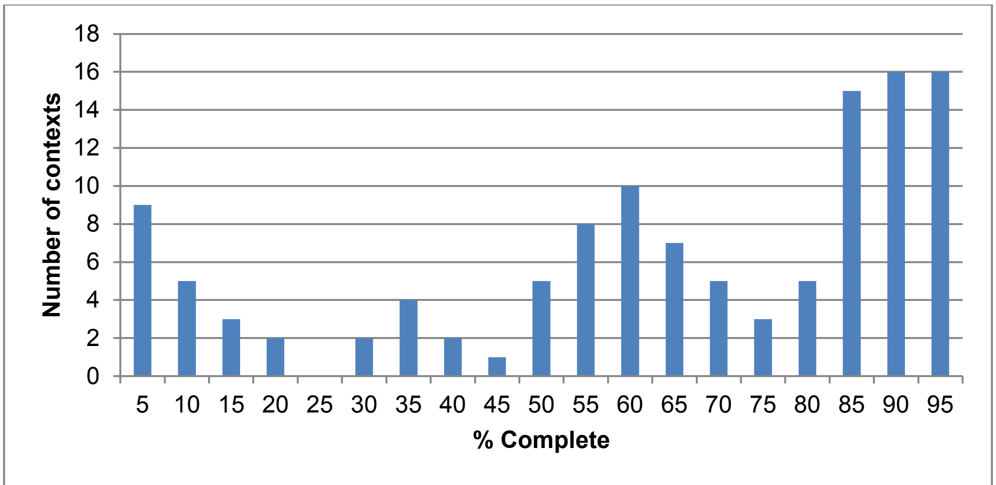

Fig 12 Completeness of Category B burials

The bones of the torso were the most commonly observed elements present (111/118: 94.1%), followed by the arms (104/118: 88.1%), pelvis (97/118: 82.2%) and legs (96/118: 81.4%). A complete, measurable crania was recorded in 14 individuals (/118: 11.9%: 13/83: 15.7% of adults and 1/35: 2.9% of subadults). Dentition was present in 70.3% of burials (83/118) (Fig 13).

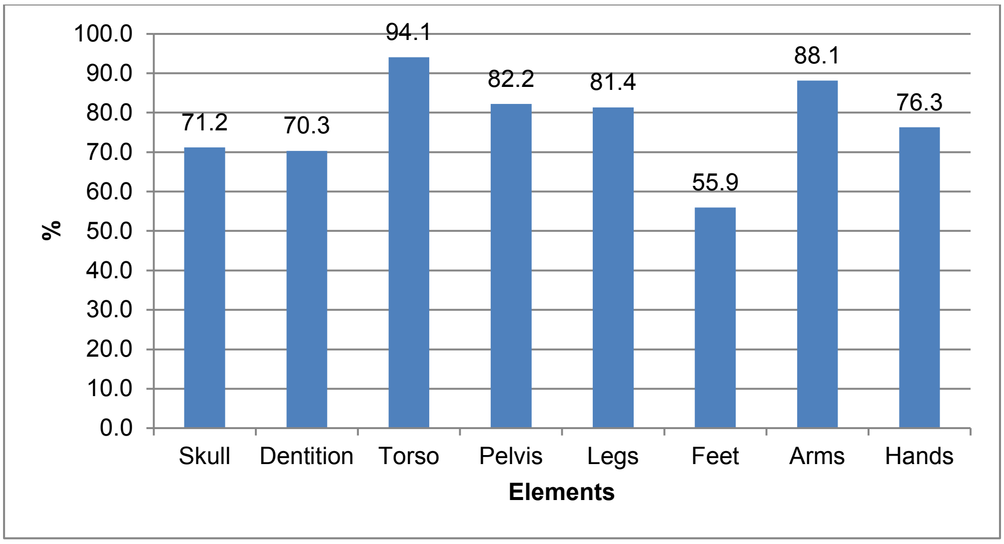

Fig 13 Percentage of identified elements present in Category B burials

<u>Associated artefacts</u>

Female [5613] was buried with a London delftware plate of 'Chinamen among grasses' style, dated *c* 1670–90, placed upside down over her lower torso.

3.3.2 Minimum number of individuals

MNI	1		2		3		4		5	
	N	%	n	%	n	%	n	%	n	%
Adult	33	39.8	39	47.0	10	12.0	0	0.0	1	1.2
Subadult	17	48.6	13	37.1	5	14.3	0	0.0	0	-
Total	**50**	**42.4**	**52**	**44.1**	**15**	**12.7**	**0**	**0.0**	**1**	**0.8**

Table 16 Category B minimum number of individuals

Of the 118 Category B burials, 68 contained the elements of more than one individual (Table 16). The majority of these inclusions were disarticulated single bones belonging to disturbed burials nearby.

3.3.3 Demography

Of the 118 individuals in the Category B burial sample, 83 were adult and 35 subadult. In the adult sample biological sex could be determined for 66 individuals with only 2 sexed as intermediate (2/118: 1.7%), leaving 17 adult skeletons undetermined. When definite and probable adult sexes were pooled there were 34 males and 30 females (34/118: 28.8%; 30/118: 25.4%), a ratio of 1:0.88 (Fig 14; Table 17). Subadults comprised 29.7% of the sample (35/118: 29.7%). The majority of subadults were aged 1 month to 6 years (14/35:40%) and 13–17 years (13/35: 37.1%). The early years of life (1 month–6 years) can be particularly hazardous for children, particularly at weaning, a period of heightened stress. The high proportion of teenage deaths is less expected and is rarely observed in archaeological samples. Traditionally this period of life is not associated with increased mortality. It is possible that this reflects a migrant population less able to gain access to the City's parish burial grounds. Migrants may also have been particularly vulnerable to the urban environment and its associated diseases. There were no neonates in the Category B burials (Fig 15).

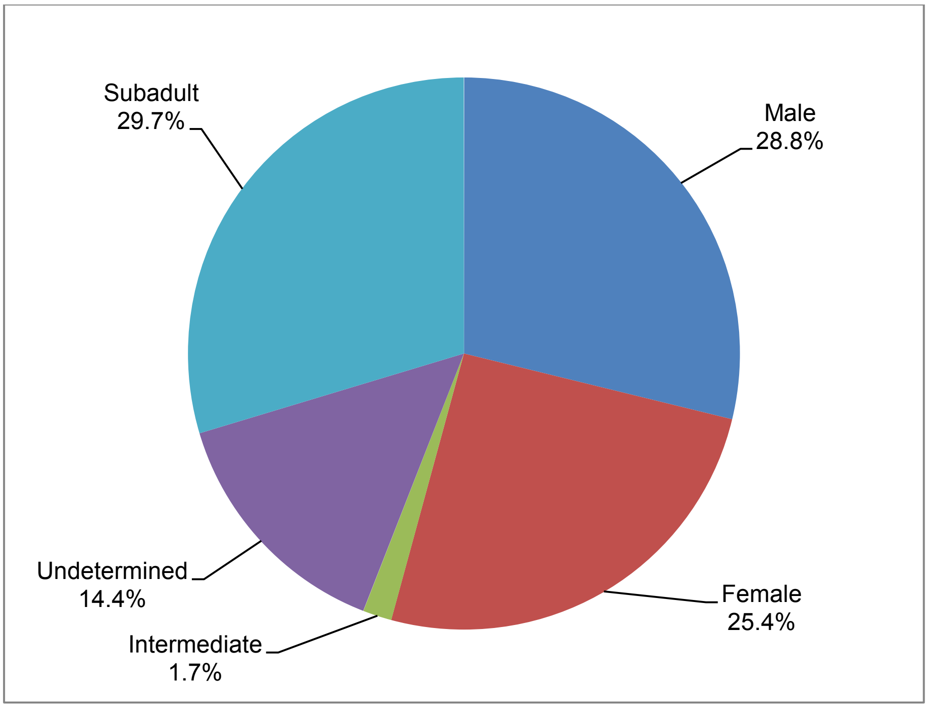

Fig 14 Demographic distribution of Category B burials

Subadult age at death

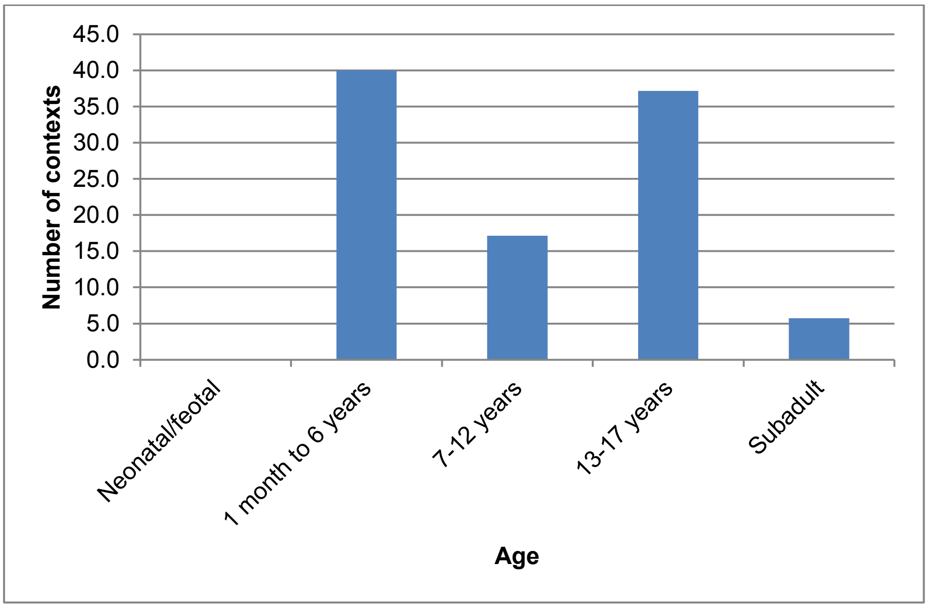

Fig 15 Category B subadult age at death distribution

Adult sex

	n	% adults
Male	21	25.3
Probable male	13	15.7
Intermediate	2	2.4
Probable female	10	12.0
Female	20	24.1
Undetermined	17	20.5
Total	**83**	**100.0**

Table 17 Category B adult age at death distribution

Named Burials

Four Category B burials had coffin lids with inscriptions formed of upholstery studs: [4692], [4909], [5695] and [7162]. The coffins for these individuals did not survive as well as those of the Category A burials (see 3.2.2). In all cases, the Category B burial inscriptions were partially distorted, disturbed and/or truncated; therefore, the reading of these inscriptions was not as confident.

The inscription on the coffin lid of [4909] read:

(missing letter) **M**
(**1692**)

The coffin lid of [4692] had the inscription:

ML or **LM**
88

The coffin lid of [5696] had the inscription:

R – (**H**)
1 6 7 6

The coffin lid of [7162] had the inscription:

R(**C**) (missing letter)
16(**9**) (missing number)

While all examples provide late 17th-century dates for these burials, only one of these inscriptions provides a clear date. The potential of these inscriptions as identification evidence is limited by their generally poor and incomplete condition.

Mass burial pit

A mass burial pit [7482] containing coffined and shrouded burials was uncovered at the north-west end of Area 1. A total of 45 articulated burials were recovered. All were retained for further analysis as Category B burials; and have thus been included in this assessment with the other retained Category B contexts. Over half of the mass burial contexts were less than 50% complete (27/45: 60.0%) (Fig 16).

The majority of mass pit burials were adults (29/45: 64.4%). Biological sex could be determined for 20 adults: males 9/29 (31.0%)/females 11/29 (37.9%) (Fig 17; Table 18).

Subadults comprised 35.6% of the mass grave assemblage (16/45). Approximately half the subadult population was aged 13–17 years (7/16: 43.8%) followed by those aged 1 month to 6 years (5/16: 31.3%). There were no neonates identified in the mass grave (Fig 18).

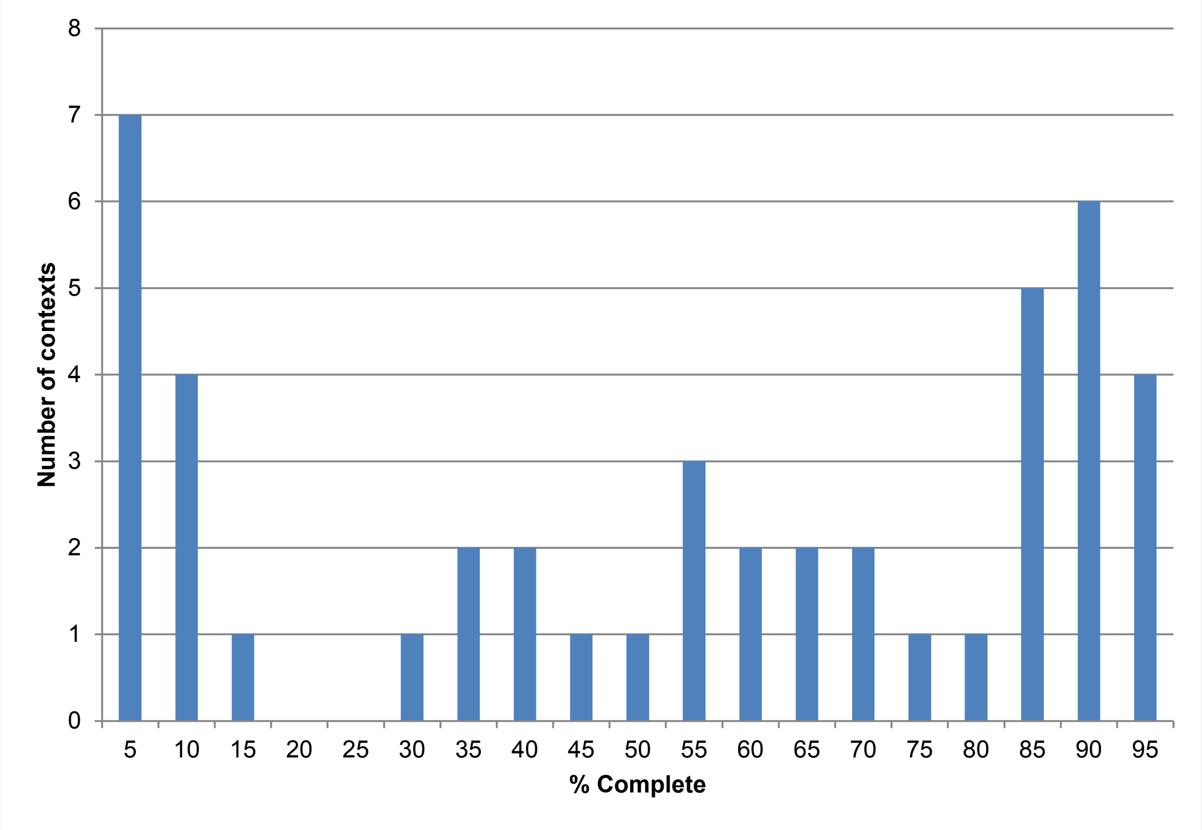

Fig 16 Completeness of Category B mass burial pit burials

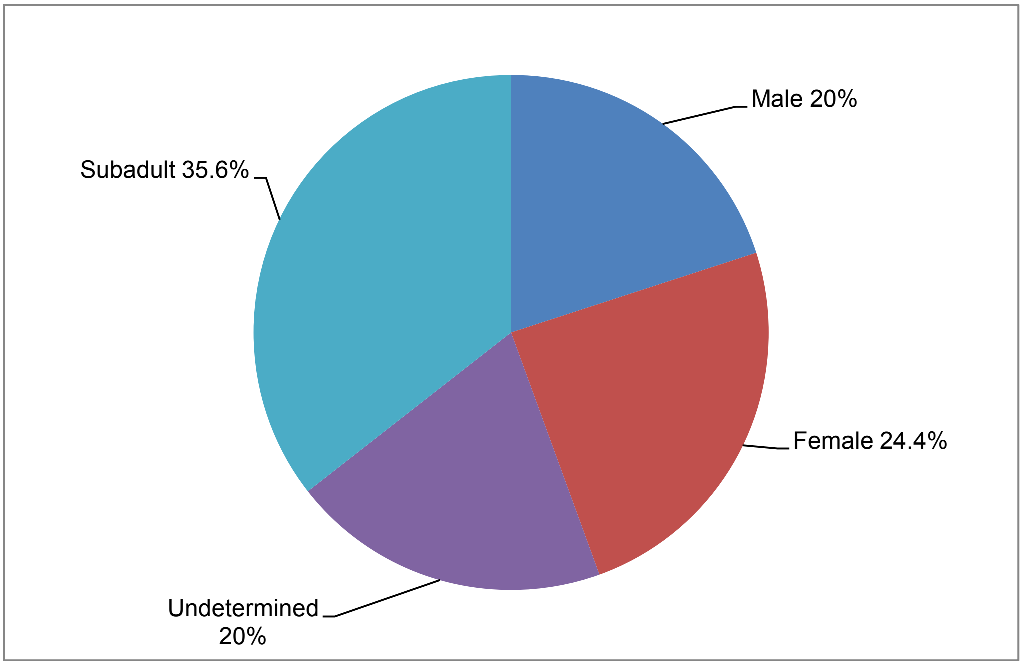

Fig 17 Demographic distribution of Category B mass burial pit burials

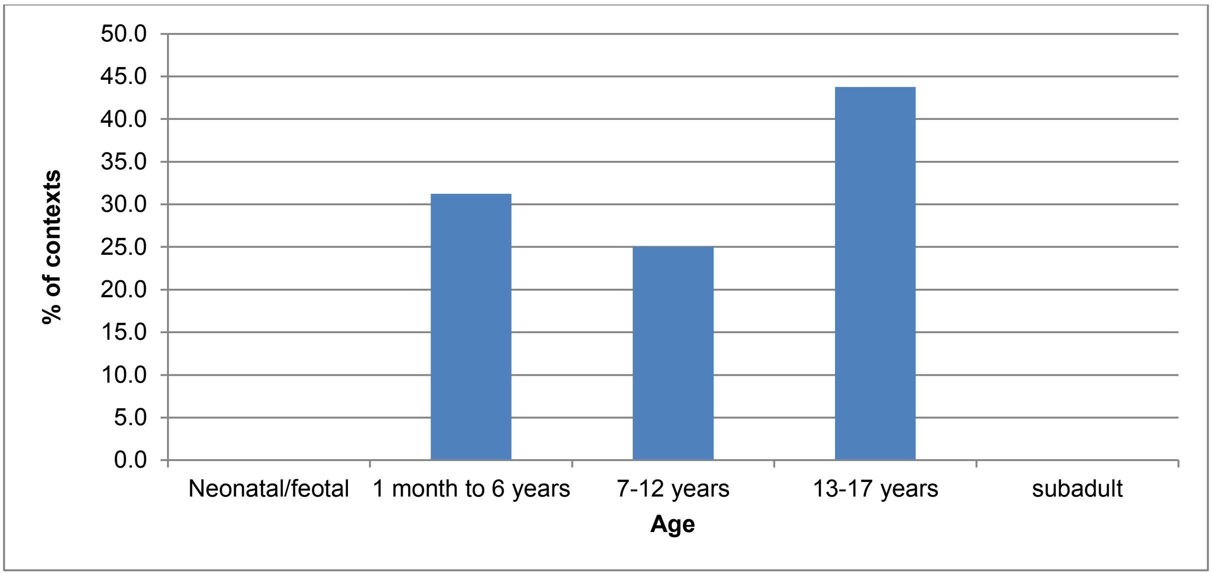

Fig 18 Category B mass burial pit subadult age at death distribution

	n	% adults
Male	4	13.8
Possible male	5	17.2
Intermediate	0	-
Possible female	4	13.8
Female	7	24.1
Undetermined	9	31.0
Total	**29**	**100.0**

Table 18 Category B mass burial pit sex distribution

3.3.4 Paleopathology

Dental health

Dentition was observable in 83 individuals (83/118: 70.3%): 73.5% of adults (61/83) and 62.9% of subadults (22/35). Dental disease was observed in 74 contexts (Table 19).

	Adult		Male		Female		Sub-adult		Total	
	83		34		30		35		118	
	n	%	n	%	n	%	n	%	n	%
Ante mortem tooth loss	36	43.4	13	38.2	18	60.0	4	11.4	40	33.9
Caries	42	50.6	20	58.8	16	53.3	11	31.4	53	44.9
Calculus	39	47.0	19	55.9	14	46.7	6	17.1	45	38.1
Enamel hypoplasia	20	24.1	10	29.4	8	26.7	7	20.0	27	22.9
Periodontal disease	15	18.1	8	23.5	5	16.7	1	2.9	16	13.6
Periapical lesions	13	15.7	6	17.6	5	16.7	2	5.7	15	12.7

Table 19 Crude prevalence of dental disease Category B burials

Ante-mortem tooth loss affected 43.4% of the adult population (36/83) with a higher proportion of females (18/30: 60%) than males (13/34: 38.2%) losing teeth during life. In addition four subadults had lost teeth prior to death (4/35: 11.4%).

The most frequent dental disease was caries recorded in 53 individuals (53/118: 44.9%). More than half of adults were affected (42/83: 50.6%).

Adult male [8184] had an impacted right mandibular 3rd molar.

Neoplastic disease

Adult female [4909] had smooth, circular masses of sclerotic bone, typical of osteomas, on the ectocranial (outer) surface of the skull. The same individual had evidence of blunt force trauma.

Congenital disease

Nine individuals exhibited congenital disorders (/118: 7.6%), seven adults (/83: 8.4%), two males (/34: 5.9%), five females (/30: 16.7%) and two subadults (/35: 5.7%) (Table 20).

	Adult		Male		Female		Subadult		Total	
	83		34		30		35		118	
	n	%	n	%	n	%	n	%	n	%
Scoliosis	2	2.4	0	-	2	6.7	1	2.9	3	2.5
Kyphosis	3	3.6	0	-	2	6.7	0	-	3	2.5
Kyphoscoliosis	1	1.2	0	-	1	3.3	0	-	1	0.8
Upper limb aplasia	1	1.2	1	2.9	0	-	0	-	1	0.8
Lower limb aplasia	0	-	0	-	0	-	1	2.9	1	0.8

Table 20 Congenital abnormalities crude prevalence rates for Category B burials

Congenital curvature of the spine was recorded in seven contexts (7/118: 5.9%). Three individuals had scoliosis (/118: 2.5%) and three kyphosis. Female [3148] had lateral and anteroposterior curvature of the spine (kyphoscoliosis).

Adult male [7700] had abnormal bone changes in the joint surfaces of the right humeral trochlea. The radial head and ulna olecranon were also remodelled. The shafts of the ulna and radius were severely shortened with extensive remodelling of the distal joint surfaces. This may result from Madelung's deformity (congenital wrist dislocation).

Two individuals had spinal developmental defects: subadult [7980] had fused cervical vertebrae that may have restricted movement of the neck. Adult male [8209] had defects in the fusion of the posterior sacrum (spina bifida occulta).

Adult male [3887] had hallux valgus, deformity of the great toe.

Infectious disease

Infectious bone changes were recorded in 18.6% of the assemblage (22/118), 20.5% of adults (17/83 %) and 14.3% of subadults (5/35) (Table 21).

	Adult		Male		Female		Sub-adult		Total	
	83		34		30		35		118	
	n	%	n	%	n	%	n	%	n	%
Non-specific periostitis	10	12.0	4	11.8	4	13.3	3	8.6	13	11.0
Non-specific osteomyelitis	4	4.8	2	5.9	1	3.3	3	8.6	7	5.9
Non-specific osteitis	1	1.2	0	-	0	-	0	-	1	0.8
Tuberculosis	5	6.0	3	8.8	1	3.3	0	-	5	4.2
Treponematosis	2	2.4	0	-	2	6.7	1	2.9	3	2.5

Table 21 Infectious disease crude prevalence rates for Category B burials

Non-specific infection was recorded in 14.4% of burials (17/118): 12 adults (/118: 10.2%) with an equal proportion of males (5/34: 14.7%) and females (4/30: 13.3%) affected. Five subadults also displayed non-specific infectious changes (/35: 14.3%). Non-specific periostitis was recorded in 11% of individuals (13/118), with areas of new bone predominantly on long-bone shafts. Plaque-like inflammatory bone growth was observed on the interior of the maxillary sinuses of two individuals (2/118: 1.7%, 2/30: 6.7% of females). Adult [3912] had new bone growth on the visceral rib surfaces. Non-specific osteomyelitis was recorded in seven individuals (/118: 5.9%) and osteitis in just one [3214].

Eight individuals had bone changes suggestive of specific infection (/118: 6.8%, 7/83: 8.4% of adults, 3/34: 8.8% of males, 3/30: 10% of females and 1/35: 2.9% of subadults).

Tuberculosis was recorded in five adults. Possible treponemal disease in the form of syphilis were observed in three individuals (3/118: 2.5%).

Joint disease

A quarter of the Category B burials showed evidence of joint disease 26.3% (31/118).

Schmorl's nodes were observable in 10.2% of the sample, affecting 14.5% of adults (12/83). There was higher prevalence amongst males (8/34: 23.5%) compared to females (3/30: 10%) (Table 22).

	Adult		Male		Female		Sub-adult		Total	
	83		34		30		35		118	
	n	%	n	%	n	%	n	%	n	%
Schmorl's nodes	12	14.5	8	23.5	3	10.0	0	-	12	10.2
Osteophytes	12	14.5	5	14.7	5	16.7	1	2.9	13	11.0
Intervertebral disc disease	2	2.4	2	5.9	0	-	0	-	2	1.7
Osteoarthritis	3	3.6	1	2.9	2	6.7	0	-	3	2.5

Table 22 Spinal joint disease for Category B burials

Adult male [5675] displayed a possible neurotrophic arthropathy (Charcot joint) with lytic erosion of the left tibial femoropatella joint. This individual may also have suffered from tuberculosis.

Osteoarthritis affected seven adults (/83: 8.4%) with an equal distribution amongst males and females. Adult female [6170] had osteoarthritis in the right hip joint and male [3238] exhibited osteoarthritic changes secondary to severe trauma in the left foot (Table 23).

	Adult		Male		Female		Sub-adult		Total	
	83		34		30		35		118	
	n	%	n	%	n	%	n	%	n	%
Osteoarthritis	7	8.4	3	8.8	3	10.0	0	-	7	5.9
Diffuse idiopathic skeletal hyperostosis (DISH)	1	1.2	1	2.9	0	-	0	-	1	0.8
Neurotrophic arthropathy (Charcot joint)	1	1.2	1	2.9	0	-	0	-	1	0.8

Table 23 Joint disease for Category B burials

Trauma

Trauma was evident in 26 individuals (/118: 22%), with a greater frequency amongst males (14/34: 41.2%) compared to of females (6/30: 20.0%). Trauma was recorded in 14.3% of subadults (5/35) (Table 24).

	Adult		Male		Female		Sub-adult		Total	
	83		34		30		35		118	
	n	%	n	%	n	%	n	%	n	%
Compression fracture (vertebrae)	1	1.2	0	-	1	3.3	1	2.9	2	1.7
Fracture with secondary infection	3	3.6	2	5.9	1	3.3	0	-	3	2.5
Joint fracture	1	1.2	1	2.9	0	-	0	-	1	0.8
Healed fracture	10	12.0	8	23.5	2	6.7	2	5.7	12	10.2
Subluxation	1	1.2	1	2.9	0	-	0	-	1	0.8
Soft tissue trauma	5	6.0	3	8.8	1	3.3	2	5.7	7	5.9
Sharp force trauma (healed)	1	1.2	1	2.9	0	-	0	-	1	0.8
Blunt force trauma (healed)	3	3.6	2	5.9	1	3.3	0	-	3	2.5

Table 24 Trauma for Category B burials

Healed fractures affected approximately a quarter of males 23.5% (8/34) compared to 6.7% females (2/30) and 5.7% of subadults (2/35).

Fractures with secondary infection occurred in 2.5% of the sample (3/118). Adult male [5228] had a healed condylar fracture in the right distal humerus. Compression fractures to the vertebrae were observed in two individuals (/118: 1.7%).

Fractures were most commonly observed in the lower limbs, followed by the torso. Adult male [7950] had rib fractures and bilateral os acromiale of the scapulae.

Soft tissue trauma was recorded in seven individuals (7/118: 5.9). Adult [3912] had fusion of a distal tibia and fibula, perhaps secondary to an ankle injury.

Three adults displayed healed blunt force cranial trauma (/83: 3.6%). Males [5005] and [5349] both presented healed depression to the frontal bone. A healed sharp force injury was recorded in male [6245].

Metabolic disease

Metabolic disease was present in 14 individuals (/118: 11.9%, 1/83: 1.2% of adults and 13/35: 37.1% of subadults) (Table 25).

	Adult		Male		Female		Sub-adult		Total	
	83		34		30		35		118	
	n	%	n	%	n	%	n	%	n	%
Rickets	1	1.2	0	-	0	-	12	34.3	13	11.0
Scurvy	0	-	0	-	0	-	1	2.9	1	0.8

Table 25 Metabolic disease for Category B burials

Vitamin C deficiency (scurvy) was recorded in a single subadult [8213] with swollen diaphyses of the femora and tibiae. Rickets affected 13 individuals (/118: 11%). Over half the cases of rickets involved subadults aged 1 month to 6 years.

Miscellaneous conditions

	Adult		Male		Female		Sub-adult		Total	
	83		34		30		35		118	
	n	%	n	%	n	%	n	%	n	%
Cribra orbitalia	1	1.2	0	-	0	-	1	2.9	2	1.7
Porotic hyperostosis	1	1.2	1	2.9	0	-	0	-	1	0.8
Endocranial lesions	0	-	0	-	0	-	2	5.7	2	1.7
Dental abnormalities	5	6.0	5	14.7	0	-	0	-	5	4.2
Other	1	1.2	1	2.9	0	-	0	-	1	0.8

Table 26 Miscellaneous conditions for Category B burials

Pitted lesions to the roof of the orbits (cribra orbitalia) were recorded in two individuals (/118: 1.7%). Porotic hyperostosis affected a single adult male (/34: 2.9%). Endocranial lesions on the inside of the skull were seen in two subadults (/35: 5.7%).

Dental abnormalities were recorded in five adult males (/34: 14.7%). Two adults displayed pipe notches and adult [8147] also had a severe overbite (Table 26).

3.4 Assessment of the Category C burials (1265 no.)

3.4.1 Condition and disturbance

Preservation

There was variability in the preservation of the bone from the articulated burials, reflecting both the differing conditions of deposition and the state of preservation of the associated coffins and coffin furniture. The majority of articulated contexts were well-preserved (791/1265: 62.5%) with 33.8% (427/1265) considered moderately well-preserved and only 3.7% (47/1265) poorly preserved ().

When the assemblage was separated into adult and subadult individuals, this pattern of preservation continued with 623 adults (/1041: 66.9%) and 168 subadults (/251: 61.4%) displaying good preservation. A slightly higher number of subadults (71/251: 35.1%) had poorer preservation compared to 356 (/1041: 28.3%) recorded as moderate.

Hair was present in 0.5% of contexts (6/1265) including five adults (1 male, 4 females) and one subadult. Iron staining was present on 12 individuals (/1265: 0.9%) including nine adults (5 males, 1 female) and three subadults (/251: 1.2%). Green staining was present on 31 individuals (/1265: 2.45%) including thirty adults (8 males, 14 females) and one subadult. Purple staining was evident on the endocranial surface of the cranium of adult male [7062].

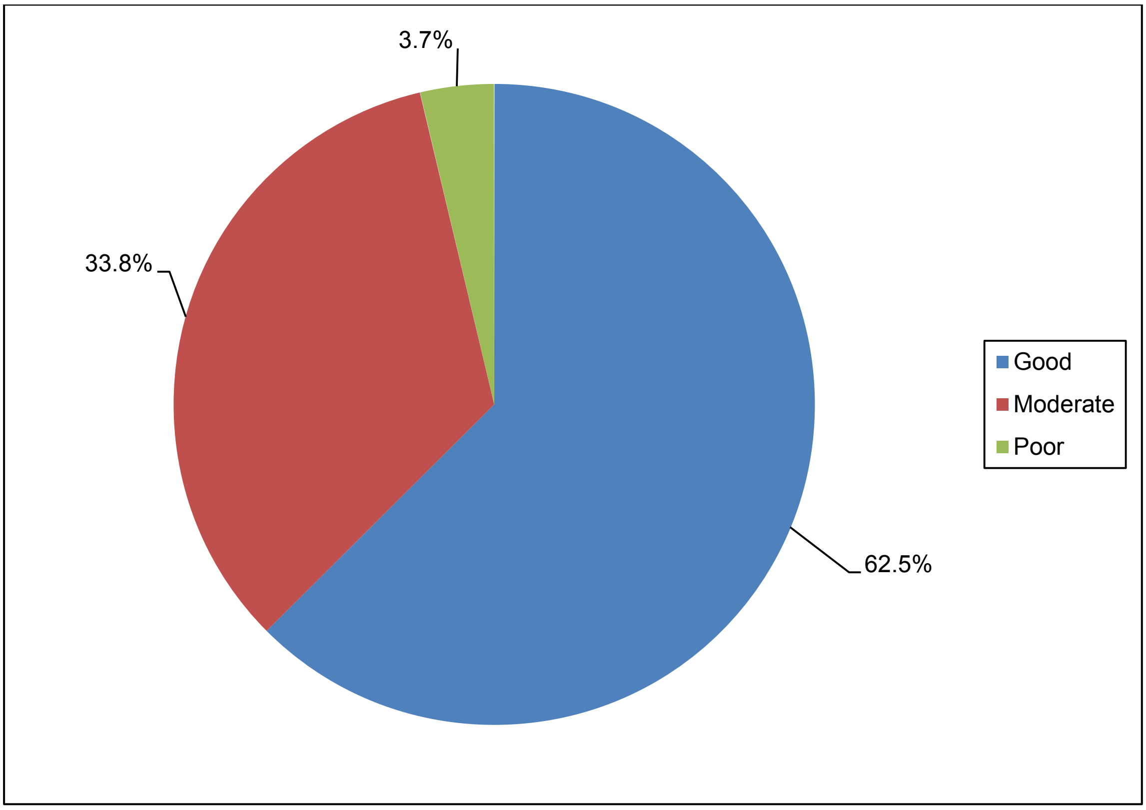

Fig 19 Percentage bone preservation in Category C burials

Green staining is usually associated with the presence of copper or copper-alloys (and could derive from items such as brass/bronze coffin furniture, nails/handles etc). It has been suggested that permanganate ions can stain bone purple. However, contact with permanent marker, such as that used to write our labels on site can cause purple staining on the bone if the ink fails to dry. This will be further examined at analysis.

<u>Completeness</u>

When percentage completeness was considered, 26% (329/1265) burials were 75% complete or greater (Fig 20). However, the majority were less than 50% complete (723/1265: 57.2%). Many of the graves had been truncated and disturbed by later burials and construction during the Victorian period.

The bones of the torso were the most commonly observed elements present (968/1265: 76.5%), followed by arms (923/1265: 73%) and legs (877/1265: 69.3%) (Fig 21). The feet were the least frequently recorded element (560/1265: 44.3%). Complete, measurable crania were observed in 5.6% of individuals (71/1265). Dentition was present in 44.8% of individuals (567/1265).

When the assemblage was divided into adult and subadult individuals the most commonly recorded adult elements were the torso (749/1014: 73.9%) and arms (726/1014: 71.6%). The torso (220/251: 87.6%) and arms (198/251: 78.9%) were also the most common subadult element.

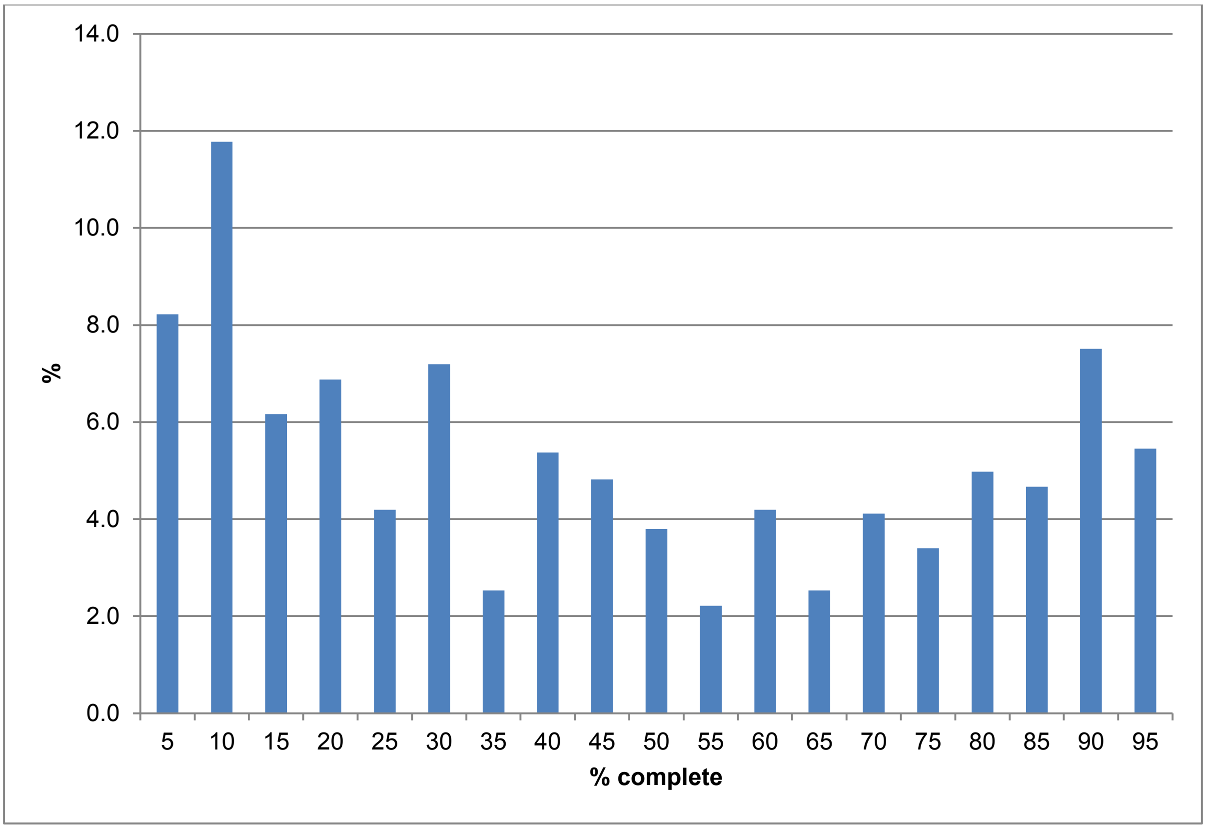

Fig 20 Percentage completeness of Category C burials

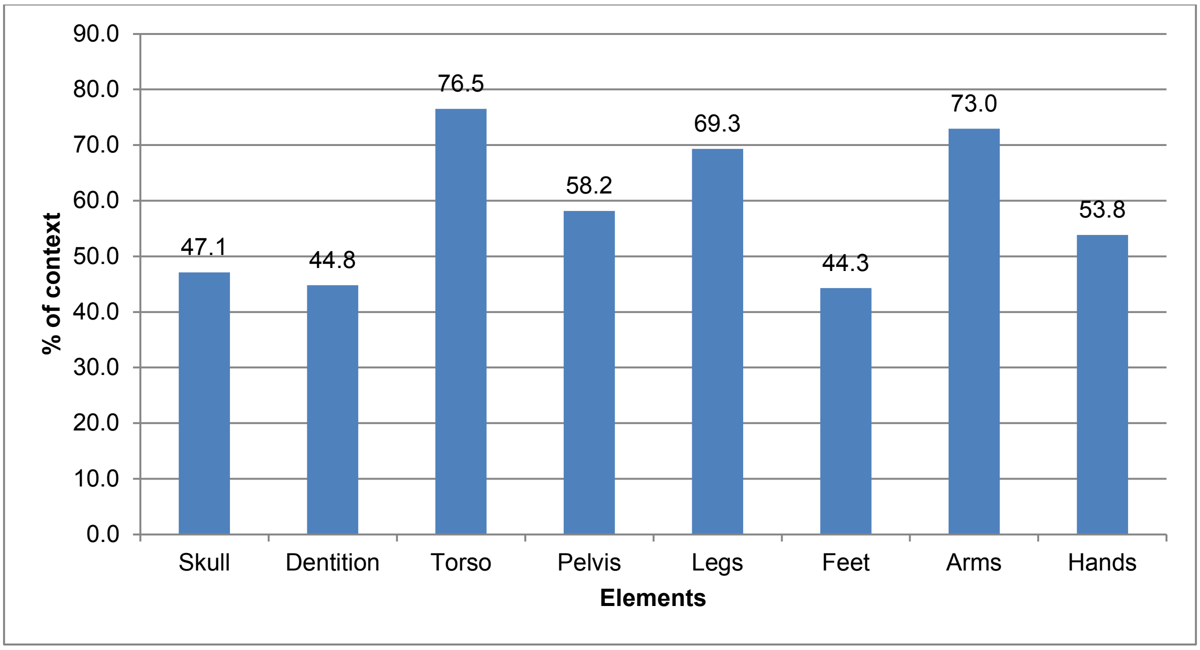

Fig 21 Percentage of identified elements present in Category C burials

3.4.2 Minimum number of individuals

A total of 1265 articulated contexts were subject to osteological assessment and used in calculations of preservation and completeness.

One individual was present in 91.1% of the articulated contexts (1153/1265), intrusive remains were present in 8.9% of the assemblage (112/1265) (Table 27).

MNI	1		2		3	
	n	**%**	**n**	**%**	**n**	**%**
Adult	929	73.4	78	6.2	7	0.6
Subadult	224	17.7	23	1.8	4	0.3
Total	**1153**	**91.1**	**101**	**8**	**11**	**0.9**

Table 27 Category C minimum number of individuals

3.4.3 Demography

There were a higher number of adult burials (1014/1265: 80.2%) when compared to subadults (251/1265: 19.8%).

The assemblage had a slightly higher proportion of males than females. When the data was pooled 30.5% of the sexed adults were male (309/1014) and 31.9% female (323/1014) with a ratio of 0.96:1 (Fig 22; Table 28). It was not possible to sex 36.9% of the adult population (374/1265). Eight adult individuals (8/1014: 0.8%) displayed intermediate morphological characteristics.

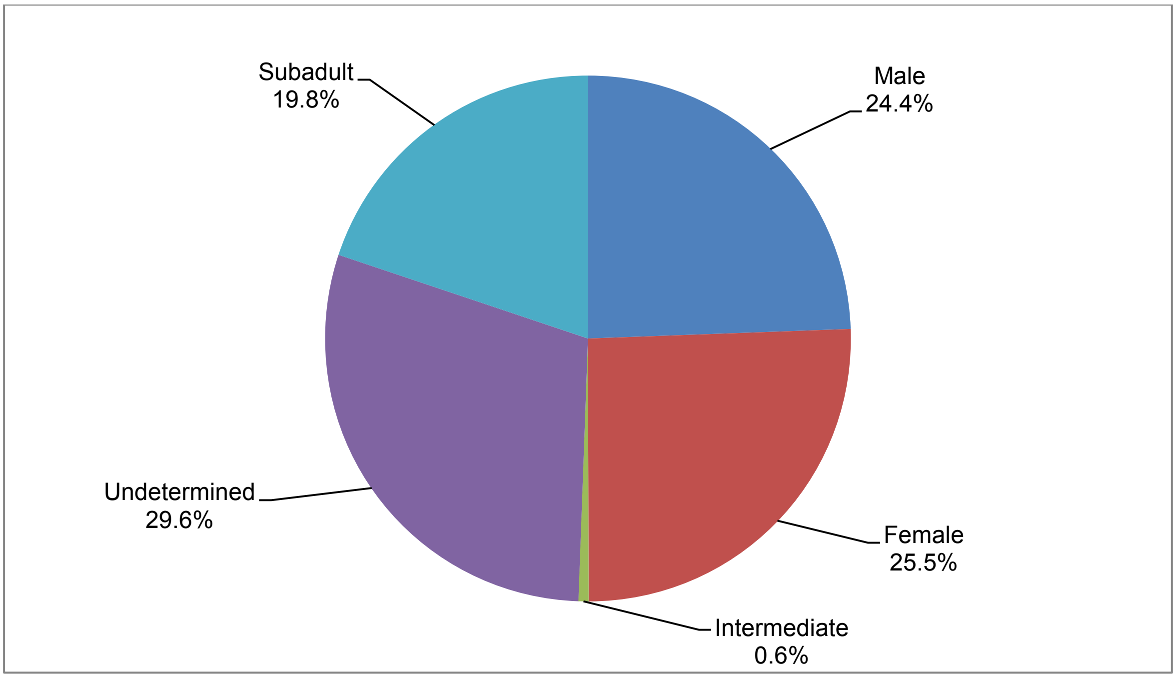

Fig 22 Demographic distribution of Category C burials

<u>Subadult age at death</u>

The majority of subadults (31.5%: 79/251) were aged between 13–16 years at death. Neonate or foetal burials comprised 7.6% of the subadult population (19/251), 22.3% were aged between one month and six years (56/251) and 10% between 7–12 years (25/251). Absence of dentition or fragmentary remains prevented further ageing of 28.7% individuals (72/251) who were assigned the general ‘subadult’ age category (Fig 23).

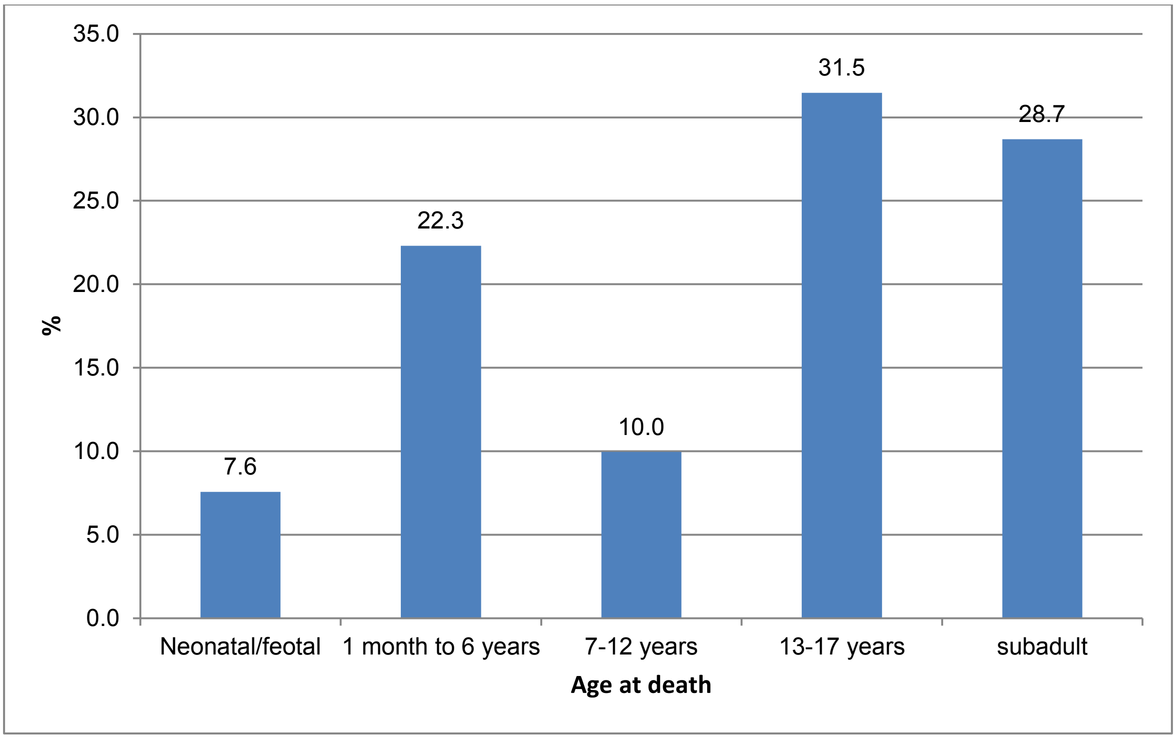

Fig 23 Category C Subadult age at death distribution

<u>Adult sex</u>

	n	% adults
Male	156	15.4
Possible male	153	15.1
Intermediate	8	0.8
Possible female	163	16.1
Female	160	15.8
Undetermined	374	36.9
Total	**1014**	**100.0**

Table 28 Category C adult sex distribution

3.4.4 Paleopathology

<u>Dental health</u>

Dentition was observable in 44.8% of contexts (567/1265) comprising 77.2% adults (438/567), 32.6% of males (185/567) and 39.3% females (223/567). Teeth were present in 24.8% of subadults (129/521) (Table 29).

	Adult		Male		Female		Sub-adult		Total	
	1014		309		323		251		1265	
	n	%	n	%	n	%	n	%	n	%
Ante mortem tooth loss	250	24.7	95	30.7	139	43.0	13	5.2	263	20.8
Caries	184	18.1	70	22.7	106	32.8	27	10.8	211	16.7
Calculus	139	13.7	65	21.0	65	20.1	10	4.0	149	11.8
Enamel hypoplasia	112	11.0	48	15.5	56	17.3	25	10.0	137	10.8
Periodontal disease	74	7.3	29	9.4	42	13.0	4	1.6	78	6.2
Periapical lesions	36	3.6	13	4.2	20	6.2	1	0.4	37	2.9

Table 29 Dental disease crude prevalence rates for Category C burials

Rates of ante-mortem tooth loss were high (263/1265: 20.8%), affecting 30.7% of the male assemblage (95/309) and 43.0% of females (139/323). Caries affected 16.7% of individuals (211/1265), 18.1% of adults (184/1014) and 10.8% of subadults (27/251). Enamel hypoplasia was observed in 10.0% of subadults (25/251) and 11.0% of the adult assemblage (112/1014).

Ten individuals had impacted teeth (10/1265: 0.8%). A mandibular torus was present in two adults, male [3186] and female [7027]. Peg teeth were observable in four individuals (4/1265: 0.3%).

Neoplastic disease

Seven adult contexts had possible neoplastic disorders (7/1014: 0.7%) including 1.0% males (3/306) and 0.9% females (3/323) (Table 30).

	Adult		Male		Female		Subadult		Total	
	1014		306		323		251		1265	
	n	%	n	%	n	%	n	%	n	%
Osteoma	5	0.5	3	1.0	2	0.6	0	-	5	0.4
Osteochondroma	1	0.1	0	-	1	0.3	0	-	1	0.1
Unidentified	1	0.1	0	-	0	-	0	-	1	0.1

Table 30 Neoplastic disease in Category C burials

Five adults (/1014: 0.5%) displayed osteomas: three males with button osteomas on the cranial ectocranial surface of the skull (3/306: 1.0%), a female [3927] with an osteoma on the shaft of the right ulna and a male [4684] with an osteoma on the shaft of the femur. One adult female [6000] had a bony spur on the distal right ulna shaft, which displayed the characteristics of an osteochondroma.

Circulatory disease

Evidence of circulatory disorders were recorded in 3 adults (/1265: 0.2%) (Table 31).

Two adult males displayed changes typical of Scheuermann's disease (/306: 0.7%) in the form of multiple herniations located behind the annular rims of the lower thoracic and lumbar vertebrae. One adult female had osteochondritis dissecans (/32: 0.3%) on the left femoral lateral condyle.

	Adult		Male		Female		Subadult		Total	
	1014		306		323		251		1265	
	n	%	n	%	N	%	n	%	n	%
Osteochondritis dissecans	1	0.1	0	-	1	0.3	0	-	1	0.1
Scheuermann's disease	2	0.2	2	0.7	0	-	0	-	2	0.2

Table 31 Circulatory disorders in Category C burials

Congenital disease

Congenital disorders were noted in 3.3% of burials (42/1265): 5.6% of males (17/306), 4.6% of females (15/323) and 2.0% of subadults (5/251) (Table 32).

	Adult		Male		Female		Subadult		Total	
	1014		306		323		251		1265	
	n	%	n	%	n	%	n	%	n	%
Skull malformation (general)	1	0.1	0	-	1	0.3	0	-	1	0.1
Bathrocephaly	3	0.3	0	-	3	1.0	0	-	3	0.3
Craniofacial abnormality	1	0.1	1	0.3	0	-	0	-	1	0.1
Spinal disorders	2	0.2	1	0.3	1	0.3	1	0.4	3	0.2
Scoliosis	4	0.4	0	-	4	1.2	0	-	4	0.3
Hallux Valgus (Limb abnormality)	7	0.7	2	0.7	2	0.6	0	-	7	0.6
Lower limb aplasia/ hypoplasia/ malformation	3	0.3	1	0.3	1	0.3	0	-	3	0.2
DDH	2	0.2	1	0.3	0	-	0	-	2	0.2
Spondylolysis (bilateral)	5	0.5	3	1.0	2	0.6	0	-	5	0.4
Spondylolysis (unilateral L)	1	0.1	1	0.3	0	-	0	-	0	-
Other (Congenital)	10	1.0	8	2.6	2	0.6	4	1.6	14	1.1

Table 32 Congenital disease in Category C burials

One adult female [5737] had evidence of skull malformation in the form of an elongated skull (dolychocephalic). Bathrocephaly was observed in three adult females (/323: 1.0%). Craniofacial abnormality was observed in one adult male [3186] (/306: 0.3%).

Scoliosis was present in four adult females (/323: 1.2%). An adult male [5518] had congenital non-fusion of the first cervical vertebra and a subadult aged 13–16 years [6438], an adult male [3410] and two adult females, [6457] and [3769], had bifurcated sternal shafts of the first and second ribs, the result of two ribs fusing together (Mann and Hunt 2005, 115).

Hallux valgus was present in seven adults (7/1014: 0.7%) (two males, two females). Coxa vara was found in two adults (/1014: 0.2%) and one subadult aged 13–16 years (1/251: 0.4%). Congenital hip dysplasia (DDH) was present in two adults (2/1014: 0.2%).

Bilateral spondylolysis occurred in five adults (1014: 0.5%) (3 males, 2 females) and unilateral spondylolysis on the left side was present in one adult male. Spina bifida occulta was present in six adult males (/306: 2%) and three subadults (/251:1.2%).

<u>Infectious disease</u>

Bone changes as a response of infectious disease were identified in 5.8% (73/1265) of the assemblage: 6.4% of adults (65/1014) and 3.2% of subadults (8/251) (Table 33).

	Adult		**Male**		**Female**		**Sub-adult**		**Total**	
	1014		**306**		**323**		**251**		**1265**	
	n	**%**	**n**	**%**	**n**	**%**	**n**	**%**	**n**	**%**
Non-specific periostitis	51	5.0	21	6.9	14	4.3	6	2.4	57	4.5
Non-specific osteomyelitis	1	0.1	0	-	1	-	1	0.4	1	0.1
Non-specific osteitis	0	-	0	-	0	-	1	0.4	1	0.1
Tuberculosis	1	0.1	1	0.3	0	-	0	-	1	0.1
Treponematosis	2	0.2	1	0.3	1	0.3	0	-	2	0.2

Table 33 Infectious disease in Category C burials

Non-specific infection was recorded in 5.5% of burials (70/1265), comprising 6.1% adults (62/1014), with more males (24/306: 7.8%) than females (21/323: 6.5%) affected. Eight subadults also displayed non-specific infectious changes (8/251: 3.2%). Non-specific periostitis was noted in 4.5% of individuals (57/1265) comprising 5.0% of adults (51/1014) (21 males, 14 females) and 2.4 % of subadults (6/251). The incomplete and fragmented nature of many crania allowed for observation of the internal cranial structures. Eight adults (/1014: 0.8%), including 1.0% males (3/306) and 1.5% females (3/323), had proliferative new bone growth in the maxillary sinuses.

New bone on the visceral surfaces of the ribs was observed in 0.7% of adults (71014), 0.7% of males (2/306) and 1.2% of females (4/323). In three individuals (/1014: 0.3% of adults) these lesions were active at the time of death.

Non-specific osteomyelitis was recorded in 0.1% of individuals (1/1265). An expansive change suggestive of osteitis was observed in the mandible of a subadult aged 13–16 years [7906] (1/251: 0.4%:).

Bony changes resulting from tuberculosis were recorded in an adult male [7051] (1/306: 0.3%) in the form of an active lytic lesion situated on the anterior bodies of the fourth and fifth lumbar vertebrae.

Bone changes as a result of treponemal disease (venereal syphilis) were recorded in two adults (2/1014: 0.2%) (1 male, 1 female). Adult male [8022] consisted only of a cranium and partial torso and displayed active lytic lesions to the cranial vault, with areas of pitted bone to the frontals, parietals, and occipital. Adult female [7963] had possible acquired syphilis in the form of changes to both tibiae giving them a ‘sabre’ or thin appearance which may have been a result of congenital syphilis acquired during foetal development (Aufderheide and Rodríguez-Martín 1998, 165).

Joint disease

Joint disease was recorded in 359 individuals (359/1265: 28.4%). This included 34.3% of adults (348/1014): 47.1% of males (144/306), 42.7% of females (138/323) and 4.4% of subadults (11/251).

Spinal joint disease had a high prevalence with Schmorl's nodes affecting 17.4% of adults (176/1014) and 3.6% of subadults (9/251), all aged between 13–16 years at death (Table 34).

	Adult		Male		Female		Sub-adult		Total	
	1014		306		323		251		1265	
	n	%	n	%	n	%	n	%	n	%
Schmorl's nodes	176	17.4	86	28.1	57	17.6	9	3.6	185	14.6
Osteophytes	170	16.8	68	22.2	69	21.4	1	0.4	171	13.5
Intervertebral disc disease	15	1.5	9	2.9	6	1.9	0	-	15	1.2

Table 34 Spinal joint disease in Category C burials

Extra spinal joint disease was recorded in 88 adult individuals (/1014: 8.7%) with a greater proportion of females (43/323: 13.3%) than males (31/306: 10.1%) affected (Table 35).

Osteoarthritis was the most prevalent joint disorder affecting 80 adults (/1014: 7.9%). In four adults (/1014: 0.4%) these changes were secondary to other underlying pathological changes. Three individuals had osteoarthritis secondary to Bennett's fractures. One adult [3995] had a dislocated right talocrural joint with secondary osteoarthritis and associated remodelling of the distal tibia and fibula.

	Adult		Male		Female		Sub-adult		Total	
	1014		306		323		251		1265	
	n	%	n	%	n	%	n	%	n	%
Osteoarthritis	80	7.9	26	8.5	40	12.4	1	0.4	81	6.4
Ankylosing spondylitis	2	0.2	0	-	2	0.6	0	-	2	0.2
Gout	1	0.1	1	0.3	0	-	0	-	1	0.1
Diffuse idiopathic skeletal hyperostosis (DISH)	5	0.5	4	1.3	1	0.3	0	-	5	0.4

Table 35 Extra spinal joint disease in Category C burials

Four males [3497], [3565], [5481] and [6295] and one female [4380] exhibited ossification and fusion at the anterior ligament over at least four thoracic vertebral bodies, combined with normal maintenance of intervertebral disc spaces, diagnostic of diffuse idiopathic skeletal hyperostosis (DISH) (Mann and Hunt 2005, 84, Aufderheide and Rodríguez-Martín 1998, 97). Two adult females [5001] and [5183] had bony changes associated with ankylosing spondylitis.

Trauma

Eighty-eight individuals (/1265: 7.0%) displayed evidence of traumatic injury: 8.2% of adults (83/1014), 13.1% of males (40/306) and 8.4% of females (27/323). Trauma also affected 2% of subadults (5/251) (Table 36).

	Adult		Male		Female		Sub-adult		Total	
	1014		306		323		251		1265	
	n	%	n	%	n	%	n	%	n	%
Subluxation	3	0.3	0	-	1	0.3	0	-	3	0.2
Avulsion injury	1	0.1	0	-	1	0.3	0	-	1	0.1
Compression fracture (vertebrae)	1	0.1	1	0.3	0	-	0	-	1	0.1
Soft tissue trauma	2	0.2	2	0.7	0	-	0	-	2	0.2
Fracture with secondary infection	5	0.5	2	0.7	2	0.6	0	-	5	0.4
Healed fracture	71	7.0	34	11.1	24	7.4	5	2.0	76	6.0
Joint fracture	2	0.2	2	0.7	0	-	0	-	2	0.2
Undetermined	1	0.1	1	0.3	0	-	0	-	1	0.1

Table 36 Trauma in Category C burials

Seventy-six individuals (/1265: 6.0%) presented healed fractures: 7.0% of adults (71/1014) and 2.0% of subadults (5/251). There was a higher crude prevalence of healed fractures amongst males (34/306: 11.1%) compared to females (24/323: 7.4%). These included 26 (/1265: 1.2%) fractures to the lower limb. Twenty-two individuals had fractures of the upper limb (/1265: 1.7%). The most prevalent fracture location was the torso (mainly rib fractures) (34/1265: 2.7%). Five adults (/1265: 0.4%) had fractures with secondary infectious complications (2 males, 2 females). Adult [7332] had a fractured left distal fibula with associated reactive bone on the fibula and the tibia.

Soft tissue injuries (myositis ossificans traumatica) were observed in two adult males (/306: 0.7%). Context [4976] had a large bony spur on the lateral border of the proximal shaft of the left tibia and [7557] had a bony spur on the right humerus.

One adult [4707] had two healed sub-oval blunt force injuries located on both parietals either side of sagittal suture at lambda.

Metabolic disease

Metabolic disease was present in 40 individuals (/1265: 3.2%): 2.2% of adults (22/1014) with an almost equal proportion of females (2.2%: 7/323) and males (2.6%: 8/306) affected. Metabolic bone changes were also present in 7.2% of subadults (18/251).

Rickets was observed in 37 individuals including 2.2% of adults (22/1014) and 6% subadults (15/251) (Table 37). One subadult with rickets was aged less than seven years at death, four were aged 7–12 years, and eight were 13-17 years. Two affected subadults could not be assigned specific age categories.

Bowed limbs with flaring, increased metaphyseal porosity and expanded sternal ribs, were present in 0.4% of subadult individuals (1/251). Bowed deformities of the limbs, more commonly seen in the femora and tibiae and suggesting resolved rickets, were observed in 14 adults (/1014: 1.4%).

Scurvy was recorded in 3 subadults (/1265: 0.2% of individuals, 3/251: 1.2% of subadults).

	Adult		Male		Female		Sub-adult		Total	
	1014		306		323		251		1265	
	N	%	n	%	n	%	n	%	n	%
Rickets	22	2.2	8	2.6	7	2.2	15	6.0	37	2.9
Scurvy	0	-	0	-	0	-	3	1.2	3	0.2

Table 37 Metabolic disease in Category C burials

Miscellaneous conditions

	Adult		Male		Female		Sub-adult		Total	
	1014		306		323		251		1265	
	n	%	n	%	n	%	n	%	n	%
Rib deformation	14	1.4	1	0.3	11	3.4	0	-	14	1.1
Porotic hyperostosis	8	0.8	5	1.6	2	0.6	2	0.8	10	0.8
Hyperostosis frontalis interna	1	0.1	0	-	1	0.3	0	-	1	0.1
Endocranial lesions	4	0.4	3	1.0	1	0.3	1	0.4	5	0.4
Pipe notches	25	2.5	15	4.9	9	2.8	2	0.8	27	2.1
Cribra orbitalia	21	2.1	7	2.3	13	4.0	7	2.8	28	2.2
Other	0	-	0	-	0	-	1	0.4	1	0.1

Table 38 Miscellaneous conditions in Category C burials

Twenty-eight individuals (/1265: 2.2%) displayed lesions to the roofs of the orbits diagnostic of cribra orbitalia. This affected 2.1% adults (21/1014) and 2.8% subadults (7/ 251). The crude prevalence rate was lower than that recorded for the period (9.0%) (Roberts and Cox 2003, 307).

Porotic hyperostosis was recorded in 0.8% adults (8/1014) and 0.8% subadults (2/251). One adult female [7956] displayed distinct thickening, with sclerotic bone nodules on the endocranial surface of the frontal bones consistent with hyperostosis frontalis interna (Aufderheide and Rodríguez-Martín 1998, 419).

Five individuals had endocranial lesions (/1265: 0.4%): 0.4% of adults (4/1014) and 0.4% of subadults (1/251) (Table 38).

Rib deformation resulting from possible corset/stay wear was recorded in 3.4% of adult females (11/323).

Evidence of the smoking of pipes was observed in the form of smooth, rounded wear patterns, or notches, present in 2.5% of adult individuals (25/1014), 15 males and nine females. Many teeth were loose, having fallen out of their sockets post-mortem, making observation of pipe notches problematical.

3.5 Inter-comparison of the Category A, B and C human bone assemblages

This section compares the results of the on-site assessment of 1265 contexts of human bone from the Category C areas of excavation with 1971 Category A human skeletons and 118 Category B human skeletons, both of which were processed and assessed in the office. The comparison of statistics for categories included in the sections following demonstrates that for Category B the expected results were obtained, and that by implication the reasoning behind the sample selection methodology was sound.

3.5.1 Condition and disturbance

Preservation

There was evidence of variability in the preservation of bone from the three categories, reflecting the differing conditions of deposition, the state of preservation of the associated coffins and coffin furniture, the ability to determine preservation of unprocessed Category C burials and possibly the greater level of truncation in the areas selected for Category C.

The majority of articulated contexts were in good condition with slightly better preservation in Category B and slightly worse in Category C. Only 1.1% of burials in Category A were poorly preserved (21/1971), compared to 3.7% (47/1265) of Category C, and none in Category B. The improved rates of preservation observed in the Category B burials may be explained by the fact that this assemblage was selected based in part on good skeletal preservation or as a good example of a particular pathology, the identification of which was aided by better preservation.

Completeness

The completeness of the Category A, B and C burials ranged from 5–95%, reflecting the high degree of truncation and inter-cutting of burials observed during excavation. Over half of Category A (1047/1971: 53.1%) and Category B (90/118: 83.3%) burials were more than 50% complete compared to 42.8% (542/1265) of Category C burials. The reduction in completeness of Category C burials reflects the generally high rate of truncation and disturbance in many of these areas of site.

In all categories, the most commonly observed elements came from the torso, followed by the arms.

Complete, measurable crania were recorded in 149 individuals in Category A (/1971: 7.6%), in 14 individuals in Category B (/118: 11.9%) and in 71 individuals in Category C (/1265: 5.6%). The relatively high percentage in Category B reflects the selection process inherent in the site methodology.

The dentition was present in 49.9% of burials in Category A (984/1971), in 70.3% of burials (83/118) in Category B and in 44.8% of individuals (567/1265) in Category C.

3.5.2 Minimum number of individuals

In Category A, a total of 1971 in-situ articulated human skeletons were subject to osteological assessment. A single individual was present in 56.2% of burials (1108/1971); intrusive remains were present in 43.8% of the assemblage (863/1971). In Category B, a single individual was present in 42.4% of burials (50/118). In Category C a total of 1265 articulated contexts were subject to osteological assessment. A single individual was present in 91.1% of the articulated contexts (1153/1265). The increased number of intrusive elements in the Category A and B assemblages compared to Category C reflects the difficulties of identifying these bones during on site assessment.

3.5.3 Demography

In the adult sample, the relative numbers of males and females were very similar in all three categories, with an overall ratio of males to females of 0.96:1. At the 19th-century burial ground of the Catholic mission of St Mary and St Michael the male to female ratio was 1.4:1 (Henderson et al. 2013, 100). The period 17 burials (*c* 1400–1539) at St Mary Spital also had a male to female ratio of 1.4:1 (Connell et al. 2012, 34). Studies of 19th-century Baptist burial grounds, and those of other non-conformist groups, have highlighted an increased proportion of female individuals when compared to 'conformist' groups. Whilst 17th-century and 19th-century non-conformity cannot be directly compared, as many differences exist between the two groups, religious preference may be a factor in the sex ratio observed at the New Churchyard. The ratio may also be a product of patterns of migration into London.

There were a higher number of adults of undetermined sex in Category C (Category A 484/1465: 33.0%, Category B 17/83: 20.4%, Category C: 374/1014: 36.9%). During on-site assessment there was limited time to determine biological sex and sexually dimorphic morphology was sometimes obscured in soil-encrusted remains.

All three categories had relatively small proportions of subadults (Category A 506/1971: 25.7%, Category B 35/118: 29.7%, Category C 251/1265: 19.8%). This compares to 62% at St Mary and St Michael and 48.6% at Bow Baptist church (Henderson et al. 2013, 100 and 103). However, in period 17 at St Mary Spital (*c* 1400–1539), only 19.1% of the sample consisted of subadults (Connell et al. 2012, 34).

In the subadult group, there were a small number of neonatal/feotal burials (Category A 14/506: 2.8%, Category B none, Category C: 19/251: 7.6%). Orme (2001, quoted in Lewis 2007, 82), estimated that in 16th-century England approximately 27% of children died before the age of 1 year and Lewis (ibid) reports that in 1662 John Graunt estimated that in London during non-plague years, 36% of children died under the age of 6 years.

In both Category A and B, there was a peak in subadult mortality between the ages of 1 month and 6 years (Category A 159/506: 31.4%, Category B 14/35: 40.0%). However, in Category C the highest proportion of subadults died during the ages of 13–17 years (79/251: 31.5%). The 13–17 year age category contained the second highest group in both the Category A (136/506: 26.9%) and Category B (13/353: 7.1%) assemblages. The proporation of individuals dying between the ages of 11–20 years from 1728 to the 1830s in the London Bills of Mortality was lower and ranged from 2.71% to 3.78% (Roberts and Cox 2003, 304). In these records, the mortality peak for children fell between 1–2 years of age, with a range of 13.24% to 35.95% recorded (ibid). Lewis suggested that peaks in the older child/ adolescent age category (10–19 years) may reflect entry into employment, with associated exposure to hazards, together with migration to urban environments containing new pathogens (Lewis 2007, 87).

3.5.4 Palaeopathology

When the data for the three assemblages were compared, some differences in crude prevalence rates were observed in dental pathology, infectious disease, joint disease, trauma and metabolic disease. Minimal differences were observed in circulatory disease, joint disease, congenital disease and in the miscellaneous conditions.

Dental health

There were higher rates of all types of dental pathology for both adults and subadults in the Category B assemblage, with 33.9% of individuals affected by antemortem tooth loss (40/118), compared to rates of 22.3% (439/1971) in Category A and 20.8% in Category C. A rate of 44.9% (53/118) of dental caries was recovered in Category B, compared to 26.5% (522/1971) in Category A and 16.7% (211/1265) in Category C.

There was a higher rate of dental calculus in the Category B burials at 38.1% (45/118), with 24.0% (474/1971) and 11.8% (149/1265) in the Category A and Category C burials respectively. Category B rates of enamel hypoplasia (27/118: 22.9%) were almost double those of Category A (9.4%: 186/1971) and Category C (137/1265: 10.8%). When the burials from the mass pit were examined, very high rates of certain dental disease were observed, with a crude prevalence rate of 20.0% antemortem tooth loss (8/45), 40.0% calculus (18/45) and 37.8% caries (17/45).

The overall rate of caries was similar to those reported in late medieval (1376/6279: 21.9%) and post-medieval period Britain (366/2019: 18.1%) (Roberts and Cox 2003, 259, 326). The rate of dental calculus in Britain in the late medieval period was higher at 37.2% (961/2585) (ibid 258–262). However, the post-medieval rate was similar (102/658: 15.5%) (ibid 326–327). The rates of dental disease for period 17 at St Mary Spital (*c* 1400–1539 – a period immediately preceding the use of the New Churchyard) were much higher at 53.4% (347/650) for dental caries and 77.2% (502/650) for dental calculus.

Infectious disease

There were more than double the number of cases of non-specific periostitis in the Category A (198/1971: 10.0%) and Category B burials (13/118: 11.0%) when compared to Category C (57/1265: 4.5%). All rates were lower than those collated by Roberts and Cox (2003, 344) for post-medieval Britain (52/198: 26.3%).

Rates of other infectious diseases, both specific and non-specific, were low in all three categories, apart from Category B, but this was expected given that the burials from this category were deliberately selected for retention, often on the basis of pathological changes.

Trauma

The rate of healed fractures in Category B (22/118: 18.6%) and Category C (76/1265: 6.0%) was greater than that in Category A (64/1971: 3.2%). The rate of soft tissue trauma was 5.9% (7/118) in Category B, but only 1.6% (32/1971) and 0.2% (2/1265) in Category A and C respectively. There was no evidence of surgical intervention in the Category B and C burials, with only two cases in the Category A assemblage (2/1465: 0.1%).

In terms of the location of healed fractures, the majority of them occurred in the torso (mainly rib fractures) in Category A (33/103: 32.0%) and Category C (34/84: 40.5%) and in the lower limbs in Category B (8/16: 50.0%). This can be accounted for by several severe lower limb fractures selected for retention as category B contexts (Fig 24).

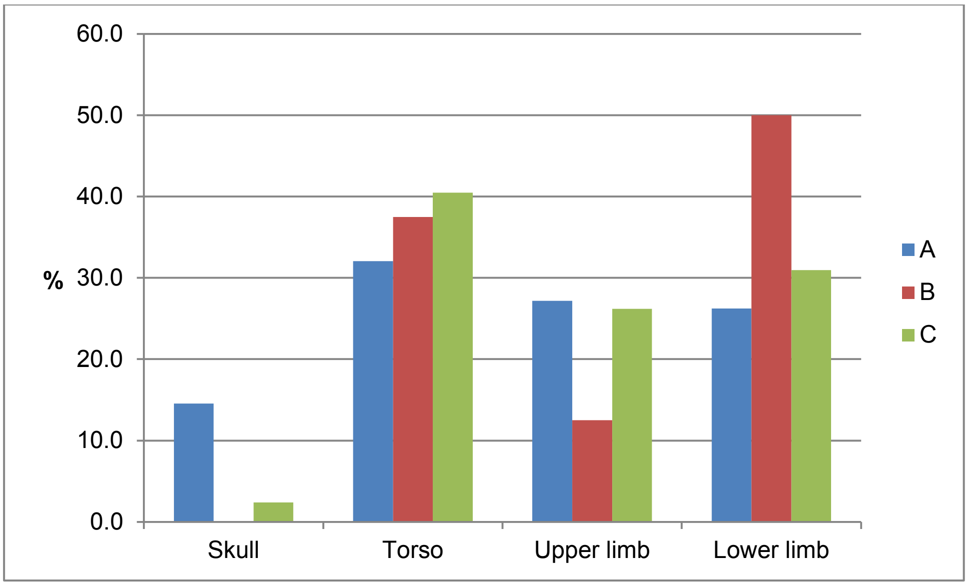

Fig 24 Fracture location by body area for Category A, B and C

<u>Metabolic disease</u>

The Category B assemblage contained almost four times as many cases of rickets (13/118: 11.0%) compared to Category A (59/1971: 3.0%) and Category C (37/1265: 2.9%). This much higher rate may be explained by the retention as Category B contexts of many severe cases of rickets observed on site in the Category C zones. In the Category B assemblage rickets was primarily observed in subadults (12/13: 92.3%), compared to Category A (33/59: 55.9%) and Category C (15/37: 40.5%), suggesting that few subadults from Category B affected by rickets survived into adulthood. When the mass pit burials were examined in isolation a rate of 11.1% of rickets (5/45), all subadult individuals, was recorded. Rates of rickets in British and Irish skeletal assemblages generally rise from the late medieval period (25/3418: 0.73%) to the post-medieval period (93/2545: 3.65%) (Roberts and Cox 2003, 247–8 and 310).

3.5.5 Conclusion

There were only small differences in terms of preservation and completeness between the three categories, with Category C burials generally less well preserved when compared to Category B. This would be expected given the nature of the two assemblages.

There was an almost equal distribution of males and females in all three categories. All had low proportions of subadults, with very few neonates. This suggests infant burials may have been more susceptible to disturbance and truncation, representing partial or total bone loss, perhaps due to interment in shallow graves.

The unexpectedly high mortality between 13–17 years may have been the result of increased risk levels as older children and adolescents entered the workplace as apprentices. Detailed investigation of adult age groups at full analysis will explore this further.

There were minimal differences observed in circulatory disease, joint disease, congenital disease and miscellaneous conditions between the three categories.

There were higher rates of dental pathology in the Category B burials. This may be influenced by the increased rates within the mass pit burials, together with the greater number of intact crania and dentition available for study in the Category B assemblage. The rates of dental pathology overall were low compared to medieval and post-medieval assemblages perhaps reflecting a younger burial sample.

There was twice the rate of non-specific periostitis in the Category A and B burials than in Category C, probably due to the on-site assessment of Category C, with lesions obscured by soil.

There was almost four times the amount of rickets in the Category B assemblage compared to Category A and Category C, as many severe cases of rickets were categorised as B burials. However, the increased rate of rickets in subadults within the mass burial pit [7482], together with the absence of adults with residual signs of the disease, suggests that this sample represents a population with increased risk of developing rickets, and reduced prospect of survival. Alternatively, the use of the mass burial pit may have been contemporary with a period of increased risk of vitamin D deficiency, possibly even reflecting seasonality, with rising levels of disease due to increased vulnerability in winter (Miles et al 2008, 160). High levels of dental disease, including calculus, caries and enamel hypoplasia, in the mass burial pit suggests these individuals had lower levels of dental hygiene and perhaps lower health status when compared to the burial ground overall. This question will be further addressed once phasing of the burial ground is complete.

3.6 Disarticulated bone

3.6.1 Overall site totals

A large quantity of disarticulated bone was recorded across various phases of excavation. Disarticulated bone from trenches 1, 2, 6, 7, 9, 13, Area 1, 2/3 and 5 were compared and quantified to give a total number of bone elements and minimum number of individuals (MNI) for all disarticulated bone. A total of 34,928 disarticulated bone elements or segments were recovered from all phases of excavation. The overall MNI for disarticulated bone was 1052 individuals: 213 subadults and 860 adults (Table 39).

Area	Bone segments	MNI adult	MNI subadult	Total MNI	Pathology
1	5038	155	28	178	Ectocranial lesions (Syphilis), AMTL, cribra orbitalia, porotic hyperostosis, spinal joint disease,1 x DISH, 3 x fracture, possible Madelung's disease, rickets, periostitis, Osteochondroma, possible syphilis, coxa vara
2/3	5465	157	36	186	Paget's disease of bone, Healed sharp force trauma, cribra orbitalia, LEH, AMTL, Dental disease, calculus, possible Bathrocephaly/ occipital bun, 1 x DISH, spinal joint disease, spondylolysis, rickets, 1 x healed fracture, OA, periostitis, osteitis
5	976	41	10	51	LEH, AMTL, Calculus, spinal joint disease, spondylolysis, rickets, 1 x fracture, OA
Pre 2015 excavation trenches					
6	946	22	4	26	Resolved rickets, periostitis
9	1131	20	6	26	Rickets, osteitis, periostitis, healed fracture
7	6654	122	36	158	Rickets, Colle's fracture, periostitis, osteitis, fracture with secondary osteomyelitis, healed fracture, spinal joint disease, dental pathology
13	1772	38	10	48	Rickets, dental pathology, spinal joint disease
1	4731	89	38	118	Dental pathology, craniotomy, Ankylosis: sternum and ribs, spinal joint disease, DISH, Sacralisation: L5, L. ulna fracture, Colles fracture, Rickets, Avulsion fracture, Ankylosis of L. ankle, slipped femoral epiphyses
2	8215	216	45	261	Dental pathology, cribra orbitalia, maxillary sinusitis, Spinal joint pathology, DISH, Subluxation: L. scapula, Colles fracture, ulna fracture, resolved rickets, active rickets, greenstick fracture, ankle trauma, osteitis, OA, Ankylosis of L. hip joint
Total	**34,928**	**860**	**213**	**1052**	

Table 39 All disarticulated bone from XSM10

Pathological conditions included joint disease, dental disease, congenital abnormalities, rickets, DISH, infection and trauma including one example of sharp force injury. Most pathology observed was consistent with conditions noted within the articulated assemblage.

3.6.2 Subtotals: Areas 1, 2/3 and 5

A large amount of disarticulated human bone was recovered from several discrete features such as charnel pits from Area 1, 2/3 and 5. With an overall MNI of 415 individuals: 98 subadults and 353 adults (Table 40).

Area	Bone segments	MNI adult	MNI subadult	Total MNI	Pathology
1	5038	155	28	178	Ectocranial lesions (Syphilis), AMTL, cribra orbitalia, porotic hyperostosis, spinal joint disease,1 x DISH, 3 x fracture, possible Madelung's disease, rickets, periostitis, Ankylosis, Osteochondroma, possible syphilis, coxa vara
2/3	5465	157	36	186	Paget's disease of bone, Healed sharp force trauma, cribra orbitalia, LEH, AMTL, Dental disease, calculus, possible Bathrocephaly/ occipital bun, 1 x DISH, spinal joint disease, spondylolysis, rickets, 1 x healed fracture, OA, periostitis, osteitis
5	976	41	10	51	LEH, AMTL, Calculus, spinal joint disease, spondylolysis, rickets, 1 x fracture, OA
Total	**11,479**	**353**	**74**	**415**	

Table 40 Disarticulated bone from XSM10 excavation Areas 1, 2/3 and 5 (excavated 2015)

Disarticulated remains were collected from eight contexts in Area 1. Contexts: [7483] and [7989] were recovered from within and around mass grave [7482]. The northern portion of the mass grave had been disturbed; consequently disarticulated bone from these contexts may have originated from within this pit (Table 41).

Context	Bone segments	MNI Adults	MNI male	MNI female	MNI subadult	Total MNI	Pathology
+	194	7	1	2	1	8	None
7040	1430	39	9	4	7	45	Ectocranial lesions (Syphilis), spinal joint disease, 1 x fracture, rickets, rickets
7057	666	21	6	4	5	24	Spinal joint disease, rickets
7077	512	19	7	7	3	22	Osteochondroma, Ankylosis carpal
7483	137	3	1	1	3	6	Possible Madelung's disease
7579	138	4	2	1	0	4	1 x fracture
7716	245	8	4	3	2	10	Rickets
7989	352	11	3	4	3	13	1 x fracture
7634	1364	43	10	6	4	46	Cribra orbitalia, porotic hyperostosis, spinal joint disease, DISH, 2 x fracture, periostitis, possible Syphilis, coxa vara
Total	**5038**	**155**	**43**	**32**	**28**	**178**	

Table 41 XSM10 Area 1 disarticulated bone

Area 2/3 comprised 10 contexts with a MNI of 33 individuals (Table 42).

Context	Bone segments	MNI Adults	MNI male	MNI female	MNI subadult	Total MNI	Pathology
3182	1015	27	9	5	6	33	Paget's disease of bone, sharp force trauma, 1 x fracture, rickets, OA
3864	1	1	0	0	0	1	None
4201	9	1	1	0	1	1	None
4202	934	30	11	7	1	31	Dental disease, LEH, calculus, AMTL, cribra orbitalia, Paget's disease of bone, rickets, periostitis
4347	907	20	9	6	3	23	Dental disease, spinal joint disease, DISH, rickets, periostitis, osteitis
4701	394	10	3	4	4	14	Bathrocephaly/ occipital bun, spinal joint disease, DISH, rickets, periostitis
4705	948	19	4	5	6	25	Spinal joint disease, rickets
4746	51	6	0	0	1	7	None
4915	757	20	6	12	5	25	Dental disease, AMTL, calculus
5716	449	23	0	0	3	26	None
Total	**5465**	**157**	**43**	**39**	**36**	**186**	

Table 42 Area 2/3 disarticulated bone from XSM10 excavation 2015

Area 5 contained only 4 contexts, with an MNI of 17 individuals (Table 43).

Context	Bone segments	MNI Adults	MNI male	MNI female	MNI subadult	Total MNI	Pathology
1714	268	11	2	1	3	14	LEH, spinal joint disease, rickets
1715	131	6	2	2	2	8	None
1719	429	14	6	4	3	17	Calculus, AMTL spondylolysis, 1 x fracture, OA
1750	148	10	2	1	2	12	None
Total	**976**	**41**	**12**	**8**	**10**	**51**	

Table 43 Area 5 disarticulated bone from XSM10 excavation 2015

Assessment work outstanding

This report details the osteological assessment of New Churchyard assemblage. The fieldwork post-excavation assessment remains in progress but at the time of issue of this document (w/c 26/10/2015) sub-grouping and grouping of the burial ground contexts is about to commence. Consequently, any remaining discrepancies in context numeration between the field and laboratory record will be identified and addressed at a very early stage of analysis. Such adjustments are commonly made between the assessment and full analysis phases of a project.

4 Potential of the data

4.1 Realisation of the original research aims

ORA-BB 8 *How can osteology studies be used to describe the population of the burial ground and what scientific samples should be taken to determine the role of various pathogens particularly in relation to potential plague victims?*

Osteological analysis has the potential to characterise the nature of the population represented by the burial sample. Such work utilises the study of demography, growth, stature, and skeletal and dental disease, as well as morphological variation and evidence of injury.

Pairs of teeth from 20 individuals, 10 from the mass burial pit and 10 from a 17th-century control sample not from the burial pit, will be sampled for stable isotope analysis. Strontium and oxygen isotopes will investigate origins and migration, while carbon and nitrogen will be used to look at variation in diet and periods of stress. While this represents a small proportion of the overall burial sample it has the potential to provide individual biographical details.

With regard to bacterial infectious diseases, recent advances in the recovery and high-throughput sequencing of ancient DNA not only helps to identify individuals exposed to Yersinia pestis, amongst other diseases, but allows genome-level work on sufficiently preserved material. As part of the sampling strategy for the New Churchyard, 20 individuals will be selected from the mass burial pit. A tooth will be removed from each specifically to test for the presence of Yersinia pestis pathogen DNA within the dentine. At the same time, a control sample will be selected from the same number of 17th century non-pit burials. The ancient DNA work will be carried out at the Max Planck Institute. Depending on the success of this work it may be possible to identify the presence of some other pathogens such as tuberculosis and leprosy.

ORA-BB 9 *Can skeletal evidence, injury, or other indicators be correlated with biographic details derived from burial records?*

Occasional preservation of coffin lid stud inscriptions and plates may allow individuals noted within the parish records to be identified. In rare cases identification may be achieved by correlating peri-mortem injuries with cause of death.

ORA-BB 10 *Can the skeletal evidence be correlated with burial records to build a picture of the population of the cemetery as a whole and establish chronological trends during the use of the cemetery relating to parish origin, age and cause of death, gender, social, occupation, and religious belief profiles etc.?*

The burial records provide a source of information for many of those buried at the New Churchyard, for whom names, date of burial, the recorded cause of death and in some cases the occupation and residential details are potentially available. The osteological data will be interrogated to investigate how the evidence correlates with that of the parish records. Trends through time will be examined once the burial ground has been phased. The correlation of bone evidence with that of the documentary records will in itself be a useful osteological test-case and will test how representative the burial sample is of the population.

ORA-BB 11 *(not numbered other than by paragraph in document C502-XRL-T1-RST-CR101-50002- Rev. 2.0) Can scientific sampling of soil samples be used to illuminate any of the other research objectives?*

Within such a crowded burial ground, which was also subject to episodes of dumping, it is rarely possible to individualise grave fills to a satisfactory extent to place the results of soil sample analysis in context. However, a small sample of soil will be forwarded to the Max Planck Institute to test for background pathogen DNA.

4.2 General discussion of potential

Over the past decade, MOLA has undertaken the osteological analysis of several large assemblages from post-medieval burial grounds, though much of this work has focused on 18th–19th-century material and the under-representation of burial populations from the 16th–17th centuries in the archaeological record, previously noted in for example Museum of London 2002 (p72), remains the case. Indeed, there is a significant gap in our knowledge of demography, health and disease between the medieval period and the 19th-century, not only in London but beyond. This was an important period in London's development which witnessed significant increases in population, principally through inward migration.

The 3354 burials from the New Churchyard, including a mass burial pit, should be contrasted with the small number of archaeological interventions that have recovered more than 1000 burials (Mays et al 2015, 2, 6). These include the medieval priory of St Mary Spital, London (c 10,500), the medieval and post-medieval churchyard of St Peter's Church, Barton on Humber (*c* 3000), the 18th–19th-century extramural burial grounds of St James, Piccadilly and Poland street workhouse, Marshall St, London (c 2500) and the medieval burials from Hereford Cathedral (*c* 2500) (Connell et al 2012; Waldron 2007; Davis et al 2009; Boucher et al 2015). The New Churchyard provides one of the largest collections of post-medieval human remains excavated under archaeological conditions in Britain. The value of large datasets to the statistical analysis of past populations cannot be overstated.

The New Churchyard, in use from 1569 until the 1730s, provides a large, statistically-robust dataset with which to conduct research into shifts in population, health and disease during this period. This will not only contribute to our appreciation of levels of migration and population diversity but will permit comparison with different socio-economic and religious groups at a local, regional and national level. The mass burial pit in Area 1 may contain burials resulting from 17th-century plague, possibly from the Great Plague of 1665. As such, the evidence from the burial ground may provide a rare opportunity to study victims of this epidemic.

Analysis will address key themes outlined in the Research Framework for London Archaeology including correlation with documentary evidence to better understand the diversity of the domestic and working lives of the population, as well as questions regarding the impact of poverty, social deprivation, disease and pollution (Museum of London 2002, 70–1). Of particular relevance to this work is the burial register database created through the Crossrail volunteer programme, which provides specific details of over 5000 Londoners buried at the New Churchyard and will compliment information recovered from the full analysis of the skeletal assemblage.

While early 16th-century industry remained small-scale and largely focused in rural areas, trade depressions and harvest failures in the south of England led to large-scale immigration from the countryside into urban areas (Roberts and Cox 2003, 300). Such newcomers, particularly those from small isolated communities, may have had limited immunity to a wide range of pathogens, leaving them vulnerable to infectious disease (Roberts and Cox 2003, 294). While London remained a largely pre-industrial city in the 18th century, changes to the local area and environment, coupled with massive population growth and rapid urban expansion, led to increased pressures on resources that probably impacted on all areas of human life and health (Roberts and Cox 2003, 293–4; 358). Whilst it is difficult to reconstruct the lives of individuals in the absence of specific documentary evidence, stable isotope analysis will be used to investigate a sample from the burial ground. Particularly detailed analysis can now identify those who were raised in other areas of Britain or Continental Europe, together with information on their movements and changes in diet. This can be combined with the macroscopic skeletal analysis to build up a remarkably detailed biography at individual-level whilst identifying group-level trends. As such, stable isotopes provide invaluable insights into the kind of detail that was hidden to past researchers. Such work has the potential to identify patterns of migration. Initial anecdotal observation at excavation highlighted a large number of late adolescent/young adult burials. If further analysis bears this out, we may be able to identify the age at which young migrants were moving to London, thereby contributing to historical studies of this period. Individuals from both the normal 'attritional' burial ground and the mass pit will be sampled to investigate any differences between plague and non-plague populations.

The relatively high level of skeletal preservation and completeness will enhance the demographic details obtainable at full analysis, providing increased definition of age at death ranges and biological sex. Metric measurements will provide data for calculation of skeletal indices including living stature and childhood growth and development. The truncated and fragmented nature of some burials will inhibit the potential for metric analysis of some individuals.

Development of the land within the burial ground in the 18th and 19th centuries resulted in a high level of disturbance and truncation. The previous intensive use of the ground was revealed during archaeological excavation in the high level of intercutting of graves in an attempt to utilise all available space. This all resulted in a large quantity of disarticulated bone, some of which was placed in the backfill of newly cut graves and some in discrete pits. A high degree of mixing of remains from different individuals was encountered in numerous contexts containing intrusive elements from surrounding graves. The employment of stratigraphic information, context records and photographs may permit the re-matching of these skeletons at analysis.

This information will also help to identify and separate different periods of use of the burial ground, allowing the osteological data to be placed within its historical perspective. This will allow for the identification of distinct or discreet patterns within the assemblage and permit intra- and inter-site comparisons of demographic and pathological patterns through time. Early burials were perhaps interred wrapped only in shrouds and laid in rows with a majority laid on an east-west orientation. Later burial practices utilised wooded coffins, some with decorative fittings or studs. The latest burials had name plates but these were too corroded to provide any biographical information. The limited evidence from surviving coffin lid upholstery stud patterns may provide additional information to illuminate documentary sources and provide data with which to test osteological methods.

The London Bills of Mortality indicate a low life expectancy for individuals in the 18th century (age of death was not recorded in the Bills before this date) when compared to modern Britain, although this would probably have fluctuated depending on socio-economic status (Roberts and Cox 2003, 303–304). At assessment, the relatively high proportion of subadults aged 13–17 years and the low rates of disorders associated with older age, such as ante-mortem tooth loss, degenerative joint disease, Paget's disease of bone and senile osteoporosis, implies a relatively low life expectancy. Prior to the adoption of aseptic practices and antibiotics, childbirth was perilous and responsible for a high mortality rate amongst many young women. The London Bills of Mortality for the 18th century suggests that approximately 6–11% of people survived past 70 years of age (Roberts and Cox 2003, 303–304). Despite the inherent problems with osteological ageing methods (Cox 2000, 75), a comparison of the age structure and historical records from parish registers, death certificates and other documents will help to determine the extent to which the New Churchyard burial sample represents a true reflection of the population.

A low number of subadults was noted at assessment and this contradicts the London Bills of Mortality for a period that reports that approximately 25–30% of children did not survive beyond their second birthday (Roberts and Cox 2003, 303–4). Greater childhood survival rates recorded at higher status burial grounds such as St Marylebone and All Saints, Chelsea, perhaps reflect the benefits of growing up within wealthier communities (Miles et al 2008, 104, Cowie et al 2008, 42). However, a paucity of subadult burials may also reflect differential preservation or cultural biases (Lewis 2000, 40). Analysis of subadult age structure and spatial location within the burial ground may identify whether this under-representation reflects a true pattern, or instead increased vulnerability to disturbance or sample bias.

Full analysis will allow refined diagnosis of pathological bone changes and the calculation of true prevalence rates for infectious and circulatory disease, non-specific stress markers, congenital and developmental disorders, trauma, degenerative joint disease and dental pathology. This will contribute to our understanding of the health status and diversity of the population, providing valuable palaeopathological data for an under-represented period of London's history. Initial crude prevalence rates of disease from the assessment appear low, but comparisons with assemblages from other periods will help determine whether this is part of a real pattern of improving health or simply a consequence of the osteological paradox (Wood et al 1994).

Poor dental health would have been almost ubiquitous in this period as a consequence of poor oral hygiene and/or diet. Variation in the form and availability of carbohydrates may be reflected in the prevalence and location of carious lesions from the burial ground, with a trend towards increased access to sugar over time (Mays 1999, 334–5; Roberts and Cox 2003, 310). Increased sugar in the diet can attract the bacteria that cause enamel destruction and consequent dental cavities. Smoking is a further cause of dental disease, carrying an increased risk of developing periodontal disease (World Health Organization 2008, 11). The identification of signs of gout and DISH in several adults may reflect rich diets high in red meat and alcohol (Roberts and Cox 2003, 310). Evidence of subadult dental health will provide information regarding infant feeding practices and periods of stress during growth, and thus allow us to explore cultural aspects of childhood and childcare.

The rising population of London over the period of use of the New Churchyard probably witnessed increasing levels of pollution from coal fires. Coal imported to London was taxed, which provides an index of its increasing use, particularly in the 17th–19th centuries. This, together with mounting population density and infant rearing practices, such as keeping the sickly wrapped up and indoors, may have contributed to vitamin D deficiency and the development of rickets. A relatively high prevalence of rickets was observed in the assessment, and this corresponds to the London Bills of Mortality that record as many as 2.5% of those who died were affected by the disease. In the 17th century this may also reflect the impact of variations in climate and resulting reductions in sunlight exposure (Roberts and Cox 2003, 308–9). The Little Ice Age was a period of cooling lasted from the16th–mid-19th century. This period was characterised by glaciers advancing dramatically and in London by the frequent freezing over of the Thames (Mann 2003). Comparison of this evidence with that for residual signs of the disease in adult skeletons will further our understanding of its prevalence over time and its relationship with other conditions such as scurvy, anaemia and general malnutrition (Henderson et al 2013, 258–259). Bone lesions on the visceral surfaces of ribs and inflammation within the maxillary sinuses may also identify changes in levels of pollution as they impacted on respiratory health (Roberts and Cox 2003, 299).

Pollutants take many forms and recent work on sampling dental calculus has shown that a remarkably wide range of evidence can become entrapped within plaque during life. This work will prove particularly interesting in reconstructing the domestic environment of the population, whether they were exposed to smoke, dust, or fungal spores associated with damp environments. Food debris can be recovered allowing us to examine direct evidence of diet. Dental calculus can also store evidence of microorganisms that existed within the mouth. By studying the balance of the oral microbiome we can further examine the background health and exposure to microbial DNA of individuals within the skeletal sample.

The acute nature of many diseases such as smallpox, recorded in historical sources as endemic at this time, prevents osteologists from assessing their prevalence, as individuals die prior to changes occurring in bone (Roberts and Cox 333; 358). However, a large number of individuals at the New Churchyard had non-specific reactive bone changes that may have been caused by infectious diseases such as tuberculosis, leprosy or treponematoses; although they can also occur as a result of metabolic and neoplastic conditions (Weston 2012, 502–3). The majority of these comprised periosteal lesions representing inflammation of the periosteum sleeve surrounding bone shafts. There may be large numbers of late adolescents/young adults within the New Churchyard burial ground sample. If so, there is the potential to explore their demographic structure and health to see whether these were youthful migrants who fell victim to microorganisms such as tuberculosis, found within an urban environment to which they had no previous exposure and consequently no immunity. Specific chronic infectious diseases, such as tuberculosis and venereal syphilis, were significant diseases in this period, and both were visible in the assessed assemblage.

Tuberculosis affected all classes in the 17th century, exacerbated by poor nutrition and crowded urban living conditions. It can be spread to humans by inter-personal droplet infection, and by animals, most commonly cattle, through droplet infection, consumption of infected meat or milk, and from working with animal products (Ortner 2003, 227). Crowded and poorly ventilated living and working conditions, environments many migrant workers may have experienced for the first time in London, are ideal for spreading the disease. While changes to the bone develop in only 5–7% of infected individuals, comparison of lesions, and of prevalence rates, with evidence from London cemetery [populations of other periods and with causes of death cited in parish records will allow us to gauge the disease load between the medieval period and the Industrial Revolution (Aufderheide and Rodríguez-Martín 1998, 133). Ultimately, DNA analysis of the skeletons may produce evidence of the evolution of the disease. By the 19th century tuberculosis was probably the most significant cause of death (Roberts and Cox 2003, 338). A reduction in frequency of the disease has been postulated for the 13th/14th century and the 15th/early 16th centuries, possibly a result of a decline in population following the Black death (Connell et al 2012, 156, Mays et al 2015, 6).

The outbreak and subsequent spread of a new disease amongst French troops in Naples in 1495, now thought to have been venereal, or acquired, syphilis, is attested by a rapid rise in reports of victims of the infection. The mobility of young males involved in the widespread European warfare in the late 15th–16th century facilitated the rapid spread of the new disease through Europe (Harper et al 2011, 99). There is a significant rise in the prevalence of affected skeletons in the final period of burial at St Mary Spital (c 1400-1539), although by the 18th century the virulence had waned (Baker and Armelagos 1988, 707–8; Roberts and Cox 2003, 340: Walker et al 2015, 95–6). Further analysis of the New Churchyard sample will permit more refined diagnosis of specific infectious bone changes. These can be compared with evidence from other burial grounds to help determine the impact, prevalence and survival of such diseases.

The London Bills of Mortality attribute 70.5% of deaths in 1665 to the 'Great Plague' (Roberts and Cox 2003, 332). The study of this disease in skeletal assemblages is limited by its acute nature, which leaves no trace on bone. At the same time, demographic analysis may sometimes help to identify catastrophic assemblages. Evidence of such has been suggested by mortality profiles that compare attractional and catastrophic samples

(Margerison and Knusel 2002, Gowland and Chamberlain 2004). Comparison of the individuals from the mass burial pit in Area 1 at Broadgate with other catastrophic assemblages such as at St Mary Spital and the East Smithfield Black Death cemetery will help to define the nature of catastrophic burial samples (Connell et al 2012, Grainger et al 2008). Additional demographic work using transition and hazard analysis will look at how novel methods of age estimation in skeletal remains can produce new insights into the health and mortality of a population. By comparing the results to previous work on the Black Death we hope to identify long-term trends and effects on health throughout the period of the second plague pandemic. The last major outbreak of the second plague pandemic in Europe was that of 1720.

Although a small sample, the results of the assessment of mass burial pit individuals suggests they suffered higher rates of dental disease when compared to the attritional sample. Therefore, we may be able to relate differences in dental hygiene and health status to a lower status group within the pit. Alternatively, the period in which the mass pit was dug may have been one where the burial population of the cemetery was suffering high levels of dental disease and stress.

Although macroscopic evidence of plague cannot be observed in bone, recent advances in the recovery of DNA from ancient remains now allow laboratories to test for the presence of disease, including *Yersinia pestis*. This will not only allow us to identify individuals exposed to the pathogen but, if sufficiently preserved, will permit genome level analysis, thus contributing not only to the present project but to the study of the history and evolution of plague and infectious diseases in general. Thus the work at the New Churchyard, as with that carried out at West Smithfield Black Death burial ground, has the potential to contribute important information on the behaviour of new and re-emerging infections (Pfizenmaier in prep). The scarcity of available genetic evidence from 17th-century plague makes this sample of particular significance. In light of this, and the rapid advances in biochemical techniques in the study of ancient bone, including DNA, we recommend that the mass pit sample (s) be retained for future study at the Centre for Human Bioarchaeology, Museum of London.

Evidence of injury can point to levels of interpersonal violence, accidents and occupational hazards, as well as provide an indication of access to treatment and care, a clue to wealth and status in different groups. Initial indications from the assessment were that rates of injury were low, with males at more risk than females. Further investigation at analysis should prove particularly interesting in light of evidence from other burial grounds. At St Mary Spital the prevalence of trauma increased over the medieval period, particularly in period 17 (*c* 1400–1539) (Connell et al 2012, 89). We might expect this trend to continue as London became ever more crowded. However, if rates of injury are found to fall, it will have important implications for our understanding of injury risk in this period. We also have the potential to investigate specific forms of bone fracture. We know that ‘parry’ fractures of the ulna were relatively prevalent in medieval London but had all but disappeared by the 19th century. By studying the evidence for these fractures at the New Churchyard we may be able to explore the mechanism of injury and the reasons for the fall in prevalence. Further to this, radiography of all bone fractures at full analysis will allow osteologists to study injury mechanism and rates of success of treatment and healing, and the resulting implications for medical care in this period.

Advances in medical science prompted the use of dissection to further knowledge of the anatomy and workings of the human body (Roberts and Cox 2003, 315). It is known that autopsies were carried out in London from the 1760s (Lane 2001). Evidence from the New Churchyard suggests that such operations were carried out prior to this date. Further work may determine whether the two individuals with craniotomies were subject to dissection or autopsy. Associated pathological bone changes may provide clues as to why these procedures were conducted.

Death rates from cancer are reported as low (0.5%) for the period of the New Churchyard in the London Bills of Mortality (Roberts and Cox 2003, 351–2). While many cases may have gone unidentified by doctors at the time, examples of metastatic carcinoma are particularly rare amongst archaeological samples. Detailed recording and analysis of the individuals with possible signs of metastatic carcinoma will increase our understanding of the type and distribution of bone lesions in malignant disease. Modern clinical treatment of cancer is increasingly successful and tends to limit, to an extent, the full development of associated lesions. By recording such changes in individuals who did not have access to modern treatments we can observe and study the uninterrupted progress of the disease, something that is rarely possible today.

Tobacco first appeared in Britain during the 16th century. Smoking, which is traceable through the observation of pipe notches worn in teeth, as well as dental staining, has previously been shown to have links with socio-economic status, gender and cultural identity, as well as impacting on health and mortality (Walker and Henderson 2012). Full recording at analysis will allow us to compare the impact of smoking in this period with evidence from 19th-century London. A count of individuals with pipe notches and dental staining will provide a minimum number of smokers within the New Churchyard sample. This will then be compared to rates from burial grounds of varying status. This will provide us, in conjunction with documentary evidence, a tool to explore the status of the burial population. Previous work has identified a link between smoking, rib lesions and lower life expectancy, possibly related to increased clinical consequences of smoking amongst tuberculosis sufferers (Walker and Henderson 2010, 218). The appliance of gas chromatography and mass spectrometry on samples of dental calculus from selected individuals within the New Churchyard will be used to examine lifestyle factors including smoking (nicotine). Further lifestyle evidence in the form of hallux valgus deformity associated with restrictive footwear has been observed in some individuals at assessment, as have rib deformities from the wearing of corsets and stays in some female burials. Such evidence of clothing may provide insights into lifestyle, status and fashion trends of the population.

Once full recording has taken place, comparisons can be drawn between the results and those of the few contemporary assemblages from London, such as St Botolph, Aldgate, from Royal Mint Square (Bekvalac 2008). This analysis of 88 burials contained 12 subadults and 76 adults (37 males and 33 females). In contrast with Broadgate Ticket Hall, there were no skeletons aged 12–17 years. Most adults died between 36 and 45 years of age. The assemblage produced low rates of rickets and no examples of diagnostic tuberculosis or treponematosis. Two male skulls had suffered peri-mortem injuries (ibid). Reference will also be made to later post-medieval assemblages, such as the high status burials at All Saints, Chelsea, St Marylebone and Paddington St (Cowie et al 2007; Miles et al 2008; Henderson et al in prep). Other sites in London which can be used for comparative purposes include St Pancras, St Mary and St Michael, Sheens Burial ground, City Bunhill, and New Bunhill fields (Miles and Coheeney 2002; Emery and Wooldridge 2011; Henderson et al 2013; Connell and Miles 2010; Miles with Connell 2011). Nonconformist burial samples suitable for comparison include Bow Baptist Church and Mare St, Hackney in London (Henderson et al 2013; Miles 2015) and West Butts Street in Poole (McKinley 2008). Comparisons with burial grounds beyond London will include St Martin's, Birmingham (Brickley et al 2006). Examination of contemporary European assemblages will include the catastrophic assemblages associated with outbreaks of plague from Bondy, France (11th–15th century), Lambesc, France (16th–18th century), Marseille, France (16th–18th century) and Copenhagen, Denmark (18th century) (Tran et al 2001; Bianucci et al 2008; Fiscella et al 2008).

The New Churchyard excavation represents one of the largest skeletal assemblages recovered in Britain, and one of the largest post-medieval assemblages known to date. The early 16–18th century date of the burials will help to further our knowledge and understanding of a hitherto archaeologically underrepresented time period (Museum of

London 2002, 72). An expanding city and population would have impacted on all areas of human life including health and disease. Those interred at the New Churchyard were witness to some of the most significant events of the period including the English Civil War, the Restoration, the Great Plague, the Great Fire of London and the Little Ice Age. Analysis of this assemblage will provide an extensive, robust and statistically significant osteological dataset with which to investigate the lives of the population represented by the burial population.

5 Significance of the data

5.1 International significance

The recovery and study of ancient pathogen DNA from 17th-century plague epidemics is significant in its potential to provide evidence for the evolutionary trajectory of *Yersinia pestis*. Fundamental questions will be addressed, such as the relatedness of 17th-century plague to previous outbreaks such as the Black Death, and the mode of recurrence of the disease in Western Europe during the second pandemic. In addition, genome analysis will add to our understanding of infectious disease in general, providing information on emerging and re-emerging infectious pathogens.

5.2 National significance

The burial ground contains one of the largest assemblages of post-medieval human remains archaeologically excavated in Britain, with burials spanning the 16th–18th centuries. Evidence from the excavation will contribute to our knowledge of the layout, function and use of non-parochial burial grounds from this period. The analysis of the population will significantly address the current paucity of osteologically examined skeletons from this period and through greatly increasing the body of data will significantly bridge the gap in archeo-osteological knowledge that the post-medieval period currently represents.

5.3 Regional significance

The assemblage has regional significance in that it will contribute to the body of data available for health and population studies. This will provide a robust osteological dataset for regional comparisons with assemblages of differing socio-economic status and religious beliefs.

5.4 Local significance

The human bone will for the first time provide important information on lifestyle, health and diversity within London's expanding urban population in the 16th–18th centuries. Further work may tie the mass burial pit to an event of historical significance, possibly the Great Plague of 1665. This will address research framework objectives on catastrophe and its impact on London (Museum of London 2002, 88).

6 Publication project: aims and objectives

6.1 Revised research aims

RRA-BB 1 *Primary*

1. *What is the demographic structure of the burial sample? Does the age at death profile conform to that expected of an attritional cemetery? Are there indications of a lower female average age at death, and can this be related to the risks of childbirth?*
2. *Does osteological data show any variation in demographic structure and health between burial type? For example, between earth cut graves and burial vaults, and between single and mass burials?*
3. *How do the attritional and catastrophic samples vary by stature and by disease prevalence, and what does this say about the health of those who succumbed to illness during high mortality episodes?*
4. *If Yersinia pestis is found, what can it tell us about human/disease co-evolution and host susceptibility? How does the strain compare with the medieval forms obtained from samples at East and West Smithfield?*
5. *Is there evidence of migrant groups within the burial ground? Can stable isotope analysis identify or confirm their presence?*

RRA-BB 2 *Secondary*

1. *What proportion of burials were within tombs and vaults? What does their distribution suggest about the organisation of the cemetery?*
2. *Can the burial ground be phased? What can be learned in terms of spatial development, maintenance of access routes and relation to entrance areas?*
3. *Is it possible to determine if the burial ground was managed over time eg were certain areas reserved for high status burials?*
4. *Can different coffin types, furniture and fittings be identified and what quality ranges do they represent. Is the range different from other excavated London burial grounds, reflecting the status or rites of local populations?*
5. *Can differences between male and female burials be discerned from coffin furniture?*
6. *What percentage of the burials can be identified from coffin plates or memorials and can this information be correlated with historical records?*
7. *How far can extended family groups be identified from the archaeological and documentary sources eg within vaults?*
8. *Can the factors which influenced burial rites, types and location over time be identified and are trends discernible? For example, does the type and quality of coffin vary by period of use?*
9. *Can the period over which the burials within a single stack took place be established? Could any of these groups be plague burials?*

10. *How do the New Churchyard burials compare to contemporary excavated burial grounds in London, such as the new churchyard of St Botolph, Aldgate (RMI05)?*
11. *Can it be demonstrated that any of the burials form part of a catastrophic assemblage? If so, do they form a heterogeneous group or a selection of different forms of mass burial?*
12. *Can the osteological data for any named individuals be correlated with biographic information? How accurate were the osteological methods for determining age at death and sex in the named adults?*
13. *Is the number of subadults a genuine pattern in mortality or does it relate to taphonomic or archaeological factors or differing burial practices?*
14. *What is the demographic structure of each burial stack? Can this be related to family plots or to catastrophic episodes?*
15. *How does adult stature compare with other contemporary London groups? Can it be used as an indicator of relative status?*
16. *Is there any evidence of a link between subadult growth, nutrition and other stress indicators?*
17. *Is there a correlation between ante-mortem tooth loss and adult age? What would be the implications for diet of a high rate of sub-adult caries?*
18. *What evidence of dentistry can be seen and what are the social and economic implications of such treatment? How do the dental prostheses add to our knowledge of dentistry? Does the pattern of adult caries indicate the use of abrasive tooth powders, toothpicks or tinctures?*
19. *Are any patterns apparent in the type and location of fractures and how do these injuries compare to contemporary and modern sources?*
20. *What are the likely mechanisms behind the fractures?*
21. *Is there any evidence of interpersonal violence within the sample?*
22. *What is the evidence for direct mid- or distal shaft ulna fractures, and how does this compare with medieval and post-medieval burial assemblages from London? Is there evidence of a significant reduction in prevalence of 'parry' fractures over the period of use of the New Churchyard?*
23. *Is there any osteological evidence for occupational or industrial disease or injury related to heavy manual labour?*
24. *What is the evidence for autopsy and dissection within the sample, are there any underlying conditions to account for post mortem intervention?*
25. *What is the age distribution and date of death for individuals with evidence of autopsy?*
26. *What evidence is there for the treatment and care of individuals with traumatic and other pathological conditions? Is there any evidence for surgical intervention?*
27. *What is the prevalence rate and demographic distribution of skeletal lesions due to vitamin D deficiency?*
28. *What does the prevalence of metabolic disease imply regarding status and child rearing practices?*
29. *What does the prevalence of resolved rickets inform us about the health of the adult population?*

30. *What is the prevalence of stress indicators in this sample? What is the evidence for the level of infant and subadult mortality? What are the implications for the socio-economic status of the cemetery population?*
31. *What evidence is there for metastatic cancer within the burial ground and how does the prevalence compare to later post-medieval samples?*
32. *Is there a correlation between spinal joint disease and age or sex? What does the prevalence of spinal joint disease say about the status of the burial population?*
33. *Is there any correlation between sinusitis, visceral rib lesions and periostitis?*
34. *What specific infectious disease is recognisable in the assemblage? How do prevalence rates compare to historical data? Is there any evidence of epidemics (plague, smallpox, influenza, typhus)?*
35. *Is there any evidence for leprosy in the burial sample? If so, what does this say about the treatment of those with the disease in London?*
36. *What is the prevalence of tuberculosis? How does this compare with medieval and post-mediaeval samples from London? What implications does this have for the evolution of the disease?*
37. *Is there any evidence of treponematosis within the burial sample? If so, how does this compare with that found at other London cemeteries, whether medieval (St Mary Spital) or post-medieval? Is there any sign of variation in the pathological changes in the bone?*
38. *Can DNA analysis help to identify specific causes of catastrophic episodes within the New Churchyard?*
39. *What can the prevalence of gout and DISH within the sample suggest about diet and status?*
40. *What does the evidence of dental disease and nutritional disorders suggest about the diet of the population?*
41. *Is there any evidence of smoking within the sample? If so, what can be inferred regarding status, mortality and skeletal signs of disease?*
42. *Is there any skeletal evidence of deformity resulting from restrictive clothing? What is the demographic distribution pattern of individuals with rib deformities or hallux valgus?*

6.2 Preliminary publication synopsis of the Human Osteology component of the proposed monograph

The human osteology analysis will form an important component of the proposed Crossrail/MOLA monograph covering the medieval and post-medieval development of the site and its immediate vicinity. The osteological section will consist of *c* 50,000 words and *c* 300 figures. The post-medieval burial ground form the central component of a hard-copy volume in the Crossrail Archaeology Series. The principal authors of the monograph will be Rob Hartle, the MOLA Osteology team and others tbc. The full volume synopsis will be presented in MOLA XSM10 PXA02.

The principal osteological sections will comprise:

Setting the scene (2,000 words)

- Background documentary evidence
  - Historical background to period
  - Results of volunteer programme (brief statistics, range of parishes (catchment area of the burial ground), dates and diseases)
- How representative of the population
- How representative of the burial sample
  - How much of the New Churchyard has been excavated? The proportion of the original burials. Archaeological methodology (brief): Categories A, B and C
  - Establishing the sample for full analysis and inclusion of LSS85
  - Archaeological phasing results and implications for studying the population over time
  - GIS plots based on assessment data rather than analysis data
  - Osteological brief methodology and preservation of the sample
- Placing the New Churchyard in context
  - The value of the project
  - The sample size
  - The sample rarity
  - How the project will contribute to our knowledge of this period

The people of London (10,000 words)

<u>The populace</u>

- Documentary sources
  - Population expansion during the use of the burial ground
  - Named burials
- Basic demography
  - Adult/subadult. Male/female ratio
- Age structure
  - Mortality profile.
  - Male/female (risks of childbirth)
- Life expectancy compared to other burial samples
- The children
  - Evidence of mother and baby burials
  - The extent to which the subadult sample is representative of the burial sample
  - Detailed mortality profile compared with other sites
- Transition analysis and implications
  - Life expectancy and the elderly

<u>Migration</u>

- Documentary sources
  - Illustrate with map of city
  - Who were the migrants?
- Demographic evidence
  - High adolescent/young adult component
- Possible risks to migrants health
  - Assault, living conditions, restricted access to resources, poverty, ‘urban’ infectious disease
- Stable isotope evidence
  - Identification of migrants within burial sample
  - Variations in diet and in levels of nutritional or health stress
  - Implications for understanding composition of burial sample

In the City: urban life (8,000 words)

Living and working in London

- In the home
  - Documentary sources
- Occupations
  - Documentary sources
  - Working conditions

Diet

- Documentary sources
- Dental disease
  - Dental calculus
  - Dental caries and sugar consumption. Change over time
- Effects on nutritional health, metabolic disease
- Stable isotope evidence

Lifestyle

- Religion
- Cultural influences on health
- Status and health
  - Stature as an indicator of relative status
  - Skeletal disease (gout and DISH)
  - Dental hygiene
- Tobacco
  - Introduction to Britain during 16th century
  - Documentary sources
  - Affordability and status
  - Osteological evidence of (pipe) smoking
  - Gender, health and mortality
- Fashion
  - Stays, corsets and rib deformity
  - Foot deformity (hallux valgus)

Burial practice

- Grave accessories and what they say about cultural practices and attitudes

Buttons (relate back to fashion)
Plates
Others

The health and wellbeing of Londoners (15,000 words)

Environmental, occupational and domestic pollution

Climate: documentary sources
Documentary reports of pollution and public health provision within a period of large-scale population expansion
Sanitation and water sources
Upper/lower respiratory disease (sinusitis/rib lesions)
Micro debris, respiratory irritants and organic compounds in dental calculus
Neoplastic disease

From the cradle to the grave

- Childhood
  - Subadult growth and mortality

Vitamin D deficiency (rickets): status and child-rearing practices
Adult resolved rickets: implications for mortality and status
Scurvy
Stress indicators (cribra orbitalia, porotic hyperostosis, enamel hypoplasia, periosteal new bone formation). Is there a correlation with subadult growth?

- Health in the elderly
  Osteoporosis
  Osteomalacia
  Osteoarthritis
  Metastatic cancer

Infectious disease

- Non-specific disease
  Periostitis, osteitis, osteomyelitis
- Specific disease
  Recorded diseases (smallpox, tuberculosis, syphilis, typhus)
  Tuberculosis
  Spread of syphilis: sex ratio. Bone changes. Effect of social change, population movement and warfare of syphilis
  History and evolution of syphilis

The oral microbiome

Results and implications of dental calculus work

Trauma

Injury risk by age and sex
Injury mechanism: accidental injury v interpersonal violence
Occupational hazards and evidence of heavy manual labour (trauma and joint disease (Schmorl's nodes))
'Parry' fractures: disappearing injury?

Care, treatment and post-mortem intervention

- Care
  Life expectancy of those with severe congenital/development conditions
- Treatment
  Fracture complications
  Success of fracture treatment
  Dental treatment
- Surgery and post-mortem intervention
  Documentary sources
  Surgery
  Distinguishing dissection from autopsy

'The towne grows very sickly': plague in London (15,000)

Unwelcome visitations

- Plague: the disease and its effects
  Pathogen
  Forms: bubonic, septicaemic, pneumonic
- Origins of plague in London
  The Great Mortality (Black Death)
  West Smithfield burial ground
  East Smithfield burial ground
- Living with the plague: the 16th and 17th centuries

Plague outbreaks – dates, frequency, mortality, experience of London(ers)
Provisions and preparations, 'cures' (Royal College of Physicians)
The end of the second pandemic

Plague victims and the New Churchyard

- Parish records – numbers/dates/parishes. Compare with other studies of parish records.
- Evidence for emergency interments in the burial ground
  - Documentary sources (*c* 5% of burials)
  - Mass pits
- Osteological evidence
  - Category A burials – some would have been plague victims. Any related osteological anomalies?
  - Area 1 mass burial pit
  - Other multiple burials
  - Attritional v catastrophic burial. The mortality profile and evidence of health and stress in plague victims. Compare with other mortality profiles.

Yersinia pestis: ancient DNA and the story of plague

- Past DNA studies of *Yersinia pestis* in archaeological human bone
  - Justinian and before
  - East Smithfield burial ground
  - West Smithfield Burial ground
  - Other cemeteries (Paris / Germany / Marseilles)
- DNA evidence of plague at the New Churchyard
  - Reporting of any positive results
  - Implications for evolution of the disease during the second pandemic – how may the strain compare with that from 14th century outbreaks?
  - Comparison with recent studies (Paris / Germany / Marseilles)
  - Implications for epidemic / endemic disease in London and Europe – was there long-term persistence of plague in Europe?
- DNA evidence of other infectious diseases at the New Churchyard
  - Tuberculosis, streptococcal, hepatitis, leprosy?
- Plague – the next steps.
  - Counter arguments – other possible causes of plague including combination of two or more diseases
  - Consequences for study of infectious disease in general

Plague and the future of infectious disease

- Plague – current state of play (Madagascar, USA)
- Emerging and re-emerging diseases – theory and practice (Monica Green)
- The future – how will archaeology contribute

Conclusion (500 words)

Short summary: what we have learnt

Separate digital output

Digital on-line output: archive report (methods and results), osteological tables and summaries

To include:-

- Graphics: Tables, charts, photographs, radiographs and distribution plots, comparative osteological charts and graphs

- The statistics for the Category A and B burials will be kept separate at analysis. The Category A burials formed a random sample, but the Category B burials were selected for special characteristics, and therefore formed a deliberately biased selection. The statistics for the burials from mass pit [7482] will be examined and compared to the attritional sample from Category A.

Osteological aims and objectives

Definition of the bio-cultural approach and the linking of osteological and archaeological data. Discussion of sub-sampling and sampling strategy. This represents one of the largest assemblages of post-medieval burials excavated in the UK and creates a robust dataset with which to conduct research. Analysis of the rarely uncovered 16th- to 17th-century burials aims to place the buried population into context through detailed historical research.

Nature of the evidence

Discussion regarding the completeness, preservation and recovery of skeletal remains including the intentional truncation of burials during excavation. The importance of the assemblage. This section will include illustrative figures for demonstrating completeness, preservation and possible GIS plots.

Methods

Full osteological methodology, including sub-sampling strategy, radiography and scientific and statistical analysis.

Demography

Stature and growth

Skeletal indices

Non-metric traits

Palaeopathology

- Dental health
- Infectious disease
- Trauma
- Joint disease
- Congenital and developmental abnormalities
- Neoplastic disease
- Circulatory disease
- Nutritional and metabolic disease

Appendix

Category C assessment results

6.3 Human bone method statement

The principal criteria for the programme of analysis

A sub-sample of burials was selected for full analysis following the principles outlined by Historic England and the Advisory Panel on the Archaeology of Burials in England (APABE 2015) (Table 44; Table 38). Burials were selected on the following basis:-

- Category A burials greater than 65% complete with sufficient survival to allow estimation of age in the case of subadults, and estimation of biological sex in the case of adults. Total 652 burials (or *c* 30% of 1971 Category A).
- Category B burials comprising 140 burials (118 burials identified on site and a further 22 selected at assessment). Total 140 burials.

Category	n
A	652
B	140
Total	**792**

Table 44 Sub-sample for full analysis

Fifty contexts formerly loaned to Birkbeck, University of London, have already been recorded. This brings the sample size to 842.

This sample will be further enhanced by the inclusion of *c* 300 burials from excavations that took place 30 years ago (site code LSS85), just to the north of the recent works, to be recorded by the Centre for Human Bioarchaeology at the Museum of London. This will provide an overall sample of *c* **1100** individuals.

External analysis of human bone

This section contains recommendations for scientific analysis, beyond that of standard MOLA osteological recording, photography and radiography. All involve recent advances in analytical techniques, chiefly in the field of biochemical investigation.

<u>Ancient DNA</u>

Recent developments in ancient DNA sequencing techniques, together with work on the East and West Smithfield emergency Black Death burial grounds (Bos et al 2011; Schuenemann et al 2011; Pfizenmaier and Walker 2014) demonstrated it was possible to identify the *Yersinia pestis* pathogen in archaeological tooth samples from London. Samples from 17th-century burial grounds, and particularly those contemporary with the 1665 outbreak, are rare and in great demand as aDNA scientists investigate the evolution of the disease.

Initial work would involve screening for *Yersinia pestis* (Yp) in an attempt to detect the presence of plague in the New Churchyard burials. Variations in levels of aDNA preservation and contamination within the burial ground will determine the level of success of such a project. This work should be completed and results obtained prior to July 2016.

Longer term work on the samples, going beyond 2016, would include full genomic analysis, including investigation of the relatedness to the Black Death strain, the virulence of the 1665 pathogen, evidence of increased/decreased susceptibility to the disease and the phylogenetic relationship to other near-contemporary outbreaks such as Marseilles (1720). The pace of this work would depend on the level of Yp within the teeth (the higher the level, the faster the work will go). Finally, if the samples do not contain Yp, further work can investigate whether it is an artefact of taphonomy or an absence of infection. Although this work continues beyond the end of the Crossrail project it has unprecedented potential to contribute to current international epidemiological research into plague, not only increasing our knowledge of the disease but helping us to understand how emerging and re-emerging infectious pathogens may behave in the future. Results from such samples are likely to contribute to decades of research in this important field.

Sampling strategy is particularly important in this work and relies on identifying two or more subsets within the burial ground, ideally one that is associated with a catastrophic episode. This purpose is served by the mass burial pit in Area 1 which potentially contains victims of one of the large 17th-century plague epidemics. The value of the sample will be enhanced by selecting a control sample taken from 'normal' or 'attritional' 17th-century burials. In general, the larger the number of samples the greater the chance of finding well preserved aDNA. Considering the size of the samples and the plan for reburial, a sample of 40 teeth, 20 from the mass pit and 20 from the attritional burials, is proposed.

The aDNA analysis will be carried out by Kirsten Bos, Group Leader of Molecular Palaeopathology at the Max Planck Institute for the Science of Human History, who collaborated in the reconstruction of the draft genome of *Yersinia pestis* from Black Death victims (Bos et al 2011). The costs of the project will be covered by the Max Planck Institute who will deliver a report on their findings by July 2016.

Stable isotope analysis

Isotopic analysis of strontium and oxygen can provide information on local geology and rainfall, helping to identify where an individual was raised. This allows us to examine childhood residence and mobility. Using more than one tooth allows us to look at a longer period of childhood development, producing more detailed information on each individual. This method can identify even short-term changes in residency. Burials at the New Churchyard covered a period of rapid population growth fed by migration. Hypothetically, a relatively large number of migrants would have been buried here when compared to the parish burial grounds. Stable isotope analysis will distinguish those who were raised 'locally' (on London clay) from those who came from further afield. Whilst it would be no surprise to find a mix of native and local people, this information will compliment data from the macroscopic study of the bone, as well as carbon and nitrogen isotope analysis on dentine and bone (rib fragments), to produce both biographical details of individual lives and a comparison of the health risks encountered by those raised in the urban and rural environment.

Reconstruction of dietary timelines for individuals can now be attempted through serial analysis of very small samples of dentine and bone. Recent stable isotope analysis on the remains of Richard III demonstrated the remarkable level of biographical information recoverable (Lamb et al 2014). This process has been refined to allow comparison of the ante- and post-partum period. In addition, the weaning practices in those that died in childhood can be compared with those who survived. Carbon isotope ratios can distinguish between diets of terrestrial and marine origin and can distinguish consumption of C_3 plants (including those grown in Britain) and C_4 plants. Nitrogen isotope ratios reflect variation in protein sources in the diet. A vegetarian diet should produce different values to a mixed or meat-based diet. Variations in nitrogen ratios may also distinguish periods of heightened stress in early life, perhaps reflecting age of weaning, and can identify periods of breast feeding. Combining carbon and nitrogen values can help to distinguish terrestrial from marine diets.

In summary, depending on the number of teeth sampled per individual, stable isotope analysis provides increasing levels of information on childhood residency, migration, diet and health within a burial population. This will compliment evidence obtained from documentary sources, archaeological investigation, dental calculus and macroscopic osteological analysis.

It is proposed that two teeth are sampled from each of 20 individuals (a total of 40 teeth).Ten of these individuals will be selected from the mass pit and 10 from non-pit burials. This will only use teeth already sampled for aDNA analysis to reduce the level of destructive sampling. The strontium analysis will be conducted by Janet Montgomery at Durham University, the oxygen, carbon and nitrogen by Julia Beaumont at University of Bradford. In order of preference, the following two teeth should be used for analysis: 1st and 3rd molars, canine and 3rd molar, 1st and 2nd molars. These will be supplemented by rib samples to establish any variation in diet and locality in later life. A report on the analyses will be delivered by the end of July 2016.

Dental calculus

New biomolecular, microscopic, and chemical methods are revolutionising the study of past health and disease, and can provide important information on the socio-environmental factors that influence health in urban contexts. The study of dental calculus has received renewed interest over the last decade, as it provides a 'non-destructive' method with potential to recover wide-ranging datasets from microfossils preserved within the calculus. These include, microorganisms, food debris, plant microfossils (phytoliths, starch granules), soot, dust, tobacco smoke and fungal spores (Warinner et al 2015). DNA analysis of calculus using next generation sequencing (amplicon and shotgun sequencing) is an important field of current research. It can now be used to greatly amplify the DNA allowing us to characterise the oral microbiome (microbes that generally exist in harmony with human hosts but when unbalanced can cause/reflect poor health). Microbial cells are far more numerous in the body than human cells. This has important implications for the study of oral health (caries, gum disease) and systemic health (diabetes, cardiovascular disease). It seems likely that this area of research will receive a great deal of future attention, in studies of both ancient disease and modern clinical medicine.

Last year, the University of York recovered the first ancient DNA evidence for the pathogens that cause whooping cough, bacterial pneumonia, influenza, meningitis, gonorrhea and diphtheria from the mouths of medieval skeletons (Warinner, C. et al., 2014). While their recovery does not constitute a diagnosis of disease or active infection, this molecular evidence can confirm an individual's exposure to agents of infectious disease.

Objectives of proposed research:-

1) Characterize the oral bacteria within the human skeletons and identify exposure to infectious pathogens (DNA analysis)
2) Identify inhaled microdebris and respiratory irritants and explore urban air quality and particulate exposure (microscopic analysis)
3) Identify lifestyle factors influencing health and disease (e.g. smoking, caffeine consumption, exposure to industrial pollutants) through the analysis of organic compounds entrapped in calculus (TD-GC-MS, Py-GC/MS)

DNA will be extracted from dental tartar on 20–30 teeth within an ancient DNA clean-room facility. A 'shotgun' metagenomic approach will be applied to simultaneously amplify all DNA trapped in the tartar (viruses, bacteria, archaea, fungi), and screen the sequences against reference databases to identify and quantify opportunistic, systemic and oral pathogens in each skeleton (1). The calculus will be microscopically examined to identify and potentially quantify inhaled microdebris to examine air quality in the urban setting (2). Sequential thermal desorption-gas chromatography-mass spectrometry (TD-GC-MS) and pyrolysis-gas chromatography mass spectrometry (Py-GC/MS) will be used to identify organic compounds in the calculus, to detect lifestyle factors influencing health such as smoking (nicotine), tea/coffee consumption (caffeine), etc. (3). A report on the results of the analyses will be delivered by the end of July 2016.

Transition analysis

Transition analysis will be undertaken by Sharon DeWitte of the Department of Anthropology, University of South Carolina. It will examine the health and demographic characteristics of individuals buried in the New Churchyard. This period witnessed the Great Plague, the Great Fire, and an extraordinary acceleration in the growth of the city, all of which could have substantially affected the health and demographic composition of the population. This project will build on previous work examining the mortality patterns of the Black Death, deterioration in health prior to the Black Death (which might have contributed to the very high mortality rates during the epidemic), and improvements in health following the Black Death (*c.* 1350-1540) (DeWitte 2010; DeWitte 2014; DeWitte and Slavin 2013). The New Churchyard bridges a substantial gap between the Reformation and the eve of the Industrial Revolution and would thus allow Sharon DeWitte to examine long-term trends in health and demography in London from 1000 to 1842. She is particularly interested in determining whether improvements in demography and health that occurred following the Black Death persisted into the 16th and 17th centuries despite major threats to health such as the Great Plague and massive urban growth. For this project, Sharon will collect data on skeletal stress markers previously shown to be informative about health and risk of mortality. She will use a newly developed method of age estimation (transition analysis) that avoids the biases associated with traditional methods, and importantly allows for the estimation of ages even for the oldest adults in a cemetery assemblage (rather than providing a broad terminal estimate, such as 46+, which is typical of traditional methods). This is crucial because changes in health during childhood and younger adulthood within a population can dramatically impact demographic and health patterns at the latest adult ages. She will also apply hazard analysis, which is ideally suited to skeletal studies, as it smooths the random variation often present in skeletal samples without imposing any particular pattern on the data. By applying hazard analysis to large skeletal samples, it is possible to examine how factors such as age and sex affect risk of death during epidemics. Hazard analysis is a highly interpretable method of carrying out comparative research between groups,

In the event that ancient DNA analyses using material from the site reveal DNA diagnostic of *Yersinia pestis*, the pathogen responsible for both the 14th-century Black Death and modern bubonic plague, the demographic analyses proposed here will be informative about temporal changes in plague epidemiology. Understanding how plague might have changed between the medieval to the post-medieval period might provide insights into human-pathogen co-evolution, and is particularly important given that plague continues to kill people in contemporary populations and has the potential to re-emerge as an important threat to human health. The funding for this project will be covered by the University of South Carolina with a report delivered by the end of July 2016.

Radiocarbon dating

As the 17th century calibration curve is relatively steep, it is recommended that five teeth from five different mass pit individuals are sent for dating. If this was a plague pit, the dating could tell us which epidemic it is likely to be from.

Timetable

Tooth samples (80 samples taken from 40 individuals (20 from mass pit, 20 from non-pit burials)) will be collected by the Max Planck Institute in November 2015. Forty teeth (from all 40 individuals) will be sampled for DNA analysis. These teeth, together with the 40 intact teeth will be sent direct to Durham University either just before Christmas or in January. At the same time, rib samples from 20 individuals (10 from mass pit, 10 from non-pit burials) will be sent to University of Bradford. Remaining dental collagen from five mass pit individuals will then be forwarded to Chrono at Queen's University Belfast for radiocarbon dating.

7 Publication project: resources and programme

The resources and programme required for the proposed schedule of works will be presented in a separate.

Table 45 Tabulation of MOLA analysis tasks

Task	Task description	Staff	Days
Task 1	Oracle database training for new osteologists	Osteo	6
Task 2	Contextual error sorting and stratigraphic consultation	Osteo	5
Task 3	Osteologist preparation and photography of DNA sample teeth	Osteo	10
Task 4	Osteologist time: radiography	Osteo	3
Task 5	Photography (osteologist)	Osteo	16
Task 6	Inputting digital photographs details into Oracle	Osteo	10
Task 7	Osteologist sample selection of ribs and teeth for stable isotope analysis	Osteo	4
Task 8	Osteologist selection of dental calculus samples and assistance in sample	Osteo	2
Task 9	Osteologist preparation for and overseeing of transition analysis	Osteo	2
Task 10	Record 792 contexts of articulated human bone (@ 2.5per day)	Osteo	317
Task 11	Inter context matching of elements	Osteo	22
Task 12	Osteologist preparation and set up of studio photography	Osteo	3
Task 13	Liaison with Senior Archaeologists and external specialists	Osteo	4
Task 14	Data integrity checks	Osteo	4
Task 15	ArcGIS operation training	Osteo	4
Task 16	Data interrogation, ArcGIS analysis and generation of tables	Osteo	40
Task 17	Publication text authorship	Osteo	40
Task 18	Geomatic graphic preparation	Senior Geomatics Officer	5
Task 19	Publication graphics	Senior Designer/ Illustrator	18
Task 20	Photography of human bone specified by osteologist	Photographer	9
Task 21	Integration of external text and tables	Osteo	5
Task 22	Peer reviewed articles and other complementary dissemination	Osteo	10
Task 23	Managerial/QA (Head of Environmental and Osteology)	Manager (Mary Ruddy)	5
Task 24	Managerial/QA/edits tasks (Senior PXPM)	Manager (Julian Hill)	20

Table 46 Tabulation of external analysis task

Externals				
Task ID	**Supplier**	**Task description**	**Staff**	**units**
Task_(E) 1	Radiography (City University)	days	EXT	3
Task_(E) 2	aDNA (Max Planck)	analysis of c 40 individuals	EXT	40
Task_(E) 3 Stable isotope analysis (Durham University and University of Bradford)		per tooth sample	EXT	40
		per rib sample	EXT	20
		report	EXT	1
Task_(E) 4 Dental calculus analysis (University of York)		initial screening of 20–30 individuals	EXT	30
		gas chromatography and mass spectrometry	EXT	10
		DNA analysis per10–20 samples**	EXT	10
Task_(E) 5	Transition analysis (University of South Carolina)	transition analysis	EXT	-
Task_(E)_23	CHRONO Belfast	radiocarbon dates (cemetery)	EXT	5
		collagen extraction (cemetery)	EXT	5

8 Acknowledgements

Thanks to Jay Carver, Iain Williamson, Marit Leenstra, John Doyle, Luke Mason, Rohan Perrin and Victoria Richardson, all of Crossrail. Also, from Laing O'Rourke, Siu Mun Li, Richard Gresham, Ross Lankshear and Brian Beatty. MOLA would also like to acknowledge the advice of Kathryn Stubbs from City of London, Sylvia Warman from Historic England and Rekha Gohil of the Ministry of Justice.

The excavation project was managed by Nicholas Elsden with Elaine Eastbury and Simon Davis. Julian Hill is in charge of the post-excavation work.

Thanks to the Laing O'Rourke team on site: Petrit Bajraktari, Martin McDonagh, Vaidas Cvilikas, Valdas Dauparas, Gintaras Gelazanskas, Balvir Ram, Mann H Singh, Tarlochan Singh.

The MOLA field team was led by Alison Telfer and comprised James Alexander, Portia Askew, Waltraud Baier, Vesna Bandelj, Martin Banikov, Adam Barker, Silvia Barlassina, Dan Bateman, Isa Benedetti, James Best, Charlotte Booth, Hannah Bosworth, Barbora Brenderova, Matt Bosomworth, Andrew Brown, Jess Bryan, Ashley Bryant, Jonathan Buttery, Rose Calis, Sasathorn Charoenphan, Harry Clark, Tegan Daley, Andy Daykin, Jozef Doran, Stephen Foster, Brigid Geist, Chris Gerontinis, Cat Gibbs, Matt Ginnever, Emily Glass, Cat Godsiffe, Lara Gonzalez Carretero, Danny Harrison, Robert Hartle, Chris Hawksworth, Sam Herbertson, William Herring, Isca Howell, Tim Johnston, Rebecca Jones, Bonnie Knapp, Greg Laban, Giulia Lazzeri, Rachel Legge, Paul McGarrity, Karl Macrow, Laura Malric-Smith, Ruairi Manktelow, Alice Marconi, Sinead Marshall, Roberta Marziani, Charlotte Mecklenburgh, Jacqui Mellows, Lauren Neal, Cosimo Pace, Jorge Parreira, Dave Parry, Sam Pfizenmaier, Dalia Anna Pokutta, Serena Ranieri, Stefano Ricchi, Philip Roberts, Dave Sankey, Gavin Smith, Jack Smith, Jessica Stevens, Alexa Stevenson, Jason Stewart, Karen Stewart, Piotr Szmyd, Leo Sucharyna Thomas, Claudia Tommasino, Sarah Trehy, Adam Tuffey, Mike Tunnicliffe, Rob Tutt, Richard Ward, Lorna Webb, Tomasz Wisniewski, Emily Wright and Nicolas Zorzin.

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10 Appendix: management, delivery and quality control

MOLA (Museum of London Archaeology) is a company limited by guarantee registered in England and Wales with company registration number 07751831 and charity registration number 1143574. The Registered Office is Mortimer Wheeler House, 46 Eagle Wharf Road, London N1 7ED). It has its own independent Board of Trustees but works in partnership with the Museum of London via a Memorandum of Understanding.

MOLA is a 'Registered Organisation' with the archaeological professional body, the Chartered Institute for Archaeologists (CIfA). The C*IfA Register* is a rigorous Quality Assurance scheme for archaeologists. In order to be accepted, MOLA has passed a Board resolution to comply with the CIfA Code of Conduct and Standards, to demonstrate that compliance through bi-annual re-registration, to submit to regular IfA inspections, and to ensure that all MOLA activities are under the overall direction of a Member grade (MifA) 'responsible post-holder'. The Registered Organisation scheme also provides procedures for investigating and handling of external complaints.

MOLA subscribes to and abides by the general principles and specific terms of the *Code of Good Practice On Archaeological Heritage in Urban Development Policies* established by the Cultural Heritage Committee of the Council of Europe, and adopted at the 15th plenary session in Strasbourg on 8-10 March 2000 (CC-PAT [99] 18 rev 3). In particular to the following points: ….*archaeologists shall be aware of development costs and adhere to agreed timetables* (Para 3 'The Role of the Archaeologist'), with all work *'carried out to written statements setting out standards timetables and costs'* (para 4 ibid).

MOLA further subscribes to and ensures that its activities comply with and/or are guided by the following policies, procedures and guidance:

- Appropriate local and regional planning authority archaeology guidance – eg for London: English Heritage, Standards for *archaeological work* (2014)
- Appropriate Archaeological Research Framework for the region – eg for London: English Heritage Archaeology Division, *Research Agenda* (1997); Museum of London, *A research framework for London archaeology (*2002); and *Historic Environment Research Strategy for Greater London* (in prep. CBA/MoL/Rowsome).
- English Heritage, *Management of Archaeological Projects* (MAP2), (1991)
- English Heritage Centre for Archaeology, *Guidelines* (various)
- Museum of London Archaeological Service*, Archaeological Site Manual (1994)*
- Museum of London Archaeological Service, *Archaeological Finds Procedure Manual* (2006)
- National archive disposition standards including Museum and Galleries Commission, *Standards in the Museum Care of Archaeological Collections* (1992) and Society of Museum Archaeologists, *Towards an Accessible Archaeological Archive: the Transfer of Archaeological Archives to Museums: Guidelines for Use in England, Northern Ireland, Scotland and Wales* (1995)
- Relevant local archive deposition standards, eg for London, Museum of London, *General Standards for the preparation of archaeological archives deposited with the Museum of London*, (2009).

MOLA governance and organisational strategy are determined by the Senior Management Group (SMG), led by the Chief Executive Officer and comprising the Finance Director, the Head of Operations, and four Directors heading the Planning, Development Services Research & Education and Northanmpton divisions. The SMG reports regularly to an independent Board of Trustees, who oversee MOLA's performance and strategic direction. As a charitable company MOLA is monitored and regulated by the Charities Commission.