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Differential preservation of children's bones and teeth recovered from early medieval cemeteries: possible influences for the forensic recovery of non-adult skeletal remains

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Abstract: The skeletal preservation of 421 non-adult skeletons from four early medieval sites in England, Scotland and Wales were compared to assess whether geographical location and geology have an impact on overall bone preservation of children's remains in the burial environment. Skeletons were examined from the cemeteries of Auldhame in Scotland, Edix Hill and Great Chesterford in England and Llandough in Wales. The bone preservation was examined using three preservational indices: Anatomical preservation index (API), Qualitative preservation index (QBI) and the bone representation index (BRI). A similar pattern existed across all the sites with regard to what bones are preserved, bones with relatively high density, such as the temporal bone of the skull, the long bones of the upper and lower limbs tend to be abundant in the samples, with the more small and fragile bones, such as the facial bones tending to be less well represented either as a result of low bone density or due to loss at excavation. The study of the dental elements also revealed a pattern with regard to what is preserved, with high numbers of molars and incisors found. This may be related to both the size and number of roots; but also the position in the mouth which may offer protection against loss. A difference in preservation was observed between the sites and the classes of preservation, particularly local differences between the sites of Edix Hill and Great Chesterford. From this study it remains unclear as to the extent the role of geology has on the non-adult skeleton, but the results of this study show that age is not the dominating factor in bone preservation as previously thought.

Key words: bone preservation, deciduous and permanent dentition, under-representation, taphonomy, forensic science, age

Introduction

This paper aims to examine bone preservation in a number of non-adult skeletal assemblages from early medieval Britain. The skeletal remains of infants and children are often limited in numbers when recovered from cemeteries and this has given rise to discussions on the possible causes such as taphonomic processes,

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burial practices and or excavation techniques (Mays 2010; Bello et al. 2006; Henderson 1987; Nawrocki 1999). Previous studies have shown that non-adult remains are less well preserved than those of adults (Bello et al. 2006; Djuric et al. 2011; Buckberry 2000; Guy et al. 1997). Taphonomic factors can be divided into two forms: intrinsic (resistance of bone) and extrinsic (environmental influences), both of which exert influence on the long term survival of non-adult bone. The most prominent intrinsic factor is that of age (Manifold 2010; 2012) with the bones of children both smaller and less dense than those of adults, therefore, leaving them more vulnerable to decay, ease of dispersion and loss. Child remains are easier to disarticulate and remove by scavenging which can result in loss of elements (Waldron 1987; Morton and Lord 2002; 2006) from both archaeological and forensic contexts. There is variation in the preservation of different bones. The bones most vulnerable to destruction are thought to be those with a high proportion of cancellous material, such as the sternum, vertebrae, ribs and the epiphyses. It has been thought that the lumbar vertebrae are the least and the cervical the most affected by soil erosion (Mays 1991). This may also depend on the position of the body during burial, and if grave intercutting occurred. According to Mays (1991), the small bones of the hands and feet are almost always poorly represented, whilst bones with a high proportion of cortical bone, such as the skull, mandible and long bones appear to be less affected by preservation. A similar pattern was reported by Waldron (1987) on a study of West Tenter Street, London, who also pointed out that this pattern of preservation is not necessarily the same for all sites. However, similar findings were reported by Ingvarsson-Sundström (2003) from Asine, in Greece. Von Endt and Ortner (1984) have shown that rates of decay are inversely proportional to the bone size. They found when bones of different sizes were kept in water at constant temperature; nitrogen is released at a rate which is inversely proportional to bone size. Any weakening of the protein-mineral bonding of bone will enhance its degradation. Groundwater and its dissolved ions can penetrate bone, and bone size, both the external and internal surface area (Porosity), available to groundwater is important in bone breakdown (Von Endt and Ortner 1984).

Porosity is an important factor for diagenetic change in bone. There is an increase in porosity as a result of mineral dissolution. Chaplin (1971) noted that the rate of dissolution is dependent on the porosity of the skeletal tissue, as more porous tissue decays more rapidly than less porous tissue. This is important for non-adult bone as it has been shown that non-adult remains are more susceptible to diagenetic contamination (Von Endt and Ortner 1984; Zapata et al. 2006; Hanson and Buikstra 1987) and this can be from the surrounding soil. Amour-Chelu and Andrews (1996) found that a chalk environment was not favourable for bone preservation at Overton Down, where surface modification of non-adult remains occurred within a few years due to their porous nature. The pore structure, which can be defined as the distribution of porosity for a given pore radius, can influence the amount of diagenesis. An increase in the rate of mineral dissolution process, will lead to greater porosity (Nielsen-Marsh 2000). Hedges and Millard (1995) have highlighted pore structure of being of central importance when modelling bone mineral loss. Pore structure governs the internal surface area which is available for solid solution reactions. It also determines the rate at which groundwater can flow through the bone, and the rate at which diffusion can take place. Pore size also determines which pores will be filled with water and which will be empty, and so controls which parts of bones will interact with soil water. But according to Nicholson (1996:523) who identified bone density as an important variable, but stressed that bone size was also of importance and that *'it is unclear at what point bone size becomes more important than bone density...in influencing bone loss'*. Bone mineral density (BMD) reflects the degree of mineralisation of the organic bone matrix, and this varies in every bone. BMD increases with growth and eventually reaches a plateau in early adulthood and subsequently decreases with advancing age. BMD is affected by many factors, including age, genetics, sexual maturation, physical activity and dietary calcium (Maynard et al. 1998). A number of studies have explored bone density in relation to child health and growth in past populations (Bennike et al. 2006; McEwan et al. 2005). More recently, Djurić et al. (2011) found that the density of the femur was greater than that of the fibula, due to its function as a weight-bearing bone. They also attributed the poor preservation of infants in their sample to bone density. In a study of the proximal femur and radius from two sites in England, Manifold, (forthcoming), found that there was an increase in BMD in infancy (0–1 years) in both the femur and radius, followed by a decrease in early childhood (2–8 years), followed by an subsequent increase in late childhood (9–15 years).

Pathological conditions and injuries are known to speed up the decomposition of buried bone. When bone is damaged through trauma or as a result of illness, it is easier for micro-organisms to enter; also the same may be said of those individuals with infectious diseases and blood poisoning. When there is a breakdown of bone in life such as with metabolic disease, this can have an effect on the rate of preservation (Henderson 1987; Breitmeier 2005). Rickets is caused by vitamin D deficiency in children, preventing calcium from being deposited in the developing cartilage as well as in the newly formed osteoid, which impedes bone mineralisation. The macroscopic appearance of rickets in non-adults tend to be long bone bending deformities and metaphyseal swelling. However, in cases of active rickets there is increased porosity of bone surfaces in particular the cranium and the growth plates. This increased porosity can lead to the bone appearing to 'dissolve' in the burial environment, which can make recovery of remains difficult. Another metabolic disease which is not frequently diagnosed is scurvy, a condition caused by the lack of vitamin C in the diet. This condition also leads to an increase in porosity in non-adult skeletons. Conditions such as this cause a decrease in the mineralisation of bone and this lack of mineralisation can be misinterpreted as poor preservation rather than disease (Lewis 2010).

Extrinsic factors should also be considered alongside intrinsic bone preservation. The presence of groundwater is important, especially in relation to porosity of bone. Hedges and Millard (1995) defined three hydrological environments: diffusive, recharge and flow. The diffusive regime refers to an environment where movement is limited, in waterlogged conditions or where soils are not permanently saturated. With a recharge regime bones go through wetting and drying cycles, and as a result, porosity increases and the formation of large pores which increases the effects of the water cycle. Finally, in the flow regime the presence of bone buried in such an environment tends to depend on the volume of water, (i.e rainfall and seasonal factors) (Hedges and Millard 1995). Groundwater is the medium for all processes such as recrystallisation, dissolution, hydrolysis, microbiological attack and ion-exchange to take place (Nielsen-Marsh 2000). In general, bone buried in soil where water movement is limited and calcium and phosphorous concentrations are high, has the potential to survive for an indefinite period. Where water movement is greater there tends to be greater dissolution, and therefore, less well-preserved bones, both macroscopically and microscopically (Nielsen-Marsh and Hedges 2000). Unfavourable geological conditions can have an impact on what bones are likely to survive, but how much influence this has on sites within the UK and skeletal remains remain unclear. Preservation of bone will vary considerable, not only from soil to soil, but also from one area of burial to another. Environments affect bone in different ways. In acidic environment, which can consist mostly of podsols, these soils tend to be abundant in northern England and Scotland, where there is a tendency for the soils to be thin, acidic and wet, which may or may not have a negative impact on bone preservation (French 2003; Henderson 1987). On the other hand, many peat environments have revealed excellent preservation due to the acidic nature of the sites, due to the lack of microbial attack (French 2003). In a more alkaline environment, which consists of calcareous soils can result in mixed preservation, if remains are recovered from this soil type and have a high pH, they tend to be in good condition (Brothwell 1981; Ferllini 2007), and these soils tend to be found in East Anglia and eastern and southwest England. In soils of a neutral pH, there can be varied conditions, these soils are well-drained and mostly located on the gravel and chalk areas of southern England. An increase in biological activity leads to a breakdown of organic matter, which results in a well-mixed, aerated soil and can lead to poor preservation (French 2003). Locock et al., (1992) found, that soil pH was not the main controlling factor in the preservation of buried bone. Some demineralisation of bone may occur as a result of the action of organic acids released during decomposition of the soft tissues, and therefore present in the soil where the bones are exposed (Child 1995). Overall, the literature has produced some contradictions as to what environment is best for bone preservation.

Other factors such as flora and fauna, plant roots and human impact should also be bore in mind. Flora and fauna can attack bone directly resulting in damage and destruction of bone tissue, but also indirectly resulting in scattering and breakage of bone (Henderson 1987). Insects can destroy human remains, their influence varies with conditions of burial and factors such as season, latitude and altitude (Erzinclioglu 1983). Snails and other mammals can prey on bones, destroying and or alternating them which can lead to suggestions of pathology (Henderson 1987). Plant roots can lead to marks which resemble pathological conditions and thus, cause misinterpretation of disease (Wells 1967). Large roots leave indentations on the surface of bones and often the roots grow through the bones leaving holes which can be misinterpretation as ante-mortem injuries. Roots can creep into bones and exert strong pressure on the bone walls, eventually causing fragmentation. They can also cause the dissolution of mineral components of bones by excreting humic acids. Lyman (1996) described 'root etching' which results in erosion of the cortical surface and can lead to complete dissolution of the bones. The treatment of the body after death can have significant impact on what skeletal elements are recovered. With regard to the remains of children this is particularly important as there is the common perception that graves belonging to the younger individuals tend to be shallow or pit graves, which can be easily exposed to plough damage, thus resulting in the loss of remains, especially those of infants. This has been observed at a number of cemeteries. At the Roman site of Cannington in Somerset, the graves of the infants had a greater tendency towards shallow graves, whereas the graves of the older children were similar in depth to the adults (Rahtz et al. 2000). Scull (1997) observed at Watchfield cemetery in Oxfordshire that infants and young children were interred in shallow graves and those burials recovered were within or at the base of the ploughsoil. The purpose of this paper is to examine the bone preservation using three preservational indices: Anatomical preservation index (API), Qualitative preservation index (QBI) and the Bone representation index (BRI) of a number of early medieval non-adult skeletal remains from different geographical and geological locations in the UK.

Materials

A sample of 421 skeletons from four early medieval archaeological sites of different geographical locations within the United Kingdom were studied (Table 1; Fig. 1).The sites included that of Edix Hill, and Great Chesterford, both in Cambridgeshire. The Scottish site of Auldhame, East Lothian and the Welsh site of Llandough. Each of the sites will be discussed in turn.

Edix Hill, Cambridgeshire

Edix Hill is situated on the western edge of Barrington parish close to the village of Orwell, which lay 12km south-west of Cambridge (Malim and Hines 1998). The site was dated from the sixth to the

Table 1. Archaeological sites studied

Period	Site	Total no. of non-adult skeletons	Geology and pH	Reference
Early Medieval	Great Chesterford Cambridgeshire, UK	82	Neutral	Waldron (1988)
Early Medieval	Edix Hill Cambridgeshire, UK	41	Chalk	Duhig (1998)
Early Medieval	Auldhame, East Lothian Scotland	72	Alkaline	Melikian (2005)
Early Medieval	Llandough South Wales	226	Waterlogged	Loe and Robson-Brown (2005)
Total		421		

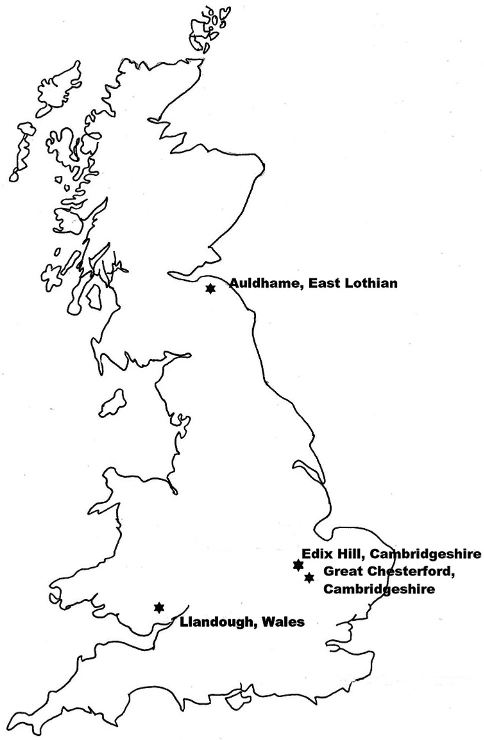

Fig. 1. Location of sites

seventh centuries. The cemetery of Edix Hill was situated on chalk Knoll surrounded by lower lying claylands (Gault clay) which is underlying geology of the area that had been exposed through localised erosion of the chalky upper deposits. The burials at Edix Hill were generally shallow and mostly comprised single interments with only a few graves containing more than one individual. There was little patterning in the orientation of the graves and it would appear that topographical factors were of more importance (Malim and Hines 1998). A concentration of non-adult burials was apparent in the area on the brow of the knoll, which may indicate a particular area of burial for children of all ages, as both infants and adolescents were buried here (Malim and Hines 1998). Otherwise, the graves of the children appear to have been evenly spread out across the cemetery. The remains were damaged by agricultural processes as a result of the shallowness of the graves. The total number of individuals recovered was 148, forty-six of which were children.

Great Chesterford, Cambridgeshire

The site of Great Chesterford (AD 410–1065) lies on the gravel terraces of the east bank of the river Cam, south of Cambridge city (Evison 1994). The town of Great Chesterford is approximately 15km south east of Edix Hill. Great Chesterford was an Anglo-Saxon cemetery built upon a Romano-British extramural cemetery (Evison 1994). The total number of individuals recovered was 167, eighty-three of which were non-adults. The non-adults were mostly buried in single graves, although there were three multiple graves. The graves of Great Chesterford lie in one of two directions, some with their head to the south (south-north graves) and some with the head to the west (west-east graves). Orientations were recorded for fifty-eight of the non-adult graves. Most of the non-adults were buried south-north (62%; 25/40).

Auldhame, East Lothian

The site of Auldhame, East Lothian was uncovered in 2005 by AOC archaeology where 260 individuals were recovered, and a further sixty-six burials indentified but were left *in situ*. The multi-phased remains of a chapel were also recovered. Four phases of activity indentified – Phase One (AD 650–950–1000); Phase Two (c. AD 950–1200); Phase Three (c. AD 1250–1450) and Phase Four (AD 1470–1680) (Melikian 2005). The remains mark the site of a previously unknown medieval cemetery, and lie within the possible promontory fort of Seacliff. It is not known when a settlement at Auldhame first appeared, but discoveries within the locality, such as the prehistoric round cairn at St Baldred's Cradle and Iron Age burials at Greghans Cave, suggest occupation from at least the Bronze Age (Hindmarch and Melikian 2006). All burials were supine and extended, with most following the west to east alignment with the head at the western end. An isolated group of juvenile burials was discovered directly to the west of the building which had alignments of south-west to north-east. This may indicate inter-cutting of later graves and the avoidance of *in situ* burials. A total of 78 non-adults were recovered (Melikian 2005).

Llandough, South Wales

The site of Llandough lies in the north of Penarth on sloping ground near the crest of an escarpment which overlooks the estuary of the river Ely (Holbrook and Thomas 2005). The excavation of the burial ground was undertaken by Cotswold Archaeological Trust in 1994 ahead of development. The excavations area lay to the north of the church yard wall and extended to the edges of the escarpment. Within this area 1026 graves were recovered. There were 814 articulated skeletons and 212 disturbed skeletons recovered. Of these 226 were non-adults. Many of the skeletons were buried in very shallow graves and there was evidence to suggest activity which post-dated the cemetery which had truncated much of the site. During excavation burials were divided into three areas. Area I was situated in the south of the cemetery, which included burials that were contained within a possible curvilinear boundary which was indicated by the line of burials on a north-east to south-west alignment (Loe 2003). Areas II and III lay to the west and north of Area I. Burials in Area II lay further to the west outside the limits of the excavation. Area III was the most extensively used part of the cemetery. The burials were aligned east-west. This area contained a large proportion of infant and non-adults remains, which was clustered into two distinct groups; one which was central and the other in an adjacent area to the north. It is likely the burials in Area I relate to the monastic community which was established in the 6th century. This area of the cemetery would have included the monks and lay aristocracy (Davies 1982). The Areas II and III are thought to comprise the lay population who were afforded the right to be buried in monastic cemeteries from about the 6th century, this would account for the distribution and the majority of burials.

Methods

Age-at death

The age of death of the non-adults was assessed using the dentition (Moorrees, Fanning and Hunt 1963ab) long bone lengths (Ubelaker 1989), and bone development (Buikstra and Ubleaker 1994). The foetal remains were aged using long bone lengths (Scheuer, Musgrave and Evans 1980) and pars basilars (Scheuer and MacLaughlin-Black 1994). Of the 421 skeletons studied, 376 could be aged accurately. The skeletons were placed into five age groups: < 40 weeks, 0–1.5 years; 1.6–4.5 years, 4.6–10.5 years and 10.6–17.0 years (Table 2).

Table 2. Age at death

Site	Age at death					Total
	<40 weeks	0–1.5 years	1.6–4.5 yrs	4.6–10.5 yrs	10.6–17.0 yrs	
	n (%)	n (%)	n (%)	n (%)	n (%)	
Auldhame	6 (9)	20 (29)	9 (13)	25 (37)	8 (12)	68
Edix Hill	0	2 (6)	10 (29)	7 (20)	15 (44)	34
Great Chesterford	26 (37)	28 (40)	7 (10)	7 (10)	2 (3)	70
Llandough	4 (2)	53 (26)	45 (22)	64 (31)	38 (19)	204
Total	36	103	71	103	63	376

Bone Preservation

Anatomical preservation index (API)

The Anatomical Preservation Index (AP1, Bello et al. 2006) expresses the ratio between the scores of preservation; the percentage of bone preserved for each single bone, and the skeleton's total anatomical number of bones. Each individual bone was then categorised and classed according to the six classes including the bones that were absent (Table 3).

Qualitative bone index (QBI)

The state of preservation of the cortical surfaces were evaluated using the Qualitative Bone Index (QBI, Bello et al. 2006), being the ratio between the sound cortical surfaces and the damaged surfaces of each bone. The cortical surface of each bone was examined and a class of preservation, which was most appropriate, was applied.

Table 3. Preservation classes (after Bello et al. 2006)

Class of Preservation	% of bone preserved
Class 1	0 not preserved or absent
Class 2	1–25 up to quarter preserved
Class 3	25–50 up to half preserved
Class 4	50-75 up to three quarters preserved
Class 5	75–100 between three quarters and total preserved
Class 6	100 total preservation

Bone preservation index (BRI)

The Bone Representation Index (BRI) was devised by Dodson and Wexlar, (1979) and measures the frequency of each bone and bone type in the sample. It is the ratio between the actual number of bones removed during the excavation and the theoretical number of bones that should have been present according to the minimum number of individuals (MNI) in the sample. Using the skeletal inventory each bone was scored as absent or present. The dentition was scored on an absence or presence basis, taking into account age. Both the deciduous and permanent teeth were recorded.

Intra-observer and inter-observer error

The intra-observer error is the error between two measurements taken at two times by the same observer on the same sample and using the same methods of measurement. The inter-observer error is the error between two observers on the same sample using the same criteria. The scores of preservation for both the anatomical preservation index (API) and the qualitative bone index (QBI) were estimated on sixty-eight bone elements of two skeletons by the author and another experienced osteologist to test for errors. The scores of preservation for the API and QBI were estimated by the author and produced a P value equal to 1. Therefore, the difference was not considered significant. The inter-observer error was estimated and produced a P value of 0.883, which means there was no significant difference between the measurements taken.

Statistical analysis

All data for each of the preservation scores was entered into an excel database and analysed according to the following: (i) difference between bone preservation expressed in terms of (API) and (QBI) and site (location) both nationally and locally, (ii) difference between bone preservation and age of the non-adult.

Trends were analysed using Chi Square statistical test to test the null hypothesis that there was no difference between trends (Shennan 1997). A significance level of 1% ($p<0.001$) was used for all tests.

Results

Anatomical Preservation Index (API)

Site differences in preservation

The anatomical preservation index (API) was calculated for each sample according to the six classes of preservation. Those bones in classes 1 to 3 were considered to be less well-preserved, whereas those bones in classes 4 to 6 were considered to be well- preserved. All sites had a high percentage of bones not preserved (Class 1). Significant differences were recorded between all the sites at all classes of preservation (Fig. 2; Tables 4–5).

Regional difference in bone preservation

The region in which a site is located may be a deciding factor in the preservation of bones, due to the local geology and burial environment. Using the Chi-Square test

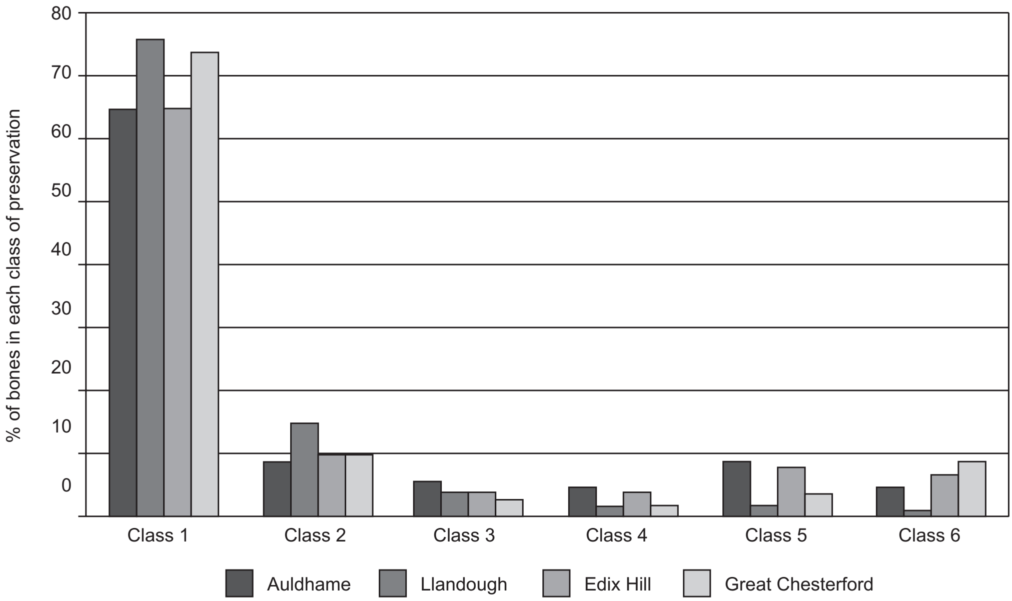

Fig. 2. Percentage of bones in each class of preservation (API)

Table 4. Number and percentage of bones preserved (API) at each class and age group for Auldhame, Llandough, Great Chesterford and Edix Hill

Age Group	Class 1 n (%)	Class 2 n (%)	Class 3 n (%)	Class 4 n (%)	Class 5 n (%)	Class 6 n (%)
Auldhame						
< 40 weeks	195 (72)	15 (5)	9 (3)	16 (6)	29 (11)	8 (3)
0–1.5 years	996 (50)	140 (7)	68 (3)	53 (3)	74 (4)	29 (1)
1.6–4.5 years	318 (40)	69 (9)	41 (5)	29 (4)	54 (7)	33 (4)
4.6–10.5 years	936 (37)	43 (6)	119 (5)	120 (5)	208 (8)	174 (7)
10.6–17.0 years	222 (44)	23 (5)	25 (5)	26 (5)	38 (8)	5 (1)
Llandough						
< 40 weeks	301 (60)	18 (4)	8 (2)	0	5 (1)	8 (2)
0–1.5 years	1573 (52)	343 (11)	66 (2)	32 (1)	21 (1)	5 (0.1)
1.6–4.5 years	1238 (51)	240 (10)	59 (2)	33 (1)	34 (1)	8 (0.3)
4.6–10.5 years	1147 (48)	270 (11)	111 (5)	50 (2)	37 (1)	13 (0.5)
10.6–17.0 years	567 (47)	120 (10)	36 (3)	44 (4)	38 (3)	11 (1)
Great Chesterford						
< 40 weeks	1240 (79)	125 (8)	28 (2)	16 (1)	34 (2)	121 (8)
0–1.5 years	1257 (48)	179 (7)	55 (2)	43 (2)	92 (4)	92 (4)
1.6–4.5 years	373 (41)	71 (8)	26 (3)	31 (3)	46 (5)	65 (7)
4.6–10.5 years	280 (40)	44 (6)	17 (2)	20 (3)	35 (5)	80 (11)
10.6–17.0 years	73 (53)	9 (7)	9 (7)	7 (5)	14 (10)	24 (18)
Edix Hill						
< 40 weeks	40 (59)	10 (15)	7 (10)	3 (4)	6 (8)	2 (3)
0–1.5 years	71 (35)	8 (2)	8 (2)	7 (3)	21 (10)	21 (10)
1.6–4.5 years	587 (53)	82 (7)	36 (3)	38 (3)	51 (5)	29 (3)
4.6–10.5 years	259 (37)	69 (10)	33 (5)	32 (4)	46 (6)	37 (5)
10.6–17.0 years	666 (42)	100 (6)	34 (2)	47 (3)	111 (6)	120 (7)

the regional differences were analysed to observe if any differences were present. It was found that significant differences were present between each class of preservation and each site (Table 5). There were considerably more poorly preserved bones at the sites of Edix Hill and Great Chesterford, in all classes except 3 and 6 demonstrating that differences can exist only between sites which are from the same geographical location, in this case, only 15 km apart. The Scottish site of Auldhame was compared to the English and Welsh sites to assess if there is any difference in preservation between north and south. By considering the percentage of bone in each class of preservation, the same pattern emerged with large percentages of bone elements in class one and subsequent decrease as the preservation classes increased. This was significant in the number of bones present between all sites and classes. This would also indicate that there is a difference in bone preservation and geology of each site, and that the preservation of bone cannot be classified according to a particular area or region. The same pattern of preservation was followed at sites in England and Wales. It was hypothesised that the soils in the north of England and Scotland were less suitable to good

Table 5. Statistical analyses of bones per each class of anatomical preservation (API) between all the sites

Class	Auldhame vs Edix Hill	Auldhame vs Great Chesterford	Edix Hill vs Great Chesterford	Llandough vs Great Chesterford	Llandough vs Edix Hill	Llandough vs Auldhame
Class 1	$\chi^2=149.3$ df=1 $p=0.001$	$\chi^2=40.5$ df=1 $p=0.001$	$\chi^2=50.9$ df=1 $p=0.001$	$\chi^2=5810.9$ df=1 $p=0.001$	$\chi^2=3416.8$ df=1 $p=0.001$	$\chi^2=5637.4$ df=1 $p=0.001$
Class 2	$\chi^2=4.2$ df=1 $p=0.05$	$\chi^2=62.1$ df=1 $p=0.001$	$\chi^2=89.7$ df=1 $p=0.001$	$\chi^2=114$ df=1 $p=0.001$		
Class 3	$\chi^2=40.9$ df=1 $p=0.001$	$\chi^2=79.7$ df=1 $p=0.001$		$\chi^2=1192$ df=1 $p=0.001$	$\chi^2=831$ df=1 $p=0.001$	$\chi^2=509.7$ df=1 $p=0.001$
Class 4	$\chi^2=26.2$ df=1 $p=0.001$	$\chi^2=170.3$ df=1 $p=0.001$	$\chi^2=38.2$ df=1 $p=0.001$	$\chi^2=14.3$ df=1 $p=0.001$	$\chi^2=120.3$ df=1 $p=0.001$	$\chi^2=939.9$ df=1 $p=0.001$
Class 5	$\chi^2=118.5$ df=1 $p=0.001$	$\chi^2=345.7$ df=1 $p=0.001$	$\chi^2=36.8$ df=1 $p=0.001$	$\chi^2=45.9$ df=1 $p=0.001$		$\chi^2=377.6$ df=1 $p=0.001$
Class 6		$\chi^2=54.7$ df=1 $p=0.001$		$\chi^2=17.8$ df=1 $p=0.001$	$\chi^2=11.4$ df=1 $p=0.001$	$\chi^2=28.3$ df=1 $p=0.001$

bone preservation, due to the tendency for soils to be wet and acidic which can lead to poor bone preservation. With the soils of the south of the United Kingdom having a more desirable affect on human bone preservation.

Age differences

In order to assess if age has an impact on the state of preservation, each of the sites and age groups were analysed (Table 4 and Table 5). No significant differences were observed at any age group between the poorly preserved remains and those exhibiting excellent preservation at the sites of Llandough and Great Chesterford. At the site of Edix Hill a significant difference was noted between < 40 weeks and 0-.1.5 years at class 1 ($\chi^2=7.38$, $p=0.05$, df=1), class 2 ($\chi^2=13.0$, $p=0.001$, df=1) and class 3 ($\chi^2=9.1$, $p=0.05$, df=1). At Auldhame a difference was noted between the ages of 4.6–10.5 years and 10.6–17.0 years at class 1 ($\chi^2=5.1$, $p=0.05$, df=1) and in the younger individuals (<40 weeks and 0.1.5 years) at class 5 preservation ($\chi^2=4.6$, $p=0.05$, df=1). Each of the sites were assessed for differences between good preservation and poor preservation between infancy and later childhood. The only difference was noted at Great Chesterford ($\chi^2=7.4$, $p=0.05$, df=1). Also bone preservation was assessed at each age group and between each of the sites. No differences were recorded at less than 40 weeks for any for the sites, for example, Auldhame/Edix Hill ($\chi^2=0.1$, $p=0.05$, df=1), Llandough and Great Chesterford ($\chi^2=2.1$, $p=0.05$, df=1). At 0–1.5 years, differences were noted between Auldhame/ Edix Hill ($\chi^2=9.7$, $p=0.05$, df=1), Edix Hill/Great Chesterford ($\chi^2=4.1$, $p=0.05$, df=1), Llandough/ Great Chesterford ($\chi^2=3.9$, $p=0.05$, df=1), Llandough/Edix Hill ($\chi^2=12.6$, $p=0.001$, df=1). At the age groups of 1.6–4.5 years and 4.6–10.5 years, differences were recorded between the sites of Llandough/ Great Chesterford (χ^2=7.1, p=0.05, df=1; χ^2=10.3, p=0.05, df=1 respectively), and between the sites of Llandough / Auldhame (χ^2=4.0, p=0.05, df=1; χ^2=6.8, p=0.05, df=1 respectively). In the older children (10.6–17.0 years) differences in good and poor preservation were also noted between a number of the sites, Auldhame/Edix Hill (χ^2=4.4, p=0.05, df=1), Auldhame/ Great Chesterford (χ^2=10.8, p=0.05, df=1), Llandough/ Great Chesterford (χ^2=11.6, p=0.001, df=1), Llandough/ Edix Hill (χ^2=4.8, p=0.05, df=1).

Qualitative Bone Index (QBI)

Site differences

The preservation of the cortical bone surfaces was assessed according to the six classes of preservation, where Class 1 denotes that the cortical surface was completed eroded, Class 2 that up to 25% of the surface was preserved, Class 3 that up to 50% of the bone's surface was preserved, Classes 4 and 5 were recorded when 75% of the cortical surface was intact and Class 6 was recorded when the bone's surface was completely preserved. Overall, the majority of the sites had at least 50% of the bone surfaces present (i.e., high percentage of Class 3 preservation) (Fig. 3; Table 6). At the northern site of Auldhame, the poorly preserved cortical bone at classes 1–3 was significant when compared to Edix Hill (χ^2=149.29, p=0.001, df=1). Thus indicating a geological influence. Cortical bone preservation also differs across a small geographical area, for example at Edix Hill and Great Chesterford, the poor cortical bone preservation at Edix Hill was due to the affects of chalk and was significant at Class 1 (χ^2=96.2, p=0.001, df=1) and Class 2 (χ^2=404.7, p=0.001, df=1) (Table 7).

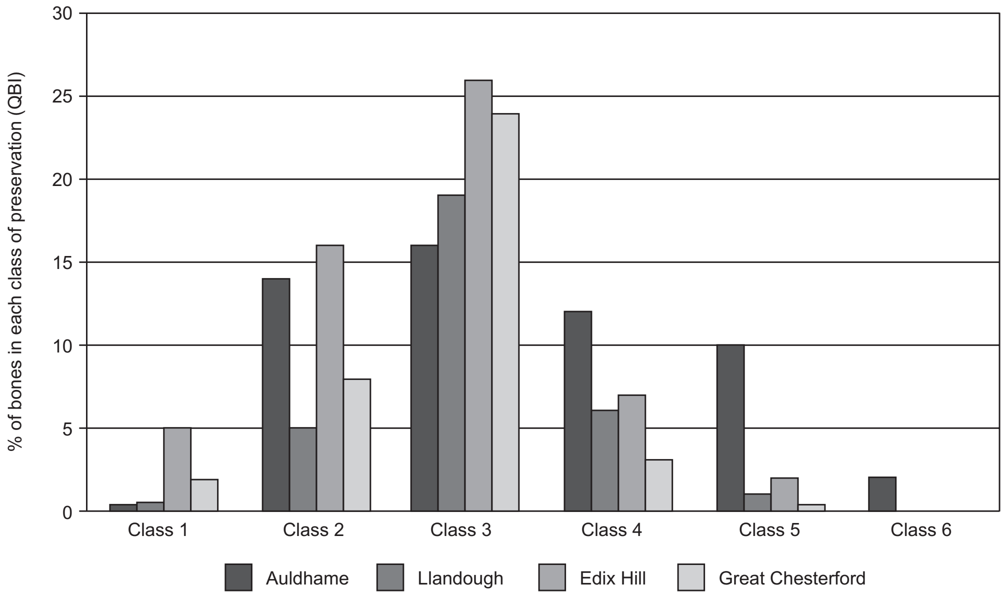

Fig. 3 Percentage of bones in each class of preservation (QBI)

Table 6. Number and percentage of bones preserved (QBI) at each class and age group for Auldhame, Llandough, Great Chesterford and Edix Hill

Age Group	Class 1	Class 2	Class 3	Class 4	Class 5	Class 6
	n (%)	n (%)	n (%)	n (%)	n (%)	n (%)
			Auldhame			
< 40 weeks	0	47 (24)	32 (17)	15 (8)	5 (3)	0
0–1.5 years	1 (0.05)	122 (6)	147 (7)	86 (4)	44 (2)	1 (0.05)
1.6–4.5 years	2 (0.2)	87 (9)	110 (11)	63 (6)	28 (3)	3 (0.3)
4.6–10.5 years	1 (0.04)	153 (6)	160 (7)	162 (7)	210 (9)	41 (2)
10.6–17.0 years	0	53 (7)	66 (9)	37 (5)	15 (2)	5 (1)
			Llandough			
< 40 weeks	0	10 (5)	43 (22)	2 (1)	0	0
0–1.5 years	4 (0.1)	58 (2)	270 (10)	33 (1)	3 (0.1)	0
1.6–4.5 years	5 (2)	58 (2)	188 (9)	61 (3)	0	0
4.6–10.5 years	20 (1)	71 (3)	268 (12)	90 (4)	11 (1)	0
10.6–17.0 years	2 (0.2)	5 (0.4)	90 (8)	76 (7)	49 (4)	0
			Great Chesterford			
< 40 weeks	24 (3)	84 (10)	111 (13)	0	0	2 (0.2)
0–1.5 years	18 (1)	135 (3)	381 (24)	26 (2)	1 (0.06)	0
1.6–4.5 years	20 (1)	45 (3)	246 (16)	58 (4)	1 (0.06)	0
4.6–10.5 years	7 (0.1)	11 (1)	153 (15)	69 (7)	9 (1)	0
10.6–17.0 years	0	3 (1)	57 (28)	2 (1)	1 (0.06)	0
			Edix Hill			
< 40 weeks	0	5 (10)	19 (39)	7 (14)	0	0
0–1.5 years	0	34 (7)	77 (15)	22 (4)	2 (0.4)	0
1.6–4.5 years	12 (3)	54 (14)	73 (19)	18 (5)	3 (1)	0
4.6–10.5 years	33 (5)	59 (8)	91 (13)	38 (5)	20 (3)	0
10.6–17.0 years	53 (5)	157 (10)	156 (10)	41 (3)	1 (0.06)	0

Age Differences

Age was also assessed in relation to the state of preservation of the cortical surfaces (QBI) of the remains. The age of the non-adults at each site were compared statistically to observe if any differences existed between the sites. No differences were observed at the four sites or for each age group for each of the preservation classes. Neither were there any differences in good and poor preservation noted between the sites at each age group. The only difference recorded was between Auldhame/Edix Hill at 4.6–10.5 years ($\chi^2=6.8$, $p=0.05$, df=1).

Grave depth and age at Great Chesterford and Edix Hill

In order to assess whether non-adults are poorly preserved because of shallow burial depth, burial depth, age, API and QBI were analysed for the sites of Great Chesterford and Edix Hill. A difference was found between grave depth, cortical surface preservation and age, at the ages of 0–1 years and 1–4 years ($\chi^2=9.3$; $p=0.005$, df=1) and a significant difference was also found at the ages of 5–10 years and 11–17 years ($\chi^2=24.8$; $p=0.001$, df=1). There were no significant differences between the API, age

Table 7. Statistical analyses of bones per each class of qualitative bone preservation (QBI) between all the sites

Class	Auldhame vs Edix Hill	Auldhame vs Great Chesterford	Edix Hill vs Great Chesterford	Llandough vs Great Chesterford	Llandough vs Edix Hill	Llandough vs Auldhame
Class 1	χ^2=149.3 df=1 p=0.001	χ^2=24.6 df=1 p=0.001	χ^2=96.2 df=1 p=0.001	χ^2=22.6 df=1 p=0.001	χ^2=206.6 df=1 p=0.001	
Class 2		χ^2=181.3 df=1 p=0.001	χ^2=404.8 df=1 p=0.001		χ^2=217.1 df=1 p=0.001	χ^2=196.4 df=1 p=0.001
Class 3	χ^2=40.9 df=1 p=0.001			χ^2=6.8 df=1 p=0.001	χ^2=12.9 df=1 p=0.001	χ^2=16.1 df=1 p=0.001
Class 4	χ^2=26.2 df=1 p=0.001	χ^2=302.4 df=1 p=0.001		χ^2=69.9 df=1 p=0.001	χ^2=6 df=1 p=0.025	χ^2=106.7 df=1 p=0.001
Class 5	χ^2=118.5 df=1 p=0.001	χ^2=494.4 df=1 p=0.001		χ^2=31.1 df=1 p=0.001	χ^2=6.9 df=1 p=0.001	χ^2=399.1 df=1 p=0.001
Class 6	χ^2=31.2 df=1 p=0.001	χ^2=78.9 df=1 p=0.001				χ^2=96.2 df=1 p=0.001

and grave depth at in the younger individuals, but a significant difference was found in the older children, 5–10 years and 11–17 years age group (χ^2=52.6; p=0.001, df=1).

Bone frequencies at each site

The number and percentages of each bone from both the cranium and post-cranium was calculated for each site (Table 8). A total of sixty-eight bones from each skeleton, including left and right. The bones of the skull tend to vary in their preservation. Here, the cranial bones most frequently preserved included the temporal, occipital, parietal and mandible. The temporal bone was represented at Auldhame (67; 48% of skeletons), at Great Chesterford (76; 49%), Llandough (23; 27%) and Edix Hill (48; 58% respectively). This may be due to its relatively high density, especially the petrosa portion. The occipital bone was well-represented at Auldhame (45; 64%) and Great Chesterford (45; 58%). The pars basilaris was especially abundant at all sites, this is an important element in that it can facilitate in the ageing of infants in the absence of dental remains. The parietal and frontal bones tend to be present, however, they are usually recovered in fragmented form, this may be as a result of burial position (i.e supine) and it is also vulnerable to plough and excavation damage. The mandible and maxilla were less well-represented, with all samples having less than half present. This is surprising as the mandible is dense and compact in nature and is often used in the estimation of MNI evaluations (Brezillion 1963). The small bones of the face, for example the lacrimal and ethmoid, tend to be poorly represented at all the sites. This is likely due to the fragmentation of the skull and also these bones can be difficult to recognize during excavation. The small bones of the ear (malleus, incus and stapes) when recov-

Table 8. Frequency of bones represented at each site (n=421)

Bone	Auldhame	Great Chesterford	Edix Hill	Llandough
	n (%)	n (%)	n (%)	n (%)
Temporal	67 (48)	76 (49)	48 (58)	123 (27)
Parietal	32 (45)	75 (49)	53 (65)	114 (50)
Frontal	31 (44)	38 (49)	27 (66)	41 (18)
Sphenoid	32 (46)	30 (39)	20 (49)	43 (19)
Occipital	45 (64)	45 (58)	26 (63)	69 (30)
Zygomatic	33 (23)	31 (20)	28 (34)	22 (5)
Nasal	3 (2)	2 (1)	4 (5)	0
Vomer	4 (3)	2 (1)	2 (2)	0
Lacrimal	3 (2)	0	2 (2)	0
Ethmoid	4 (3)	3 (2)	3 (4)	0
Palatine	1 (1)	2 (1)	0	0
Malleus	9 (6)	15 (10)	1 (1)	5 (1)
Incus	7 (5)	15 (10)	1 (1)	2 (1)
Stapes	1 (1)	3 (2)	2 (2)	2 (1)
Hyoid	7 (5)	0	2 (2)	0
Mandible	38 (54)	34 (44)	25 (61)	43 (19)
Maxilla	30 (43)	26 (34)	20 (49)	23 (10)
Humerus	89 (79)	107 (69)	51 (62)	140 (31)
Radius	87 (62)	74 (48)	45 (55)	78 (17)
Ulna	85 (61)	66 (43)	48 (58)	104 (23)
Clavicle	77 (55)	82 (53)	38 (46)	68 (15)
Scapula	81 (58)	70 (45)	45 (55)	86 (19)
Carpals	24 (17)	2 (1)	13 (16)	15 (3)
Metacarpals	64 (46)	30 (19)	34 (41)	38 (8)
Manual phalanges	62 (44)	30 (19)	35 (43)	43 (9)
Cervical Verts	55 (78)	42 (54)	26 (63)	70 (31)
Thoraic Verts	58 (83)	48 (62)	26 (63)	58 (26)
Lumbar Verts	50 (71)	37 (48)	24 (58)	34 (15)
Ribs	126 (90)	117 (76)	58 (71)	172 (38)
Stemum	18 (26)	10 (13)	10 (24)	10 (4)
Pelvis	113 (81)	68 (44)	58 (71)	116 (26)
Sacrum	34 (48)	15 (19)	17 (41)	36 (16)
Coccyx	1 (1)	0	0	0
Femur	102 (73)	93 (60)	62 (76)	141 (31)
Tibia	91 (65)	76 (49)	53 (65)	118 (26)
Fibula	79 (56)	61 (40)	45 (55)	102 (22)
Patella	15 (11)	1 (1)	20 (24)	10 (2)
Tarsals	36 (26)	24 (15)	33 (40)	34 (7
Metatarsals	36 (26)	20 (13)	33 (40)	43 (10)
Pedal phalanges	31 (22)	8 (5)	20 (24)	35 (8)

ered are always in excellent condition, this may be due to the protection of the temporal bone, with the malleus and stapes tending to be better represented than the incus.

The humerus was well-represented across three of the sites; at Auldhame (89; 79%); Great Chesterford (107; 69%) and Edix Hill (51; 62%). At Llandough the bone was less preserved (140; 31%). There was a similar pattern for the radius and ulna; as well as for the clavicle and scapula. The bones of the hand were poorly represented at all sites, for example at Llandough: carpals (15; 3%), metacarpals (38; 8%) and phalanges (43; 9%). The bones of the spine are normally abundant in assemblages, and in this study the cervical and thoracic vertebrate were the most represented (Table 8). This is in contrast to other studies (Mays 2010; Bello and Andrews 2006) reporting that the lumbar vertebrae as the most commonly preserved portion of the spinal column. The bones of the lower limb were well preserved at all sites with the femur being the most abundant followed by the tibia. The bones of the feet were also poorly represented.

Bone frequencies and age

The frequency of each of the long bones was calculated for each age group (Table 9). The long bones are the most frequently recovered bone elements of the non-adult skeletons and in this study there was variation in numbers recovered when compared to age. There were significant fewer long bones in the less than 40 weeks' age category, however, this may as a result of a small sample size. The humerus was the best preserved at (44; 61%). The second age category 0–1.5 years had a substantial number of bones present, again the humerus was the best represented at (125; 61%) followed by the femur at (109; 53%) and the ulna (89; 34%). There is a decrease in numbers in those aged between one and four years, followed by an increase in those aged between 4.6–10.5 years (Table 9). In the oldest children the long bones appeared less well preserved with the fibula the least represented bone (47; 37%). With regard to the cranial bones, the temporal bone was the best preserved, especially in early infancy (97; 47%), and in 4 to 10 years (80; 39%). This was followed by the parietal bone (71; 34%) and (79; 38%) respectively (Table 9). Contrary to a previous study by Djuric et al. (2011), the mandible was less well preserved in this study (Table 9).

Dental frequencies

The recovery of non-adult dental remains is not only important for ageing but also for the study of stress and malnutrition in the form of dental enamel hypoplasias, but also gives clues towards diet, for example high levels of caries would indicate a diet high in carbohydrates and or sugar. The frequency of tooth type was calculated for all sites (Tables 10–11). The dental elements most frequently recovered for the maxillary deciduous teeth are molar one, canine and the lateral incisor. The deciduous mandibular teeth also show a similar pattern with molar one, the canine and the central incisor most frequently present. In the permanent dentition again molar one, the canines and the incisors were most frequent for both the maxillary and mandibular teeth.

Discussion

The primary aim of this study was too compare the bone preservation of children's skeletal remains by examining as-

Table 9. Frequency of bones at the different age groups for the whole sample (n=376)

Bone	<40 weeks	0–1.5 years	1.6–4.5 years	4.6–10.5 years	10.6–17.0 years
	n (%)	n (%)	n (%)	n (%)	n (%)
Cranial bones					
Temporal	16 (22)	97 (47)	54 (38)	80 (39)	46 (36)
Parietal	19 (26)	71 (34)	69 (48)	79 (38)	46 (36)
Frontal	10 (28)	44 (42)	27 (38)	29 (28)	18 (28)
Sphenoid	9 (25)	55 (53)	21 (29)	31 (30)	14 (22)
Occipital	12 (33)	42 (41)	31 (44)	40 (39)	21 (33)
Zygomatic	14 (19)	24 (12)	17 (12)	39 (19)	28 (22)
Mandible	8 (22)	34 (33)	26 (36)	35 (34)	23 (36)
Maxilla	7 (19)	19 (18)	17 (24)	27 (26)	18 (29)
Long bones					
Humerus	44 (61)	125 (61)	63 (44)	108 (52)	49 (39)
Radius	39 (54)	72 (35)	50 (35)	95 (46)	49 (39)
Ulna	38 (53)	89 (43)	54 (38)	104 (50)	41 (32)
Femur	36 (50)	109 (53)	69 (48)	101 (49)	57 (45)
Tibia	31 (43)	73 (35)	59 (41)	96 (47)	51 (40)
Fibula	23 (32)	60 (29)	55 (38)	88 (43)	47 (37)

semblages from four early medieval cemeteries of different geographical location and geology within the United Kingdom. Some scholars have argued that bone preservation is not the dominating factor in the absence of such remains from archaeological sites, but that cultural and religious beliefs may have a more influential role (Crawford 1991; Sundick 1978). However, with regard to the bone preservation, numerous contradictions exist surrounding the best environment for excellent preservation. Unfavourable geological conditions are often cited as a cause of poor preservation, but how much influence this has on sites and skeletal remains in Britain remains unclear. The geology of the United Kingdom is complex, with varying types and amounts of soils in each region (Manifold 2012). Therefore, preservation of bone varies considerably, not only from soil to soil, but also from one place of burial to another. Environments affect bone in different ways. In acidic environments, which mostly consist of podsols, these soils tend to be abundant in Northern England and Scotland, where there is a tendency for the soils to be thin, acidic and wet, which may or may not have a negative impact on bone preservation (French 2003). On the other hand, many peat environments have revealed excellent preservation due to the acidic nature of the sites, due to the lack of microbal attack and on an accumulation of organic matter, which leads to the formation of blanket bog (French 2003). In a more alkaline environment, which consists of calcareous soils which can result in mixed preservation if remains are recovered from this soil type and have a high pH, then they tend to be in good condition (Brothwell 1981), these soils tend to be found in East Anglia and eastern and south-west England. In soils of a neutral pH, there can be varied conditions, these soils are well drained and mostly located on the gravel and chalk areas of southern England. An increase in biological activi-

Table 10. Frequency of deciduous maxillary and mandible dentition at each site (n=421)

Tooth type	Auldhame	Edix Hill	Great Chesterford	Llandough
	n (%)	n (%)	n (%)	n (%)
Maxilla				
Left Deciduous Molar 2	17 (24)	12 (29)	13 (16)	24 (11)
Left Deciduous Molar 1	18 (25)	12 (29)	17 (21)	29 (14)
Left Deciduous Canine	10 (14)	8 (19)	12 (15)	11 (5)
Left Deciduous Incisor 2	8 (11)	5 (12)	8 (10)	5 (2)
Left Deciduous Incisor 1	11 (15)	8 (19)	11 (14)	13 (6)
Right Deciduous Incisor 1	13 (18)	8 (19)	8 (10)	16 (7)
Right Deciduous Incisor 2	13 (18)	7 (17)	7 (8)	6 (3)
Right Deciduous Canine	9 (13)	7 (17)	15 (18)	15 (7)
Right Deciduous Molar 1	16 (22)	15 (36)	17 (21)	34 (16)
Right Deciduous Molar 2	14 (20)	13 (32)	18 (22)	30 (14)
Mandible				
Left Deciduous Molar 2	20 (28)	17 (41)	16 (19)	35 (16)
Left Deciduous Molar 1	24 (32)	17 (41)	17 (21)	35 (16)
Left Deciduous Canine	12 (17)	9 (22)	11 (13)	15 (7)
Left Deciduous Incisor 2	11 (15)	9 (22)	11 (13)	18 (8)
Left Deciduous Incisor 1	12 (17)	10 (24)	12 (15)	23 (11)
Right Deciduous Incisor 1	13 (18)	10 (24)	18 (22)	23 (11)
Right Deciduous Incisor 2	11 (15)	7 (17)	17 (21)	17 (8)
Right Deciduous Canine	13 (18)	7 (17)	13 (16)	15 (7)
Right Deciduous Molar 1	17 (25)	15 (36)	17 (21)	34 (16)
Right Deciduous Molar 2	18 (25)	13 (32)	15 (18)	28 (13)

ty leads to a breakdown of organic matter, which results in a well-mixed , aerated soil and can lead to poor bone preservation (French 2003). The main constituents of bone, the organic part (collagen) and mineral part (hydroxyapitite), are preserved at opposing pH levels (Mays 1998). It is generally known that soils with a neutral or alkaline pH are better for preservation of bone rather than acidic soils (Henderson 1987; Ferllini 2007), but this is not always the case. Locock et al. (1992) found that soil pH was not said to be the main controlling factor in the preservation of buried bone. Some demineralisation of bone may occur as a result of the action of organic acids released during decomposition of the soft tissues, and therefore present in the soil where the bones are exposed (Child 1995). Overall, it would appear that the literature has produced some contradictions as to what environment is best for bone preservation. Henderson (1987:48) stated that the speed of decomposition is increased in light porous soils, whilst dense clay soils may decrease the rate of decomposition, and the deeper the burial, the poorer the preservation due to waterlogged clay (Henderson 1987; 460). However, there may be limitations to these studies using animal bones, which may react differently to those of the human skeleton to soil conditions. Nicholas (1996) found acid moorland (pH 3.5–4.5) was the most destructive to

Table 11. Frequency of permanent maxillary and mandible dentition at each site (n=421)

Tooth type	Auldhame	Edix Hill	Great Chesterford	Llandough
	n (%)	n (%)	n (%)	n (%)
		Maxilla		
Right Molar 3	3 (4)	6 (15)	2 (2)	1 (0.5)
Right Molar 2	10 (14)	12 (29)	4 (5)	11 (5)
Right Molar 1	14 (20)	16 (39)	11 (13)	27 (13)
Right Premolar 2	10 (14)	9 (22)	3 (4)	5 (2)
Right Premolar 1	10 (14)	10 (24)	5 (6)	10 (5)
Right Canine	10 (14)	12 (29)	3 (4)	14 (7)
Right Incisor 1	12 (17)	12 (29)	3 (4)	6 (3)
Right Incisor 2	15 (21)	17 (41)	7 (8)	21 (10)
Left Incisor 2	12 (17)	10 (24)	5 (5.6)	19 (9)
Left Incisor 1	11 (15)	10 (24)	2 (2.2)	12 (6)
Left Canine	9 (13)	11 (27)	5 (6)	9 (4)
Left Premolar 1	8 (11)	11 (27)	3 (4)	11 (5)
Left Premolar 2	10 (14)	9 (22)	1 (1)	7 (3)
Left Molar 1	16 (22)	14 (34)	10 (12)	23 (11)
Left Molar 2	11 (15)	10 (15)	6 (7)	7 (7)
Left Molar 3	2 (3)	5(3)	2 (2)	2 (1)
		Mandible		
Right Molar 3	2 (3)	7 (17)	1 (1)	0
Right Molar 2	11 (15)	13 (31)	8 (10)	12 (6)
Right Molar 1	14 (20)	16 (39)	12 (15)	29 (14)
Right Premolar 2	10 (14)	9 (22)	0	8 (4)
Right Premolar 1	11 (15)	13 (31)	0	11 (5)
Right Canine	11 (15)	13 (31)	5 (6)	13 (6)
Right Incisor 1	14 (20)	16 (39)	3 (4)	6 (3)
Right Incisor 2	17 (24)	17 (41)	6 (7)	24 (11)
Left Incisor 2	17 (24)	18 (44)	6 (7)	22 (10)
Left Incisor 1	14 (20)	15 (36)	6 (7)	18 (8)
Left Canine	11 (15)	13 (31)	2 (2)	13 (6)
Left Premolar 1	11 (15)	11 (27)	1 (1)	12 (6)
Left Premolar 2	10 (14)	11 (27)	2 (2)	7 (3)
Left Molar 1	16 (22)	22 (27)	7 (8)	17 (8)
Left Molar 2	9 (13)	11 (27)	7 (8)	17 (8)
Left Molar 3	1 (1)	7 (17)	1 (1)	1 (0.5)

bone and a chalk environment (pH 7.5–8.9) was the most favourable. However, between these two sets of figures there are many variables and should be used as an indication of the extremes. Maat (1987) reported that the role of soils in preservation may be overestimated. This should be viewed with caution, as a study based on the decomposition of juvenile rates has shown that microbial activity is a major contributor to cadaver decomposition in soil, and it also shows persistence of cadaver in soil can be influenced by the surrounding temperature and soil type (Carter et al. 2008). In a study by Nord and colleagues (2005) on degradation of archaeological objects and bones from prehistoric graves in Sweden, it was found that the environment affects preservation in three ways: firstly, the chemical environment (soil activity) mainly affects the macroscopic appearance of bone, secondly, the microbial activity, composed mainly of bacteria and fungi have a destructive affect on the organic contents of bone and histological structures. Thirdly, the inorganic material is mainly destroyed by soil activity, whereas proteins degrade at a higher pH. It would appear that calcareous soils are the most suitable for the good preservation of macroscopic structure of human bone (Nord et al. 2005).

Geographical differences in bone preservation

In this study all sites showed a similar pattern of preservation for both the anatomical preservation index (API) and the qualitative bone index (QBI) from Figures 2; 3 with large percentages of bones not present (class1) at all sites and a low percentage of well preserved bones (class 6) (Figures 2; 3). As for age groups, there was also a similar pattern with large numbers of bones not preserved (class 1) for all age groups (Tables 4; 6) with a gradually decrease in percentages in class 6. Although there was a similar pattern with regard to well preserved bones at each of the sites, significant differences were noted between the sites (Tables 5 and 7).

At the site of Auldhame in the north, there was evidence of shallow burial with many of the skeletons exhibiting damage caused by plough damage. This was also noted at the Welsh site of Llandough coupled with the effects of the water-logged soil which resulted in overall poor preservation. At the site of Edix Hill, many of the skeletons had their cortical surfaces damaged by the abrasive action of the chalk. This was also observed at the Experimental Earthworks project at overton down in Wiltshire, southern England, where bone samples were buried over a long period of time show bone modifications due to the chalk (Amour-Chelu and Andrews 1996). Chalk is pure limestone and is created by the deposits of solid calcium carbonate in water. Soils which develop upon calcium carbonate are known as rendzinas, these types of soils are usually shallow, porous, well-aerated and permeable and this can serve to protect bones in some cases (Ferllini 2007).

Evidence from many archaeological sites suggest that children are buried in shallower graves than there adult counterparts which may expose them to taphonomic processes (Ascádi and Nemeskeri 1970). In order to test this, the grave depths of Edix Hill and Great Chesterford were analysed. Overall, at Edix Hill there were no major differences found between the ages groups, whereas at Great Chesterford a more pronounced difference was noted. No difference was found between the preservation of bone and depth of burial at either Edix Hill or Great Chesterford among those aged between 1–4 years, but they did occur among the older children. Differences were noted between the preservation of the cortical surfaces (QBI) and age at both sites. This would suggest the depth of burial influences the cortical surface preservation of children's bones, whereas grave depth does not appear to influence the amount of bone preserved (API). The state of the cortical surface preservation was highly significant with regard to the classes of preservation; this may be directly related to the type of soil and pH. The cortical surface of bone elements are directly in contact with the sediment type, which can have a destructive affect leading to erosion of the surfaces; this can limit the amount of detailed information regarding pathology of the skeleton.

Bone representation

Certain bone types tend to survive better in the burial environment, especially with regard to the remains of children. The cranial bones such the temporal (pars petrosa), sphenoid (body and greater wings), occipital, zygomatic, and mandible tend to be well preserved and well represented from neonate to adolescent, thus allowing the skeleton to be aged accurately. The small fragile bones of the face such as the vomer, lacrimal and ethmoid tend to be under-represented at all sites (Table 8), all bones are present at birth, with the ethmoid ossified by the seventh month of foetal life and resembles the adult morphology at birth (Scheuer and Black 2000). The under-representation of such bones can hamper the study of diseases such as leprosy. Also, their absent may be due to difficulties in recognizing them during excavation. The small bones of the ear (malleus, incus and stapes) are always recovered in excellent condition, this may be due to the protection of the temporal bone, with the malleus and the stapes tending to be better represented than the incus. This may be due to the relative small size of such bones, which can be easily missed during excavation. An under-representation of such bones hinder the study of otitis media in archaeological samples.

The post cranial bones which are well-preserved and represented are the long bones of the upper and lower limbs, ribs (especially the first and last rib) possibly due to its anatomical position in the body; the cervical vertebrae (especially the atlas and axis) tends to be better preserved than that of the lumbar. The pelvis is also well preserved and well represented in all ages. In this study the clavicle and scapulae were well preserved and represented at all sites, it has previously reported that the scapulae is poorly preserved due to its fragile nature (Bello et al. 2002). It was observed that the scapulae was often recovered in excellent condition in the younger children (i.e neonate) this may be due to the size of the body of the scapula and its compact nature during the early stages of development. When it increased in size due to growth, the body becomes more fragile and prone to breakage. Bones of the limbs (i.e femur, tibia, humerus and ulna) are very well-represented in this current study. The femur is the densest bone in the body and therefore, tends to be well preserved. In this study the ulna was also represented in high numbers, contrary to an earlier study by Bello and Andrews (2006) which reported an under-representation. The frequency of the upper limb bones such as the humerus and ulna, maybe due to burial position in the grave. However, burial position will differ from site to site and period to period. There is a differential pattern of preservation with regard to the smaller bones of the hands and feet. When the bones of the hands and feet are recovered they are usually well preserved, however, in some cases they can be misidentified. These bones are also age-dependant and may not have ossified at the time of recovery or excavation.

The metatarsals and metacarpals are generally less well represented, as are the phalanges of the extremities. The carpal bones are not present in perinatal remains, only the hamate is present at 2–4 months and the capitate emerges at around 3–5 months (Scheuer and Black 2000). The metacarpals and phalanges are present before birth. The phalanges are often unrecognized and classed as animal bone instead and there can also be difficulty in assigning them as human in some circumstances (Scheuer and Black 2000; Brothwell 1981). The talus and calcaneus are present in perinatal remains; these bones are the two largest of the foot bones and are easily recognised. The remaining five bones are present from the age of one year. The fact that they are not present in greater numbers may also be due to loss at excavation and washing. Another bone which is constantly under-represented in both adult and non-adult samples is that of the patella. In the current study it was the least represented bone in all samples. This echoes the finding of Cox and Bell, (1999) who also reported the under-representation of the patella in their forensic case study. At birth and the first few years of life, the patella is entirely cartilaginous with it not taking the adult shape until early adolescences (Scheuer and Black 2000). This could explain why it is difficult to recognise and is less likely to be present in younger individuals. The sacrum, coccyx and sternum are also under-represented; this again may be due to the fact that they are age dependent bones, however, this was taken in account during analysis. The first segment of the sacrum is normally the most represented part of the sacrum. The coccyx was absent from all samples.

The unequal representation of certain bones can be linked to bone mineral density. It has been suggested that in cases where more dense bones are absent could be due to some form of burial treatment, where bones are selected or removed for burial (Bello and Andrews 2006). However, added to this the storage and curation of human skeletal assemblages, as is often the case that certain elements get lost over time, which is due to human error and not preservation (Manifold 2010). This is particularly the case with older collections, where curation was minimum and non-adults were not always deemed to warrant investigation. Depending on the time period of the collection, the under-representation of certain bone elements maybe the result of funerary practices. This is often seen in prehistoric sites, where secondary burial practices took place thus causing elements to be displaced. The sites studied here consisted of early medieval cemeteries where burials were complete without any rituals, thus leading to suggestions that any bone loss is due to taphonomic processes and or excavation techniques. The frequencies of skeletal elements recovered in the samples studied have a similar pattern to sites in France (Bello et al. 2006) and London (Bello et al. 2006).

The importance of good recovery of dental remains of children not only contributes to the estimation of age in both archaeological and forensic cases, in a survey of forensic science journals, it was found that over half of all papers published on the skeletal remains of children focused on ageing methods using both deciduous and permanent teeth (Manifold forthcoming), but also allows the assessment of health and disease. One of the most commonly encountered is that of dental enamel hypoplasias, which can be observed as lines, pits or grooves on the enamel surface of the incisors and canines (Roberts and Manchester 2007) the presence of these defects may be a indicator of stress during growth and development during childhood. Caries are commonly encountered in archaeological remains, and especially in the lower molar teeth and if present in children may gives clues as to the type of diet but also their presence may have lead to more serious conditions such as abscesses. Diseases such as congenital syphilis, which is present at birth as a result of developing in the foetus secondary to venereal syphilis in the mother (Lewis 2007) Hutchinson's incisors, moon's molars and mulberry molars, are dental defects which occur in the early stages of the disease (Lewis 2007). In this current study the dental elements which are being well-represented include the upper and lower first molars. The molars are larger in size with the maxillary molars having three roots thus allowing better chance of recovery and preservation. Also the canine and the lateral and central incisors were well-represented across all sites. These teeth are readily identified when recovered either whole or in fragmentary form. The position of the head during burial may be a factor in what is recovered. If the head is placed either to the left or right side, the dentition especially from the maxilla would be better protected from loss. In cases where the mandible is well preserved allows better protection of those teeth at the back (i.e molars, premolars). But also during development when the dentition has yet to erupt the small and fragile dental cusps can be recovered.

There is a pattern to what bones are preserved and this is indeed similar to previous findings but there are small differences with regard to some bones.

Conclusions

The remains of non-adult skeletons can be affected by the many factors involved in bone diagensis. One of the most frequently cited factors as a possible cause of poor preservation is shallow depth of graves of children. It has been believed in the past that was the case, due to their exposure to more taphonomic processes (Acsadi and Nemeskëri, 1970), however, this is not the case here, and it was observed that the younger individuals were less likely to have been affected by a range of taphonomic processes. It was observed at the sites of Great Chesterford and Edix Hill, both of which consisted of shallow burials throughout the cemetery that the remains of the non-adults did not exhibit a high percentage of the above taphonomic factors, which would be associated with shallow burials. Among all sites there is a degree of similarity between the preservation and representation of bones, this suggests that non-adult bones have a common pattern of preservation regardless of the age of the non-adult and location and type of site. The belief that certain bones will be well-preserved (i.e skull, femur, humerus) and others not so (i.e phalanges of the hands and feet), is true in some cases, but is by no means universal. In a previous study on French cemeteries, Bello and colleagues (2006) suggested that human remains were more damaged under stronger taphonomic pressures, therefore leading to the conclusion that bones which have a low bone mineral content and a high percentage of cancellous bone are more affected than others (Bello et al. 2006). Bone preservation is a complex issue and should be treated with caution when trying to establish if and to what degree it has on the skeletal remains of non-adults. It is important factor in both archaeological and forensic contexts, where many post-depositional factors are active. From this study it remains unclear as to the extent the role of geology has on the non-adult skeleton, but the results of this study clearly show that age is not a dominating factor in bone preservation as previously thought.

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Conflict of interests

The author declares that there is no conflict of interests.

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