A study of non-specific skeletal health indicators in two non-adult populations from western Britain

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Abstract Skeletal health indicators are often employed to measure how past populations adapted to their physical environment. The skeletons of children provide a measure of population fitness, as the ability of a community to keep their younger inhabitants alive and in general good health attest their ability to adapt to their environment. In this study, skeletal remains of non-adults from foetal to 17 years of age (n=300) from two cemetery populations in western Britain, namely the early medieval site of Llandough in south Wales (n=204) and the multi-period site of St Oswald's Priory in Gloucester (n=96), were assessed. Non-specific indicators of physiological stress (*cribra orbitalia,* porotic hyperos-

Resumen Indicadores de la salud del esqueleto se emplean a menudo para medir las poblaciones del pasado adaptadas a su entorno físico. Los esqueletos de los niños proporcionan una medida de la aptitud de la población, ya que la capacidad de una comunidad para mantener con vida a sus habitantes más jóvenes y en buen estado de salud general atestigua su capacidad para adaptarse a su entorno. En este estudio, se evaluaron los restos óseos de no adultos, de fetos a 17 años de edad (n = 300), de dos poblaciones de cementerios en el oeste de Gran Bretaña, a saber, el sitio de la época medieval temprana de Llandough en el sur de Gales (n = 204) y el sitio multiepoca de St Oswald's Priory en Glouces-

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tosis, dental hypoplasia) and non-specific infections (periosteal new bone formation and endocranial lesions) are compared. Results suggest that the children from the English site enjoyed better health than their counterparts in Wales, where there was an increase in physiological stress during childhood.

Keywords: Non-adults; skeletal remains; medieval Wales; England; non-specific stress.

ter (n = 96). Se comparan los indicadores no específicos de estrés fisiológico (*cribra orbitalia*, hiperostosis porótica, hipoplasia dental) y las infecciones no específicas (nueva formación ósea perisosteal y lesiones endocraneales). Los resultados sugieren que los niños del sitio Inglés disfrutaron de una mejor salud que sus contrapartes en Gales, donde se registró un aumento en el estrés fisiológico durante la infancia.

Palabras clave: No adultos; restos óseos; Gales medieval; Inglaterra; estrés no específico.

Introduction

The study of human skeletal remains allows bioarchaeologists and anthropologists to study the health of past populations and the impact by environmental changes. This is particularly important when considering the health of children, which are thought to represent the most sensitive index of biocultural change (Van Gerven and Armelagos, 1983; Roth, 1992). The skeletal remains of the younger members of a community allow this measure of population fitness (Mensforth et al., 1978: 3). The ability of communities to keep their most vulnerable members alive and healthy is testament to their abilities to adapt to the changing environment, and exposure to specific stressors may have occurred (Ribot and Roberts, 1996). Infancy and early childhood are critical periods for growth and development and have been recognised as periods of increased mortality and morbidity, this is evident in higher mortality rates for children but also increases in stress levels, increased prevalence of certain diseases (i.e. rickets, scurvy), and also decreases in growth. The study of non-specific physiological stress indicators is frequently employed to assess the health of past populations and many studies have been carried out on non-adult skeletons both in Britain and abroad (Ribot and Roberts, 1996; Lewis, 2002; 2010; Bennike et al., 2005; Gowland and Redfern, 2010; Wheeler, 2010). It is often desirable to assess disease, nutrition and bone growth together in order to investigate the impact of poor health and nutrition on growth patterns. However, the interpretation of the health profile of skeletal populations is not straightforward due to the effects of selective mortality and hidden intra-population variability in the susceptibility to illness (Wood et al., 1992; Wright and Yoder, 2003; Pinhasi et al., 2011). Health and disease in past populations is evaluated in light of the 'osteological paradox', by Wood and colleagues (1992), and more recently outlined by Pinhasi et al. (2013), which states that, firstly, individuals who never experienced stress have none of the related skeletal lesions, secondly, individuals that experienced moderate stress which lasted long enough to result in some skeletal lesions and, thirdly, those that have suffered heavy stress which resulted in death soon after the onset of the illness may have little or no skeletal evidence of the disease/condition (Pinhasi et al., 2013). This is particularly important in assessing health and disease in infants and children who may have succumbed to a disease in the acute stages before evidence of the condition could be observed on the skeleton. Bone growth in historic skeletal collections is another popular area of study and there are numerous publications dealing with bone growth in both adults and non-adult skeletal remains (Hoppa, 1992; Humphrey, 1998; 2000; Mays, 1999; Saunders, 1992; 2000; Saunders and Hoppa, 1993; Mays et al., 2009; Schillaci et al., 2011). Bone growth patterns can vary within and between populations as a result of environmental and genetic factors (Pinhasi et al., 2013).

The principal aim of this research was to gain an insight into the health of children in the past using several commonly employed health indicators, such as *cribra orbitalia* and porotic hyperostosis; endocranial lesions, enamel hypoplasia, periosteal new bone formation and bone growth in two skeletal assemblages of children (birth to 12 years) and adolescents (13 to 17 years) from England and Wales. To date there has being little research conducted on the health of children from medieval Wales (see Loe, 2003); this may in part be due to the lack of skeletal assemblages containing large numbers of non-adult skeletons from the area.

Materials

A total of 300 non-adult skeletons (from foetal up to 17 years of age) were examined from two rural, archaeological sites. One early medieval site from Wales (n=204) and one multi-period site from western England (n=96). Both sites were situated within 90 kilometres of each other.

The site of Llandough is situated in South Wales, which lies in the north of Penarth, on sloping ground near the crest of an escarpment. The escarpment overlooks the estuary of the river Ely to the north and a stream that runs through a combe to the south (Thomas and Holbrook, 1994; Holbrook and Thomas, 2005). In 1994, excavation of the ancient burial ground was undertaken by Cotswold Archaeological Trust. The excavation area lies to the north of the churchyard wall and extends to the edge of the escarpment. Within this area 1026 graves containing human skeletal remains were recovered, consisting of 814 (79%) articulated skeletons and 212 (22%) disturbed skeletons (Thomas and Holbrook, 1994; Holbrook and Thomas, 2005). Of the 1026 graves, 226 (22%) burials were of children and adolescents. Many of the skeletons were found only a few centimetres below the ground and there were signs of activity which post-dated the cemetery and had truncated much of the site. Davies (1982) concluded that the 19th century church of Saint Dochdwy overlies the site of one of the major medieval monasteries of Glamorgan. It is thought that a monastic community existed in Llandough during the period 650-1075 AD (Davies, 1982).

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 the 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 child burials, which were clustered into two distinct groups – one that was central and another in an adjacent area to the north. These burials were aligned east-west and were cut into the adult burials, suggesting later interments. It is likely that the burials in Area I are related to the monastic community which was established in the 6th century. This area of the cemetery would have included monks and the 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 the burials. A total of 204 skeletons were studied here. Of the 204 non-adults from the early medieval cemetery of Llandough, the majority came from Area III (c. 901-1200) (n=153 or 75%), with (n=37 or 18%) and (n=4 or 7%) located within Area I and Area II respectively (Table 1 and Fig. 3). Macroscopic bone preservation at Llandough was poor due to the waterlogged burial environment. The remains of the children were fragmented but many of the cranial bones and long bones were preserved enough in order to allow study. For a more detailed report on the bone preservation of the non-adult remains from Llandough, see Manifold (2013).

The site of St Oswald's Priory from western England is a multi-period site, which lies in the fertile valley of the River Severn and to the east is the scarp slope of the Cotswold Hills. St Oswald's Priory was used as a burial ground since the Roman period. Both churches appeared to be dedicated to St Peter in the late Anglo-Saxon period, whereas in the pre-conquest period they were known as the Old Minster and the New Minster. This later became known as the Abbey church of St Peter and the later Priory church of At Oswald's (Hare, 1999). A total of 487 skeletons were recovered, 128 of which were children. Most of the burials could be placed into five different periods; namely, Roman, Anglo-Saxon, and Norman, late medieval and post-medieval, each containing a varying number of skeletons both adult and non-adult. A high proportion of the burials recovered from the Norman cemetery were those of non-adults (n=58; 64%). This may be as a result of the inclusion of the area of burial ground external and adjacent to the church wall, which contained infant burials. This may indicate, as seen in other cemeteries, a special area for unbaptised children (Gilchrist and Sloane, 2005). A total of 96 skeletons were assessed in this current study. Bone preservation of the St Oswald's Priory skeletons was good with a high degree of completion. For further information regarding the bone preservation of the children's remains, see Manifold (2015).

Table 1. Age at death and burial location of the Llandough non-adults

	Date range	<40 wks	0-0.5	0.6-1.5	1.6-2.5	2.6-4.5	4.6-6.5	6.6-8.5	8.6-10.5	10.6-14.5	14.6-17.0	Total
Area I	c. 501-800	0 (0)	1 (3)	1 (3)	2 (5)	3 (8)	4 (11)	5 (13)	7 (19)	6 (16)	8 (22)	37 (18)
Area II	c.800-900	1 (7)	1 (7)	0 (0)	0 (0)	0 (0)	2 (14)	4 (28)	1 (7)	3 (21)	2 (14)	14 (7)
Area III	c.901-1200	7 (4)	15 (10)	37 (24)	16 (10)	22 (14)	15 (10)	16 (10)	8 (5)	9 (58)	8 (5)	153 (75)
Total		8 (3)	16 (8)	38 (19)	18 (9)	25 (12)	21 (10)	25 (12)	16 (8)	18 (9)	18 (9)	204

Methods

Age-at-death

In the present study, age-at-death was determined using the standards developed by Moorrees and colleagues (1963a; 1963b) for the development and resorption of the deciduous dentition, and the development of the permanent teeth. In cases where no teeth were present, the long bone lengths (Ubelaker, 1989) and skeletal development and maturation (Buikstra and Ubelaker, 1994) were employed. The foetal remains were aged using long bone lengths (Scheuer et al., 1980) and the occipital bone, where the length and width of the pars basilaris was calculated for age estimation (Scheuer and MacLaughlin-Black, 1994). Skeletons were divided into the following ten age categories: less than 40 weeks, 0-0.5years, 0.6-1.5 years, 1.6-2.5 years, 2.6-4.5 years, 4.6-6.5 years, 6.6-8.5 years, 8.6-10.5 years; 10.6-14.5 years and 14.6-17.0 years. In the last category (14.6-17.0 years), the individual was estimated to be over 17 years if the root of the third molar was complete (Moorress et al., 1963b). Of the 300 skeletons studied, 6 could not be aged accurately due to poor preservation.

Skeletal health indicators

Non-specific skeletal health indicators are those infections and/or diseases that have an unknown aetiology. They are frequently studied and reported on in both adult and non-adult skeletal remains. In this study, six skeletal stress indicators were selected for assessing the health of the non-adult populations from Llandough and St Oswald's Priory. They included assessment of both the dentition and the skeleton, both of which may be affected by pathological conditions.

Cribra orbitalia and porotic hyperostosis

Cribra orbitalia appears as areas of porosity on the orbital roof (Fig. 1). In cases of porotic areas on the cranial vault, these lesions are referred to as porotic hyperostosis (Fig. 2). These porous lesions results from the hypertrophy of the diploë (Lewis, 2000). *Cribra orbitalia* and porotic hyperostosis are thought to be an indication of childhood malnutrition and/or pathogen loading resulting in iron deficiency anaemia (Mensforth et al., 1978; Stuart-Macadam, 1991; Ortner, 2003). However, Walker et al. (2009) suggested that these lesions may be the result of megaloblastic anaemia due to vitamin B12 deficiency and gastrointestinal infections. However, this has been rebutted by Oxenham and

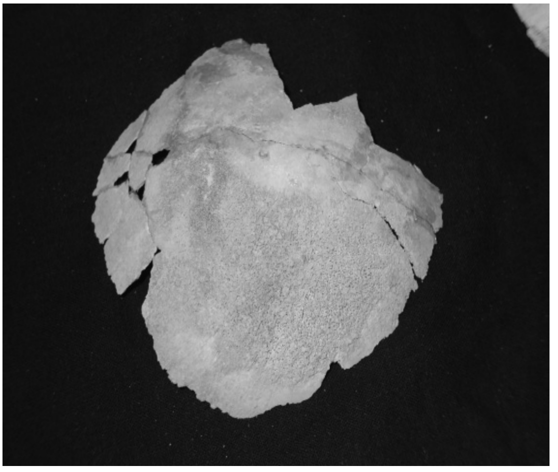

Figure 1. Porotic hyperostosis on the parietal bone of a non-adult from St Oswald's Priory, Gloucester

Figure 2. *Cribra orbitalia* in the right orbit of a non-adult skull from St Oswald's Priory, Gloucester

Cavill (2010) who claim that there was a misunderstanding of the literature with regard to the study of anaemias associated with *cribra orbitalia* and porotic hyperostosis. In this study, *cribra orbitalia* was graded according to the scheme proposed by Stuart-Macadam (1991: 109).

Endocranial lesions

Endocranial lesions can be defined as reactive new bone located on the endocranial surface of the skull (Lewis, 2004). They appear as layers of new bone, primarily on the occipital bone, but can also be observed on the parietal and frontal bones. The cause is unknown but they are thought to be as a result of inflammation or haemorrhage of the meninges (Lewis, 2004), which can be caused by meningitis, tuberculosis, congenital syphilis and vitamin deficiencies (such as vitamin A and D).

Enamel hypoplasia

Enamel hypoplasia is a dental defect due to a developmental disturbance and is observed macroscopically on the surface of the dental crowns (Roberts and Manchester, 2007). It is a deficiency in enamel thickness and it appears as depressions of isolated or aligned pits and/ or of continuous lines or grooves (Goodman and Armelagos, 1985). Many factors contribute to the development of enamel hypoplasia, they can be categorised according to localised trauma, nutritional stress, childhood illnesses, such as measles and hereditary anomalies (Roberts and Manchester, 2007).

Periosteal new bone formation

Periosteal new bone formation is one of the most commonly reported pathological lesions in archaeological human skeletal remains (Weston, 2012). New bone formation is frequently referred to as periostitis, but, as argued by Weston (2008; 2012), this term should be avoided as it refers to the soft tissue membrane and not the bone itself. Periosteal new bone formation can often be observed on the long bones of non-adults skeletons. It is recognised as the deposition of a layer of new bone under an inflamed periosteum as a result of injury or infection (Lewis, 2000). However, the interpretation of periosteal new bone formation can be problematic, particularly on the remains of infants (especially between 1 and 6 months) and children, where it can be misinterpreted as disease when the deposition of immature bone on the cortical surface is the result of normal appositional bone growth (Shopfner, 1966; Mann and Murphy, 1990).

Bone growth

The physical growth and development of children is a sensitive indicator of the quality of the social, economic, and political environments in which they live (Johnson and Zimmer, 1989). The mean diaphyseal lengths were plotted against dental age estimates to produce skeletal growth profiles. Those non-adults aged using long bone lengths were omitted. The lower limbs are considered to be the most sensitive to environmental stress, as the femur and tibia are the fastest-growing bones of the body (Eveleth and Tanner, 1990). Therefore, humeral, femoral and tibial diaphyseal length measurements were chosen to assess growth. Diaphyseal lengths of the long bones were plotted against dental age. Growth profiles for both sites were observed for the humerus, femur and tibia. These are the best preserved bones and the most appropriate to use. However, the femur is the most reliable bone for the study of growth.

Results

Age-at-death

At Llandough, infants (i.e. 0.6-1.5 years) made up the largest category (n=38 or 19%) followed by 2.6-4.5 (n=25 or 12%) and 6.6-8.5 (n=25 or 12%) year olds making up the second largest categories. The perinates (< 40 weeks) made up the smallest age category (n=8 or 3%). At St Oswald's Priory, of the 90 (93%) non-adults which could be assigned an age group, the majority came from the Norman cemetery (n=57 or 64%), followed by Anglo-Saxon (n=17 or 19%) and Post-medieval (n=10 or 11%). Perinates (< 40 weeks) made up the largest category and this was significant (n=22 or 24%; X^2= 21.97; P= 0.001, d.f.1), followed by those aged 0.6-1.5 years (n=13 or 14%) and 2.6-4.5 years (n=16 or 18%) (Table 2 and Fig. 3).

Table 2. Age at death and burial location of the St Oswald's Priory non-adults

	Date range	<40 wks	0-0.5	0.6-1.5	1.6-2.5	2.6-4.5	4.6-6.5	6.6-8.5	8.6-10.5	10.6-14.5	14.6-17.0	Total
Anglo-Saxon	c.900-1120	3 (18)	1 (6)	5 (29)	2 (12)	2 (12)	2 (12)	2 (12)	0 (0)	1 (6)	0 (0)	17 (19)
Norman	c.1120-1230	18 (31)	9 (15)	7 (12)	2 (3)	9 (15)	6 (10)	1 (2)	2 (3)	1 (2)	3 (5)	58 (64)
Late Medieval	c.1230-1540	0 (0)	0 (0)	1 (20)	0 (0)	2 (40)	1 (20)	1 (20)	0 (0)	0 (0)	0 (0)	5 (5)
Post Medieval	c.1540-1855	1 (9)	1 (9)	0 (0)	0 (0)	3 (27)	1 (9)	0 (0)	1 (9)	2 (18)	1 (9)	10 (11)
Total		22 (24)	11(12)	13(14)	4 (4)	16 (18)	10 (11)	4 (4)	3 (3)	4 (4)	4 (4)	90

Table 3. Number and percentage of stress indicators at each site

	Cribra Orbitalia		Porotic hyperostosis		Endocranial lesions		Dental hypoplasia	
	Observed	Affected	Observed	Affected	Observed	Affected	Observed	Affected
Llandough	62 (30)	46 (74)	62 (30)	10 (16)	62 (30)	9 (14)	66 (32)	16 (24)
St Oswald's Priory	59 (61)	8 (13)	69 (71)	1 (1)	60 (71)	5 (7)	58 (60)	3 (5)

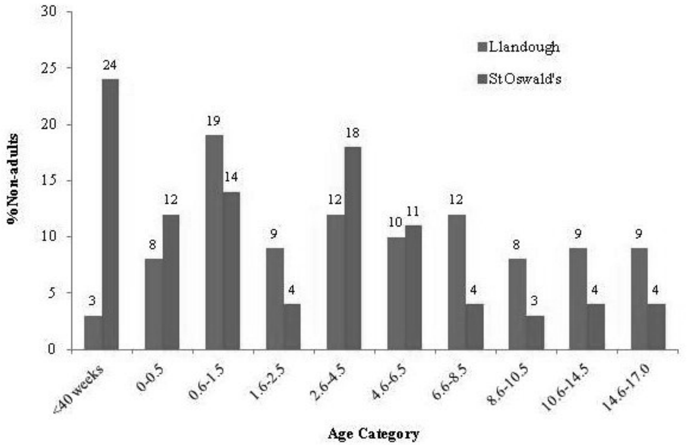

Figure 3. Non-adult mortality profile for Llandough and St Oswald's Priory

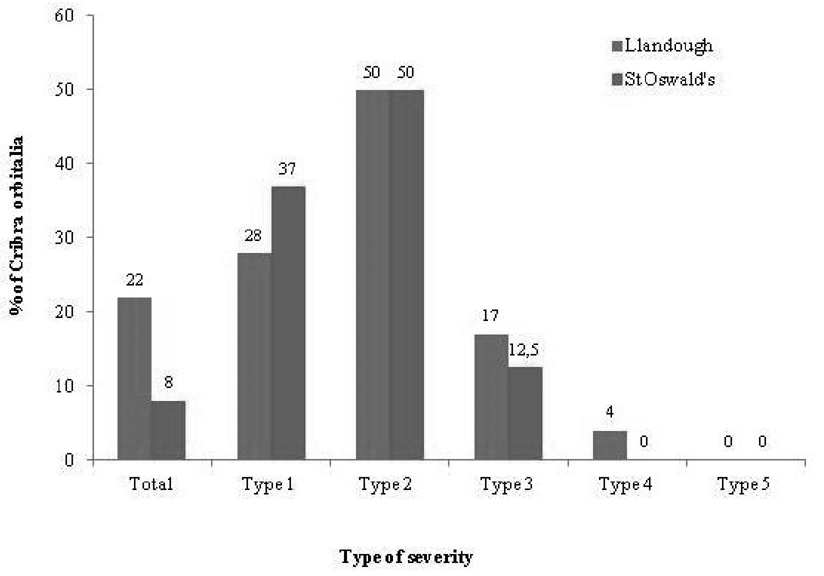

Figure 4. Percentage of *cribra orbitalia* in the non-adults by site and type of severity

Table 4. Number and percentage of stress indicators at each Phase of burial at Llandough

	Cribra Orbitalia	Porotic hyperostosis	Endocranial lesions	Dental hypoplasia	Periosteal New bone formation
Area I	10 (27)	1 (2)	1 (3)	0 (0)	2 (5)
Area II	1 (7)	0 (0)	1 (7)	2 (14)	0 (0)
Area III	32 (21)	9 (6)	7 (4)	13 (8)	24 (16)
Total	43 (28)	10 (6)	9 (4)	15 (10)	26 (17)

Table 5. Number and percentage of skeletons showing non-specific stress indicators at each age group

Site	*Cribra Orbitalia*	Porotic hyperostosis	Endocranial lesions	Dental hypoplasia	Periosteal New bone formation
Llandough					
<40 weeks	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
0-0.5	2 (12)	3 (19)	0 (0)	0 (0)	2 (12)
0.6-1.5	6 (16)	2 (5)	0(0)	0 (0)	6 (16)
1.6-2.5	8 (44)	1 (5)	5(28)	1 (5)	4 (22)
2.6-4.5	4 (16)	3 (12)	1 (4)	2 (8)	5 (20)
4.6-6.5	7 (33)	0 (0)	0 (0)	3 (14)	2 (9)
6.6-8.5	5 (20)	1 (4)	0 (0)	3 (12)	2 (8)
8.6-10.5	3 (19)	0 (0)	0 (0)	2 (12)	1 (6)
10.6-14.5	4 (22)	0 (0)	0 (0)	4 (22)	0 (0)
14.6-17.0	7 (39)	2 (11)	3 (17)	0 (0)	4 (22)
Total	46	12	9	15	26
St Oswald's Priory					
<40 weeks	1(4)	0 (0)	1 (4)	0 (0)	3 (14)
0-0.5	0 (0)	0 (0)	1 (9)	0 (0)	7 (64)
0.6-1.5	0 (0)	0 (0)	0 (0)	0 (0)	4 (31)
1.6-2.5	1 (25)	0 (0)	0 (0)	0 (0)	0 (0)
2.6-4.5	2 (12)	0 (0)	1 (6)	0 (0)	2 (12)
4.6-6.5	2 (20)	0 (0)	0 (0)	1 (10)	1 (10)
6.6-8.5	1 (25)	0 (0)	0 (0)	0 (0)	0 (0)
8.6-10.5	1 (33)	1(33)	1 (33)	0 (0)	0 (0)
10.6-14.5	0 (0)	0 (0)	0 (0)	2 (50)	0 (0)
14.6-17.0	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
Total	8	1	4	3	17

Table 6. Number and percentage of stress indicators at each period of burial at St Oswald's Priory

	Cribra Orbitalia	Porotic hyperostosis	Endocranial lesions	Dental hypoplasia	Periosteal New bone formation
Anglo-Saxon	0 (0)	0 (0)	1 (6)	0 (0)	1 (6)
Norman	4 (7)	0 (0)	3 (5)	1 (17)	12 (21)
Late Medieval	2 (40)	1 (20)	1(20)	0 (0)	0 (0)
Post Medieval	0 (0)	0 (0)	0 (0)	2 (20)	3 (30)
Total	6 (7)	1 (1)	5 (5)	3 (3)	16 (18)

Table 7. Number and percentage of periosteal new bone formation at each site

	Humerus		Radius		Ulna		Femur		Tibia		Fibula	
	Observed	Affected	Observed	Affected	Observed	Affected	Observed	Affected	Observed	Affected	Observed	Affected
Llandough	140 (34)	1(1)	78 (19)	3 (4)	104 (25)	2 (2)	141 (34)	5 (3)	118 (58)	15 (13)	102 (25)	5 (5)
St Oswald's Priory	129 (67)	5 (4)	109 (57)	2 (2)	123 (64)	2 (2)	137 (71)	7 (5)	129 (67)	9 (7)	114 (59)	2 (2)

Pathological study

Stress indicators

At Llandough, of the 204 skeletons examined, 62 (30%) had orbits present, of which 46 (75%) exhibited *cribra orbitalia* (Table 3), this was significantly higher when compared to those at St Oswald's (X^2= 18.21; P= 0.00, d.f.1). Type 1 and 2 were observed in 28% and 50% of cases, respectively (Fig. 4), 70% exhibited type 3 lesions and 4% type 4 (Fig. 4). At St Oswald's Priory, 59 (61%) skeletons had orbits preserved, of which 8 (13%) exhibited *cribra orbitalia* (Table 3), with type 1 and type 2 present, respectively, in 37% and 50% of cases (Fig. 4). Type 3 was observed in 12.5% of cases. Only one case (1%) of porotic hyperostosis was observed in the late medieval cemetery at St Oswald's Priory. Porotic hyperostosis was observed on the cranial vaults of ten skeletons (16%; X^2= 7.71; P= 0.00, d.f.1) from Llandough, with the majority of cases (n=9 or 6%) from Area III (Tables 3 and 4). At Llandough, the prevalence of *cribra orbitalia* peaked at the ages of 0.6-1.5 years (n= 6 or 16%), at 2.6-4.5 years (n= 8 or 44%) and at 14.6-17.0 years (n= 7 or 39%), whereas at St Oswald's *cribra orbita-*

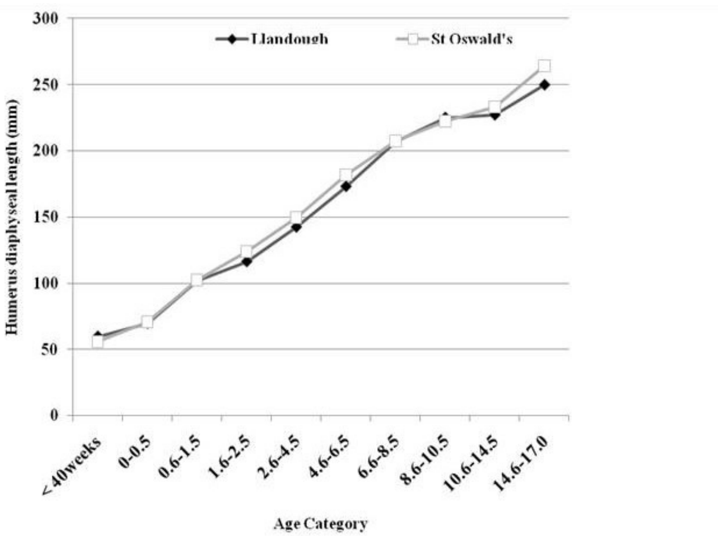

Figure 5. The mean humeral diaphyseal lengths for each age category

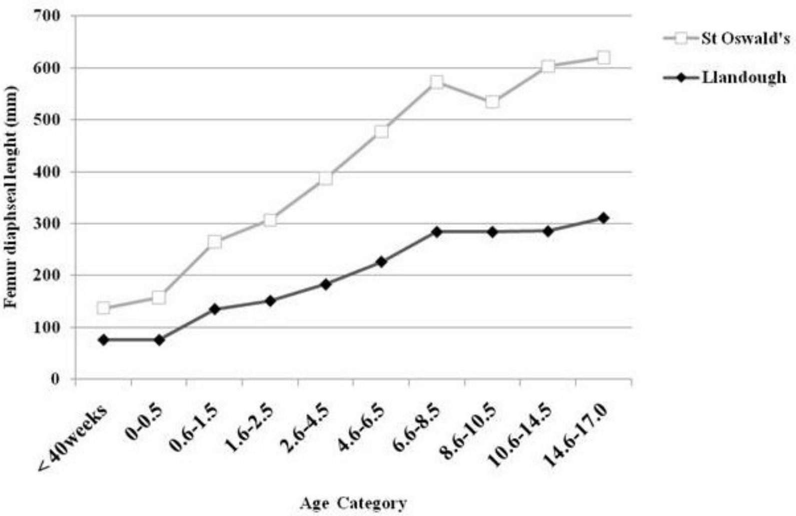

Figure 6. The mean femoral diaphyseal lengths for each age category

lia was most prevalence at age groups 2.6-4.5 years and 4.6-6.5 years (Table 5).

There were five (7%) skeletons displaying endocranial lesions at St Oswald's Priory, with most cases observed at the Norman cemetery (Table 6). Three cases affected the parietal bone, two cases the frontal bone and one case was

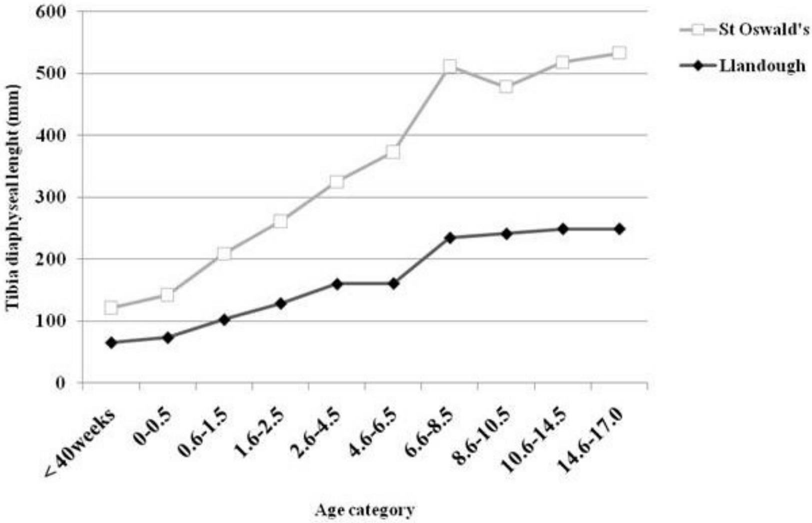

Figure 7. The mean tibial diaphyseal lengths for each age category

evident on the occipital bone. One case displayed endocranial lesions on all three bones. At Llandough, the prevalence of endocranial lesions peaked at 1.6-2.5 years (n= 5 or 28%) and at 14.6-17.0 years (n= 3 or 17%). This is in contrast to those from St Oswald's, where endocranial lesions were observed at <40 weeks (n= 1 or 4%), 0-0.5 years (n= 1or 9%), 2.6-4.5 years (n= 1 or 6%) and at the ages of 8.6-10.5 years (n=1 or 33%) (Table 5).

At Llandough, 15 (7%) of the skeletons displayed dental hypoplasia. With peaks at the ages of 4.6-6.5 years and 6.6-8.5 years (n= 3 or 4%) and also in the older age category of 10.6-14.5 years (n= 4 or 22%) (Table 5). At St Oswald's, there was a similar peak at 10.6-14.5 years (n=2 or 25%).

At St Oswald's, 24% (21/87) of the non-adults displayed periosteal new bone formation on one or more of the long bones, with the tibia the most affected bone (n=9 or 7%), followed by the femur (n=7 or 5%). The rate of periosteal new bone formation was higher at Llandough, with a total of 26 cases (13%) (Table 7). The tibia was again the most affected bone, with 15 (13%) displaying evidence of new bone formation. The femur and fibula also displayed lesions (n= 5 or 3% and n=5 or 5% respectively) (Table 7).

Long bone growth

Both sites show a similar pattern of growth for the humerus (Fig. 5), but there was substantial difference in the growth of the lower limbs (Figs. 6 and 7). Children at Llandough were considerable shorter than their peers at St Oswald's Priory at all age groups, especially so from the ages of 6.6-8.5 years up to 14.6-17.0 years.

Discussion

There are many factors which play a role in the prevalence of disease(s) diagnosed in non-adult skeletal remains. According to Wood et al. (1992), skeletal samples displaying pathological lesions and other stress indicators represent the disadvantaged within that society, however, this is paradoxical. It is likely that those individuals who display various pathological lesions are those individuals which recovered sufficiently to resume growth. Another factor which has long being recognised is selective mortality, as a cemetery population do not represent the living population (Buikstra and Cook, 1980; Wood et al., 1992). It must be remembered that any data derived from a cemetery sample measures the rate of burial and not mortality (Lewis, 2000).

There was a low number of foetal and perinate remains recovered at Llandough, thus indicating low mortality. However, limited numbers of infant skeletons have been recovered from early medieval cemeteries and this is often attributed to the fact that children were buried elsewhere, or in certain unexcavated areas of a cemetery (Crawford, 1993). By the 12th century, baptism became compulsory for all newborns, hence their burial in cemeteries (Alexandre-Bidon, 1999). This may be reflected in the numbers recovered from Area III at Llandough, albeit a small number. At St Oswald's Priory, there is an increase in the number of perinates and infants recovered from the Norman cemetery, but this area of burial may have served a different purpose, such as the burial of unbaptised children, which were commonly buried near to or outside the church walls. At the site of Llandough, it was noted by Nenk et al. (1995: 228) that the group of infants buried in the north of the cemetery was 'a special cause or event'. It has been hypothesised that these individuals were once buried within an area that was marked out by a boundary, possibly a timber structure. Such structures have been found in other early medieval Welsh cemeteries and are thought to stand over 'special graves' (James, 1992; Loe, 2003). This would suggest an earlier practice of clustering infants.

Iron deficiency anaemia is the most probable cause of *cribra orbitalia* and porotic hyperostosis observed in the children from both Llandough and St Oswald's Priory. Iron-deficiency anaemia may be caused through blood loss, poor diet, and or exposure to environments with a high pathogen load. However, Walker et al. (2009) argued that, iron-deficiency anaemia is a major health problem today and is associated with reduced synthesis of haemoglobin and red blood cell production; physiologically it cannot be responsible for the marrow expansion associated with *cribra orbitalia* and porotic hyperostosis in skeletal remains. Those authors argue that a deficiency of vitamin B9 (folic acid) and vitamin B12 is the mostly likely cause (Walker et al., 2009). Also Fairgrieve and Molto (2000) found a link between *cribra orbitalia* and a lack of folic acid. However, other causes of *cribra orbitalia* and porotic hyperostosis include scurvy, rickets, inflammatory processes and haemorrhage due to trauma (Novak and Šlaus, 2010). The highest level of *cribra orbitalia* was observed in the 1.6-2.5 years, this corresponds to other studies from early and late medieval England (Lewis, 2002). The increase in *cribra orbitalia* in the older children may occur due to the increase in growth and development and the need for iron during this period. Other potential causes may be due to that of lead-working, which was taking place in early medieval Llandough, but it would be more significant in the earlier phase of the cemetery (c. 500-800 AD), when there would have being an increase in mining and smelting (Loe, 2003). In other studies, high levels of *cribra orbitalia* have been observed. In children from southeast Asia, 75% of the skeletons (1-14 years) studied had evidence of *cribra orbitalia*, suggesting that the non-surviving were under considerable stress at the time of their death (Oxenham et al., 2008). A study by Obertová and Thurzo (2008) shows that 49% of the non-adults studied had orbital lesions, affecting most age groups; 0-4 years (72%), 5-9 years (83%) and 10-14 years (86%), also the highest level of hypoplastic lesions was observed among the 10-14 years age group (44%) (Obertová and Thurzo, 2008). There was a similar finding by Beňuš et al. (2010) on several Slavic samples, where there was an increase in *cribra orbitalia* among the 1-4 years age group and 5-9 years. In further studies from medieval Poland, high levels of *cribra orbitalia* was observed in those aged 0-7 (47%) and 7-15 years (50%) (Piontek and Kozlowski, 2002). The same happened in studies from Roman Italy (Facchini et al., 2004).

Infections such as malaria may have existed at Llandough. Although it has been suggested that woodlands would not have changed much since the Roman period, however, any clearance of woodland would have given way to marshy wetlands and thus providing a good breeding ground for malaria (Roberts and Cox, 2003). Davies (1982) refers to the presence of bogs and marshes which would make good breeding ground for the pathogen in medieval Wales. However, while there is a high prevalence of *cribra orbitalia* at Llandough, linking it to malaria would require further biomolecular investigation.

High frequency of enamel hypoplasia suggests the children survived strong metabolic stress during childhood, possibly as a result of weaning. Weaning marks a sensitive period during early childhood, where making the transition from sterile breast milk to a diet rich in microorganisms can cause a number of infectious disease that are accompanied by diarrhoea. Diarrhoea reduces appetite in children and increases metabolic loss of nutrients, for example iron, which may lead to the occurrence of anaemia despite a sufficient diet (Novak and Šlaus, 2010). Loe (2003) observed that those children aged 3 to 5 years of age showed evidence of *cribra orbitalia*, porotic hyperostosis, infection and possible scurvy. She also observed an increased in levels of enamel hypoplasis at the ages of 4 to 6 years; 10-12 years and 12-14 years, with those aged 12-14 years having the highest level of enamel hypoplasis and *cribra orbitalia*. This is similar to the findings of the current study (Table 5). It is possible that the non-adult Llandough population were subjected to repeated stress as a result of illness and nutritional deficiencies and as a result those children (4-10 years) and adolescents (12-14 years) once they reached the pubertal growth stage could not cope with additional stress, hence the observed frequency of hypoplasic lesions and *cribra orbitalia*. It is also known that in medieval Europe children as young as seven years were sent out to work within their communities (Power, 1986; Shahar, 1990; Whyte, 2009). This could have been a contributing factor in ill health of the children of Llandough, thus, depending on the amount of physical labour involved coupled with malnutrition, the children of this age group may have fallen sick more readily. In Gloucester, it was known that children of this age were involved in farming (Herbert, 1988).

Growth can be affected by nutrition, disease, socioeconomic status, urbanisation, migration, physical activity, physiological stress, noise and air pollution and climate (Bogin, 1988; Eveleth and Tanner, 1990). It was hypothesized that the children from both sites would have had similar growth profiles due to the similar rural environments, however, that is not the case as the children from Llandough were particularly disadvantaged through their growth profiles (Figs. 6 and 7), which shows them to be considerable shorter than their peers at St Oswald's Priory, particularly at the ages of 6.6-8.5 years up to 14.6-17.0 years. This coincides with the increase in *cribra orbitalia* at these ages. Also, some studies have shown that there is an association between the stress indicators such as linear enamel hypoplasia (LEH) and the lower than average diaphyseal long bone lengths (Schillaci et al., 2011; Pinhasi et al., 2013) depending on the severity of the condition.

Conclusions

The skeletal remains of children can reveal a wealth of information with regard to mortality, health and disease in past populations. The children interred at Llandough would appear to have suffered increased ill health compared to those buried at St Oswald's Priory. They displayed a higher frequency of stress indictors, which is likely as a result of higher exposure to risk and greater susceptibility of these children to infection and malnutrition. This is also supported by the growth profiles which show them to be considerable shorter than those children at the neighbouring site of St Oswald's Priory.

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