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Vitamin D deficiency rickets in early medieval Wales: a multi-methodological case study

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Abstract

Between 2014 and 2016 an early medieval cemetery dating to between the eighth and eleventh centuries AD was excavated at Whitesands Bay, Pembrokeshire, Wales. The excavation beneath St Patrick's Chapel revealed a cemetery population of adult males, females and a large proportion of non-adults below 18 years of age. Osteological analysis revealed a case of vitamin D deficiency rickets in a 2-3 year old child, which was further confirmed through the histological analysis of the first permanent molar tooth. This paper presents the results of the osteological, radiographic and histological analyses, which support the diagnosis of vitamin D deficiency. The research demonstrates the valuable contribution a multi-methodological approach can make to the investigation of non-adult health, particularly when factors such as taphonomic damage hamper the macroscopic study of the skeleton. The evidence collated here allows further exploration of the possible circumstances which led to this condition, and makes a valuable contribution to an otherwise small number of cases of rickets from early medieval Britain.

Keywords

Rickets, early medieval, histology, interglobular dentine

Introduction

Reported cases of vitamin D deficiency for early medieval populations from Britain are rare. Indeed, there are only seven cases – all from England – dating between the fifth and the tenth centuries AD (Roberts and Cox 2003: 189; Brickley and Ives 2008: 134-150). Examples include an adolescent and three younger children from the cemetery excavated at Norwich Castle, Norfolk (Stirland 1985), an infant aged 6 months - 2.5 years from Raunds Furnells, Northamptonshire (Lewis 2002), and a case from Tanner's Row, Pontefract, West Yorkshire (Lee, cited in Cox and Roberts 1999). The potential to further enhance the corpus of osteological data comes from the recently excavated eight to eleventh century AD cemetery beneath St Patrick's Chapel, Pembrokeshire (Murphy et al., in prep) (Fig. 1). Osteological analysis has revealed a population of adult males, females and a significant proportion of non-adults, representing 60% of the recorded skeletal sample. During the macroscopic analysis of the remains, a non-adult was tentatively diagnosed with vitamin D deficiency, which was subsequently confirmed through histological analysis. Moreover, the histology confirmed at least two different episodes of rickets in this individual's lifetime. This paper will first introduce the cemetery and context of the burial, whilst a brief background to vitamin D deficiency is given. The paper proceeds to reveal how the diagnosis of vitamin D was established through in-depth analysis, employing macroscopic, radiographic and histological analysis. Finally, the discussion will explore the possible reasons for the occurrence of this condition amongst a rural, coastal population.

Vitamin D deficiency

Vitamin D is a pre-hormone and must be transformed by the body in order to be utilized effectively (Pettifor 2003: 543; Holick 2007: 266; Brickley and Ives 2008: 77). Unless the pre-hormone is activated, a deficiency in the vitamin can occur (Ortner and Mays 1998: 46; Brickley et al., 2014: 49). The primary function of vitamin D is to facilitate the absorption of calcium and phosphate from the intestines, both of which are required for cellular, muscular, and skeletal functions (Holick 2007: 267; Brickley and Ives 2008: 75). Prolonged vitamin D deficiency leads to a depletion in calcium and phosphorous in the blood serum which inhibits or delays the skeletons' ability to mineralize osteoid i.e. the precursor to bone, and results in skeletal osteopenia (Brickley and Ives 2008: 75-76; Brickley et al., 2014: 52).

Conditions that cause vitamin D deficiency include genetic abnormalities (i.e. X-linked hypophosphataemia), renal disease, and gastrointestinal disorders affecting absorption. However, studies have shown that dietary vitamin D deficiency and inadequate exposure to sunlight are the more common contributing factors, with the latter being particularly significant (Pettifor 2003; Portale and Miller 2003; Holick 2007; Brickley and Ives 2008; Snoddy et al., 2016; Brickley and Mays 2018). Limited exposure to sunlight can be caused by cultural factors including the swaddling of infants, the use of long clothing and head/face coverings, as well as limitations on the amount of time spent outdoors (Hollis and Wagner 2004: 718; Holick 2007: 267; Brickley and Ives 2008: 78, 82; Pettifor and Prentice 2011: 575). In built-up or industrialised areas, exposure to sunlight can be further inhibited by air pollution and urban architecture (Brickley and Ives 2008: 78). Populations inhabiting northerly latitudes as well as parts of Europe, including the British Isles, where there are fewer daylight hours during winter, are also at increased risk of vitamin D deficiency (Holick 2007, 267; Brickley and Ives 2008: 80-81).

Rickets is the term used to describe the impact of vitamin D, calcium, or phosphorous deficiency on bone mineralization at sites of endochondral growth in the non-adult skeleton. The continual development of the cartilage within the endochondral growth sites becomes disorganized and causes the bone to splay in response to mechanical forces during weight bearing. Any new bone formation after the introduction of vitamin D will follow the template of the disorganized cartilage (Ortner and Mays 1998: 46; Pettifor 2003, 555; Brickley and Ives 2008: 90). Rickets most commonly affects infants between 3 and 24 months of age. Changes to the non-adult skeleton associated with rickets can therefore be determined by the age of the individual when the deficiency arose. For example, bowing in the arms and legs may relate to the weight bearing associated with learning to crawl (Brickley and Ives 2008: 92), whilst bowing deformities confined to the lower extremities indicate that the individual was learning, or had learnt, to walk during the onset of the condition (Ortner and Mays 1998: 52). It is therefore necessary to recognise the pattern of skeletal changes when considering when and why the condition might have arisen.

Materials and Methods

Archaeological context

Three seasons of excavation took place at the site of St Patrick's Chapel, Pembrokeshire between 2014-2016 as part of a collaborative project between Dyfed Archaeological Trust and KH. The site, which overlooks the beach at Whitesands Bay, became at risk from coastal erosion during the winter storms of 2013/2014 (Fig. 1). During this time, human remains were exposed on the seaward edge of the dune (Murphy et al., 2016). With the help of local volunteers, excavation focused on the most 'at risk' area of archaeology in front of a ruined, medieval chapel broadly dated to the twelfth to thirteenth centuries AD (Murphy et al., 2016) (Fig. 2).

The excavation revealed a cemetery beneath St Patrick's Chapel which was situated in a dune of wind-blown sand. At the time of the earliest burials, the sand was approximately 1.5m-2m deep. The first notable feature constructed at the cemetery was a large boundary wall approximately 1m high built from large boulders from the nearby beach; this wall dates to the 8th and 9th centuries AD. Two substantial boulders were used to mark the entrance to a defined rectangular area inside the wall where the earliest phase of burials were inserted (Murphy et al., in prep). Gradually, windblown sand accumulated both inside and outside the wall covering this first phase of burial, and further burials were dug into the next layer of sand. The process of sand accumulation followed by burial continued sequentially until the eleventh or twelfth century AD (Murphy et al., in prep). Radiocarbon dating suggests the main phase of burial activity spanned a *c.* 200-year period from *c.* AD 775 to AD 975 (Murphy et al., in prep).

The burials excavated at the cemetery represent various forms. Simple, unfurnished sand-dug graves were the most common form of grave type, whilst more complex grave types were also present; these include long cist graves constructed from stone slabs around the inside of the grave, lintel long cist graves with stone sides capped with lintel slabs, and cist graves capped with white quartz pebbles (Murphy et al., in press). Some skeletons appear to have been shrouded, whilst two cross-inscribed grave slabs confirm that this was a Christian community. The majority of individuals were buried as single interments in a supine position, however, there were also examples of flexed, prone, and multiple burials. Whilst excavation continues at the site, 89 graves and 85 articulated skeletons have been excavated to date. The skeletal remains include adults of both sexes, whilst non-adults of all ages form a significant group, representing 60% of the population excavated so far (Murphy et al., in prep). The excavated skeletal remains were first recorded in-situ, and subsequently transferred to the University of Sheffield for further analysis by the present authors.

Skeleton 278

Skeleton 278 was buried in a simple sand-dug grave, oriented east to west with the head at the west end of the grave (Murphy et al., 2016: 33). The body was placed in a supine position with the head turned to the right, their arms by their sides, and their left leg crossed over and resting at the ankles of the right leg (Fig. 3). Based on a combination of radiocarbon dating and stratigraphy, the skeleton can be dated to the 9th century AD.

Skeletal inventory

A macroscopic assessment of Skeleton 278 was undertaken following standard osteological methods of recording (see below). An inventory of the skeleton and dentition was completed, noting the degree of preservation, including completeness, fragmentation, and surface erosion (McKinley 2004: 16). The skeleton was a non-adult, and therefore age-at-death was estimated based on epiphyseal fusion (Scheuer and Black 2000), and dental development and eruption according to Al Qahtani et al.'s (2010) modification of Moorrees et al., (1963). It is not possible to sex non-adult skeletons through current macroscopic osteological methods. All bone surfaces were observed and skeletal pathologies were recorded noting details such as the location, size, and type of bone formation (e.g. woven/lamellar) or destruction, whilst dental pathologies were recorded on the basis of tooth affected, type of alteration (e.g. dental enamel hypoplasia) and severity (Roberts and Connell 2004: 34-39). All pathologies were photographed.

Radiography and dental histology

When an individual experiences a disruption to the synthesis of vitamin D, both the skeleton and teeth are affected. Pathological changes to the left femur (see Results) were investigated through radiographic analysis with images taken in the antero-posterior view using a NOMAD Pro handheld x-ray system at 60kVp and 2.5mAs. In the teeth, dentine mineralization is reduced or disrupted, and the calcospherites (calcium salts) within the dentine fail to grow and coalesce (Vital et al., 2012; D'Ortenzio et al., 2016: 152-153). The result is the formation of voids known as interglobular dentine (IGD). IGD appear as dark, disorganized spaces which contrast the appearance of homogenous healthy dentine (D'Ortenzio et al., 2016: 152-154). The histological analysis of teeth, specifically the crown, provides the opportunity to identify IGD and confirm the diagnosis of vitamin D deficiency in cases where the skeletal evidence would benefit from additional support. As such, a decision was made to sample a tooth from Skeleton 278 in order to identify the presence or absence of IGD.

The first permanent molar tooth was sectioned longitudinally and bucco-lingually using a diamond coated dental wheel hand-saw. One half of the tooth was reserved, whilst the other half was polished using a Buehler Metaserv grinder/polisher to remove any uneven cut marks and to create a flat surface. The polished sample was mounted on a frosted microscope slide using Norland Optical Adhesive 61 and cured under UV light for 24 hours. Once dried, a thin section was made using a Hillquist thin section machine. First, the sample was cut to a thickness of approximately 300um to remove any excess material. The sample was then ground to approximately 200um and assessed periodically under polarised light to determine the visibility of features within the sample. The thin section was ground to a final thickness of 100um-120um. Once this thickness was reached, the sample was cleaned thoroughly using deionized water and allowed to dry, after which a cover slip was adhered to the slide using Norland Optical Adhesive 61. The section was analysed under normal and polarized light using a Leica DM 2700 P microscope fitted with polarizing filters at 20Å~, 40Å~ and 100Å~ magnification, and images were acquired using a Leica MC170 HD microscope-incorporated camera.

Results

Approximately 50-75% of the skeleton was present. Whilst most long bones were complete, albeit damaged, the axial skeleton – including the ribs and spine – were significantly damaged. The cranium was present but highly fragmented, and the facial bones were destroyed. Bone surface erosion was moderate, affecting most bone surfaces and recorded as Grade 3 (McKinley 2004: 16). Based on the available dentition, the skeleton was between 2 and 3 years of age at the time of death.

Pathological changes

The following pathological bone changes affecting the cranium and post-cranial skeleton were recorded. Observation of the cranial fragments identified a small, single fragment of parietal bone which exhibited porosity on the ectocranial surface (Fig. 4). Mild linear enamel hypoplasia (LEH), caused by the disruption of enamel formation during periods of physiological stress (Hillson 2005), was identified upon both developing crowns of the permanent maxillary canines. Both linear defects were recorded as Level 2 severity according to Powers (2012), and both defects were situated at the mid-point of the developing canine crowns. Using the method of

Primeau et al., (2015: 386, Fig. 1) to estimate the age of LEH formation, these defects formed between 2 - 2.9 years of age.

Pathological changes to the skeleton are concentrated predominantly on the lower left long bones. The left femur exhibited superior flattening and flaring of the distal metaphysis. The preservation of the metaphyseal ends was generally poor, however, the portions of the metaphyseal surfaces that could be observed (namely the left proximal femur, left partial distal femur, left distal tibia, right proximal tibia) had a normal appearance (Brickley and Mays 2019: 542). Antero-posterior bowing was observed in the mid-distal segment of the left femur (Fig. 5), whilst medio-lateral bowing exists in the left fibula (Fig. 6). Unfortunately, a partial left tibia meant it was difficult to identify bowing deformities affecting this bone. The presence of bowing in the right femur could not be established due to taphonomic damage to the proximal and distal ends. The right fibula, albeit fragmentary, did not show bowing, but did exhibit lamellar bone on the medial surface of the distal portion of the diaphysis. No bowing deformities or new bone formation were observed in the upper long bones.

Radiographic assessment

Radiographic analysis was undertaken on the left femur of Skeleton 278 (Fig. 7). There are no apparent signs of a recent fracture along the shaft of the bone. Slight thinning of the cortical bone is apparent at the proximal and distal thirds of the shaft. The endosteal surface of the cortical bone is demarcated by a thick white line, and the distal metaphysis is also well defined, with no apparent fraying of the bone end, however, postmortem damage does obscure the observation of the metaphyseal surface. The presence of a clearly defined endosteal surface suggests that at the time of death, the episode of vitamin D deficiency was not active, but rather the long bone diaphysis demonstrates evidence of healing (Brickley and Ives 2008: 106-107). In the distal segment of the diaphysis, two radiopaque transverse lines – commonly known as Harris' lines – can be observed (Fig. 7); these lines are thought to reflect periods of delayed growth caused by episodes of malnutrition and/or disease, followed by catch-up growth (Mays 1995; Alfonso-Durruty 2011; Geber 2014).

Differential diagnosis

Bowing of the long bones is often taken as evidence for the occurrence of rickets, however, other conditions can result in bowing deformities, including trauma (i.e. traumatic bowing deformity), osteogenesis imperfecta, Blount's disease, Caffey's disease, and metaphyseal chondrodysplasia (see Brickley and Ives 2008: 115-117). There is also a close relationship between rickets and vitamin C deficiency (scurvy), and changes associated with rickets such as flaring and swelling of the costochondral rib junctions, and the flaring of the distal metaphyses of the long bones can also manifest in cases of scurvy (Brickley and Ives, 2008: 57). Macroscopic features of scurvy also include extensive new bone formation affecting the ends of the long bones, extensive porosity and/or new bone formation affecting the cranium and orbits, as well as fractures (Ortner 2003; Brickley and Ives 2008: 56-61; Lewis 2017: 218). The alternative diagnosis of scurvy is in doubt here as only a small area of lamellar bone was identified on the right fibula, whilst only a single parietal fragment exhibited porosity (Fig. 4). Given the asymmetry of the bowing changes affecting the left leg, traumatic bowing is a possible differential diagnosis. There are no signs of fracture in the radiograph (Fig. 7), but traumatic bowing does not necessarily leave clear radiographic signs (Verlinden 2015: 75; Lewis 2017: 102). However, as the deformity affected both the left femur and left fibula, a systematic condition rather than a single traumatic event seems a more likely cause.

In cases such as this where the osteological evidence remains ambiguous, histological analysis of the teeth can offer additional support to the diagnosis. Recent advances in the study of vitamin D deficiency have highlighted the potential of analyzing tooth dentine in order to identify microscopic mineralization defects that arise in vitamin D deficient individuals (D'Ortenzio et al., 2016: 161; Veselka et al., 2019).

Histological analysis

Observation of the dental thin section for Skeleton 278 revealed the presence of interglobular dentine arising from the disrupted fusion of dentine calcospherites (Fig 9). Figure 9 shows two separate bands of IGD; Band 1 is located below the margin of the tooth crown, whilst Band 2 is close to the upper margin of the pulp horn. Based on the scoring system of D'Ortenzio et al. (2016: 157), both bands of IGD exhibit moderately large interglobular spaces and are thus classed as Grade 2 (IGD+) severity. Consideration was given to the location of the IGD bands in order to estimate the approximate age of the individual at the time of band formation using D'Ortenzio et al. (2016, Fig. 5). The proximity of Band 1 to the tooth crown suggests that the first disruption to dentine formation spans the period between 6 and 18 months of age, whilst Band 2 suggests a second episode of disruption between 2 and 2.5 years of age.

Discussion

The case presented here is that of a young child from an early medieval population, whose health and physiological development during the first few years of life was compromised. The combination of skeletal changes and histological evidence for disrupted dentine formation indicate this child experienced vitamin D deficiency from infancy. The following can therefore be inferred about this child's life based on the available evidence.

The occurrence of rickets in pre-Industrial societies is likely to reflect factors associated with living conditions, infant care practices, and/or diet (Brickley and Ives 2008: 96). The child from St Patrick's Chapel developed rickets for the first time in the second half of their first year of life, and therefore it is necessary to consider the influence that infant care practices may have had on the child. For example, we might assume the child was breastfeeding since carbon and nitrogen isotope data indicates that infants in this population were breastfed for the first year of life (Hemer et al., 2017). The possibility that the first episode of IGD may reflect a maternal vitamin D deficiency that compounded an existing deficit in the breastfeeding child was considered. However, in their study of rickets in the Roman Empire, Mays et al. (2018: 491) argue that breastmilk contains so little vitamin D that milk from a deficient mother is unlikely to influence the levels in the feeding infant. Likewise, consideration was given to the consumption of inadequate weaning foods such as the cereal-based 'pap' (a mixture of flour or bread in water), which was used for weaning during the medieval period in Britain (Brickley and Ives 2008: 84, 93; Gilchrist 2012: 50; Brickley et al., 2014: 51). However, as Mays et al. (2018: 491) note, most foods are low in vitamin D, and prior to the advent of fortification, would have made little contribution to a person's daily vitamin D intake. As such, other factors unrelated to diet have to account for vitamin D deficiency in pre-Industrial populations (Mays et al., 2018). The most significant factor appears to be exposure to sunlight, or lack thereof, which can arise from childcare practices such as swaddling.

Swaddling was recommended in the twelfth and thirteenth centuries as a way to strengthen and protect the limbs of infants (Gilchrist 2012: 79; MacLehose 2006: 50-54). For example, in the twelfth century, the Welsh clergyman and author of *Topographia Hibernum*, Giraldus Cambrensis, refers to infants in Ireland as:

> "not placed in cradles, or swathed, nor are their tender limbs either fomented by constant bathings, or adjusted with art"
>
> (Giraldus Cambrensis, Ch. 10, Forester 2000: 68)

Giraldus Cambrensis travelled extensively around the British Isles, and therefore his account from Ireland may also reflect some familiarity with, or perhaps even comparison to, childcare practices in Wales and England. That said, it is uncertain how much further back into the early medieval period practices such as swaddling were known or used (Mui 2015: 155). Indeed, Crawford (1999: 68) argues that earlier tenth-century imagery does not show the use of tightly plaited bandages portrayed in later medieval illustrations; for example, images in the tenth-century Junius manuscript look more like loose wrappings (Mui 2015). This is also reinforced by textual evidence; the tenth century writings of the homilist Aelfric of Eynsham describe Christ being wrapped in cloths but not tightly swaddled. This might therefore be a better representation of how infants in the early medieval period in England, and perhaps also in Wales, were clothed (Crawford 1999: 68).

Loose wrappings would have been better for the child, since tight swaddling has been known to cause bowing and fractures in the long bones and ribs of young infants (Brickley and Ives 2008: 92), although wrapping would still have reduced the amount of sunlight exposure during the day. Whether or not infants were allowed to crawl during this time is unclear; certainly in the case of Skeleton 278, no bowing deformities were evident from the upper limbs. It is possible that bowing of the forearms did occur initially, but then remodeled after the first rachitic episode, and during a period of recovery (Brickley and Mays 2019: 541). Moreover, since only the left leg displays bowing may be due to the fact that originally the deformations were more severe on this side than the other. As nearly two years passed before the child died, it is possible that the initial deformities remodeled completely.

The histological evidence shows the child developed rickets again in the first half of their third year of life. It is possible that the vitamin D deficiency was seasonal – coinciding with two successive winters – with the child developing rickets at the age of 1 and then again at the age of 2. The area of normal dentine formation between the two bands of IGD represents a period of improved vitamin D synthesis arising from greater sunlight exposure, perhaps alongside a more nutritious diet (Fig. 8). Although the age estimates for the bands of IGD are broad, other studies have reported similar evidence for the occurrence of so-called seasonal vitamin D deficiency through the identification of IGD. Veselka et al. (2019: 129) report multiple IGD episodes in teeth from two 19th-century populations from northern Holland, and Colombo et al. (2019: 391) report similar evidence for seasonal variation in teeth from medieval France. In the case of Skeleton 278, seasonal vitamin D deficiency may explain why the individual's skeleton shows some evidence of 'catch-up growth'. The two Harris' lines indicate two episodes of poor health followed by a period of improvement (Pinhasi et al., 2006) (Fig. 7). Likewise, the presence of hypoplastic lesions on the crowns of the developing permanent canines followed by the formation of 'healthy' enamel (without defects) also indicate an episode of ill health and subsequent recovery during the third year of life. The changes noted in the skeleton were certainly not severe, perhaps either because the child was of limited mobility, or because the deformation of the lower limbs remodeled rapidly during a period of improved health.

Other factors limiting exposure to sunlight and thus influencing vitamin D synthesis must also be considered. It is possible that the child was kept indoors for a different reason, for instance, a different illness that is not otherwise visible on the skeleton. This has been suggested previously to explain rickets in children from other rural medieval villages (Ortner and Mays 1998: 54; Veselka et al., 2015). For example, in their discussion of rickets amongst the medieval rural settlement of Wharram Percy, Yorkshire, Ortner and Mays (1998: 54) suggest the condition may have occurred in sickly infants who subsequently developed rickets because of their confinement in dark smoky houses and limited exposure to sunlight. It is possible that such a scenario arose in the case of Skeleton 278 who, due to illness, was kept indoors on at least two occasions during which time they developed vitamin D deficiency.

The episodes of vitamin D deficiency experienced by this child resulted in cortical thinning to the point where some bone deformation occurred. Whilst the *observed* skeletal changes were not severe, consideration must be given to the possible perception of the child's illness whilst they were alive. Physical symptoms of rickets include excessive perspiration, breathing difficulties leading to cessation of breath (apnea), involuntary muscle contractions, and spasms of the face, hands and feet (Brickley and Ives 2008: 92; Uush 2013: 208). Swelling would have occurred at their wrists as the growth plates widened, whilst other physical changes could have included the 'rachitic rosary' – small beads of localized swelling visible in the chest – caused by broadening of the costochondral joints (Pettifor 2003: 549). Given the age at which both episodes occurred, the child could have also experienced delayed development in terms of crawling, standing, and walking due to muscle weakness although as the condition healed once during their lifetime, this might have been temporarily resolved (Pettifor 2003: 549).

The changes to Skeleton 278's left leg would potentially have been visible at death, and might be connected to the position of the child within the grave. It appears as though a purposeful decision was made to bury the child with their left leg – that is, the leg exhibiting bowing – resting on, and crossed at, the ankles of the right leg. This is not the only example from early medieval Wales whereby the burial of a child who was unwell or physically impaired reflects an awareness of their condition (Hemer 2010). For example, at the sixth to eleventh century cemetery of Brownslade in Pembrokeshire, a two year old child with achondroplasia – short-limbed dwarfism – was buried in a stone-lined cist with their body resting on their side with their legs flexed (Sables 2010; Groom et al., 2011: 144). It has been suggested that the flexed position may have been used to minimise the physical appearance of the dwarfism – including the rotation of the hips and bowing of the legs – which would be more striking in an individual laid on their back (Groom et al., 2011: 144). Also in early medieval Wales is the possible association between the burials of young children who were visibly unwell, and the inclusion of natural objects such as quartz pebbles and shells (Hemer 2010). It is proposed that such items may have performed an apotropaic function that was used to protect the deceased from harm (Hemer 2010). Indeed, at St Patrick's Chapel, the body of a perinate was protected beneath three shale slabs, whilst limpet shells were purposefully deposited in the sand between these stones and the body. Another infant who exhibited endocranial lesions, suggesting a period of infection, was buried in a lintel long cist with a cross-incised stone capping the grave

(Murphy et al., in press). These examples, and the care taken to carefully position the body of Skeleton 278 in their grave, suggest that those responsible for their burial wanted to ensure that, even upon death, their physical health or visible condition did not deny them an appropriate Christian burial. There was perhaps concern for these children even into the afterlife, and there may have been recognition that the most vulnerable and youngest members of society required on-going support or protection.

Conclusion

The analysis of the skeletal remains from the early medieval cemetery beneath St Patrick's Chapel, Pembrokeshire provided the opportunity to identify and contribute a case of vitamin D deficiency rickets to an otherwise small sample of known cases from pre-Industrial populations in Britain. Identifying IGD through dental histology has been instrumental in substantiating the skeletal evidence, and confirming the diagnosis of vitamin D deficiency that was otherwise open to scrutiny due to the extent of taphonomic damage, and the number of skeletal changes visible upon the skeleton. The histological evidence also highlighted multiple episodes of vitamin D deficiency that were not observable from the macroscopic assessment, and has provided the opportunity to explore the potential causes of these periods of ill health. The question remains as to whether the child was in a chronic state of vitamin D insufficiency – a possible scenario for many past populations according to Snoddy et al. (2016: 189) – accompanied by two very severe deficiency episodes represented by the IGD. Or whether the IGD represents two episodes of deficiency in an otherwise 'healthy' child. The fact their skeleton exhibited Harris' lines, evidence of catch-up growth, and enamel hypoplasia may suggest the former scenario. Certainly, the evidence presented here necessitates the further investigation of the remaining population using a combined osteological and histological approach in order to explore whether or not other members of the community were also affected by vitamin D deficiency. Through a combination of multiple sources of evidence, as discussed, it has been possible to speculate about Skeleton 278's early life experience, and the attitude of those responsible for their burial.

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Figure captions

Figure 1. Map of Wales illustrating the location of the cemetery beneath St Patrick's Chapel, Whitesands Bay, Pembrokeshire.

Figure 2. Aerial photograph of the cemetery under excavation illustrating the location of the boundary wall (white arrow) in relation to the medieval chapel. Photograph by Stephen Rees.

Figure 3. Burial of Skeleton 278 illustrating the position of the body in the grave.

Figure 4. Cranial fragment exhibiting porosity.

Figure 5. Antero-posterior bowing in the mid-distal segment of the left femur of Skeleton 278.

Figure 6. Left tibia and fibula of Skeleton 278 illustrating medio-lateral bowing of the left fibula.

Figure 7. Radiograph of the left femur of Skeleton 278 in an antero-posterior view. The taphonomic damage to the distal end is observable. Two white arrows mark the location of the Harris' lines. Note the image is a composite of separate radiographic images.

Figure 8. Thin section of the first permanent molar from Skeleton 278 exhibiting two bands of interglobular dentine; Band 1 (first episode) is indicated by a single black arrow, whilst Band 2 (second episode) is indicated by two black arrows.