A CASE OF OSTEOMALACIA IN HUMAN SKELETAL REMAINS FROM ST HRIPSIME CHURCH (HOROM, ARMENIA)


1 Institute of Archaeology and Ethnography, National Academy of Sciences, Yerevan, Republic of Armenia
2 Yerevan Mkhitar Heratsi State Medical University, Yerevan, Republic of Armenia
3 Armenian Republican Medical Centre, Yerevan, Republic of Armenia
4 Shirak Centre of Armenian Studies, National Academy of Sciences, Republic of Armenia

ABSTRACT

In this study, we investigated the remains of an individual that were recovered during cleansing work of the Church of St Hripsime. Macroscopic and X-Ray inspections yielded pathological criteria which indicated osteomalacic origin. The findings of the study suggest that the individual who lived in the Late Medieval period may have gone through multiple episodes of vitamin D deficiency. Vitamin D deficiency as an effect of deficient exposure to sunlight (in particular, in rural individuals who lived in underground houses) and nourishment deficiency could be described as the main causes leading to osteomalacia in Armenia.

Keywords: Osteomalacia; pseudofracture; curvature of the sterna and sacrum; X-ray; the Middle Ages; Armenia

INTRODUCTION

Osteomalacia is a disorder which affects the skeleton; the most frequent cause of osteomalacia is nutritional vitamin D deficiency, and it occurs almost exclusively in the parts of the world where vitamin D insufficiency is endemic [9, 6]. It is characterized by mineralization insufficiency of the osteoid matrix in
the cortical and trabecular bone, resulting in amassing of osteoid tissue [18]. Factors that increase the exposure of the skin to sunlight and also the addition of dietary sources of vitamin D can contribute to the absence of skeletal manifestations of absence [26, 12]. It would be expected that vitamin D levels would be higher closer to the equator where sunlight is intense. However, other studies have shown the contrary, with levels higher in northern than in southern Europe [45, 62]. This may partly be explained by skin pigmentation [29, 30, 54, 55]. People in warmer climates tend to have darker skin pigmentation, which may affect their capacity to synthesise vitamin D. White women in South England had median 25(OH)D levels of 62.5 nmol/l in summer and 39.9 nmol/l in winter, while in Asian women living in the same geographical region the median levels were considerably lower at 24.9 nmol/l and 16.9 nmol/l respectively [38]. Type of clothing is another determinant of the amount of UVB radiation that will reach the skin [15]. Vitamin D can be ingested as ergocalciferol (vitamin D2) or cholecalciferol (vitamin D3). Ergocalciferol is received from plant sources such as mushrooms, whereas cholecalciferol is contained mainly in egg yolk and oily fish. Sustenance of adequate levels of vitamin D has a significant effect on the immune function [63] and development of neoplastic diseases [31]. Another form of osteomalacia may result from inherited and acquired conditions [26]. Vitamin D deficiency is a pathogenic factor of osteoporosis that may be modified [56, 5]. Some reviews have shown considerable differences in vitamin D levels related to age [45, 25, 4].

In the Middle East and Africa, children trend to have higher vitamin D levels than adults [23]. This can reflect the greater amount of time they spend outside compared to other age groups. However, it has been shown that these distinctions are decreasing, which may be the result of a change in lifestyle in developed regions, with younger people spending a greater amount of time indoors [24]. The extreme old-age population has been found to be a group at special risk of vitamin D deficiency.

Pseudofractures involving part of the cortex (or extending completely across bones) are the most typical X-ray signs of osteomalacia and are virtually diagnostic [58]. The classical description of this peculiarity was given by Looser [36]. Typically, pseudofractures are some millimetres in thickness and quite sharply defined from the contiguous mineralized bone. Stresses exerted on such defectively mineralized bone result in little, linear fractures [49, 39]. Clinical literature suggests two causative mechanisms for these defects; one concerning the pressure or pulsations of arteries on weakened bone tissue [35, 61, 39], and the second invoking a fracture response in weakened bone
to muscle and soft tissue forces during normal motion [39, 1, 22, 8]. The deficiency of the mineral matrix in osteomalacia can explain the localization of many of Looser’s zones. The concept that they start as easy fractures in bones which are pathologically weakened is acceptable, and their symmetry may be explained by the fact that many of the habitual stresses such as walking or breathing are likely to affect both sides of the body similarly. Pseudofractures may ultimately result in a full fracture [35]. In paleopathology, this type of fracture is a key means for suggesting the diagnosis of osteomalacia [12, 28]. With convalescence, ossification of the fracture callus will occur. This can be irregular if surplus osteoid has accumulated at the fracture sites. These factors score for the presence of speculated or amorphous new bone formation surrounding lesion margins [14].

Our interest in osteomalacia was aroused by recognising the disease in the individual discovered in the ruins of the ancient St Hripsime Church (Horom village in the Shirak Province of Armenia). Bioarchaeologically, few cases of osteomalacia have been identified, and very little work has been undertaken on documenting the scope of osteological features characteristic of the condition. Unquestionably, the full range of skeletal expressions is still not known. Studies by Mensforth [43], Brickley et al. [14] and Ives and Brickley [28] have highlighted cases of osteomalacia occurring in urban populations affected by industrial living and increased atmospheric pollution.

The aim of this study was to investigate the living conditions of the individual from Horom through an examination of the full range of pathological changes linked to osteomalacia. Specifically, we tested the hypothesis that vitamin D deficiency was linked to a range of social and economic factors that affected the village inhabitant in the Shirak Province of Armenia.

MATERIAL AND METHODS

The skeleton was recovered from a church (burial) during excavations undertaken by the Armenian archaeologists H. Khachatryan and L. Yeganyan at the village of Horom in 2018 (Figure 1). It is presently curated by the Laboratory of Physical Anthropology at the Institute of Archaeology and Ethnography, NAS RA in Yerevan. The individual was interred in a supine position and belonged to the Late Middle Ages. The body of the individual was deposited in the southeast direction. Most of the skeleton was preserved, except for the pubic region of the pelvis, right femur, tibias, fibula and foot bones. The bone inventory of the analysed skeleton can be seen in Figure 1. The sex and of the individual the age at the death were defined according to standard osteological methods.
Figure 1. St Hripsime Church, plan of Burial 1 (in situ, with a curved spine), available skeletal elements from Burial 1 in St Hripsime Church
Sex estimation was based on observation of the shape and depth of the greater sciatic notch and cranial dimorphic characteristics [17]. The age at the death was estimated, based primarily on the morphological features of the right auricular surface [57], cranial sutures, and dental wear of the molars.

Stature reconstruction was based on the length of the long bones of the limbs by the formulae of Pearson-Lee [2]. Careful macroscopic assessment of all skeletal elements was undertaken. Macroscopic analysis of a diversity of postcranial features was made following the criteria of bone changes in osteomalacia outlined in Brickley et al. [13], Ives and Brickley [15]. Lesions formed of well remodelled novel bone were considered as a healed state [53].

In the current study, X-rays were made from different sites in the skeleton that are predilected for fractures. Depending upon the bone element radiographed, exposures ranged from 65 kv/10 s for scapula, 54 kv/10 s for ribs to 87 kv/10 s for femora. Bones were radiographed at the Armenian Republican Medical Centre.

RESULTS AND DISCUSSION

The skeleton was a man’s, he had been between 40 and 55 years old at death, his height was 161.2 cm. The series of macroscopic and X-Ray evidence supporting the diagnosis of osteomalacia and social and cultural interpretations of the presence of the condition are discussed below. The pathological changes identified in this research are described below and are displayed in Table 1 and in Figures 2 and 3.
Table 1. Distribution of the skeletal changes in adult osteomalacia

<table>
<thead>
<tr>
<th>Lesion</th>
<th>Individual 17</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scapula spinous process pseudofracture</td>
<td>No</td>
</tr>
<tr>
<td>Scapula spinous process unilateral pseudofracture</td>
<td>No</td>
</tr>
<tr>
<td>Scapula spinous process bilateral pseudofracture</td>
<td>No</td>
</tr>
<tr>
<td>Scapula spinous process posterior pseudofracture</td>
<td>No</td>
</tr>
<tr>
<td>Scapula spinous process anterior pseudofracture</td>
<td>No</td>
</tr>
<tr>
<td>Single pseudofracture of scapula spinous process</td>
<td>No</td>
</tr>
<tr>
<td>Multiple pseudofractures of scapula spinous process</td>
<td>No</td>
</tr>
<tr>
<td>Scapula spinous process pseudofracture visible with small callus at margins, initial fracture healing</td>
<td>No</td>
</tr>
<tr>
<td>Scapula spinous process bridging of pseudofracture with woven formation</td>
<td>No</td>
</tr>
<tr>
<td>Scapula spinous process woven bone formation without a pseudofracture</td>
<td>Yes</td>
</tr>
<tr>
<td>Scapula spinous process lamellar bone formation</td>
<td>No</td>
</tr>
<tr>
<td>Scapula coracoid process pseudofracture</td>
<td>No</td>
</tr>
<tr>
<td>Scapula lateral border pseudofracture</td>
<td>Yes</td>
</tr>
<tr>
<td>Scapula lateral border curvature</td>
<td>Yes</td>
</tr>
<tr>
<td>Healing or unhealed rib fractures</td>
<td>Yes</td>
</tr>
<tr>
<td>Inferior pubic rami unhealed pseudofracture</td>
<td>–</td>
</tr>
<tr>
<td>Pubic symphysis angulation</td>
<td>–</td>
</tr>
<tr>
<td>Iliac crest fracture</td>
<td>No</td>
</tr>
<tr>
<td>Ilium pseudofracture</td>
<td>Yes</td>
</tr>
<tr>
<td>Sternum bending</td>
<td>Yes</td>
</tr>
<tr>
<td>Vertebra body compression fracture</td>
<td>Yes</td>
</tr>
<tr>
<td>Incomplete, linear vertebra cortical fractures</td>
<td>Yes</td>
</tr>
<tr>
<td>Healing or unhealed clavicle fracture</td>
<td>No</td>
</tr>
<tr>
<td>Distal ulna unhealed fracture.</td>
<td>No</td>
</tr>
<tr>
<td>Proximal femur pseudofracture</td>
<td>No</td>
</tr>
<tr>
<td>Linear raised pseudofracture proximal medial femur</td>
<td>No</td>
</tr>
<tr>
<td>Antero-lateral bending proximal femur without residual deformities of rickets</td>
<td>No</td>
</tr>
<tr>
<td>Antero-lateral bending proximal femur with residual deformities of rickets</td>
<td>No</td>
</tr>
<tr>
<td>Platymeria</td>
<td>No</td>
</tr>
</tbody>
</table>
Figure 2. Curvature of the sternal, sternal foramen (1), cervical vertebrae 2–3 are fused into a single block (2), view from posterior of an irregular linear pseudofracture (arrows) at the transverse process of a thoracic vertebra (3), porous woven new bone over the transverse process of a lumbar vertebra (4), a crush fracture of the vertebral body (5), raised, linear ridges of bone formation along the inferior margin of the left femoral neck (6), a severe trochanteric fracture (7), pseudofracture of the scapula (8, 10), shallow, incomplete formation of porous woven new bone over the scapula spinous process without a fracture (9), curvature of the sacrum (11).

Individual diagnosis

Scapulae. The body of the right scapula had one elongated defect extending on the lateral and posterior edge of the middle third of the body top (Figure 2–10). The lower vertical fracture started from the lateral end of the transverse fracture and ended at the lower medial third of the body. The individual had a spread of porous woven bone formation over the scapula spinous process (Figure 2–9). This was similar to the deposit of woven bone that had formed over a thin fracture line. Fractures in this region are reported in osteomalacic individuals examined in pathological collections [13, 46]. The left scapula showed a pseudofracture on the medial border of the left scapula (Figure 2–8). The feature occurred bilaterally, although variation existed as to the severity of the defect between the left and the right scapulae. Posterior curvature of the scapula (viewed from medial side) as a result of softened bone was also noticeable.
Sternum. Lateral curvature of the sternum was observed. A round perforation was noted on the distal portion of the gladiolus of the sternum (8.5 × 5.5 mm) (Figure 2–1). It was located at the level of articular facets of the fifth costal cartilages in the midline. However, it is possible that this is a sternal foramen where 2 sternebrae did not fuse completely during formation. Ives and Brickley [28] believe that the curvature in the scapula and sternum are connected to underlying osteomalacia.

Vertebrae. Spinal defects can happen in osteomalacia, whereby softening of the bone in the vertebral body will lead to weakening and a failure to withstand weight-bearing pressure and thus collapse [13].

At the time of excavation, the spine of the individual had an unusual curvature (Figure 1). Cervical vertebrae 2–3 were malformed and fused into a single block (Figure 2–2). The vertebrae were fused through adjoining articular facets and bodies. The intervertebral disc space had disappeared, but small, not fused areas in the anterior part could be seen. The lateral direction roentgenogram revealed that the fusion of the posterior parts was complete, the radiolucent areas between the two vertebral plates suggested ankylosis. Such bone growth is unlikely to be accounted for by osteomalacia. However, where spinal defects are present with scapula fractures and rib fractures (see below), review should be given to an underlying vitamin D deficiency.

The inter-vertebral discs expanded and pressed against the adjacent bone, producing a concavity in the superior and inferior surfaces of the body because of the softened condition of the bone [51]. This type of vertebral deformity has been marked as “biconcave codfish appearance” [22, 13]. Such defects can promote spinal curvature defects and can be seen in both osteomalacia and osteoporosis [13].

Three upper thoracic (T2–T4) and lumbar laminae (L3–L4) (Figures 2–3, 2–4) were affected by a series of small, incomplete, linear cortical fractures. These fractures were located adjacent to the inferior margins of the transverse process and were surrounded by porous friable new bone. These appeared like osteomalacic pseudofractures [28].

Ribs. This individual had a mixture of well-healed, and remodelling fractures (Figure 3). Multiple fractures (12 of 24 ribs) often occurred close together. Rib fractures can result from interpersonal violence, accidental trauma and pathological conditions [10, 33, 40].

Sacra. Features of osteomalacia in this region included severe curvature (or angulation) predominantly occurring at the inferior margin of the third sacral segment [13]. The body of the sacrum was displaced anteriorly, which,
appearing with anterior kyphosis of the lower lumbar vertebrae, contributed towards obstructing the pelvic canal. The angulation deformity was severe and noticeable (Figure 2–11).

*Figure 3. Multiple rib fractures*

*Ilium of pelvis.* The acetabulum also demonstrated a fracture (Figure 2–7). The bone in the acetabulum had become thickened; this may result from attempts at mechanical strengthening following the injury or abnormal positioning.
**Femur.** The femoral head had split into five parts, two large fragments and three small ones (Figure 2–12). Bone degeneration of the femoral head over time causes its collapse. Subchondral cysts and porosity were present, and shortening and expansion of the femoral cervix was observable. The femoral fracture co-existed with the pelvic pseudo fractures reported above. An X-ray was performed, which showed flattening and increased radiological density of the femoral head and confirmed its mushroom shape (Figure 2–12). There was considerable reduction in the mediolateral diameter of the head. Femora also demonstrated raised, linear ridges of bone formation along the inferior margin of the left femoral cervix, indicating a linear fracture callus formed above an underlying pseudo fracture (Figure 2–6). Similar fractures frequently occur as a result of lower-energy falls from standing height with a rearwards or side impact to the hip [32]. Intracapsular hip breaks are related with the femoral neck, and extra-capsular fractures happen in the trochanteric region [59]. Both may result in external rotation of the distal broken portion and shortening of the leg. Long bone fractures in osteomalacia are likely to be caused by an accidental injury affecting the pathologically loosened bone [13].

Thus, the Late Middle Ages specimen can be regarded as the first record of osteomalacia identified in paleoanthropological materials of Armenia. The findings from the study suggest that the individual who lived in the Late Medieval period can have gone through plural episodes of vitamin D deficiency. The individual from St Hripsime Church was diagnosed as having osteomalacia primarily based on the presence of multiple, macroscopically apparent pseudo fractures. Overall X-ray analysis reconfirmed the macroscopic diagnosis by pointing out decreased bone density, a coarsened trabecular pattern and typical radiolucent Looser’s zones (“pseudo fractures”). Probably, osteomalacia strengthened skeletal fragility and muscle weakness [27], which, along with co-occurring osteoporosis in this individual, is likely to have contributed to the growth of the fractures. Pseudo fractures also can occur in a variety of circumstances, including osteogenesis imperfecta, osteopetrosis, Paget’s disease and congenital syphilis [39, 14]. However, the design of skeletal occurrence and trend towards bilateral locations affected, particularly in the scapulae and ribs may be correlated with defective mineralisation pointing to vitamin D deficiency [14, 58, 39].

Among researchers, it is broadly assumed that vitamin D deficiency only occurred after humans had left Africa [30]. The earliest evidence of vitamin D deficiency comes from Tabun and Skhul, Late Pleistocene sites from Mount Carmel, Israel [11]. The prevalence of vitamin D deficiency (osteomalacia) in
adult ancient Egyptian population from Baharia oasis was 7.4%, all of whom were adult males. The cases that were detected in the Greco-Roman period of Egypt may be due to mechanical stress during wine and textile production [20]. Ives and Brickley [28] analysed 1081 skeletons from multiple urban contexts in post-mediaeval England (c. 1700–1855). Twelve adults with a proof of osteomalacia were identified. When seven cases preliminarily identified by Brickley et al. [14] are added, the individual abundance rate increases to 19 of 1323 individuals (1.43%). Increased abundance of osteomalacia evident in the post-Medieval period is ascribable to poor diet and industrial pollution in urban areas [41, 14]. Research is also continuing to document the occurrence of this condition across the social classes. The study of Ives and Brickley [28] has also enlarged the wide range of macroscopic lesions of adult osteomalacia, maintained by comparisons with clinical cases and microscopic identification of mineralization defects. Vitamin D deficiency as a result of insufficient exposure to sunlight (in particular, in rural individuals who lived in tiny underground houses) and nutritional deficiency could be described as the basic causes leading to osteomalacia in Armenia. A major characteristic of diets in rural Armenia is the high concentration of unrefined cereals [34]. These cereals have a high phytate content, which, in turn, deteriorates calcium absorption [15]. Severe cases of calcium deficiency may additionally result in secondary hyperparathyroidism, which in turn will influence bone structure and health [15]. Similarly, Özgür et al. [48] have suggested that high levels of strontium can inhibit the parathyroid glands and contribute to a reduction in the production of active vitamin D metabolites by the kidneys. In persons, osteomalacia caused by nutritional origin can be rather common [3, 21, 52]. Certain dietary preferences can also drive to a deficiency in vitamin D and calcium. Children and adults consuming stringent vegetarian diets have been shown to be prone to developing vitamin D deficiency [19, 44, 47, 15]. Such diets are bereft of any animal products and, without supplementation, radically limit the amount of vitamin D and calcium being consumed [19, 44, 47, 50]. Another factor that could promote osteomalacia in older individuals is a decrease in intestinal absorption of vitamin D with age [52]. In addition to vitamin D deficiency, general malnutrition (particularly a deficiency of protein and fat), low intake or excessive loss of calcium and phosphorus can promote the development of osteomalacia. Knowing the reasons for vitamin D deficiency will ensure a greater understanding of the lived experience of individuals with osteomalacia in the ancient past. The new manifestation of osteomalacia reported here can help identify more examples in future research. Such research will also help better understand the range of possible causes and factors that operated in the past.
CONCLUSIONS

We presented an instance of an incomplete skeleton which provided valuable information on pathological changes connected with osteomalacia. This study aimed to grasp the expression of vitamin D deficiency in the skeleton of an adult via detailed analysis of human bones from St Hripsime Church. The subject under study appeared to be a very interesting instance of an individual whose skeleton showed pathological variations connected with the subject’s vitamin D deficiency.

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Address for correspondence:
Dr. Anahit Khudaverdyan
Institute of Archaeology and Ethnography
National Academy of Sciences
Charents St.15, Yerevan, 0025
Republic of Armenia
E-mail: ankhudaverdyan@gmail.com