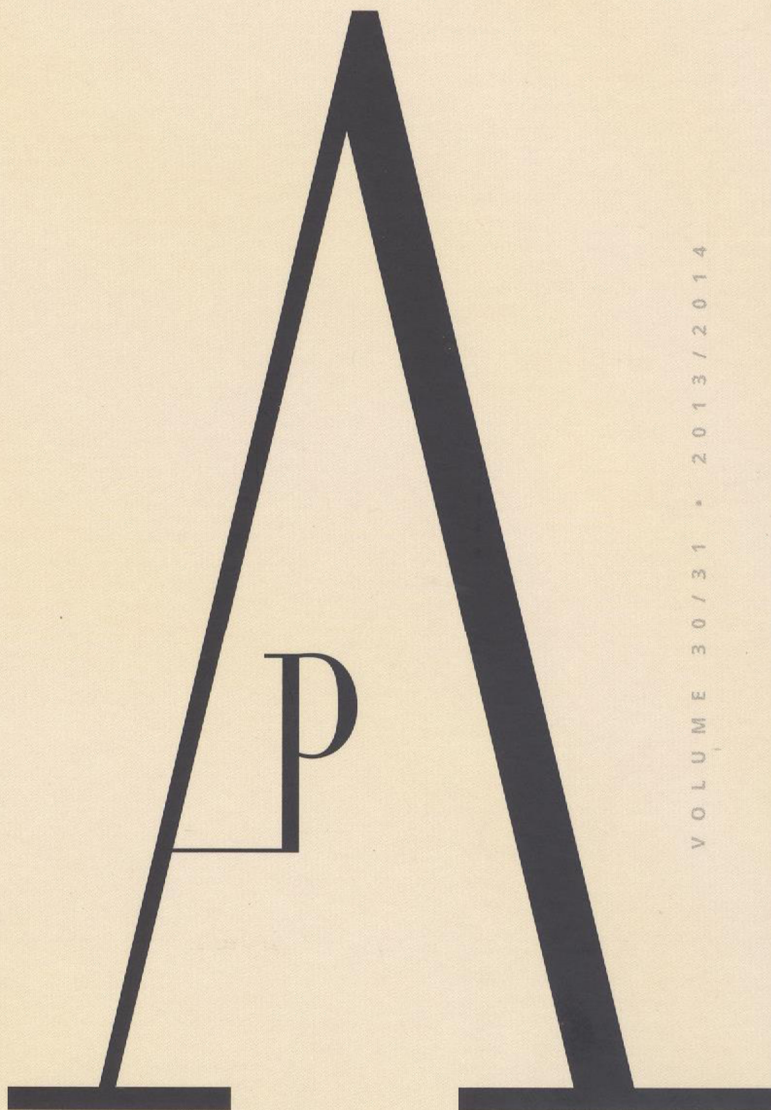


ANTROPOLOGIA  
PORTUGUESA



VOLUME 30/31 • 2013/2014

CENTRO DE  
INVESTIGAÇÃO  
EM ANTROPOLOGIA  
E SAÚDE  
UNIVERSIDADE  
DE COIMBRA

# Osteoporosis and nutrition – a paleopathological insight



**Francisco Curate**<sup>1,2</sup>

fcurate@uc.pt

DOI: [http://dx.doi.org/10.14195/2182-7982\\_31\\_2](http://dx.doi.org/10.14195/2182-7982_31_2)

**Abstract** The association of osteoporosis and nutrition has long been documented, and nutrition is acknowledged as a major risk factor for bone loss, affecting bone health in distinct ways. Both biomedicine and anthropology (or, more precisely, paleopathology) have strived to fully understand the contribution of diet to bone health, especially the relationship between the physiological economy of calcium and bone maintenance. Taking this into consideration, the present article is intended to summarize and comment the main empirical contributions of paleopathology to the body of knowledge

**Sumário** A associação entre a osteoporose e a nutrição tem sido bastante documentada, e a nutrição é reconhecida como um dos principais fatores de risco para a perda óssea, afetando a saúde esquelética de diferentes formas. Tanto a biomedicina como a antropologia (ou, mais precisamente, a paleopatologia) têm procurado compreender de um modo global a contribuição da dieta para a saúde óssea, particularmente a relação entre a economia fisiológica do cálcio e a manutenção óssea. Tendo em consideração estas preocupações disciplinares, o presente artigo tem o objetivo de resumir e comentar as principais con-

<sup>1</sup> Research Centre for Anthropology and Health, Department of Life Sciences, University of Coimbra, Coimbra, Portugal.

<sup>2</sup> Interdisciplinary Center for Archaeology and Evolution of Human Behavior, University of Algarve, Faro, Portugal.

on bone health, specifically the relation between bone loss and nutrition.

**Keywords:** Diet; bone loss; bone health; dietary calcium; paleopathology.

## Introduction

Osteoporosis (OP) is a metabolic pathological condition characterized by the decline in bone mass, compromised bone quality and ensuing increase in the risk of fracture (Consensus Development Conference, 1993; NIH Consensus Development Panel, 2001). OP is an asymptomatic disease prior to bone fracture (Wylie, 2010), being typically associated with fractures in the hip, the vertebral body and the distal radius (Johnell and Kanis, 2006).

This metabolic disorder has long been associated with estrogen withdrawal after menopause (Albright et al., 1941); and, like other chronic diseases, its incidence follows a Gompertzian pattern, increasing with age (Melton III, 1990). Although sex steroids and aging are of utmost relevance to OP etiopathogeny, the disease stems from a complex landscape of risk factors, including genetics, physical activity, reproductive history, and nutritional status (Burnham and Leonard, 2008; Curate et al., 2012; Heaney, 2008;

tribuições empíricas da paleopatologia para o corpo de conhecimento relativo à saúde óssea, especificamente a associação entre a perda óssea e a nutrição.

**Palavras-chave:** Dieta; perda óssea; saúde óssea; cálcio na dieta; paleopatologia.

Livshits et al., 2004; Møller et al., 2012; Recker et al., 2004; Zhang et al., 2009). It is thus appropriate to consider OP the consequence of a stochastic process, i.e., while risk factors for osteoporosis occur at different levels, they are not mutually exclusive, affecting bone health within a reticulate network of reciprocal influence (Heaney, 2008; Nordin, 2008).

Nutrition, as a risk factor, is unsurprisingly a major facet of OP heterogeneity and complexity, affecting bone health by itself or interacting with other etiological factors (Heaney, 2008). The hypothesis that OP is caused primarily by calcium (Ca) deficiency, particularly in aged individuals, was originally proposed in opposition to Fuller Albright's estrogen deficiency theory (Raisz, 2005). Indeed, decreased calcium intake, decreased intestinal absorption of calcium due to disease or senescence, and/or vitamin D deficiency may elicit secondary hyperparathyroidism, and all the harmful consequences associated with it: high bone turnover, bone loss, mineralization defects, and fractures (Lips, 2001). Type

ll osteoporosis' definition by Riggs and Melton III (1986) – although heuristically significant, the Riggs and Melton III model does not account for the convoluted OP etiopathogenesis – acknowledge this by stressing the mutual effects of remodeling incompetence, appropriateness of dietary consumption of Ca and vitamin D, intestinal mineral absorption and parathyroid hormone secretion. An adequate intake of calcium, and other nutrients, is recognized as essential for the acquisition and maintenance of skeletal health (Barger-Lux et al., 2005; Heaney, 2008).

The recent and extreme modification of the world's demographic profile prompted a significant increase in the total and relative numbers of aged individuals from both sexes. OP afflicts a sizeable proportion of the world population, causing fractures with costly human and economic outcomes: the total number of older individuals at high risk of osteoporotic fracture in 2010 was estimated at 158 million (Becker et al., 2010; Odén et al., 2015). In Portugal, the incidence of osteoporosis and associated fractures is also increasing (Pina et al., 2008; Silva et al., 1999). OP and related sequels are recognized as major public health concerns affecting the elderly community (Becker et al., 2010).

Although usually identified as a "modern disease", OP has a long history (Agarwal, 2008; Curate et al., 2009; Curate et al., 2013). The frequency of the disorder (and derivatives) changed as its etiologi-

cal agents, such as age at menopause or nutrition, varied throughout human history (Curate et al., 2013). Hence, the diachronic study of osteoporosis and fragility fractures is critical for a clearer picture of the epidemiology of the disease. The discipline of paleopathology – defined as the study of diseases in the past, both in humans and animals, employing different sources (Ortner, 2003) – has been involved in the research of age-related bone loss since the 1960's (Dewey et al., 1969; van Gerven et al., 1969). As such, this article aims to recapitulate and critically address the foremost contributions of paleopathology to the body of knowledge on bone loss, particularly those related to the effect of nutrition on skeletal health.

### **Nutrition and risk for OP: a summary of the biomedical evidence**

The biomedical body of knowledge recognizes not only a constellation of etiologic factors that cause disease but also identifies disease heterogeneity as another dimension of complexity in the etiopathogenesis of diseases. As such, the rhizomatic association between the causal factors of disease must be addressed when defining and evaluating the role of any specific factor, whether physical activity, heredity or nutrition – as in this particular case. Hence, not only

are diet and nutrition just two of multiple interacting features of bone loss, but, likewise, they may play different roles (or none at all) in OP etiopathogenesis (Heaney, 2008). Matkovic et al. (1979) first proposed this view, showing that high Ca intake was related with an emphatic decrease in hip fracture risk but not with a changed risk of distal radius fracture.

Absolute caloric intake, calcium and vitamin D have been acknowledged as crucial determinants of bone growth and development. Undoubtedly, a severe deficit of any nutrient impacts bone growth and strength (Bogin, 1998; Heaney et al., 2000; Petit et al., 2008). The investigation efforts for the understanding of OP and nutrition interaction has been almost completely on Ca and vitamin D but, in recent years, the focus has shifted to the role of other nutrients, namely protein, magnesium, potassium, carotenoids and vitamins K, B and C (Tucker, 2009). Nutrition affects skeletal health in two different ways. The deposition, maintenance and repair of bone tissue result from cellular processes and, understandably, the cells responsible for these actions rely on energetic inputs through nutrition, like any other body cell. The production of bone matrix, for example, hinges on the synthesis and modification of collagen and other proteins. The nutrients involved in this process include proteins, vitamins C, D and K, and several minerals. Additionally, the skeleton

stores large quantities of calcium and phosphorus, and the dimension of the reserve depends on the daily equilibrium between the absorption and excretion of these minerals (Calvo and Tucker, 2013; Heaney, 2008).

Calcium and vitamin D are important nutrients for bone health. Calcium intake in a number of modern populations is usually suboptimal, because it does not comply to the daily minimum requirements (Alaimo et al., 1994; Tucker, 2009) or because of subnormal absorption and greater excretory losses (Heaney and Recker, 1986; Nordin et al., 1987). Daily calcium needs are rather high, while the absorption efficiency is low, further decreasing between 40 and 60 years of age, especially in women (Fishbein, 2004). When dietary Ca absorption is inadequate to offset urinary and fecal losses, calcium is resorbed from the skeletal reserves to maintain serum Ca at a steady level (National Osteoporosis Foundation, 2010). The serum calcium levels are stringently orchestrated by the parathyroid hormone (PTH) and a minor decrease in extracellular Ca stimulates the secretion of PTH, which then mobilizes calcium from the skeleton reserves through a feedback mechanism and promotes the renal reabsorption of Ca (Jorde et al., 2000; Rodríguez-Ortiz et al., 2014). PTH also promotes, albeit indirectly, intestinal  $\text{Ca}^{++}$  absorption by stimulating the synthesis of 1,25(OH)<sub>2</sub>D (calcitriol, the active

metabolite of vitamin D) in the kidneys. In short, both calcium and vitamin D reduce PTH secretion, which in turn decrease osteocyte responsiveness and general bone remodeling (Heaney, 2008).

After the attainment of peak bone mass – i.e., the maximum amount of bone mass achieved after skeletal maturation (Bonjour et al., 1994) –, the skeletal system becomes reasonably insulated from many ensuing nutritional deficiencies (Heaney, 2008; Matkovic and Landoll, 2000). An ecological study from Croatia (Matkovic et al., 1979; 1980) originally suggested that peak bone mass could be modified by environmental factors, especially nutrition. Overall, it is probable that discrepancies in calcium intake early in life may account for a 5-10% difference in peak adult bone mass and, consequently, calcium intake at a younger age greatly influences fracture risk later in life (Matkovic and Landoll, 2000; Mølgaard et al., 2011).

From birth through young adulthood, bone mass steadily accumulates, with higher calcium requirements during infancy and adolescence (Koo and Walyat, 2013; Matkovic and Landoll, 2000). Dietary calcium at (or above) the threshold level is required throughout the bone modeling and consolidation phase (Matkovic and Landoll, 2000; Petit et al., 2008). The higher Ca demands in infancy and adolescence mandate a greater calcium absorption, mediated by 1,25(OH)<sub>2</sub>D (Ilich et al., 1997). As such, improving vita-

min D status is one of the keystones to optimize skeletal growth and to maximize peak bone mass (Koo and Walyat, 2013). Although vitamin D is synthesized following skin exposure to sunlight in the ultraviolet spectrum, in some situations – such as living at higher latitudes or during winter – the supply of exogenous vitamin D through diet is required (Engelsen, 2010; Koo and Walyat, 2013).

Numerous nutritional factors affect calcium demands, particularly protein, sodium, caffeine and fiber. Sodium and protein have a great significance in the calcium economy, impacting its urinary excretion, while caffeine and fiber exert minimal influence on calcium absorption (Barger-Lux and Heaney, 1995; Heaney, 2008). Protein intake is possibly associated with calcium phosphate metabolism, bone mass and osteoporotic fracture risk (Metz et al., 1993). Notwithstanding, it has been challenging to identify any long-term effect of dietary protein on bone metabolism and mass (Rizzoli and Bonjour, 2010). Phosphorus is also fundamental for the regular skeletal formation, playing a cardinal role in bone development. Phosphorus is present in almost every food consumed by humans (Calvo and Tucker, 2013; Matkovic and Landoll, 2000) and excessive intake (especially uneven consumption relative to calcium) is probably associated to a compromised peak bone mass, increased bone resorption and greater

risk of fracture (Calvo and Tucker, 2013). At last, magnesium is associated with an inhibition of PTH secretion (Rodríguez-Ortiz et al., 2014), while alcohol consumption probably influences bone metabolism – with a controversial effect on bone mass (Nordin, 2008).

### **Dietary calcium in human phylogenetic history**

In a more general approach, dietary calcium intake has been painstakingly considered in the anthropological literature, even though recent clinical and epidemiological studies have raised critical interrogations over the specific effects of calcium on bone loss (Agarwal, 2008).

Regular requirements of calcium are high, mostly because of urinary and fecal losses, which account for 150 to 250 mg of calcium lost per day. Indeed, the body absorbs, on average, only 25% of dietary calcium (Hunt and Johnson, 2007). Mean calcium absorption and intake are usually highly correlated but fractional calcium absorption is inversely associated with calcium intake when the intake is exceedingly low (Hunt and Johnson, 2007; Ireland and Fordtran, 1973). Furthermore, calcium absorption efficiency declines 20–35% with age, at least among women (Fishbein, 2004; National Osteoporosis Foundation, 2010). When

dietary calcium is insufficient to meet body requirements, the calcium stored in the skeleton – which accounts for 99% of all bodily calcium, while the remainder is present in blood, extracellular fluid, muscle and other tissues – is transferred to the blood circulatory system.

The physiology of calcium homeostasis evolved in a calcium-enriched environment that prompted a conditional inefficiency in the intestinal and renal absorption of the element (Stini, 1995). Furthermore, cutaneous losses are unregulated, and renal conservation is weak (Heaney, 2008). This homeostatic system performed efficiently in the past, but in modern-day Westernized societies the decline in calcium consumption and the blatant demographic changes promote a maladaptive calcium physiology (Stini, 1995). Osteoporosis occurs predominantly after menopause (i.e., after the end of the reproductive phase of a woman's life) and in aged individuals from both sexes: it is thus a pathological condition almost freed from the selective pressures of natural selection. Since it afflicts individuals mainly after their reproductive period, OP does not reduce individual fitness, being conceivably an expression of an antagonistic pleiotropy maintained in the human genome by selective advantage (Heaney, 2008; Stini, 1995). In that sense, genetic traits that uphold the inefficiency of calcium homeostasis, incidentally favor bone loss.

Natural mammal diets are abundant in calcium. The dietetic regime of the first anatomical modern humans was also rich in calcium, comprising between 1500 and 3000 mg of this element per day (Eaton and Nelson, 1991; Heaney, 1986; 2008). Nowadays, humans ingest only a third of the calcium consumed by early *Homo sapiens* (Davies et al., 1995; Heaney, 2008). Furthermore, it can even be inferred that the earliest hominids (according to the traditional taxonomic classification, which highlights the adaptative divergence of humans from the other living members of their clade – in this scheme only our extinct ancestors and relatives are placed in the family Hominidae; see for example Marks, 2011) consumed more calcium than modern humans. With the expansion from the tropics to other environments, the earliest hominids no longer relied on an overwhelmingly vegetarian diet – richer in calcium. Also, dietary calcium levels conceivably declined as the first *Homo* developed tools and hunting strategies, incorporating more meat in the diet (Heaney, 2008; Nelson et al., 2003).

Vitamin D is the major regulator of calcium homeostasis, being essential for the normal mineralization of bone (Feldman et al., 2008). It is produced in the skin by a photochemical reaction in which ultraviolet light transforms 7-dehydrocholesterol into previtamin D. The first hominids and early *Homo sapiens* probably evolved in East Africa (Klein, 2009;

Mcdougall et al., 2005; White et al., 2003). With plenty solar light available, mechanisms that prevent the excess accumulation of vitamin D evolved and with the expansion to northern latitudes, early humans faced another problem: vitamin D production in high latitudes declines steeply (the sun is so low in the sky in winter that ultraviolet wavelengths do not get through the atmosphere), and varying degrees of vitamin D deficiency are common without dietary supplementation (Heaney, 2008; Webb et al., 1988).

The transition from hunting and gathering to food production (the “Neolithic Revolution” or the “agricultural/pastoral revolution”) originated in independent locations worldwide, starting around 12,000 BP or even earlier (Barker, 2009). The transition generated striking changes in micronutrient intake, largely for the worse. Nutritional change during the Neolithic Revolution is associated with lower bone mass in the first agricultural populations (Pfeiffer and Lazenby, 1994; Nelson, 1984; Nelson et al., 2003) – a substantial modification in the sources and quantities of calcium certainly occurred (Agarwal, 2008; Brickley and Ives, 2008). Agricultural societies that subsisted mainly on cereal crops and legumes would have had diets with very low calcium densities, insufficient to sustain bone health (Heaney, 2008).

The sources and quantities of dietary calcium (and other important nutrients)



changed dramatically during the course of human evolution. While it has been estimated that the dietary consumption of calcium during the Paleolithic was at least 1500 mg per day (Eaton and Nelson, 1991; Heaney, 2008), calcium intake was only one factor among a complex reticulate of causal agents that affected bone health in the past (Nelson et al., 2003).

### **Bone loss and nutrition in paleopathology**

A study by Dewey et al. (1969) comprising Nubian skeletal samples from the Meroitic (350 BC–350 AD), X-Group (350–550 AD) and Christian (550–1400 AD) periods probably features the first analysis of bone loss in the past and was of radical importance since it established osteoporotic bone decline as an age-related degenerative disorder with a vast historical depth. Shortly after, van Gerven and colleagues (1969) analyzed the cortical bone thickness in a sample of Native-Americans (1540–1700 AD). Both studies highlighted the cortical bone decline with age – steeper and earlier in women – but Dewey et al. (1969) related the earlier onset of osteoporosis in women with extended lactation and inadequate calcium intake. Since these seminal works, numerous paleopathological analyses have focused on the connection between bone mass and nu-

trition (Agarwal, 2008; Brickley and Ives, 2008). The apparent poorer nutrition in several historical populations possibly influenced the acquisition of bone during growth (Mays, 2008), affecting peak bone mass and bone mass later in life (Rizzoli and Bonjour, 2010).

The data acquired in the Nubian osteological samples have been explained as a reflex of enduring malnutrition (Dewey et al., 1969; Martin and Armelagos, 1979; Martin et al., 1985). Moreover, nutritional stress has been related with other risk factors (i.e., pregnancy, lactation and workloads), all concurring for the marked bone loss in a sub-sample of Nubian females (Martin and Armelagos, 1979). The greater intracortical porosity and higher bone turnover in younger Nubian females when compared to younger males have been attributed to nutritional and reproductive stress in females (Martin et al., 1984; Martin et al., 1985). Armelagos et al. (1972) stated that the growth patterns of the prehistoric Nubian population examined showed no significant evidence of any general malnutrition or deficiency disease; nonetheless, they suggested that a moderate nutritional insufficiency obstructed normal growth throughout the earlier growth period.

In a study of osteoporosis in ancient Egyptians of two social classes (high officials and workers) from the Old Kingdom in Giza, Zaki et al. (2009) did not detect a significant earlier bone loss in young

females. The authors suggest that the “protection” against early bone loss in females may be due to the dietary habits of ancient Egyptians, which included cereals and proteins – unlike the Nubians, whose diet was based on grain (millet, barley and sorghum), low in calcium, iron and proteins.

Nutritional stress has also been associated with bone loss in numerous Native- American and Arctic skeletal samples (e.g., Bridges, 1989; Cassidy, 1984; Cook, 1984; Ericksen, 1976; 1980; Nelson, 1984; Pfeiffer and King, 1983; Richman et al., 1979; Stout, 1978; Thompson and Gunness-Hey, 1981). For example, Stout (1978) contrasted rib cortex remodeling rates in samples from Middle and Late Woodland (USA), ascribing the higher remodeling rates in the latter series to secondary hyperparathyroidism stemming from low tryptophan levels associated with a diet rich in maize. Ericksen (1980) related the high-protein diet of the Eskimo and the low-protein diet of the Arikara with the observed dissimilarities in bone remodeling parameters on both skeletal assemblages. Although protein consumption possibly influences calcium phosphate metabolism and bone mass, so far clinical studies failed to detect any long-term effect of dietary protein on bone metabolism (Rizzoli and Bonjour, 2010). In their study of the Eskimo skeletons from St. Lawrence Island, Kodiak Island, and Southampton Island,

Thompson and Gunness-Hey (1981) found differences in cortical thickness between Yupik and Inupiaq Eskimos, which they attributed to dissimilar diet and activity patterns. Cassidy (1984) recognized that malnutrition influenced skeletal health in an adverse way in different samples from the Central Ohio River Valley (USA). Also, Cook (1984) speculated that the relative early onset of cortical involution and lack of diachronic modification reverberate the stable dietary attributes of Joseph Caldwell’s “primary forest efficiency” in the North-American Midwest. Bridges (1989) suggested that most of the differences in cross-sectional area and structure of the femur in two Southeastern United States groups are due to changing activities related with the introduction of agricultural practices, although diet probably had an effect on cortical area in females.

Against the general trend in the research of bone health in Native-American and Arctic communities, Perzigian (1973) advocated that nutrition was not a significant contributor to the maintenance of cortical and trabecular bone during aging in prehistoric samples from Indian Knoll and Pete Klunk (USA). Although archaeological and osteometric data suggest that diet at Pete Klunk was more adequate and reliable than at Indian Knoll, both males and females at Pete Klunk lost bone at a faster rate than their counterparts at Indian Knoll.

Also in North America, but in the period of the post-Reconstruction (1878-1930), an analysis of African-American skeletons highlighted an association between dietary deficiencies and features of bone health, such as low percent cortical area and high rates of bone resorption. Moreover, both females and males experienced difficulties with calcium homeostasis and normal maintenance and repair of bone. Taken together, the data supported the interpretation that diet and health were subnormal in the post-Reconstruction South of USA (Martin et al., 1987). More recently, a comparison of an African-American sample (St. Louis, Missouri, USA) with an European-American sample (forensic cases from Missouri, USA) shows composite patterns for differences in measures of rib intracortical remodeling and cortical area, which are explained by both genetic and environmental factors, including diet (Cho et al., 2006).

In studies of European skeletal samples, diet has also been acknowledged as an important factor in the preservation of bone health (e.g., Cho and Stout, 2011; González-Reimers et al., 2007; Mays, 1996; 2001).

The high frequency of osteopenia in prehistoric Guanche collective burials (Gran Canaria, Spain) has been explained by periods of food scarcity and dietetic insufficiencies (González-Reimers et al., 1998; 2007). Nonetheless, age at death in most of the Guanche samples was not

estimated (and, occasionally, the sex was also not identified), which seriously hinders any interpretation that links nutrition with bone loss in these populations (Agarwal, 2008).

In the Roman site of Ancaster (UK), peak cortical bone levels are also reduced, suggesting a suboptimal acquisition of cortical bone during the growth period that ultimately reflects a poorer nutrition in this community (Mays, 2006). Another radiogrammetric study, also during the Roman Period (Velia, Italy), relates the observed lower cortical index with chronic malnutrition (Beauchesne and Agarwal, 2014). The authors note that proper nutrition was probably atypical in the Roman world. The isotopic dietary profile of adults at Velia displays a diet high in cereals and legumes, with a generally low intake of animal or marine protein (Craig et al., 2009). It is important to note that this dietary profile is not irreconcilable with good skeletal health and normal bone mineral maintenance. Also during the Roman period, individuals at Isola Sacra (south of Rome, Italy) showed normal age-related bone loss, with females exhibiting steeper intracortical porosity and reduced bone mass (Cho and Stout, 2011). The differences between the sexes have been attributed to life events such as lactation and menopause, in addition to lower nutritional status. The middle class in the Portus (the majority of the skeletal sample) probably had an

adequate diet (Garnsey, 1998). Moreover, owing to their location in the artificial harbor of Rome they would benefit from an above-average diet, dominated by cereals and other terrestrials resources, as well as a plethora of marine resources (Prowse et al., 2005). Cereals, typically wheat and barley, leguminous plants, and different quantities and qualities of animal protein, composed the dietary profiles of Imperial Rome. Wheat and barley are high in calories and sources of vitamins B and E, calcium, and iron (Garnsey, 1998). Fish was also a food resource at Portus, being a good source of proteins, calcium, iron and vitamins A, B and D (Prowse et al., 2005). A critical aspect of the diet at Isola Sacra relates to the probable differential allocation of food according to age and sex: infants were nutritionally disadvantaged due to cultural behavior towards infant feeding and inadequate weaning foods, and females had less access to marine food resources (Cho and Stout, 2011; Prowse et al., 2005). This nutritional discrepancy probably was a major contributor to bone health later in life, especially in females (Cho and Stout, 2011).

A study of bone mineral density (BMD) in a medieval population from Norway (Trondheim, St. Olav's church, 1100–1600 AD) found loss of BMD at an early age in women that was justified by inadequate nutrition and stresses related with childbearing (Mays et al., 2006). Turner-Walker et al. (2001) proposed

that, in medieval times, recovery of bone mass ensuing gestation and breastfeeding might have been decelerated by inferior maternal nutrition. This can explain, at least partially (other factors are certainly involved), the apparent greater loss of bone throughout the reproductive age in medieval females.

A sequence of studies has documented osteoporosis and bone loss in the identified skeletal sample of Christchurch, Spitalfields (London, UK). Lees et al. (1993) studied the patterns of bone loss in the proximal femur of the women from Spitalfields and suggested that these women lost less bone than their modern counterparts. The authors, while acknowledging that milk, meat and green vegetables were widely available, also propose that nutritional aspects alone are not sufficient to explain BMD differences between the Spitalfields and modern women. On the contrary, Simon Mays (2000; 2001) unambiguously related poor childhood nutrition and deficient appositional bone growth in both men and women at Spitalfields. These individuals were less well-nourished during the growing years than modern subjects – thus, it is probable that poor nutrition during the growing years negatively affected cortical bone at Spitalfields, with the involvement of other unidentified factors.

The peak cortical thickness in the Spitalfields' young adults from both sexes is reduced when compared with

a more recent group, a phenomenon also recorded in radiogrammetric studies performed in other European skeletal samples (e.g., Beauchesne and Agarwal, 2014; Ekenman et al., 1995; Mays, 1996; 2006; Rewekant, 1994). This has been interpreted in the context of a link between substandard childhood nutrition and deficient cortical thickness (Garn et al., 1969; Himes et al., 1975). Albeit metacarpal cortical thickness was deficient in the young adults of Wharram Percy, a British medieval sample, the peasants' diet was probably not deficient in calcium, since the archaeological materials found at the site are suggestive of milk and dairy products consumption (Mays, 1996; Mays et al., 1998).

The radiogrammetric and densitometric studies of a sample from the Coimbra Identified Skeletal Collection (CISC) exposed slightly different paleo-epidemiological trends in the reduction of bone mass (Curate et al., 2009; 2013). Bone mineral density (evaluated in the proximal femur) decline patterns in both females and males are essentially the same in the skeletal collection from the CISC and in two modern Portuguese samples (Curate et al., 2013) – in spite of major dissimilarities in the lifestyle (including nutritional differences) of the three equated samples. Nevertheless, the radiogrammetric analysis of the femur shows that the cortical index is reduced in the younger age classes

when compared to a modern Finnish sample (Curate et al., 2009). Episodes of malnutrition during growth can be causally linked to a reduced bone mass in younger adults (Jessup et al., 2003). Also, calcium relevance to the peak bone mass seems uncontroversial (Bogin, 1998; Matkovic and Landoll, 2000). The historical records on the consumption of calcium among the underprivileged in Coimbra during the early 20<sup>th</sup> century are, at least, ambiguous. Cereals and fresh vegetables (prepared as soups and broths), accompanied by potatoes and some olive oil, composed the majority of the dietary regime in the deprived socioeconomic classes. Fish consumption, especially codfish and sardines, was commonplace. The bread was almost always made from corn (Roque, 1982; Santos, 1995). Bread and most vegetables are not good calcium sources – unlike sardines, which are high in calcium (Fishbein, 2004). Lopes (1999) mentions the absence of dairy products in the diet of the orphans at the “Misericórdia” of Coimbra. In this social institution for orphaned children, the deficient calcium intake during growth could have compromised skeletal health later in life. Of course, the early 20<sup>th</sup> century Coimbra was still very “rural” – farms, pastures and orchards were very frequent within the city limits. Moreover, animal trade increased in the city during the 19<sup>th</sup> and early 20<sup>th</sup> centuries (Roque, 1982; 1988).

As such, the access to dairy products, even for the underprivileged, was probably relatively easy. It is also important to note that, in a sample of adults from the CISC born in the city of Coimbra, two individuals (i.e., 2.3%; 2/101) presented a cause of death unequivocally related with nutrition (Santos, 1995). Notwithstanding, the provisional assumption is that other factors, like age at menarche in women, physical activity or genetics, also played a critical role in the achievement of peak bone mass.

### **Nutrition and bone health: what's next in paleopathological studies?**

In living persons, most of the nutritional factors that affect bone health can be evaluated to some extent, but an assortment of unavoidable information inaccuracies and gaps hinders the correct determination of dietary patterns in modern communities – and, even further, in past populations (Fishbein, 2004). For example, within a population, subgroups may have contrasting dietary profiles (Nelson et al., 2003). It is impossible to acquire dynamic measurements of physiological processes and it is challenging to assess diet in past individuals and populations. The archeological body is one of coincidence without development (Curate, 2014): the skeleton func-

tions as a capsule of time, providing an imperfect snapshot of the individual's health at the decisive moment of death. As such, diet and nutrition in the past – and their association with bone health – must be explored through multiple research pathways, including historical records, material culture, archeozoology, paleobotany, dental anthropology, genetic studies or stable isotopes analysis.

The study of osteoporosis and bone loss in the past is grounded in a different set of methods, besides paleopathology, that offer diverse (and not necessarily contradictory) views on bone health (see, e.g., Curate, 2014; Mays, 2008). Likewise, the analysis of ancient subsistence and diets is supported by different technical approaches, which contribute to bolster the knowledge about such elusive parameters of human life. The examination of historical records and material culture within the framework of archeology certainly give precious, albeit indirect, hints on past diets (Garnsey, 1998; Samuel, 1996; Santos, 1995). Also, the study of the archeological remains of food itself has the potential to provide unique insights into the nutrition of ancient societies (Samuel, 1996; 2002). The latent possibilities for archeozoological and paleobotanical finds within the archeology of diet are immense, especially when coupled with isotopic evidence (Bocherens, 2002; Boyd et al., 2008; van der Merwe et al., 2002). Archeological and documentary

evidences have classically been used to reconstruct paleodiets, and whilst these sources convey us invaluable information about the variety of available food at any given historical moment, isotopic analysis offers complementary paths of knowledge, specifying what was consumed or giving evidentiary details about the variance in intra-population access to food resources (Prowse et al., 2005; Schwarcz and Shoeninger, 1991; Umbelino, 2006). Isotopic reconstructions of diet have so far unveiled valuable information about paleodiets in different archeological contexts (e.g., Ambrose et al., 2003; Katzenberg, 1989; Hiller et al., 2008; Lubell et al., 1994; Prowse et al., 2005; Umbelino, 2006; Umbelino and Cunha, 2012; van der Merwe et al., 2002). Traditionally, dental pathology has also been employed in the reconstruction of past diets (Henry et al., 2011; Lanfranco and Eggers, 2010; Wasterlain, 2006). More recently, a genetic analysis of oral microbiota trapped inside dental calculus disclosed new evidences of dietary effects, health modifications and oral pathogen genomic evolution in the past (Adler et al., 2013).

The paleopathological analysis of the association between osteoporosis and nutrition is thus securely substantiated around a set of techniques that allow us to create reasonable models of bone health and diet in past human populations. The problem is not one of methodology but of method: these two

features of human health have rarely been interpreted together with the appropriate techniques. As such, an integrated approach to osteoporosis and nutrition, concerting relevant theoretical questions with the available techniques, is required for a thorough paleopathological analysis of their biological and sociocultural relations.

## Acknowledgements

Fundação para a Ciência e Tecnologia (grants #SFRH/BPD/74015/2010 and #PTDC/CSANT/120173/2010 – Paleoepidemiology of osteoporosis and osteoporotic fractures in Portugal since the Mesolithic: a transdisciplinary study), Research Centre for Anthropology and Health (UID/ANT/00283/2013), and two anonymous reviewers.

## References

- Adler, C. J.; Dobney, K.; Weyrich, L. S.; Kaidonis, J.; Walker, A. W.; Haak, W.; Bradshaw, C. J. A.; Townsend, G.; Sołtysiak, A.; Alt, K. W.; Parkhill, J.; Cooper, A. 2013. Sequencing ancient calcified dental plaque shows changes in oral microbiota with dietary shifts of the Neolithic and Industrial revolutions. *Nature Genetics*, 45: 450-455.

- Agarwal, S. 2008. Light and broken bones: examining and interpreting bone loss and osteoporosis in past populations. *In: Katzenberg, A.; Saunders, S. (eds.) Biological Anthropology of the human skeleton*. Hoboken, NJ, John Wiley & Sons: 387-410.
- Alaimo, K.; McDowell, M. A.; Briefel, R. R. 1994. *Dietary intake of vitamins, minerals, and fiber of persons ages 2 months and over in the United States: Third National Health and Nutrition Examination Survey, Phase 1, 1988-1991*. Hyattsville, Maryland, National Center for Health Statistics.
- Albright, F.; Smith, P. H.; Richardson, A. M. 1941. Postmenopausal osteoporosis: its clinical features. *JAMA: The Journal of the American Medical Association*, 116: 2465-2474.
- Ambrose, S. H.; Buikstra, J. E.; Krueger, H. W. 2003. Gender and status differences in diet at Mound 72, Cahokia, revealed by isotopic analysis of bone. *Journal of Anthropological Archaeology*, 22: 217-226.
- Armelagos, G.; Mielke, J.; Owen, K.; van Gerven, D.; Dewey, J.; Mahler, P. 1972. Bone growth and development in prehistoric populations from Sudanese Nubia. *Journal of Human Evolution*, 1: 89-119.
- Barger-Lux, M. J.; Davies, K. M.; Heaney, R. P. 2005. Calcium supplementation does not augment bone gain in young women consuming moderately low calcium diets. *Journal of Nutrition*, 135: 2362-2366.
- Barger-Lux, M. J.; Heaney, R.P. 1995. Caffeine and the calcium economy revisited. *Osteoporosis International*, 5: 97-102.
- Barker, G. 2009. *The Agricultural Revolution in prehistory: why did foragers become farmers?*. Oxford, Oxford University Press.
- Beauchesne, P.; Agarwal, S. C. 2014. Age-Related cortical bone maintenance and loss in an Imperial Roman Population. *International Journal of Osteoarchaeology*, 24: 15-30.
- Becker, D. J.; Kilgore M. L.; Morrissey, M. A. 2010. The societal burden of osteoporosis. *Current Rheumatology Reports*, 12: 186-191.
- Bocherens, H. 2002. Preservation of isotopic signals ( $^{13}\text{C}$ ,  $^{15}\text{N}$ ) in Pleistocene mammals. *In: Ambrose, S. H.; Katzenberg, M. A. (eds.) Biogeochemical approaches to paleodietary analysis*. New York, Kluwer: 65-88.
- Bogin, B. 1998. Milk and human development: an essay on the "Milk Hypothesis". *Antropologia Portuguesa*, 15: 23-36.
- Bonjour, J. P.; Theintz, G.; Law, F.; Slosman, D.; Rizzoli, R. 1994. Peak bone mass. *Osteoporosis International*, 4 (Suppl 1): 7-13.
- Boyd, M.; Varney, T.; Surette, C.; Surette, J. 2008. Reassessing the northern limit of maize consumption in North America: Stable isotope, plant microfossil, and trace element content of carbonized food residue. *Journal of Archaeological Science*, 35: 2545-2556.
- Brickley, M.; Ives, R. 2008. *The bioarchaeology of metabolic bone disease*. San Diego, Academic Press.



- Bridges, P. S. 1989. Bone cortical area in the evaluation of nutrition and activity levels. *American Journal of Human Biology*, 1: 785-792.
- Burnham, J.; Leonard, M. 2008. Bone mineral acquisition in utero and during infancy and childhood. *In: Marcus, R.; Feldman, D.; Nelson, D.; Rosen, C. (eds.) Osteoporosis*. San Diego, Academic Press: 705-442.
- Calvo, M. S.; Tucker, K. L. 2013. Is phosphorus intake that exceeds dietary requirements a risk factor in bone health? *Annals of the New York Academy of Sciences*, 1301: 29-35.
- Cassidy, C. M. 1984. Skeletal evidence for prehistoric subsistence adaptation in the central Ohio River Valley. *In: Cohen, M. N.; Armelagos, G. J. (eds.) Paleopathology at the origins of agriculture*, New York, Academic Press: 307-345.
- Cho, H.; Stout, S. D.; Bishop, T. A. 2006. Cortical bone remodeling rates in a sample of African American and European American descent groups from the American Midwest: comparisons of age and sex in ribs. *American Journal of Physical Anthropology*, 130: 214-226.
- Cho, H.; Stout, S. D. 2011. Age-associated bone loss and intraskeletal variability in the Imperial Romans. *Journal of Anthropological Sciences*, 89: 109-125.
- Consensus Development Conference. 1993. Diagnosis, prophylaxis, and treatment of osteoporosis. *The American Journal of Medicine*, 94: 646-650.
- Cook, D. C. 1984. Subsistence and health in the Lower Illinois Valley - Osteological evidence. *In: Cohen, M.; Armelagos, G. (eds.) Paleopathology at the origins of agriculture*. Orlando, Academic Press: 237-270.
- Craig, O. E.; Biazzo, M.; O'Connell, T. C.; Garnsey, P.; Martinez-Labarga, C.; Lelli, R.; Salvadei, L.; Tartaglia, G.; Nava, A.; Renò, L. 2009. Stable isotopic evidence for diet at the Imperial Roman coastal site of Velia (1st and 2nd Centuries AD) in Southern Italy. *American Journal of Physical Anthropology*, 139: 572-583.
- Curate, F. 2014. Osteoporosis and paleopathology: a review. *Journal of Anthropological Sciences*, 92. DOI: 10.4436/JASS.92003.
- Curate, F.; Albuquerque, A.; Correia, J.; Ferreira, I.; Pedroso de Lima, J.; Cunha E. 2013. A glimpse from the past: osteoporosis and osteoporotic fractures in a Portuguese identified skeletal sample. *Acta Reumatológica Portuguesa*, 38: 20-27.
- Curate, F.; Pedroso de Lima, J.; Albuquerque, A.; Ferreira, I.; Correia, J.; Cunha, E. 2012. Parto, morte e massa óssea na Coleção de Esqueletos Identificados do Museu Antropológico da Universidade de Coimbra (Portugal): alguns avanços preliminares. *Cadernos do GEEVH*, 1: 57-65.
- Curate, F.; Piombino-Mascalì, D.; Tavares, A.; Cunha, E. 2009. Assottigliamento corticale del femore e fratture da fragilità ossea: uno studio della Collezione Scheletrica Identificata di Coimbra

- (Portogallo). *Archivio per l'Antropologia e la Etnologia*, 139: 129-146.
- Davies, K.; Stegman, M.; Heaney, R.; Recker, R. 1995. Prevalence and severity of vertebral fracture: The Saunders county bone quality study. *Osteoporosis International*, 6: 160-165.
- Dewey, J.; Armelagos, G.; Bartley, M. 1969. Femoral cortical involution in three Nubian archaeological populations. *Human Biology*, 41: 13-28.
- Eaton, S. B.; Nelson D. A. 1991 Calcium in evolutionary perspective. *American Journal of Clinical Nutrition*, 54: 281S-287S.
- Ekenman, I.; Eriksson, S.; Lindgren, J. 1995. Bone density in medieval skeletons. *Calcified Tissue International*, 56: 355-358.
- Engelsen, O. 2010. The relationship between ultraviolet radiation exposure and vitamin D status. *Nutrients*, 2: 482-495.
- Ericksen, M. F. 1976. Cortical bone loss with age in three Native American populations. *American Journal of Physical Anthropology*, 45: 443-452.
- Ericksen, M. F. 1980. Patterns of microscopic bone remodeling in three aboriginal American populations. In: Browman, D. L. (ed.) *Early Native Americans: prehistoric demography, economy, and technology*. New York, Mouton Publishers: 239-270.
- Feldman, D.; Malloy, P.; Krishnan, A.; Balint, E. 2008. Vitamin D: biology, action, and clinical implications. In: Marcus, R.; Feldman, D.; Nelson, D.; Rosen, C. (eds.) *Osteoporosis*. San Diego, Academic Press: 317-382.
- Fishbein, L. 2004. Multiple sources of dietary calcium—some aspects of its essentiality. *Regulatory Toxicology and Pharmacology*, 39: 67-80.
- Garn, S. M.; Guzman, M. A.; Wagner B. 1969. Subperiosteal gain and endosteal loss in protein-calorie malnutrition. *American Journal of Physical Anthropology*, 30: 153-156.
- Garnsey, P. 1998. *Cities, peasants and food in classical antiquity: essays in social and economic history*. Cambridge, Cambridge University Press.
- González-Reimers, E.; Velasco-Vázquez, J.; Arnay-de-la-Rosa, M.; Machado-Calvo, M. 2007. Quantitative computerized tomography for the diagnosis of osteopenia in prehistoric skeletal remains. *Journal of Archaeological Sciences*, 34: 554-561.
- González-Reimers, E.; Velasco-Vázquez, J.; Barros-Lopez, N.; Arnay-de-la-Rosa, M.; Santolaria-Fernandez, F.; Castillagarcía, A. 1998. Corticomedular index of the right tibia in the diagnosis of osteopenia in prehistoric skeletal remains. *American Journal of Human Biology*, 10: 37-44.
- Heaney, R. P. 1986. Calcium, bone health, and osteoporosis. In: Peck, W. A. (ed.) *Bone and mineral research*. Amsterdam, Elsevier Science Publishers: 255-301.
- Heaney, R. P. 2008. Nutrition and risk for osteoporosis. In: Marcus, R.; Feldman, D.; Nelson, D. A.; Rosen, C. J. (eds.) *Osteoporosis*. San Diego, Academic Press: 799-836.

- Heaney, R. P.; Abrams, S.; Dawson-Hughes, B.; Looker, A.; Marcus, R.; Matkovic, A.; Weaver, C. 2000. Peak bone mass. *Osteoporosis International*, 11: 985-1009.
- Heaney, R. P.; Recker, R. R. 1986. Distribution of calcium absorption in middle-aged women. *American Journal of Clinical Nutrition*, 43: 299-305.
- Henry, A. G.; Brooks, A. S.; Piperno, D. R. 2011. Microfossils in calculus demonstrate consumption of plants and cooked foods in Neanderthal diets (Shanidar III, Iraq; Spy I and II, Belgium). *Proceedings of the National Academy of Sciences - USA*, 108: 486-491.
- Hiller, M. L.; Boaventura, R.; Richards, M. 2008. Diet and mobility in Late Neolithic populations of central-south Portugal: isotopic analysis of human remains from the Lisbon and Alentejo regions of Portugal. *Apontamentos de Arqueologia e Património*, 1: 29-34.
- Himes, J. H.; Matorell, R.; Habicht, J-P.; Yarbrough, C.; Malina, R. M.; Klein, R. E. 1975. Patterns of cortical bone growth in moderately malnourished preschool children. *Human Biology*, 47: 337-350.
- Hunt, C. D.; Johnson, L. K. 2007. Calcium requirements: new estimations for men and women by cross-sectional statistical analyses of calcium balance data from metabolic studies. *American Journal of Clinical Nutrition*, 86: 1054-1063.
- Ilich, J. Z.; Badenhop, N. M.; Jelic, T.; Clairmont, A. C.; Nagody, L. A.; Matkovic, V. 1997. Calcitriol and bone mass accumulation in females during puberty. *Calcified Tissue International*, 61: 104-109.
- Ireland, P.; Fordtran, J. S. 1973. Effect of dietary calcium and age on jejunal calcium absorption in humans studied by intestinal perfusion. *Journal of Clinical Investigation*, 52: 2672-2681.
- Jessup, J.; Horne, C.; Vishen, R.; Wheeler, D. 2003. Effects of exercise on bone density, balance, and self-efficacy in older women. *Biological Research for Nursing*, 4: 171-180.
- Johnell, O.; Kanis, J. 2006. An estimate of the worldwide prevalence and disability associated with osteoporotic fractures. *Osteoporosis International*, 17: 1726-1733.
- Jorde, R.; Sundsfjord, J.; Haug, E.; Bønaa, K. H. 2000. Relation between low calcium intake, parathyroid hormone, and blood pressure. *Hypertension*, 35: 1154-1159.
- Katzenberg, M. A. 1989. Stable isotope analysis of archaeological faunal remains from southern Ontario. *Journal of Archaeological Science*, 16: 319-329.
- Klein, R. 2009. *The human career: human biological and cultural origins*. Chicago, University of Chicago Press.
- Koo, W.; Walyat, N. 2013. Vitamin D and skeletal growth and development. *Current Osteoporosis Reports*, 11(3): 188-193.
- Lanfranco, L. P.; Eggers, S. 2010. The usefulness of caries frequency, depth, and location in determining cariogenicity and past subsistence: a test on Early and Later Agriculturalists from the Peruvian coast. *American Journal of Physical Anthropology*, 143: 75-91.

- Lees, B.; Molleson, T.; Arnett, T.; Stevenson, J. 1993. Differences in proximal femur bone density over two centuries. *The Lancet*, 341: 673-675.
- Lips, P. 2001. Vitamin D deficiency and secondary hyperparathyroidism in the elderly: consequences for bone loss and fractures and therapeutic implications. *Endocrinology Review*, 22: 477-501.
- Livshits, G.; Deng, H.; Nguyen, T.; Yakovenko, K.; Recker, R.; Eisman, J. 2004. Genetics of bone mineral density: evidence for a major pleiotropic effect from an intercontinental study. *Journal of Bone and Mineral Density*, 19: 914-923.
- Lopes, M. 1999. *Pobreza, assistência e controlo social em Coimbra (1750-1850)*. Tese de doutoramento em História Moderna e Contemporânea. Coimbra, Faculdade de Letras, Universidade de Coimbra.
- Lubell, D.; Jackes, M.; Schwarcz, H.; Knyf, M.; Meiklejohn, C. 1994. The Mesolithic-Neolithic transition in Portugal: isotopic and dental evidence of diet. *Journal of Archaeological Science*, 21: 201-216.
- Marks, J. 2011. *An alternative introduction to Biological Anthropology*. New York & Oxford, Oxford University Press.
- Martin, D.; Armelagos, G. J. 1979. Morphometrics of compact bone: an example from Sudanese Nubia. *American Journal of Physical Anthropology*, 51: 571-577.
- Martin, D.; Armelagos, G.; Goodman, A.; van Gerven, D. 1984. The effects of socio-economic change in prehistoric Africa: Sudanese Nubia as a case study. In: Cohen, M.; Armelagos, G. (eds.). *Paleopathology at the origins of agriculture*. Orlando, Academic Press: 193-214.
- Martin, D.; Goodman, A.; Armelagos, G. 1985. Skeletal pathologies as indicators of quality and quantity of diet. In: Gilbert, R.; Mielke, J. (eds.). *The analysis of prehistoric diets*. New York, Academic Press: 227-279.
- Martin, D.; Magennis, A.; Rose, J. 1987. Cortical bone maintenance in an historic Afro-American cemetery sample from Cedar Grove, Arkansas. *American Journal of Physical Anthropology*, 74: 255-264.
- Matkovic, V.; Ciganovic, M.; Tominac, C.; Kostial, K. 1980. Osteoporosis and epidemiology of fractures in Croatia: an international comparison. *Henry Ford Hospital Medical Journal*, 28: 116-126.
- Matkovic, V.; Kostial, K.; Simonovic, I.; Buzina, R.; Brodarec, A.; Nordin, B. E. C. 1979. Bone status and fracture rates in two regions of Yugoslavia. *American Journal of Clinical Nutrition*, 32: 540-549.
- Matkovic, V.; Landoll, J. D. 2000. Non-genetic determinants of peak bone mass. In: Henderson, J. E.; Goltzman, D. (eds.) *The osteoporosis primer*. Cambridge, Cambridge University Press: 147-169.
- Mays, S. A. 1996. Age-dependent bone loss in a medieval population. *International Journal of Osteoarchaeology*, 6: 144-154.
- Mays, S. A. 2000. Age-dependent cortical bone loss in women from 18th and early 19th century London. *American Journal of Physical Anthropology*, 112: 349-361.

- Mays, S. A. 2001. Effects of age and occupation on cortical bone in a group of 18th-19th century British men. *American Journal of Physical Anthropology*, 116: 34-44.
- Mays, S. A. 2006. Age-related cortical bone loss in women from a 3rd-4th century AD population from England. *American Journal of Physical Anthropology*, 129: 518-528.
- Mays, S. A. 2008. Metabolic bone disease. In: Pinhasi, R.; Mays, S. A. (eds.) *Advances in human palaeopathology*. Chichester, John Wiley & Sons, Chichester: 215-252.
- Mays, S. A.; Lees, B.; Stevenson, J. 1998. Age-dependent bone loss in the femur in a medieval population. *International Journal of Osteoarchaeology*, 8: 97-106.
- Mays, S. A.; Turner-Walker, G.; Syversen, U. 2006. Osteoporosis in a population from medieval Norway. *American Journal of Physical Anthropology*, 131: 343-351.
- Mcdougall, I.; Brown, F. H.; Fleagle, J. G. 2005. Stratigraphic placement and age of modern humans from Kibish, Ethiopia. *Nature*, 433(7027): 733-736.
- Melton III, L. 1990. A "Gompertzian" view of osteoporosis. *Calcified Tissue International*, 46: 285-286.
- Metz, J. A.; Anderson, J. J.; Gallagher Jr, P. N. 1993. Intakes of calcium, phosphorus, and protein, and physical-activity level are related to radial bone mass in young adult women. *American Journal of Clinical Nutrition*, 58: 537 - 542.
- Mølgaard, C.; Larnkjær, A.; Mark, A. B.; Michaelsen, K. F. 2011. Are early growth and nutrition related to bone health in adolescence? The Copenhagen Cohort Study of infant nutrition and growth. *American Journal of Clinical Nutrition*, 94(suppl.): 1865S-1869S.
- Møller, U. K.; Strey, S.; Mosekilde, L.; Rejmark, I. 2012. Changes in bone mineral density and body composition during pregnancy and postpartum. A controlled cohort study. *Osteoporosis International*, 23:1213-1223.
- National Osteoporosis Foundation. 2010. *Clinician's guide to prevention and treatment of osteoporosis*. Washington, DC, National Osteoporosis Foundation.
- Nelson D. A. 1984. Bone density in three archaeological populations. *American Journal of Physical Anthropology*, 63: 198.
- Nelson, D. A.; Sauer, N.; Agarwal, S. 2003. Evolutionary aspects of bone health. *Clinical Reviews in Bone and Mineral Metabolism*, 1: 169-179.
- NIH Consensus Development Panel. 2001. Osteoporosis prevention, diagnosis, and therapy. NIH Consensus Development Panel on Osteoporosis Prevention, Diagnosis, and Therapy. *JAMA: The Journal of the American Medical Association*, 285: 785-795.
- Nordin, B. E. C. 2008. Reflexions on osteoporosis. In: Marcus, R.; Feldman, D.; Nelson, D. A.; Rosen, C. J. (eds.) *Osteoporosis*. San Diego, Academic Press: 46-69.
- Nordin, B. E. C.; Polley, K. J.; Need, A. G.; Morris, H. A.; Marshall, D. 1987. The problem of

- calcium requirement. *American Journal of Clinical Nutrition*, 45: 1295-1304.
- Odén, A.; McCloskey, E. V.; Kanis, J. A.; Harvey, N. C.; Johansson, H. 2015. Burden of high fracture probability worldwide: secular increases 2010–2040. *Osteoporosis International*, DOI: 10.1007/s00198-015-3154-6.
- Ortner, D. 2003. *Identification of pathological conditions in human skeletal remains*. San Diego, Academic Press.
- Perzigian, A. 1973. Osteoporotic bone loss in two prehistoric Indian populations. *American Journal of Physical Anthropology*, 39: 87-96.
- Petit, M. A.; MacDonald, H. M.; McKay, H. A.; Lloyd, T. 2008. Bone acquisition in adolescence. In: Marcus, R.; Feldman, D.; Nelson, D. A.; Rosen, C. J. (eds.) *Osteoporosis*. San Diego, Academic Press: 743-758.
- Pfeiffer, S. K.; King, P. 1983. Cortical bone formation and diet among protohistoric Iroquoians. *American Journal of Physical Anthropology* 60: 23 – 28.
- Pfeiffer, S. K.; Lazenby, R. A. 1994. Low bone mass in past and present aboriginal populations. In: Draper, H. H. (ed.) *Advances in Nutritional Research*, Vol. 9. New York, ed. Plenum: 35-51.
- Pina, M.; Alves, S.; Barbosa, M.; Barros, H. 2008. Hip fractures cluster in space: an epidemiological analysis in Portugal. *Osteoporosis International*, 19: 1797-1804.
- Prowse, T.L.; Schwarcz, H.P.; Saunders, S.R.; Macchiarelli, R.; Bondioli, L. 2005. Isotopic evidence for age-related variation in diet from Isola Sacra, Italy. *American Journal of Physical Anthropology*, 128: 2-13.
- Raisz, L. 2005. Pathogenesis of osteoporosis: concepts, conflicts, and prospects. *Journal of Clinical Investigation*, 115: 3318-3325.
- Recker, R.; Lappe, J.; Davies, K. M.; Heaney, R. 2004. Bone remodeling increases substantially in the years after menopause and remains increased in older osteoporosis patients. *Journal of Bone and Mineral Research*, 19: 1628-1633.
- Rewekant, A. 1994. Aging in prehistoric and contemporary human populations. *Variability and Evolution*, 4: 57-65.
- Richman, E.; Ortner, D.; Schuller-Ellis, F. 1979. Differences in intracortical bone remodeling in three aboriginal American populations: Possible dietary factors. *Calcified Tissue International*, 28: 209-214.
- Riggs, B.; Melton III, L. 1986. Involutional Osteoporosis. *The New England Journal of Medicine*, 314: 1676-1684.
- Rizzoli, R.; Bonjour, J-P. 2010. Determinants of peak bone mass acquisition. In: Adler, R.A. (ed.) *Osteoporosis: pathophysiology and clinical management*. Totowa, Humana Press: 1-22.
- Rodríguez-Ortiz, M. E.; Canalejo, A.; Herencia, J. M.; Martínez-Moreno, C.; Peralta-Ramírez, A.; Perez-Martinez, P.; Navarro-González, J. F.; Rodríguez, M.; Peter, M.; Gundlach, K.; Steppan, S.; Passlick-Deetjen, J.; Muñoz-Castañeda, J. R.; Almaden, Y. 2014. Magnesium modulates parathyroid hormone secretion

- and upregulates parathyroid receptor expression at moderately low calcium concentration. *Nephrology Dialysis Transplantation*, 29: 282-289.
- Roque, J. L. 1982. *Classes populares no distrito de Coimbra no século XIX (1830-1970): Contributo para o seu estudo*. Tese de doutoramento em História. Coimbra, Faculdade de Letras, Universidade de Coimbra.
- Roque, J. L. 1988. *A população da Freguesia da Sé de Coimbra (1820-1849). Coleção Estudos*, 6. Coimbra, Faculdade de Letras da Universidade de Coimbra.
- Samuel, D. 1996. Approaches to the archaeology of food. *Petits propos Culinaires*, 54: 12-21.
- Samuel, D. 2002. Bread in archaeology. *Civilisations*, 49. DOI: 10.4000/civilisations.1353.
- Santos, A. L. 1995. Death, sex and nutrition: analysis of the cause of death in the Coimbra Human Skeletal Collection. *Antropologia Portuguesa*, 13: 81-91.
- Schwarcz, H. P.; Schoeninger, M. J. 1991. Stable isotope analyses in human nutritional ecology. *Yearbook of Physical Anthropology*, 34: 283-321.
- Silva, J.; Carapito, H.; Reis, P. 1999. Diagnóstico densitométrico de osteoporose: critérios de referência na população portuguesa. *Acta Reumatológica Portuguesa*, 93: 9-18.
- Stini, W. 1995. Osteoporosis in biocultural perspective. *Annual Review of Anthropology*, 24: 397-421.
- Stout, S. D. 1978 Histological structure and its preservation in ancient bone. *Current Anthropology*, 19: 600-604.
- Thompson, D.; Guness-Hey, M. 1981. Bone mineral-osteon analysis of Yupik-Inupiaq skeletons. *American Journal of Physical Anthropology*, 55: 1-7.
- Tucker, K. L. 2009. Osteoporosis prevention and nutrition. *Current Osteoporosis Reports*, 7: 111-117.
- Turner-Walker, G.; Syversen, U.; Mays, S. A. 2001. The archaeology of osteoporosis. *European Journal of Archaeology*, 4: 263-269.
- Umbelino, C. 2006. *Outros sabores do passado: as análises de oligoelementos e de isótopos estáveis na reconstituição da dieta das comunidades humanas do Mesolítico Final e do Neolítico Final/Calcolítico do território português*. Tese de Doutoramento em Antropologia Biológica, Coimbra, Departamento de Antropologia, Universidade de Coimbra.
- Umbelino, C.; Cunha, E. 2012. The Sado shell middens: anthropological and paleodietary depiction. In: Gibaja, J.F.; Carvalho, A. F.; Chambon, P. (eds.) *Funerary practices in the Iberian Peninsula from the Mesolithic to the Chalcolithic*. Oxford, Archaeopress: 91-102.
- van der Merwe, N. J.; Tykot, R. H.; Hammond, N.; Oakberg, K. 2002. Diet and animal husbandry of the Preclassic Maya at Cuello, Belize: isotopic and zooarchaeological evidence. In: Ambrose, S. H.; Katzenberg, M. A. (eds.) *Biogeo-*

*chemical approaches to paleodietary analysis*. New York, Kluwer: 23-38.

van Gerven, D.; Armelagos, G.; Bartley, M. 1969. Roentgenographic and direct measurement of femoral cortical involution in a prehistoric Mississippian population. *American Journal of Physical Anthropology*, 31: 23-38.

Wasterlain, S. N. 2006. *'Males' da boca: estudo da patologia oral numa amostra das coleções osteológicas identificadas do Museu Antropológico da Universidade de Coimbra: finais do séc. XIX inícios do séc. XX*. Tese de Doutoramento em Antropologia Biológica, Coimbra, Departamento de Antropologia, Universidade de Coimbra.

Webb, A. R.; Kline, L. W.; Holick, M. F. 1988. Influence of season and latitude on the cutaneous synthesis of vitamin D3: Exposure to winter sunlight in Boston and Edmonton will not promote vitamin D3 synthesis in human skin. *Journal of Clinical Endocrinology and Metabolism*, 67: 373-378.

White, T. D.; Asfaw, B.; DeGusta, D.; Gilbert, H.; Richards, G. D.; Suwa, G.; Howell, F. C. 2003. Pleistocene *Homo sapiens* from Middle Awash, Ethiopia. *Nature*, 423(6491): 742-747.

Wylie, C. D. 2010. Setting a standard for a "silent" disease: defining osteoporosis in the 1980s and 1990s. *Studies in History and Philosophy of Biological and Biomedical Sciences*, 41: 376-385.

Zaki, M.; Hussien, F.; El Banna, R. 2009. Osteoporosis among ancient Egyptians. *International Journal of Osteoarchaeology*, 19: 78-89.

Zhang, H.; Sol-Church, K.; Rydbeck, H.; Stabley, D.; Spotila, L.; Devoto, M. 2009. High resolution linkage and linkage disequilibrium analyses of chromosome 1p36 SNPs identify new positional candidate genes for low bone mineral density. *Osteoporosis International*, 20: 341-346.