

# The history of osteoporosis: why do Egyptian mummies have porotic bones?

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**ABSTRACT** Paleopathologists have identified osteoporosis in ancient skeletons and modern physicians and scientists have identified risk factors for osteoporosis today, but they are not clearly linked, making it more difficult to clarify the causes of osteoporosis in the past. The evidence for osteoporosis in the remote past, its causes, and the management of this disease is reviewed in the light of evolving and improving diagnostic modalities, more precise definitions, and the recent rapid expansion of therapeutic options. While the specific effects of parity and lactation on the development of osteoporosis are still not entirely clear, duration of reproductive span and age at first pregnancy appear to be significant predisposing factors.

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## INTRODUCTION

In the future, the clinician treating hip fractures, confronted with the daunting projected increase in this condition by the middle of this century, may well perceive osteoporosis as a disease of the 20th and 21st centuries. The incidence of hip fractures in Australia for example is expected to increase from around 20,000 today to 50,000 by 2050 as the population ages.<sup>1</sup> This growth can be attributed to the increase in post-menopausal life expectancy and the reduction in osteogenic bone loading activities thanks to labour-saving devices and electronic communication. However, paleopathology, a term first used by Ruffer in 1921 to describe the science of the diseases which can be demonstrated in human and animal remains of ancient times, suggests the disease was present five millennia ago.<sup>2</sup>

The World Health Organization (WHO) definition of osteoporosis describes it as a systemic skeletal disease characterised by low bone mass and micro-architectural deterioration of bone tissue, with a consequent increase in bone fragility and susceptibility to fracture risk.<sup>3</sup> Our understanding of this disease is progressing rapidly, such that although many women have suffered from the disease for millennia, we can look forward to steady therapeutic improvements and, perhaps, totally effective preventative treatment in the future.

The incidence of minimal trauma fractures has increased dramatically during the last century as life expectancy increases. Women now may live for 30–40 years after the menopause and experience progressive bone loss and fractures. Modern technological devices have largely removed the bone-loading activities that promote

osteogenesis. Walking, shopping, carrying burdens, delivering messages, manual labour and washing clothes have been replaced by motor vehicles, the internet, shopping trolleys, emails, power tools and washing machines.

However, skeletal remains, one of mankind's bequests to the history of medicine, reveal osteoporosis to have existed millennia ago.<sup>4</sup> The history of osteoporosis, its causes and its management are related through the perspective of developing diagnostic investigations, more accurate definitions and increasing therapeutic options.

## DIAGNOSTIC METHODS AND BONE PRESERVATION

Evidence of osteoporosis in the past is only as good as the subject material and the diagnostic methodology used to identify it. Evidence supported by out-of-date definitions and investigations is unreliable. Approximately 20–40% of bone mass must be lost before osteoporosis can be diagnosed on lateral spinal films, and X-ray appearance can be affected by many factors such as exposure, soft tissue thickness and film development, although this is less of a problem with digital radiographs.<sup>5</sup>

Early studies show that osteoporosis was diagnosed using X-rays to detect cortical thickness or the relative prominence of weight-bearing trabeculae compared with thinner non-weight-bearing trabeculae, an investigation of limited accuracy. Dual-energy X-ray absorptiometry (DEXA) scans have increased diagnostic precision, yet this technology is already being supplemented by even more accurate techniques.

Average height has increased with the passage of time, and humans today are several centimetres taller than only a few centuries ago. However, while large frames are associated with an increased fat mass, bone mineral density does not vary much with changes in size.<sup>6</sup>

The DEXA scan is standardised for surrounding soft tissue and, therefore, isolated skeletal bones must be surrounded by a substance equivalent to soft tissue before measurement. The commonest equivalents in paleopathology are water and rice, but identical direct comparisons are obviously not possible and bones from the past cannot be quantitatively directly compared with those of living individuals of today. Frigo and Lang, for example, believe they can only be compared with other skeletons buried at the same site and about the same time.<sup>7</sup> The WHO definition of osteoporosis includes the term 'micro-architectural deterioration', yet DEXA cannot detect this, while new low radiation dose peripheral quantitative computerised tomography (pqCT) programmes can. Although our disease definition and permissible therapies are inextricably linked to DEXA, this form of imaging may soon be replaced in clinical practice by the more specific pqCT, which is also being used in modern paleopathology studies.

Bones buried in the ground may have been damaged by factors such as soil acidity, water and temperature. Bones with external erosions are unsuitable for analysis. Trabecular bone decays faster than cortical bone in inhospitable soil.<sup>8</sup> They will ultimately undergo diagenesis, when bone minerals are leached out of the skeleton; bones will eventually equilibrate with the mineral content of the soil, thus having a minor effect on DEXA analysis. Soil-dwelling micro-organisms may cause structural changes in bones, perhaps by destroying collagen which precipitates calcium and affects bone density. Soil inclusions appear on X-rays as patches of increased radiodensity and can be excluded.<sup>9</sup> Dry bones free of soil are ideal for analysis. Age is often determined from dental erosion, rather than known dates. Bone histology, perhaps the most accurate investigation, obviously involves permanently removing a part of that bone, which may be inappropriate with very old or incomplete skeletons. In spite of the limitations of DEXA scans, they, along with pqCT and bone histology, remain the most accurate techniques for assessing osteoporosis and the use of these is described in this paper.

## RECOGNITION OF OSTEOPOROSIS

Although osteoporosis has been present in humans for millennia, affecting Egyptian women over 4,000 years ago, it is only in the last three centuries that the disease has been recognised and quantified. Two hundred and

fifty years ago, John Hunter (1728–93), the famous Scots-born anatomist and surgeon, discovered remodelling,<sup>9</sup> the process by which new bone is laid down in the body and the old bone is destroyed or resorbed. Sir Astley Cooper (1768–1841), surgeon and anatomist, recognised that the age-related decline in bone density increased the risk of fracture. French pathologist Jean Lobstein (1777–1835)<sup>10</sup> is credited with developing the term 'osteoporosis' or porous bone in the 1830s to describe holes in bones which he found were larger in some patients than others. The term osteoporosis appears to have been used incorrectly in the 1860s, according to the current definition and understanding, by both Wilks when describing hyperostosis of the skull<sup>11</sup> and Partridge to describe bone affected by osteomyelitis.<sup>12</sup>

The first indication that oestrogen levels may affect bone density came from Preston Kyes (1875–1949) and Potter in 1934,<sup>13</sup> who found that male pigeons had a large femoral marrow cavity full of a pulpy dark red marrow unattached to the bone cortex, but that female pigeons, especially those ovulating with large ovarian follicles, demonstrated marked marrow ossification with histologically normal trabecular bone growing into the marrow cavity. A century after Lobstein, and progressing from Kyes' discovery, Fuller Albright (1900–69) and colleagues<sup>14,15</sup> advanced our understanding of osteoporosis by noting a deficiency of osteoblasts in the affected bone. He also described the predominant involvement of the spine, pelvis and long bones, and the association with disuse and senescence. Albright discovered that frail bones were more common in post-menopausal women, particularly those who underwent an early menopause, which made them more susceptible to osteoporosis. He developed the first effective treatment for osteoporosis by prescribing oestrogen, thus preventing damage to the skeleton by halting continued bone loss. Albright also recognised possible causes of osteoporosis which are similar to modern causes, including gastric hypoacidity and the use of proton pump inhibitors,<sup>16</sup> as well as Cushing's disease and current corticosteroid therapy.

In the 1955 Lumleian lecture to the Royal College of Physicians, Alexander Cooke (1899–1999) defined osteoporosis as a disease of inadequate bone formation from lack of 'matrix'.<sup>17</sup> He noted the lack of osteoblasts to replace osteoclastic erosions and considered that the diagnosis could only be made by histological examination, though radiological and clinical features were highly suggestive. Cooke noted both the benefits and the adverse effects of androgens, including one he described as 'an unseemly increase in libido'.<sup>17</sup>

Subsequent therapeutic trials with fluoride, anabolic steroids and calcitonin met with limited success and each had some side-effects. It was the discovery of

bisphosphonates by Herbert Andre Fleisch (1933–2007) in the 1960s that revolutionised the treatment of osteoporosis.<sup>18</sup> The 1960s also saw the development of devices for detecting bone loss, including densitometers which determine bone density by measuring changes in the absorption of energy passing through various bones, enabling diagnosis and instigation of management of osteoporosis at an early stage.

Current investigations into the intracellular biochemical pathophysiology along with the development of biological therapies may lead, optimistically, to the end of osteoporosis within a decade. Therapies such as a humanised monoclonal antibody that binds to and inhibits sclerostin, mimicking the hereditary clinical condition of Van Buchem's disease (AMG 785/CDP 7851), will become widely available and prescribed.<sup>19</sup>

## ANCIENT OSTEOPOROTIC BONES

Many specialists have evaluated the bone density of skeletons originally buried up to 6,000 years ago. Major discoveries are described in this section, commencing with the oldest first.

Teschner used micro-computerised tomography to examine the ninth vertebra of a 20- to 25-year-old male skeleton found near Heidelberg and demonstrated by radiocarbon investigation that the man had been buried some 6,000 years ago. The vertebra was found to have greater bone volume and trabecular number compared with similar bones of today, implying that in this young man at least, his more active lifestyle had a beneficial effect on his bone density.<sup>20</sup>

Using the DEXA scan, Frigo and Lang measured the femoral bone density of an early Bronze Age Austrian woman, buried about 4,000 years ago aged around 45. They found a bone mineral density (BMD) of 0.831 gm/cc<sup>2</sup>, compared with the mean value of all 14 women in the grave of the same age of 0.981 gm/cc<sup>2</sup>. Furthermore, the mean value for five men in the same grave was 1.195 gm/cc<sup>2</sup>, indicating that women had lower BMD than men and that some women still developed osteoporosis in spite of the active outdoor lifestyle of a farming community.<sup>7</sup>

In contrast, Jackes and Lubbell measured femoral cortical thickness in Portuguese Neolithic bones dated to around 4,700 BC and found considerable reduction in the cortical thickness in older women, identified by the loss of nearly all the enamel on molar teeth.<sup>21</sup> Agarwal et al. measured metacarpal cortical thickness in Neolithic skeletons in Turkey, finding a decline in cortical thickness with age in both men and women.<sup>22</sup> Perzigian found skeletons in Kentucky over 4,000 years old with a rate of bone loss similar to that seen today.<sup>23</sup> Kneissel et al. examined trabecular bone in 4,000-year-old Bronze Age Austrian skeletons, comparing different methods for

validity in the presence of diagenesis and bone replacement by micro-organisms.<sup>24</sup> The methods used included stereoscopic photography, DEXA scans, digitised radiographic images calibrated and computed to produce a radiographic bone density, electron microscopy to calculate trabecular bone volume, silver staining of calcium with image analysis to calculate volume and, lastly, fibre optic and laser scanning electron microscopy. Results comparing the 30–40 age cohort with the 40–60 year old cohort showed a dramatic fall in the quantity and quality of trabecular bone in the older group, but the DEXA scans and radiographic and electron microscopy images were adversely affected by diagenesis.

Giuffra et al. examined 33 Egyptian mummies stored in Italian museums.<sup>25</sup> Ancient Egyptian mummies are well preserved and free from soil damage. These bodies dated from the New Kingdom period (1550–1070 BC) to the Roman period (30BC–395AD). Osteoporosis was diagnosed using conventional radiology to detect the predominance of vertical bone bundles and relative loss of horizontal bundles, a technique of limited accuracy. Osteoporosis was found in four subjects, three female and one male, all aged over 35 years. Life expectancy in ancient Egypt was between 35 and 45 years, and only 10% are estimated to have survived beyond the age of 50.<sup>8</sup> Healing fractures were found in six mummies, involving the clavicle on three occasions and also the fibula twice, the ribs and the tibia.

Armelagos et al. examined ancient Nubian bones which were well preserved in a very hot, dry environment and dated back two millennia.<sup>26</sup> They found that femoral cortical thickness in the female skeletons started to decline in the third decade of life, before an expected menopause. Nutritional deficiency and prolonged lactation were postulated as the cause, though this was still at a high point of the Nubian civilisation prior to the Islamic takeover, when Nubia, having been the earliest large African civilisation, was a rich, cultured, well-nourished and powerful society.

Cho and Stout examined bones from the imperial Roman era dating between 100 and 300 AD.<sup>27</sup> Histological examination required removal of 2–3 cms from the midshaft of ribs and demonstrated that age-related bone loss and increased cortical porosity were more marked in women than men.

Mays contrasted metacarpal radiological peak cortical thickness in third- and fourth-century female skeletons in the UK with modern women, finding reduced bone thickness and greater bone loss with age in the ancient bones.<sup>28</sup> Currently, lower BMD and more fragility fractures are found in Norwegians than in matched controls in England. Mays evaluated skeletons from medieval cemeteries in Trondheim and the deserted medieval village of Wharram Percy, England. He contrasted DEXA

scans of the proximal femur using rice as a soft tissue equivalent, finding similar peak bone densities and age-related BMD loss, but more osteoporotic fractures in the Norwegians. A colder climate and more hard surfaces causing more falls resulting in fractures are postulated as the cause.<sup>29</sup>

The skeletons of the younger females aged 18–29 found at Wharram Percy, though comparisons are not totally accurate, show a higher peak density than today's age-matched counterparts, yet the bone density of the over 50 age group skeletons have fallen to 74% of the younger women, whereas today the bone density of an over 50-year-old woman has only fallen to 82% of the younger cohort. This implies that the osteoporotic process started earlier and was more severe than in the Middle Ages.<sup>30</sup> The skeletons at Wharram Percy revealed healed rib and vertebral fractures, particularly in the women with a lower femoral neck BMD. Interestingly, there were no hip or wrist fractures, perhaps due the rarity of hip fractures before the age of 70. The children were shorter than those of today, suggesting suboptimal nutrition which, combined with genetic factors, is postulated as the cause of osteoporosis.

Carlson et al. measured cortical thickness in American Indian male and female skeletons aged up to approximately 55 years old, buried between 1540 and 1700 AD in Missouri, USA.<sup>31</sup> The femora were sawed through at five different levels to measure cortical thickness (this was done at a time when cultural sensitivity to indigenous remains appeared to have been less than today). Cortical thickness and cortical area was greater in males than females, and rate of bone loss with age was greater in females than males.

Albuquerque et al. assessed 196 nineteenth-century Portuguese skeletons for fractures using DEXA scanning, finding a mean femoral neck BMD of 0.821 g/cm<sup>2</sup> in the 20–29-year-old female group and a mean BMD of 0.468g/cm<sup>2</sup> in the females aged 80 and over.<sup>32</sup> This currently unpublished data does not include the methodology of the DEXA scanning.

Berenson et al. measured femoral neck bone density in 247 modern white women aged 16–34, finding a mean density of 0.886 g/cm<sup>2</sup>.<sup>33</sup> Liu et al. measured femoral neck bone density in 302 Asian post-menopausal women with a mean age of 66.2, finding a mean BMD of 0.57 g/cm<sup>2</sup>.<sup>34</sup> These were a 'normal well-nourished' group of Americans with a BMI of 26.2 kg/m<sup>2</sup>, and a 'normal well-nourished' group of Asian women with a mean BMI of 22.7 kg/m<sup>2</sup>, respectively. Femoral fractures were associated with low BMD.

Lees et al. evaluated skeletons of known age at death found in Christ Church Cemetery, Spitalfields, London, buried between 1729 and 1852.<sup>35</sup> Only well-preserved

dry femora were evaluated using DEXA scans, with specimens placed in water as a soft tissue equivalent. Lees stated that direct comparisons with living controls were invalid since living bone contains fat and marrow, so she compared the rate of bone loss with age in both the skeletal subject and age-matched living controls. She found significantly greater loss of femoral neck bone density in modern subjects, suggesting that long hours of arduous work in the silk weaving industry, which employed most women in the area, along with more walking and, perhaps, increased parity plus a better diet containing more fruit and less processed food, were responsible for conserving bone density in the historical subjects. The epidemiological pattern of osteoporosis 200 years ago was found to be virtually identical to that of today, in spite of the changes in lifestyle, longevity, general health and nutritional status.

Archaeological and modern investigations therefore show that in spite of local genetic and nutritional variations, osteoporosis has been found in numerous female skeletons in North and South America, Europe and Africa on many occasions over nearly seven millennia, suggesting that variations in oestrogen production may play a larger role in this condition. There is one geographical exception. Data from Melanesia and Polynesia are much more limited, though Buckel and Tayles found evidence of predominantly infectious diseases in 400-year-old bones (the time of the arrival of the first Spanish explorers), particularly from syphilis and yaws in the Solomon Islands.<sup>36</sup> Reid et al. found the forearm bone mineral content of Polynesian females to be 20% greater than Europeans, such that the post-menopausal bone loss in Polynesians reduced their bone density to that of premenopausal Europeans.<sup>37</sup> Furthermore, the incidence of hip fracture has been found to be lower in Polynesians and Solomon Islanders than in Europeans by Norton et al.<sup>38</sup> and Barss<sup>39</sup> respectively. Hence, the Pacific Islands, some of which have perhaps been inhabited for only two or three millennia, by people with genetically stronger bones, are unlikely to provide evidence of ancient bones with osteoporotic fractures.

## CAUSES OF OSTEOPOROSIS

Menarche, menopause, pregnancy and lactation are physiological events occurring during a woman's life that relate to fluctuations in oestrogen levels and bone density. The effects of these periods of hormonal change on bone density are evaluated and comparisons made with reproductive mores in past millennia.

Clearly osteoporosis was prevalent several millennia ago, dispelling the superficial impression that this is a new epidemic related to the ageing of the population and a lifestyle that is physically much less demanding. The ancient Egyptian mummies were the privileged

members of that society, growing up in one of the most fertile areas of the world, where meat, fish, dairy products, fruit and vegetables were abundant. It is difficult to attribute the osteoporosis found in their bones to nutritional deficiency, although they may well have had minimal exertion due to the predominance of servants and slaves.

Some studies have found fewer fractures in historical osteoporotic bones than are found currently.<sup>28</sup> One suggestion for this phenomenon is an increase in falls caused by the current ubiquitous prescription of benzodiazepines, selective serotonin reuptake inhibitors and antipsychotic medications, particularly among many elderly people and nursing home residents.<sup>40</sup>

Interestingly, most past populations probably achieved a lower peak bone density than today, in spite of greater activity and probably greater exposure to sunlight and higher vitamin D levels. Hence, osteoporosis was found towards the end of a life expectancy some 30 years shorter than today, and fractures occurred at a younger age. In males, malnutrition and chronic diseases, then incurable, are the only obvious causes of osteoporosis. In women, the effects of parity, lactation and reproductive span also need consideration.

## PARITY

Pregnancy is a time of pronounced hormonal change with considerable individual variation in parity and age at the time of pregnancy. The effect of pregnancy on bone density today and in past millennia is evaluated. Severe pregnancy-related osteoporosis is a rare condition with only isolated cases being reported and will therefore not be discussed further.

The developing foetal skeleton requires about 30 g of calcium in total. During pregnancy, parathyroid hormone decreases and calcitriol (1,25 [OH]<sup>2</sup> vitamin D) increases, doubling intestinal calcium absorption. Ancient Egyptians considered children a blessing, and called them 'the staff of old age'.<sup>41</sup> According to Parsons, the rate of infant mortality was one in every two or three births, hence parity averaged four to six, but some women had ten to 15 pregnancies.<sup>41</sup>

In modern women, Purdie et al. found an initial 5% decrease in BMD during early pregnancy;<sup>42</sup> Ensom et al. found a return to pre-pregnancy levels later in pregnancy;<sup>43</sup> and Bowman and Miller found greater bone loss in teenage pregnancies.<sup>44</sup> Li and Zhu studied a Chinese population and found the BMD in Ward's triangle (part of the femoral head) to be significantly higher in women with either no children or one live birth, compared with those who had four pregnancies.<sup>45</sup> However, Tuppairainen et al. followed 3,140 Finnish perimenopausal women over 2.4 years, detecting 169 low

trauma fractures.<sup>46</sup> No increase in the risk of fracture related to age at menarche, parity or lactation was found, although these were very homogenous groups with age at menarche 13.8 years vs 13.7, parity 2.8 vs 2.6 and lactation 9.8 vs 9.5 months, with the fracture group numbers first. Sioka et al. also found no significant effect of parity when evaluating BMD in post-menopausal women, but the mean number of children was just 2.2, and only six out of 124 had three or more children without more details of maximum parity.<sup>47</sup> However, Turan specifically looked at 16 grand-grand multiparous women (ten or more pregnancies) and, when comparing them with 15 women who had given birth no more than three times, found no relationship between multiparity and post-menopausal osteoporosis.<sup>48</sup>

Furthermore, Hoffman et al. evaluated the risk of hip fracture with parity in a population with a hip fracture compared with matched controls and found a 9% reduction in the risk of hip fracture with each live birth.<sup>49</sup> A total of 18 out of 348 had between five and eight children. This study was based on a contemporary American population where one-third were overweight with a BMI of 25–30, and another third were obese with a BMI >30. Cure et al. evaluated an overweight (mean BMI 27.3) menopausal population of Columbian women, and also found a non-significant protective effect of multiparity with up to 16 births, along with no significant effect of lactation up to 48 months.<sup>50</sup> In addition, Sadat-Aliet al. studied 256 female orthopaedic patients and found that women who had borne more than six children had lower rates of osteoporosis (25.4% vs 48%) and less risk of fracture (515 vs 77.5) than women with fewer than five children.<sup>51</sup>

However, age at the time of the first pregnancy does appear to be an important factor. Ward et al. found teenage mothers had reduced cortical BMD at the radial diaphyses and reduced whole body bone mineral content compared with older mothers.<sup>52</sup> Cho et al. found post-menopausal osteoporosis in Korea to be 2.2 times more common in women who had teenage pregnancies, compared with mothers whose first pregnancy occurred in their third or subsequent decade, though significant historical events, including military occupation and internal warfare with associated nutritional deficiencies at that time, may have had a confounding effect.<sup>53</sup>

Thus, the effect of parity on osteoporosis is not entirely clear. A few live births with adequate or excessive nutrition do not appear to cause problems. The data on higher parity in a nutritionally deprived society remain unclear. An initial pregnancy before achieving peak bone density appears to leave persistent reduced BMD.

## LACTATION AND MENSTRUAL DURATION

As with parity, the effect of lactation on BMD is unclear. Parsons quotes Ani, the ancient Egyptian scribe, in saying that children were suckled for three years.<sup>41</sup> Studies analysing nitrogen stable isotope ratios in infant bones found in Wharram Percy suggest that the usual duration of breast feeding was 18 months.<sup>30</sup> Li and Zhu found that the longer the period of lactation, the lower the BMD.<sup>45</sup> Hoffman et al. found a non-significant trend to hip fracture with lactation over 12 months,<sup>49</sup> while Laskey and Prentice found significant bone loss during lactation,<sup>54</sup> but full recovery during a subsequent pregnancy. Eisman reported several studies showing bone loss with lactation, but this also recovered rapidly with progressive weaning.<sup>55</sup> Armelagos et al.<sup>26</sup> and Kneisselet al.<sup>24</sup> postulated that nutritional deficiency and prolonged lactation were the causes of osteoporosis found in ancient Nubian bones. In contrast, Cumming et al. found that breastfeeding actually had a protective effect against fractures, and that multiparity with four or more births had no significant effect on fracture risk.<sup>56</sup>

Lenora et al. studied the effects of multiparity and prolonged breastfeeding on BMD in 210 Sri Lankan women.<sup>57</sup> These women were aged between 46 and 98 years with an average BMI of 21.2, number of children 3.5 and the mean total duration of lactation of 61.3 months. Among these women, neither multiparity nor prolonged breastfeeding appeared to have any significant detrimental effect on maternal BMD, including in women with five or more children and in women who breastfed for 97 months or longer.

Siokka et al. evaluated the bone density of 124 healthy Greek post-menopausal women, and found that a menstrual duration of 24–30 years with late menarche and early menopause was associated with a significantly reduced BMD, compared with women with a fertility duration of more than 30 years.<sup>47</sup>

While data indicating the impact of earlier menarche appear significant, the evidence for the effect of earlier menopause is uncertain. Aristotle wrote that the menopause usually occurred at the age of 40.<sup>58</sup> Australian Bureau of Statistics data<sup>59</sup> from the last 20 years show increasing fertility in the 30–45 age groups, and increasing age at first pregnancy over this time. Data from the French National Institute for Demographic Studies<sup>60</sup> show the average age at menarche has fallen from 16 to 12 years old over the last 190 years, and Evers and Heineman have documented a similar fall in the average age of menarche in the USA from age 17 down to 13 years old, between 1830 and 1980.<sup>61</sup> Limited data on the duration of menstruation and reproductive span all suggest that menarche was later and menopause earlier in the past, perhaps playing a significant role in the development of osteoporosis at a younger age in

women of past millennia than today, but without a confirmed increase in fractures, perhaps due to the shorter life expectancy.

## CONCLUSIONS

- Osteoporosis has been a common disease for at least five millennia in spite of reduced longevity and increased activity in the past, even in societies where food was abundant. However, it is important to note that many skeletons have been damaged by diagenesis and are therefore inappropriate for evaluation.
- Throughout recorded history post-menopausal women have always lost bone mass at a faster rate than age-matched males.
- Controversy exists over whether ancient female bones suffered bone erosion at a faster or slower rate than the bones of women today.
- The cause of osteoporosis in ancient female skeletons remains uncertain, but peak bone density was probably lower in the past.
- Lactation reduces bone mass, but this is usually replaced on weaning. The effect of prolonged lactation for multiple pregnancies with only brief periods not lactating, as was more common in the past, along with the impact of low nutrition is unknown, but available evidence suggests this may cause lower bone mass.
- The effect of chronic disease is uncertain, but may have contributed to low bone mass in both men and women.
- Increased parity up to five pregnancies in well-nourished contemporary women appears to increase bone density. Current evidence suggests that an initial pregnancy in adolescence, as was common in the past, leads to a persisting reduction of BMD. This appears to be a major factor in the causation of osteoporosis in past millennia.
- A shorter reproductive lifespan between menarche and menopause is associated with a reduced bone mass. In the past, menarche was later and menopause usually occurred earlier than today. This appears to be a second major factor responsible for osteoporosis in ancient female skeletons.

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