

Ancient Vitamin D Deficiency

Long-Term Trends

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Vitamin D deficiency is now widely recognized as one of the most common health conditions in the world, with important consequences for overall health. Levels of deficiency appear to be rising, but the extent to which past humans were affected by vitamin D deficiency and the roles of this hormone in past human health are currently unknown. The discovery that mineralization defects in tooth dentin reflect periods of deficiency and are preserved in our earliest ancestors offers a unique opportunity to provide information on past social and cultural organization and, with further work, to contribute to ongoing debates on change in skin pigmentation. Here we show that humans from some of the earliest Middle Eastern and European communities were affected by deficiency, but levels and severity appear to have increased notably through time. On a simple comparative scale, severity of deficiency was four times as high in Greek communities in 1948 CE as in early farming communities from ca. 3000 BCE; some individuals in the later periods would have had rickets. Research using interglobular dentin in humans and nonhuman primates has the potential to fill in many important gaps in understanding past and present aspects of vitamin D deficiency.

Vitamin D deficiency is now widely recognized as one of the most common health conditions in contemporary society, with over a billion individuals estimated to be affected worldwide (Robinowitz 2009). The prevalence of this deficiency is thought to be increasing in many regions (Robinson et al. 2006; Wharton and Bishop 2003), prompting considerable concerns about health consequences. There have been many claims regarding the health consequences of vitamin D deficiency (Peterlik

2012), and it is now clear that maintenance of adequate levels of vitamin D has an important effect on immune function (Wei and Christakos 2015) and development of some, but not all, neoplastic diseases (Jacobs et al. 2016). Vitamin D is synthesized in the skin that is exposed to natural light (ultraviolet B [UVB] radiation). A range of factors, including season and latitude, affect individual vitamin D levels (Brickley, Moffat, and Watamaniuk 2014; Robinowitz 2009). Vitamin D can be obtained from dietary sources, but few foods naturally contain the nutrient. Phytates, found in unprocessed nuts and grains, make calcium less biologically available and can be a vitamin D inhibitor (Chaplin and Jablonski 2009). Severe vitamin D deficiency results in skeletal deformity. Defects of growth plates of bones are termed "rickets," and the term "osteomalacia" is often applied to defects in remodeled bone (Brickley, Moffat, and Watamaniuk 2014). The role of vitamin D in building and maintaining healthy bone is now established (Peterlik 2012; Robinowitz 2009).

Appreciation of the negative health consequences of vitamin D deficiency facing contemporary society has prompted consideration of both evolutionary (Holick 2003) and historical (Holick 2006) perspectives. In particular, the contribution that vitamin D synthesis has made to skin pigmentation has been much debated, with discussions surrounding the adaptive significance of skin pigmentation and protection from UV radiation damage (Jablonski 2012; Jablonski and Chaplin 2013; Robins 2009; Rossberg et al. 2016). Until recently it was widely thought that vitamin D deficiency and cases of rickets were not present before the Industrial Revolution (Holick 2003), but advances in the use of historical texts and skeletal paleopathology have shown these assumptions to be incorrect (Giuffra et al. 2015; Ortner and Mays 1998; Steinbock 1993). Among anthropologists it is widely assumed that vitamin D deficiency occurred only once humans left Africa (Jablonski and Chaplin 2013). There are, however, still significant questions regarding the paleoepidemiology of vitamin D deficiency, and work on vitamin D metabolism in nonhuman primates (Ziegler et al. 2015) could assist in understanding the development of vitamin D metabolism in humans.

Further progress has been made with the publication of a paper by D'Ortenzio and colleagues (2016) that demonstrated that mineralization defects in dentin (interglobular dentin), found in both modern and archaeological teeth, are due to a disruption in the pathway or homeostasis of vitamin D, phosphate, or calcium. Quite a number of conditions can cause such disruptions, but most are rare, with many being incompatible with life without access to developed healthcare systems. By far the most common cause of mineralization defects in bones and teeth is vitamin D deficiency caused by inadequate UVB radiation (nutritional rickets; D'Ortenzio et al. 2016). Clearer information on the past occurrence of vitamin D deficiency provided by interglobular dentin would contribute to debates on varied skin pigmentation, migration and immigration, and long-term consequences of intrauterine and early infant health.

Evidence for Vitamin D Deficiency in the Past: Texts and Skeletal Paleopathology

Some skeletal changes will be visible in those living with severe rickets. Pathological changes that are attributable to rickets have been recognized in a number of early texts from around the world (Hess 1930). Strong indicators of vitamin D deficiency in children, such as leg deformities, have been identified in the writings of Soranus of Ephesus and Galen (both second century CE). Hess (1930:24) provides the following excerpt from a translation of Soranus's work on gynecology and pediatrics: "If it stands or walks too early, the legs (especially the thighs) will become crooked." The first clinical description was made by Whistler (1645), rapidly followed by Glisson's (1650) classic description of what he believed to be a new disease, *De Rachitide*. In the nineteenth century, with the increasing urbanization associated with the Industrial Revolution, reports

of rickets were widespread (Palm 1890). Cases continued to be reported in large cities of northern Europe and North America in the early twentieth century (Hess and Unger 1922). Texts offer a useful source of information on rickets in the past, but there are challenges in attempting retrospective diagnoses (Mitchell 2011). The key problem in investigating evolutionary aspects of vitamin D deficiency is that for much of human evolution there are no written sources available.

Skeletal paleopathology provides a more direct source of evidence on rickets (fig. 1). With the publication of clear diagnostic criteria (Mays, Brickley, and Ives 2006; Ortner and Mays 1998), cases of rickets have begun to be identified in past communities far beyond the geographic and temporal boundary of northern European cities during the Industrial Revolution (Brickley, Moffat, and Watamaniuk 2014). For example, rickets has now been identified in children from the high-status Medici court in sixteenth- and seventeenth-century Italy (Giuf-

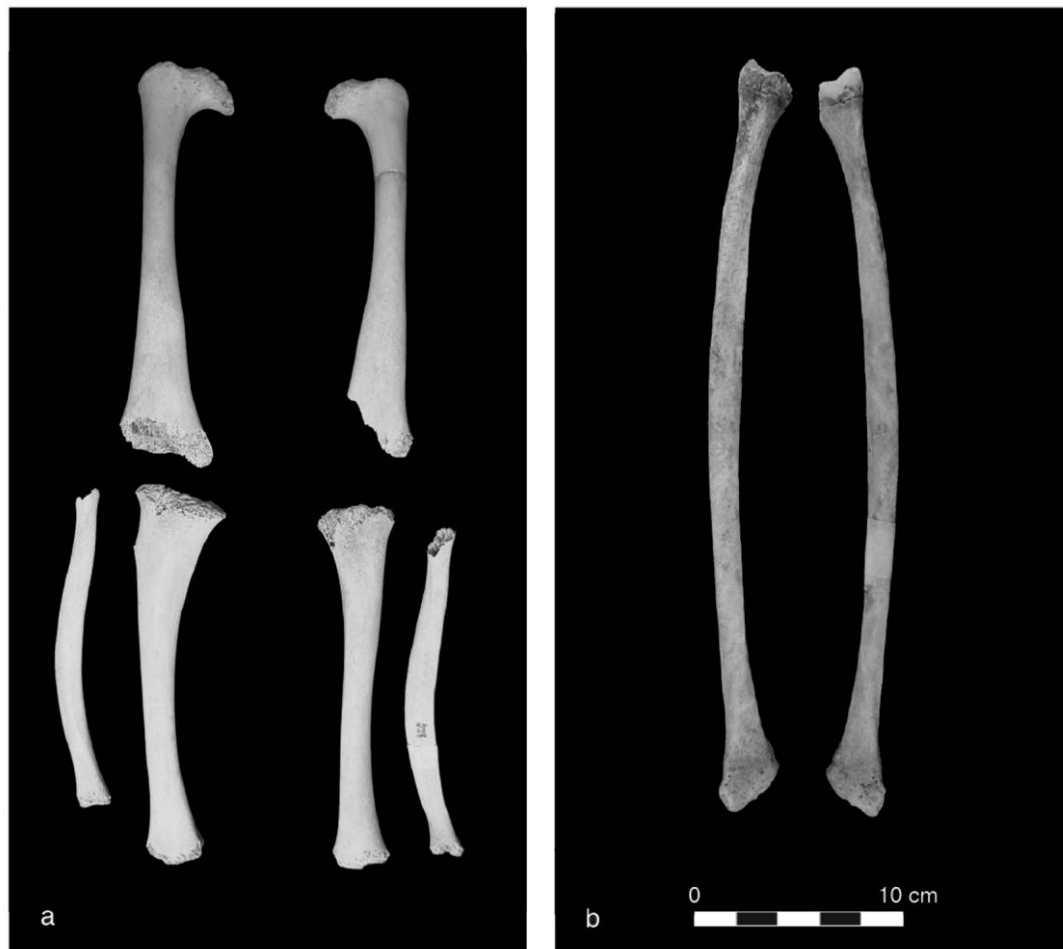


Figure 1. *a*, Leg bones (femora, tibiae, and fibulae) with severe bowing deformity from a 5–7-year-old child with healed rickets. *b*, Fibulae with marked bowing deformity due to childhood rickets from an adult with a healed case. Both individuals were buried at the Roman imperial cemetery of Isola Sacra (first to third centuries AD), Lazio, Italy. Images from a Social Sciences and Humanities Research Council–funded research project on vitamin D deficiency in the Western Roman Empire. A color version of this figure is available online.

fra et al. 2015) and a seventeenth-to-nineteenth-century farming community from the Netherlands (Veselka, Hoogland, and Waters-Rist 2015). Recent research demonstrates that the occurrence of rickets is linked to a range of social and cultural variables and that there is considerable intracommunity variation (Brickley, Moffat, and Watamaniuk 2014). Care is therefore required in making interpretations when sample size is small. Cases of rickets provide a useful indication of levels of vitamin D deficiency within past communities, although skeletal paleopathology is not without its limitations, as discussed below (Brickley, Mays, and Ives 2010; Brickley, Moffat, and Watamaniuk 2014).

Skeletal paleopathology is unlikely to identify all individuals diagnosed as having vitamin D deficiency by using clinical serum 25(OH)D (25-hydroxyvitamin D) levels, limiting suggestions regarding relative levels of deficiency in past and present communities. Some of the limitations of serum 25(OH)D measurement and reporting are discussed by Ziegler and co-workers (2015). Another problem is that many individuals who survive periods of childhood deficiency may not be identified by skeletal paleopathology. Hess (1930) estimated that in cases of rickets with visible leg deformity, only 10%–25% of individuals retained these changes into adulthood. In paleopathology, where bone can be examined directly, bone deformity would probably be visible in more cases. The 25% retaining deformity into adulthood suggested by Hess can safely be taken as a minimum, but there is a strong possibility that growth, remodeling, and individual variation will preclude identification of less severe cases. Where cases are identified, the number of episodes of vitamin D deficiency that occurred throughout the individual's lifetime cannot be determined. It is clear that many cases, and details of cases observed, will be missed.

Evidence for Vitamin D Deficiency: Interglobular Dentin

Dentin defects found in teeth, interglobular dentin, will provide new means of investigating past episodes of vitamin D deficiency. Interglobular dentin is a sign of mineralization defects produced when calcospherites (tiny spherical deposits of calcium salts) do not grow sufficiently and fail to fuse, leaving poorly mineralized patches of dentin (Hillson 1996). It has recently been demonstrated that interglobular dentin is well preserved in archaeological teeth (fig. 2), and analysis of evidence for systemic mineralization defects that follow lines of incremental growth (Hillson 1996:190) can be used to determine the number and severity of periods of deficiency (D'Ortenzio et al. 2016). To date most work on microstructural aspects of teeth has utilized histology: teeth have been embedded in resin and thin sections made. With polarized-light microscopy interglobular dentin can be observed in such sections (Hillson 1996; D'Ortenzio et al. 2016). The discovery of interglobular dentin, first described by Czermańk (1850), marks the start of what could be the answer to unraveling evolution-

ary aspects of vitamin D deficiency. Mellanby (1929) demonstrated that interglobular dentin formed in the teeth of dogs with experimentally produced rickets, but vitamin D was poorly understood at this time (Steinbock 1993).

Although interglobular dentin has been identified in cases of rickets with a genetic cause (Seow, Romaniuk, and Sclavos 1989), the link between vitamin D deficiency and these defects was not fully appreciated. Dental anthropologists and those working in dental histology have long known that interglobular dentin is not an uncommon finding in both archaeological and recent teeth (Hillson 1996).

Writing in 1956, Sognaes (1956) noted the experimental work undertaken on dogs by Mellanby (1929) but attributed interglobular dentin to more general metabolic and nutritional stress. Working on nonhuman primates, Molnar and Ward (1975) regarded interglobular dentin as an important indicator of environmental stress, noting the importance of calcium and its balance with phosphorous. Ivanhoe (1982) was far less cautious, directly linking interglobular dentin to rickets. Ivanhoe (1982) took the position that nutritional rickets was the cause of interglobular dentin, rather than reviewing all potential causes to demonstrate a link between vitamin D deficiency and interglobular dentin. Ivanhoe's work came before the recent rise in interest in vitamin D deficiency that allowed the link between nutritional rickets and interglobular dentin to be established (D'Ortenzio et al. 2016). Unlike bone, dentin is not remodeled, meaning that interglobular dentin provides the perfect medium with which to explore evolutionary aspects of vitamin D deficiency. The value of interglobular dentin is now clear; it is a precise tool with which to evaluate vitamin D deficiency (D'Ortenzio et al. 2016).

With this new information, the importance of previously published research on interglobular dentin can now be reanalyzed. A search was undertaken for articles reporting data on interglobular dentin, using PubMed and relevant references from articles. Taken together with the current understanding of vitamin D deficiency, these data provide evidence of the date and extent of the occurrence of vitamin D deficiency in past societies and provide a clear foundation for future research.

Results and Discussion

Four reports on interglobular dentin in humans were identified; Sognaes's (1956) article on the histological structure of 233 teeth from 12 archaeological and modern collections covering a wide time depth is of particular importance. We took these data and added supporting information from Ivanhoe (1982), Molnar and Ward (1975), and our research (D'Ortenzio et al. 2016) to investigate the first reported appearance of these defects and temporal changes from the late Pleistocene to the twentieth century. Information provided in the papers considered are summarized in table 1. Direct comparisons are possible for the 110 teeth from Greece, dating from 3000 BCE to CE 1948, analyzed by Sognaes (1956) with a semiquantitative scoring system, and these are shown in table 2.

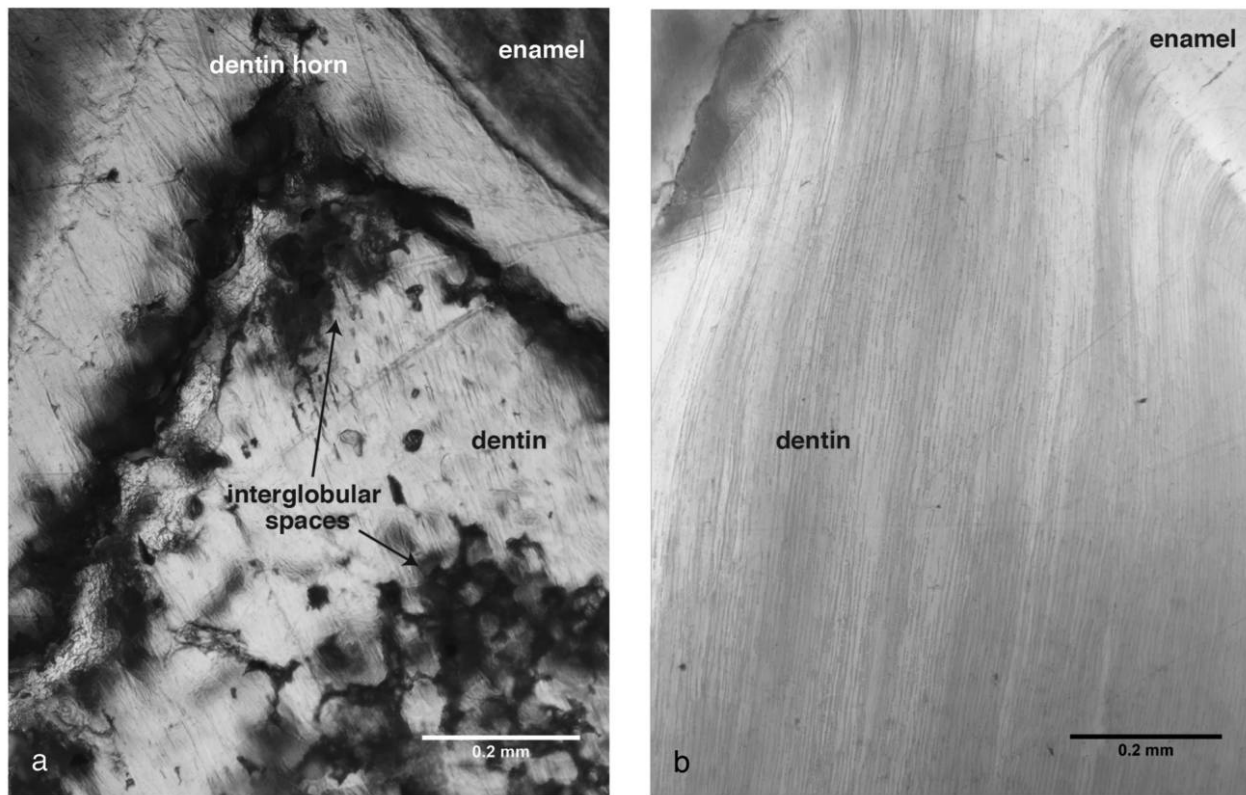


Figure 2. *a*, Tooth from a 23-year-old archaeological male from St. Matthew, Quebec (1771–1860), displaying two episodes of childhood vitamin D deficiency: one under the dentin horn and the other seen in the lower right-hand corner of image. Interglobular spaces in the dentin appear as bubbles where calcospherites have failed to fuse during a deficient episode. *b*, Tooth from a 19-year-old healthy modern male; dentin appears homogeneous, lacking the bubbled appearance, as calcospherites have fused properly. A color version of this figure is available online.

Factors such as ozone concentration, earth-sun distance, and the obliquity of the earth's axis have varied through time, affecting the amount of UV radiation reaching the earth's surface (Chaplin and Jablonski 2009; Relethford 1997). There would have been slight changes in seasonal intensity of UVB radiation over the time periods represented by individuals considered in this paper. Type of clothing is another important determinant of the amount of UVB radiation that will reach the skin (Brickley, Moffat, and Watamaniuk 2014). The wide time depth and geographical distribution of sites in table 1 mean that there was considerable variation in clothing worn due to climatic conditions, technologies and materials available, and cultural preferences. There are many unknowns regarding material used in the study by Sognaes (1956), and precise reconstruction of past UVB radiation levels, climatic conditions, and clothing types is not possible, but these variables should be kept in mind.

Reported Interglobular Dentin: The Late Pleistocene

The earliest evidence of vitamin D deficiency comes from Tabun and Skhul, late Pleistocene sites from Mount Carmel, Israel (table 1). This finding provides evidence that vitamin D

deficiency has been present since very early time periods and is not just an issue faced by current communities. The total number of individuals from these early sites is, however, very small ($n = 7$). Four out of five disarticulated teeth analyzed from Tabun show some level of interglobular dentin. Two of these teeth, a first permanent mandibular molar and a first permanent maxillary incisor, were suggested to be Neanderthal (Sognaes 1956). Records relating to the teeth are not sufficiently clear to establish whether they would be considered Neanderthal if subjected to current methods of analysis. Small interglobular spaces were reported in the molar but not in the incisor. Reported differences in age at death of the two individuals represented by these teeth indicate that they may have come from different individuals. The first permanent maxillary incisor and first mandibular molar have considerable overlap in development; in modern humans these teeth start developing approximately 3 months after birth and in utero, respectively (Gustafson and Koch 1974). Notes on the location of interglobular dentin in the molar (Sognaes 1956) indicate that it may have formed before the age at which dentin starts forming in the incisor. However, there has been discussion of dental development in *Homo* species, especially the

Table 1. Reported cases of interglobular dentin (IGD) in archaeological and modern teeth

Time period	Geographical location	N	Key findings	Source for key findings
Late Pleistocene, 122 ± 16 BCE ^a	Tabun, Israel	5	80% (4/5) had IGD (very slight in at least 2)	Sognaes 1956
Late Pleistocene, 66–117 BCE ^a	Skhul, Israel	2	100% (2/2) had IGD: one had suffered at least two episodes of deficiency in childhood; the second had large spaces in IGD	Sognaes 1956
Predynastic, ~5500–2700 BCE	Egypt	4	100% (4/4) had IGD (marked in 1 tooth, small and scattered in the remaining 3)	Sognaes 1956
Late archaic/Middle Woodland, 0 CE–1000 BCE	Kentucky, USA	3	Mean IGD area 10.3% (range 9%–12%)	Molnar and Ward 1975
Late archaic/Middle Woodland	Michigan, USA	10	Mean IGD area 16.6% (range 10%–22%)	Molnar and Ward 1975
Late archaic/Middle Woodland	Saskatchewan, Canada	3	Mean IGD area 20% (range 10%–22%)	Molnar and Ward 1975
Mayan, 400 BCE ^b	Kaminaljuyú, Guatemala	11	100% (11/11) had marked IGD	Sognaes 1956
Anglo Saxon, 425–625 CE ^c	Abingdon, Berkshire, UK	37	40% had IGD (15/37)	Ivanhoe 1982
Middle Ages, 500–1500 CE	Norway	23	57% (13/23) had IGD; 4 had small but numerous areas and 9 moderate areas	Sognaes 1956
Old Icelandic, ~1000–1850 CE	Iceland	2	100% (2/2) teeth from one individual; few IGD areas	Sognaes 1956
Pueblo III, 1275–1400 CE	Arizona and New Mexico, USA	8	Mean IGD area 11.1% (range 2%–24%)	Molnar and Ward 1975
Historic, 1450–1790 CE ^d	Pecos Pueblo, New Mexico, USA	76	25% (19/76) had marked or severe IGD	Sognaes 1956
Historic, 1225–1798 CE	St. Jacques, northern France	4	Individuals with healed rickets had IGD; 2/4 experienced two episodes	D’Ortenzio et al. 2016
Historic, 1771–1860 CE	St. Matthew and St. Marie, Quebec, Canada	2	Individuals with healed rickets had IGD; one died in early childhood; the second, who died around 23 years, experienced 4 episodes	D’Ortenzio et al. 2016
Historic, 1781–1825 CE	St. Bride’s Church, London	54	60% (32/54) had IGD	Ivanhoe 1982
Modern, 1975 CE	St. Louis, USA	14	1–4 teeth analyzed per person (individuals had mean IGD areas 8%–33%); mean IGD area for individuals in the group 17%	Molnar and Ward 1975

Note. All dates in the first column are approximate, and some changes have been made to the reference system used for calendar notations for consistency.

^a Dating information from Mounier and Lahr (2016).

^b Dating information from Wright and Schwarcz (1998).

^c Dating information from Leeds and Harden (1936).

^d Dating information from Levine and LaBauve (1997).

question of whether Neanderthal tooth growth was faster than that of modern humans (Dean, Stringer, and Bromage 1986; Ramirez Rozzi and Bermudez de Castro 2004) or similar (Dean et al. 2001; Macchiarelli et al. 2006) and the issue of whether postcanine and anterior teeth differ (Smith et al. 2010). In light of this, the statement made by Ivanhoe (1970:578) that Sognaes had produced “unequivocal evidence of serious vitamin D deficiency in Neanderthal man” cannot be accepted. To determine whether interglobular dentin representing systemic mineralization defects was present in Neanderthals, analysis would have to be undertaken on teeth that had been clearly determined to be Neanderthal.

The question of whether Neanderthals experienced vitamin D deficiency is important because genetic information on possible skin pigmentation in the species (Lalueza-Fox et al. 2007) has been used to support suggestions on the speed of such changes in humans with the move from Africa (Holick 2011). Synthesis of vitamin D is widely accepted to be the most significant factor in the development of different levels

of skin pigmentation in humans (Holick and Chen 2008; Jablonski 2012), although there is still some debate (Robins 2009). Melanin pigmentation plays a significant role in the rate at which synthesis of vitamin D occurs (Holick and Chen 2008), and natural selection has been suggested to influence the development of lighter skin pigmentation (Chaplin and Jablonski 2013). In the future, interglobular dentin should be considered in light of the chronology of dental growth in fossil hominins. Recording episodes of interglobular dentin across the dentition of individuals will provide a valuable tool for future dental development chronology studies. Interglobular dentin yields life-history benchmarks, since timing of the formation of teeth can be considered in light of the manifestation of stress episodes across the dentin (Smith et al. 2007).

Serum 25(OH)D levels have been shown to be high for modern individuals living traditional lifestyles close to the equator in Africa (Luxwolda et al. 2012), and it has been proposed that levels of vitamin D deficiency might have been high for humans leaving Africa (Chaplin and Jablonski 2009). Vi-

Table 2. Directly comparable data from Greek teeth

Time period	Teeth analyzed	Average score	Key findings
Prehistoric, 3000 BCE–750 CE	40	5+	75% (30/40) had IGD; the 3 teeth dating to 2000–3000 BCE had no IGD, which raises the proportion of individuals from 2000 BCE–750 CE to 81% (30/37)
Archaic-Classical, 750–338 BCE	12	7+	83% (10/12) had IGD
Hellenistic-Roman, 388–325 CE	7	7+	86% (6/7) had IGD
Historic, 330–1800 CE	4	9+	100% (4/4) had IGD
Historic, nineteenth century CE	23	9++	95% (22/23) had IGD
Modern, 1948 CE	24	20+++	92% (22/24) had IGD; analyzed teeth were extracted as a result of dental caries

Note. This table and notes are adapted from table II in Sognaes (1956:556). Average score is the average number of interglobular dentin (IGD) spaces within a 1-mm² area of dentin for all individuals from each time period. Individual data are not available. The plus signs are an estimate of the relative size of the IGD spaces.

tamin D deficiency, revealed through interglobular-dentin data, offers an opportunity to investigate the speed and extent to which vitamin D deficiency played a role in changes in human skin pigmentation. Work on the vitamin D status of nonhuman primates could play a big role in evaluating changes in vitamin D status relative to sun exposure, but consideration will have to be given to recent work that shows differences in vitamin D metabolism between humans and various nonhuman primate species (Ziegler et al. 2015). Other factors that will have to be considered in relation to hominins are developments of clothing, housing/shelter types, and lifeways that may affect the amount of skin exposure and dietary components such as phytates, which can prevent calcium absorption (Brickley, Moffat, and Watamaniuk 2014). Further work using securely dated dental samples is required, but this approach offers a clear opportunity to answer questions relating to skin pigmentation in hominin species.

Reported Interglobular Dentin: 5500 BCE to the Late Twentieth Century

The small numbers of teeth analyzed from early sites, coupled with limited amounts of contextual information, make it difficult to fully evaluate exact changes in prevalence of vitamin D deficiency. The two data sets that can be directly compared (Sognaes 1956 for Greek data and Ivanhoe 1982 for British data) indicate an increase of vitamin D deficiency through time, particularly with a move to urban living. Direct comparisons of averaged data for each time period are possible for the teeth from Greece dating from 3000 BCE to 1948 CE analyzed by Sognaes (1956; table 2). Various researchers have used systems to quantify interglobular dentin, with the most recent being that by D'Ortenzio et al. (2016). It is now known that interglobular dentin is linked to severity of disruption in mineralization. Sognaes developed a semiquantitative scoring system to evaluate the level of defects found in dentin by counting the average number of interglobular spaces per square millimeter and measuring the size of developmental defects (on a scale of + to +++).

Sognaes's paper (1956) indicates that no defects were found in the small sample of teeth from the very earliest time periods

but that moderate dentin defects were present in over 80% of individuals from 2000 BCE onward. Teeth from recent and contemporary Greece revealed not only that more people had interglobular dentin but also that the severity of defects had increased. On a simple comparative scale, severity of deficiency was four times as high in Greek communities in 1948 CE as in early farming communities from ca. 2000 BCE. The increase is particularly marked in recent history, after 1800 CE (Sognaes 1956). The thin sections made by Sognaes were not available for reanalysis, but from the description of scoring we estimate that Sognaes' scores 10–13 approximate D'Ortenzio et al.'s (2016) grade 2 and his scores 14–20 grade 3. All individuals with interglobular dentin scored as grade 2 or 3 in the investigation by D'Ortenzio and coworkers (2016) had severe rickets. For individuals analyzed from Greece, rickets could well have been present from 750 CE, with cases certainly present from 1800 CE onward. Although it has not received widespread attention, rickets was shown to be common in and around Athens in recent history. Lapatsanis and colleagues (1968) found rickets in 23% of those not receiving supplements. Molnar and Ward (1975) also found that the teeth with the highest proportion of interglobular dentin came from modern individuals (dating to 1975 CE).

The two groups from the United Kingdom investigated by Ivanhoe (1982) showed marked differences in interglobular dentin, with individuals living in the Industrial Revolution in London (1781–1825 CE) showing higher levels than those from the Anglo-Saxon (425–625 CE) community (see table 1). Ivanhoe estimated that 60% of those from London may have had rickets during infancy, compared to 40% from the earlier group. Using interglobular dentin, the severity of defects was scored, and the scores were also higher in individuals from London. Although Ivanhoe cautioned that the method used should be considered semiquantitative, it appears fairly conclusive that, as expected, levels of vitamin D deficiency were much higher in the group from a large industrial city. Holick (2003) suggests that during the Industrial Revolution levels of vitamin D deficiency would have been epidemic in cities. The two UK groups investigated by Ivanhoe were located at approximately the same latitude and within a 2,000-year time frame. The important differences would have been levels of

technological development and associated social practices, represented by factors such as the built environment, industrial activity, and atmospheric pollution, along with clothing and sunlight exposure. Ivanhoe (1982) focused on hours of sunlight available due to latitude, but recent research on vitamin D deficiency demonstrates that although latitude and sunlight are important factors, some of the highest levels of vitamin D deficiency come from very low latitudes (Mithal et al. 2009). Social and cultural factors are key variables in the development of vitamin D deficiency. Diet, which Ivanhoe (1982) did consider, is also important. Fish consumption has been shown to be responsible for high vitamin D levels in countries located at high latitudes, such as Finland (Lamberg-Allardt et al. 2013), and phytates, which are a vitamin D inhibitor, have been considered in relation to diets of early humans (Chaplin and Jablonski 2009).

The numbers of individuals investigated by D'Ortenzio et al. (2016) are small, but detailed information on vitamin D deficiency represented by interglobular dentin is provided. Individuals from both sites showed evidence for multiple episodes of deficiency, with a young man from Quebec City showing four episodes (two of the individuals from France showed two episodes). These individuals, from sites dating from the thirteenth to nineteenth centuries, were selected for analysis because of the presence of skeletal indicators of severe childhood rickets (D'Ortenzio et al. 2016) and so are probably not representative of the whole community. Future work on both communities is planned. Investigations on individuals from Quebec City will incorporate isotopic analysis to provide information on diet and immigration status. Work on the collections from St. Jacques in northern France will include examination of the archival material relating to Douai, the location of the cemetery. The archives available are among the richest in France and will provide information on diet and cultural practices.

Lifestyle and evolutionary aspects of vitamin D in human societies have been considered by Chaplin and Jablonski (2009), but until now such investigations have relied on using current data to construct theoretical models of past patterns of deficiency. In a study of Scotland (Chaplin and Jablonski 2013), evidence from environmental archaeology for utilization of marine resources and cow's blood (relatively high in D₃) for making black pudding by past communities is considered. The highland potato famine of the 1840s is suggested to be a decisive moment in time for communities living in Scotland (Chaplin and Jablonski 2013). A significant change in lifestyle occurred for many individuals, as they were forced from the land and moved to urban environments. Diet and time spent outdoors would have changed significantly for many people. Until now it has been difficult to estimate the vitamin D status of past groups (Chaplin and Jablonski 2013). Integration of data on interglobular dentin would provide clear information on changes in cultural and dietary practice to be determined for past groups and allow more to be learned concerning vitamin D metabolism, including the effect of intrauterine vitamin D deficiency on future health (D'Ortenzio et al. 2016; Ziegler et al. 2015).

Conclusions

Vitamin D deficiency is one of the most significant health problems facing the world's population today, and it tends to be thought of as a modern health problem. Data reviewed here provide clear evidence that vitamin D deficiency has been present in human communities from the earliest time periods. Understanding past patterns of vitamin D deficiency through interglobular dentin has significant potential to provide information on the importance of intrauterine and early infant vitamin D deficiency for long-term health, variation in skin pigmentation, immigration, and social and cultural factors operating in past communities. Data currently available indicate that the move from simple farming to complex urban communities had a significant impact on levels of vitamin D deficiency. The approaches presented will enable future studies to fully investigate such changes. Application of information on interglobular dentin revealed by the various branches of anthropology will elucidate issues concerning contemporary health problems associated with the deficiency.

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