D-lightful sunshine disrupted: Vitamin D deficiency as a method for the reconstruction of changes in sociocultural practices due to industrialisation in 17th - 19th century Netherlands

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1 Introduction

AIMS AND OBJECTIVES OF THIS RESEARCH

Many aspects of daily life changed in the Netherlands over the course of the 17th to 19th centuries. Some of these changes had important repercussions for health and disease. Although the Netherlands did not experience the Industrial Revolution in the same way the United Kingdom or other European countries, the process of industrialisation did significantly affect Dutch populations, especially in the 19th century (De Vries 2000; De Vries and Van der Woude 1997; Mokyr 1976; 2000; Wintle 2000). Historic sources provide us with data on the economic and political changes that various Dutch centres experienced. Indeed, industrialisation must have affected both urban and rural centres by intensification of production processes and task specialisation (De Vries 2000; Falger et al. 2012; Sypkens Smit 1964; Van der Bent et al. 2011; Van Gastel 1995; Wintle 2000). This in turn, must have influenced sociocultural practices in the various communities in response to these new demands. However, the way industrialisation impacted daily life and how sociocultural practices changed are poorly understood, especially in smaller towns and rural villages.

The use of just historic sources to assess the influence of industrialisation on the various communities in the Netherlands provides an incomplete understanding. Most of these sources describe general trends, some aspects of elite lifestyle, or are focussed on inhabitants from large, highly industrialised urban centres (Clerx 1985; De Vries and Van der Woude 1997; De Vries 2000; Drukker and Tassenaar 1997;

Mokyr 2000; Wintle 2000). Information on rural populations and individuals from small urban centres, as well as and women and children in general, is lacking, even though political and economic changes of industrialisation must have affected these groups. To improve our understanding of the impact of industrialisation on various Dutch communities, both rural and urban, the analysis of human skeletal remains can be undertaken. Human skeletal remains provide direct information on individuals and communities from the 17th - 19th centuries, and may improve our insights into behavioural changes which were integral to the industrialisation process.

A way to obtain information about behavioural changes is by looking at vitamin D deficiency. It is a pathological condition caused by inadequate levels of vitamin D. Cutaneous synthesis under the influence of ultraviolet B (UVB) radiation in sunlight is the most effective way of acquiring vitamin D (Holick 2006). The amount of vitamin D, however, that is produced in the skin is dependent on several variables. These include geographic latitude, age, occupation, behavioural factors related to social status and gender, cultural traditions, and religious practices that influence sunlight exposure. In addition, the contribution of vitamin D from dietary sources, while low in non-fortified foods from the past (Holick 2006), must be considered. Therefore, the study of vitamin D deficiency may provide information on sociocultural practices, as has been observed in modern (e.g. Van der Meer et al. 2006; Underwood and Margetts 1987; Yassin and Lubad 2010) and archaeological populations (e.g. Giuffra et al. 2015; Palkovich 2012). Moreover, the analysis of vitamin D deficiency, as visible in the human skeleton, can provide information on lifestyle, tradition, gendered activities, and diet, that often cannot be obtained from historic sources (Brickley et al. 2014).

The aim of this research is to improve our understanding of the changes in sociocultural practices of 17th - 19th century Dutch populations before and during industrialisation by using osteoarchaeological data on vitamin D deficiency prevalence. This will (a) contribute to existing knowledge provided by historic sources on the influence of industrialisation, (b) assess ideas and assumptions about lifestyles in the past, (c) improve our knowledge of regional variation in the influence of industrialisation, and (d) decrease the paucity of research on rural populations and small urban centres in the Netherlands. The main research question is:

How does the occurrence of vitamin D deficiency in 17th to 19th century Dutch communities enhance our knowledge of changing sociocultural practices as a result of industrialisation?

This chapter will be arranged in four sections. Section 1 contains information about the economic and political frameworks of 17th to 19th century Netherlands. The functions and importance of vitamin D are described in section 2, and a description of the macroscopic, radiologic, and microscopic skeletal features that may occur as a result of vitamin D deficiency in various age groups is provided. Section 3 describes the demographic and historic characteristics of the skeletal collections that are used for this research. Research sub-questions are presented and a description of the dissertation's structure is provided in section 4. Finally, this chapter is concluded with an explanation of the importance and value of this research.

SECTION 1: THE NETHERLANDS IN THE 17TH TO 19TH CENTURIES

By the end of the 16th century, the Republic of the Seven United Netherlands, as the Netherlands was called in that time, consisted of eight sovereign states: Groningen, Friesland, Drenthe, Overijssel, Gelderland, Utrecht, Holland (Noord and Zuid), and Zeeland. Drenthe was a sovereign state without representation in the parliament and the remaining provinces of Noord-Brabant and Limburg were part of the Republic but were not sovereign states (De Vries and Van der Woude 1997). Roughly, the Republic could be divided into three major areas with similar economic characteristics: (1) urban, (2) modern agricultural, and (3) traditional rural (De Vries and Van der Woude 1997), as depicted in figure 1. The city of Amsterdam and the sites analysed in this study are also depicted in figure 1 and will be discussed in section 3.

At the beginning of the 17th century, the urban part of the Republic consisted of the provinces of Zeeland, Noord- and Zuid- Holland. This area was characterised by relatively large urban centres famous for their industry (e.g. the sugar-refining industry in Amsterdam), although agriculture did exist in these provinces and was dominated by horticulture and dairy farming (De Vries and Van der Woude 1997). The importance of Zeeland's seaports declined over the course of this century and agriculture became more important. By the end of the 18th century, Zeeland, Groningen and Friesland were considered to be modern agricultural areas, characterised by large-scale, specialised and market-oriented dairy farming and agriculture (De Vries and Van der Woude 1997). Rich alluvial soils typified the provinces of the urban and modern agricultural parts of the Republic, whereas the rest of the provinces (Drenthe, Overijssel, Gelderland, Utrecht, Noord-Brabant, and Limburg) had poor diluvial soils (De Vries and Van der Woude 1997; Mokyr 1976). The latter provinces were considered to be rural traditional, meaning the agriculture in this part of the Republic had a more local and regional character, and was focused on self-sufficiency instead of international trade (De Vries and Van der Woude 1997; Mokyr 1976).

In the 17th century, the Republic experienced an economic rise, population growth, and an explosive increase of international trade that heralded the start of the Golden Age (De Vries and Van der Woude 1997). The need for skilled and unskilled labour rose due to several economic developments. The process of land

Figure 1. Division of the Netherlands in urban, modern agricultural, and rural traditional areas.

reclamation (AD 1608 – 1640) gave rise to six major polder drainage projects in the province of Noord-Holland and more than 100 industrial windmills were built to enable this (De Vries and Van der Woude 1997). The VOC (Dutch East-India Company) and the WIC (Dutch West-India Company), that were founded in this century, employed a large number of individuals on ships and in the harbours (De Vries and Van der Woude 1997; Mokyr 2000). Population growth increased the need for agricultural products, and during this time, wages and the prices of commodities rose. The second phase of the Golden Age, AD 1623 – 1663, is characterised by stagnation in economic growth, partially due to the rising resistance of powerful competitors and the limited options for further expansion of Dutch international trade (De Vries and Van der Woude 1977). Although land reclamation provided room for the much needed agricultural and settlement expansions, it also led to the salinisation of surface water and gradual silting of the harbours (De Vries and Van der Woude 1977). The poor quality of the surface water caused many problems, whereby the increasing brackishness of the water gave way to mosquitos bearing malaria (Wintle 2000). In addition, several plague epidemics were followed by outbreaks of dysentery and small pox, responsible for a large number of deaths (De Vries and Van der Woude 1997; Wintle 2000). At the end of the Golden Age, three naval wars with England and the French invasion of the Republic in AD 1672 disrupted the international trade profoundly. A sharp reduction in population growth can be observed in these decades, and unemployment rose (De Vries and Van der Woude 1997).

The 18th century is characterised by further deterioration of the surface water quality in the coastal provinces affecting the industries dependent on water (e.g. breweries) and the living conditions of its inhabitants, whereby malaria epidemics increased (De Vries and van der Woude 1977); Wintle 2000). The herring fishery, that was an important contributing factor to the economic rise at the beginning of the Golden Age, suddenly collapsed as did the whaling industry. Prices of agricultural products began declining at the end of the 17th century and continued to drop during the 18th century causing an agricultural depression from AD 1650 – 1750 (De Vries and Van der Woude 1977). Several outbreaks of the cattle plague (AD 1714 – 1720, 1744 – 1754, and 1769 – 1784) caused a substantial drop in dairy production and a decline in the export of cheese (De Vries and Van der Woude 1997). England declared war on the Republic in AD 1780 and attacked the VOC. The growing political unrest in the Republic led to the Patriot Revolt in AD 1787 that was initially crushed by regent Willem V (De Vries and Van der Woude 1977). With the help of the French Revolutionary Army, the Patriots overthrew the government of Willem V in AD 1795 and founded the Batavian Republic, for which the Republic paid dearly in the form of high taxes putting further pressure on the economy (De Vries and Van der Woude 1977; Mokyr 1976). The only production sector that experienced growth was agriculture. Commercial farmers intensified their dairy and grain production causing increasing prosperity in a period characterised by urban crisis and general impoverishment (De Vries and Van der Woude 1997).

The beginning of the 19th century, is marked by the incorporation of the Batavian Republic into the French Empire in AD 1810 and in the years thereafter (AD 1811 – 1813) all that was left of the Dutch industry collapsed (De Vries and Van der Woude 1977). During the Batavian and French period, the Netherlands had undergone a thorough reorganisation of its tax system, the guild system was dissolved, a central government was established, whereby the Kingdom of the Netherlands emerged in AD 1814. Its economy remained stable until the 1840s, when several consecutive crop failures, and multiple outbreaks of the typhoid fever, and cholera in 1838 and 1848, brought about years of misery and hunger (De Vries and Van der Woude 1997;

Wintle 2000). The Industrial Revolution that began in England at the end of the 18th century and took place in other northern European countries at the beginning of the 19th century, was not observable as such in the Netherlands (De Regt 1977; Mokyr 1976). Industrial innovation took place in the remote area of Twente (province of Gelderland), and the province of Noord-Brabant which embraced new techniques in the production of textiles, whereas the maritime provinces in the west of the Netherlands did not experience industrialisation in that period (Mokyr 1976). Many factors are suggested to be responsible for the absence of a clearly defined Industrial Revolution in the Netherlands, including the already relatively modern economy during the Golden Age and the political and economic instability caused by many wars (De Vries 2000; Mokyr 2000; Wintle 2000).

Although the Golden Age brought about prosperity to the Republic in general, just a small percentage of individuals were postulated to be actually wealthy (De Vries and Van der Woude 1977). About half of the urban population consisted of individuals without steady work and often without an address (e.g. vagabonds, paupers, and beggars), individuals that on occasion earned some money (e.g. street peddlers, and market sellers), and numerous unskilled and semiskilled labourers (e.g. domestic servants, sailors, and soldiers) whose living conditions were poor and their income uncertain (Clerx 1985; De Regt 1977; De Vries and Van der Woude 1977). In rural areas, large differences in landownership or tenancy of agricultural land existed between local communities that caused marked dissimilarities in wealth between farmers (De Vries and Van der Woude 1977). Rising prices of agricultural products must have brought about prosperity for most farmers, whereas the agricultural depression of AD 1650 – 1750 likely impoverished many.

Most historic data on occupations are about male labour, but females and children also formed an important part of the labour force (De Vries and Van der Woude 1977; Van Cuyningen 2005; Schenkeveld 2008). Until the 19th century, the participation of females and children from the middle and low socioeconomic classes was considered to be normal (Clerx 1985; De Vries and Van der Woude 1977). Typical female activities were the preparation of dairy products, spinning, and all sorts of housework. Women also worked in the salt refinery, stacked and dried peat, and were employed to periodically turn the stored grain to prevent it from overheating (De Vries and Van der Woude 1977). Although females formed an important part of the labour force, their work was generally considered to be less important, stressed by the fact that they were not part of guilds and their wages tended to be lower (De Regt 1977; De Vries and Van der Woude 1977). Moreover, the men were considered to be head of the household and responsible for the family income, whereas the income of women was regarded as additional. During the 19th century, the participation of women in the labour market decreased. This may be partly explained by improved wages for the men, but foremost due to the increasing pressure of society that stressed that women were primarily needed at home to tend to their husband and children (De Regt 1977; Van Poppel et al. 2009). Although already before the 19th century this was the primary task of women, the situation at many households worsened during the difficult times of the 18th and beginning of the 19th century leading to an increase in the number of neglected or even abandoned children and poorly cleaned houses (Clerkx 1985; De Regt 1978). Since this was primarily the women's responsibility, pressure of society on women to stop working outside their home increased and the number of women participating in various jobs dropped (Van Poppel et al. 2009). Clerkx (1985) reports groups of neglected and orphaned children who wandered around the towns, begging and stealing. They were regarded as cheap labourers and were put to work in large numbers (Clerx 1985; De Vries and Van der Woude 1977). In urban centres, children were commonly employed in paper mills, brickwork factories, and performed various chores in the textile industry (De Vries and Van der Woude 1977). The children's part in agriculture and dairy farming was more important, whereby sometimes children were already put to work at the age of 6 years (Schenkeveld 2008).

Individuals working long hours indoors are postulated to have elevated risks of developing vitamin D deficiency, since their exposure to sunlight is decreased. Factors commonly attributed to the Industrial Revolution, such as tall densely-packed buildings and air pollution, would have further reduced the availability of sunlight even for individuals that were unemployed or otherwise free to be outside often. As outlined, the economic and political situations of the Netherlands in the 17th to 19th centuries suggest it is unlikely that high prevalences of vitamin D deficiency would be observed in most communities from that time period. If indeed vitamin D deficiency was prevalent, it is expected to only be observable in the urban area, the provinces of Noord- and Zuid-Holland, where most urbanisation and settlement expansion took place, whereas in the modern agricultural and rural traditional areas of the Netherlands, vitamin D deficiency is unlikely to be prevalent.

SECTION 2: VITAMIN D

For the main research question to be answered, information on vitamin D and its function in the human body is needed. Furthermore, a clear understanding of the consequences of inadequate vitamin D levels is required.

Vitamin D and its functions

Vitamin D is considered to be a hormone, rather than a vitamin, since it is produced in the human body as opposed to true vitamins (Brickley and Ives 2008; Holick 2005a; Holick and Adams 1990; Lockau and Atkinson 2017). Although there are several forms of vitamin D, the most common are vitamin D3 (cholecalciferol), which is produced in the skin, and vitamin D2 (ergocalciferol), that can be derived from plants (Holick 2005a). Vitamin D3 is produced in the skin under the influence of UVB radiation in sunlight that causes photolysis of 7-dehydrocholesterol to previtamin D3 (Holick 2003; 2005a; 2005b). Both vitamin D3 and D2 undergo two hydroxylations before the most active form of the vitamin, 1,25(OH)2D, is produced. The first hydroxylation takes place in the liver, and the second in the kidneys (DeLuca 1980; Holick 2005b; Horst et al. 2005; Wasserman 2005).

Vitamin D has several functions in the human body. Classic actions are those that influence calcium and phosphate homeostasis, while non-classic actions include the regulation of cell proliferation and differentiation, modulation of immune function, and vitamin D is known to have several endocrine functions (Remuzzi 2007). The most commonly known function of vitamin D is that of calcium homeostasis, whereby vitamin D is needed for the mineralisation of newly formed bone, osteoid. During growth (deposition of new bone; also called modelling) and remodelling (replacement of old and damaged bone), osteoid is deposited after which mineralisation is required to provide the bone with strength and hardness. This firmness is needed to withstand muscular tension and gravity. Vitamin D deficiency may lead to bending, flaring, and thickening deformities in the skeleton, because mineralisation of the newly formed osteoid is inadequate or impaired. Especially important for diagnosis are the weight bearing bones, such as the arm bones during periods of crawling and leg bones once an individual can walk. These bones will more easily bend due to gravity and/or muscular tension. This bent, poorly mineralised bone is also more susceptible to fracture. More osteoid is secreted to repair the damage from bending and/or fracture, but the accumulation of unmineralised osteoid in the joints will cause thickening, flaring, and cupping deformities of the metaphyses (unfused proximal and distal ends of the long bone) (Brickley et al. 2018; Brickley and Ives 2008; Ives and Brickley 2014; Mankin 1974). In nonadults (< 18 years of age), vitamin D deficiency lesions are referred to as rickets, whereas in adults (18+ years of age) vitamin D deficiency is referred to as osteomalacia. Remnant lesions of rickets still visible in the adult skeleton is referred to as residual rickets.

Macroscopic detection of vitamin D deficiency

Rickets

As described by Chesney (2001), and Pearce and Cheetham (2010), common clinical features that result from a deficiency in vitamin D in nonadults are: (1) large head with prominent frontal bossing due to softening of the cranial bones and a delay in the closure of the fontanelles, (2) rachitic rosary (thickening/swelling of sternal rib ends), (3) deformity of the chest resembling a pigeon chest, (4) flaring/thickening of wrist and knee, (5) presence of fractures, (6) bending of the lower limbs, (7) growth retardation, (8) increased prevalence of pneumonia, (9) stridor (a harsh noise when breathing), (10) muscle weakness and pain, (11) involuntary muscle contractions, especially in the hands and feet, and (12) waddling gait. Not all clinical features of rickets are visible in skeletal remains, as obviously only the skeletal lesions can be assessed.

Cranial lesions that can occur because of vitamin D deficiency include thinning of the cranial bones, frontal and parietal bossing, craniotabes (softening of the parietal bones), a square-shaped head, orbital roof porosity, and layers of irregular porous bone (Brickley et al. 2018; 2014; Hess 1930; Mays et al. 2006; Ortner and Mays 1998; Schatmann et al. 2016). These lesions are not strongly diagnostic for vitamin D deficiency and can also result from normal variation, or other pathological conditions such as scurvy and congenital syphilis (Brickley and Ives 2008). However, these lesions can occur and need to be scored to improve our understanding of lesion development of vitamin D deficiency in various affected individuals. Although delayed eruption of teeth (deciduous and permanent), enamel hypoplasia, and dental caries may result from a vitamin D deficiency (Berry et al. 2002; Brickley et al. 2014; Hess 1930; Mankin 1974), these features are not diagnostic and can be caused by various pathological conditions and nutritional stress (Brickley and Ives 2008). One feature of the skull that is considered quite diagnostic of vitamin D deficiency is medial angulation of the mandibular ramus. This deformity of the mandibular ramus is presumably caused by the pull of chewing muscles, whereby the weakened bone is not able to withstand the tension (Brickley et al. 2018; 2014; Mays et al. 2006; Ortner and Mays 1998; Schatmann et al. 2016).

In rickets, the vertebral column may show an abnormal forward (kyphosis) or sideways (scoliosis) curvature. (Brickley et al. 2014; Hess 1930; Mankin 1974). The ribs may display an alteration in the rib neck angle, lateral straightening of the shaft (narrowing of the chest), swelling of the costochondral rib ends (rachitic rosary), and/or pigeon-chest deformity (Brickley et al. 2018; 2014; Hess 1930; Mays et al. 2006; Ortner and Mays 1998; Schatmann et al. 2016). All of these features are considered diagnostic for rickets (Brickley and Ives 2008). Diagnostic features of the pelvis include a more pronounced medio-lateral curvature of the ilium, and more dorsally located acetabulae that may be angled anteriorly (Brickley et al. 2018; 2014; Hess 1930; Mays et al. 2006; Schatmann et al. 2016).

Long bones in rachitic affected individuals may display several diagnostic features that include flaring and swelling of the distal metaphyses, underlying porosity of the growth plate, cupping of the metaphyses and growth plates, bending in various directions, concave curvature porosity, angulation of the femoral neck, and thickening (Brickley et al. 2018; 2014; Hess 1930; Mays et al. 2006; Ortner and Mays 1998; Schatmann et al. 2016). The presence of underlying porosity of the growth plate is considered to be a macroscopic feature indicative of the active stage of rickets (Brickley et al. 2018; Mays et al. 2006). Angulation of the knees, stunted growth, and fractures may occur, but are not considered to be diagnostic for vitamin D deficiency because they have many other causes (Brickley and Ives 2008).

Residual rickets

In residual rickets, nonadult vitamin D deficiency was overcome. Growth and remodelling of the bones will usually have obliterated most skeletal lesions, such that only the more pronounced deformities will remain visible in the adult skeleton (Brickley et al. 2017a; 2010; Hess 1930). Residual frontal or parietal bossing and a square-shaped head may still be visible and the mandibular ramus may show medial angulation (Brickley et al. 2014). Scoliosis and/or kyphosis may be observable in the vertebral column (Brickley et al. 2018). Angulation of the rib neck, narrowing of the chest or a pigeon-chest deformity, and bending of the sternum may be present (Brickley et al. 2018; 2014). Lateral narrowing of the pelvis, abnormal curvature of the ilia, narrowing of the pelvic inlet, more dorsally located acetabulae, and anterior angulation of the sacrum are likely to remain and are diagnostic features of residual rickets (Brickley et al. 2018; 2014). Residual bending and thickening of the long bones and a more pronounced femoral neck angle may still be observed, and are also diagnostic features of residual rickets (Brickley et al. 2018; 2014).

Osteomalacia

Growth has ceased in the adult skeleton and only remodelling takes place. Therefore, clinical manifestations of adult vitamin D deficiency are almost always much subtler. Parfitt (1990) describes classic symptoms of adult vitamin D deficiency to be: (1) muscle weakness, (2) difficulty in walking, and (3) bone pain and tenderness. The features we may observe in the skeletal remains are described below.

In human skeletal remains, most macroscopic manifestations of osteomalacia are not pathognomonic for the disease. That includes all of the following lesions. The cranium may display diffuse porosity of the cranial vault and be of low weight, but this feature is not considered to be diagnostic for osteomalacia (Brickley and Ives 2008; Mankin 1974). The vertebra may show loss of body height, irregularity of the endplates, buckling of the body, multiple bodies may show biconcave compression, and kyphosis and/or scoliosis may be present (Brickley et al. 2018; 2014; 2007; 2005; Ives and Brickley 2014). The scapulae may display increased posterior curvature, and display a collapsed superior border (Brickley et al. 2018; 2014; 2007; 2005; Ives and Brickley 2014). The ribs may show a rib neck angulation and lateral straightening of the shafts (Brickley et al. 2014; 2005). The sternum may display bending in severe cases (Brickley et al. 2018; 2014; 2005; Ives and Brickley 2014). The ilia may protrude into the pelvic inlet, collapse, fold or fracture, the pubic rami may be dislocated or angled, and the sacrum may display extreme ventral angulation (Brickley et al. 2018; 2014; 2007; 2005; Ives and Brickley 2014). The femora may show anterolateral bending of the shafts, the knees may show medial bending, and the angle of the femoral neck may be reduced (Brickley et al. 2018; 2014; 2007; 2005; Ives and Brickley 2014).

Strongly diagnostic for osteomalacia are “pseudofractures” or “stressfractures”, which are small linear fractures that arise in defectively mineralised bone due to stress. The term “pseudofractures” may be problematic because it suggests that the observed lesions are not true fractures. However, it is a frequently used term in clinical and paleopathological literature (Berry et al. 2002; Brickley et al. 2018; 2014; 2007; 2005; Ives and Brickley 2014; Mankin 1974; Schamall et al. 2003) and therefore will also be used in this research. Pseudofractures are most commonly observed in the ribs, pubic rami, medial aspect of the ilium adjacent to the greater sciatic notch, femoral neck, lateral border of the scapula, and inferior lateral margin of the spinous process. Less frequently observed are pseudofractures in the ulna, radius, clavicle, humerus, tibia, fibula, metacarpals and metatarsals (Brickley et al. 2018; 2014; 2007; 2005; Ives and Brickley 2014; Mankin 1974; Schamall et al. 2003). Pseudofractures may develop into true fractures with irregularly formed fracture margins (Brickley et al. 2018; 2014; 2007; 2005; Ives and Brickley 2014).

Radiographic and microscopic detection of vitamin D deficiency

Radiographic features

Not all macroscopic lesions attributed to vitamin D are severe, and not all affected individuals develop clear macroscopic lesions (Brickley et al. 2017a; Hess 1930). The use of radiographic and microscopic methods for vitamin D deficiency assessment can aid in detecting additionally affected individuals and may support diagnoses. Radiographs of bone can provide further information on the stage of the disease. Porosity of the bone along the growth margin, thinning of the cortex, and fraying of the growth plate are radiographic features that are attributed to active pathological changes due to rickets, whereas healing changes observable on radiographs include thickening of the cortex, more defined growth plate margins, and trabecular coarsening in distal metaphyses due to mineralisation (Berry et al. 2002; Brickley and Ives 2008; Hess 1930; Pettifor and Daniels 1997). Radiographic features of residual rickets are few, since vitamin D deficiency in childhood was overcome and the process of growth and remodelling will have obliterated most features of rickets (Brickley and Ives 2008). Thickening of the cortical bone on the opposing side of the location were bending deformities occurred may be visible on radiographs (Hess 1930; Mankin 1974). Radiographic features of osteomalacia include generalised osteopenia (lower bone mineral density), pseudofractures in the ribs and sternum, the pelvis, long bones, scapulae, hands, and feet (Berry et al. 2002; Brickley and Ives 2008; Brickley et al. 2007; 2008; Hess 1930; Mankin 1974).

Radiographs taken from permanent molars enable assessment of the pulp chamber shape, whereby a constricted or chair-shaped pulp chamber is indicative of vitamin D deficiency (D'Ortenzio et al. 2017). Micro-CT scans of the teeth enable the assessment of interglobular dentine (IGD), a microscopic mineralisation defect attributed to vitamin D deficiency (Brickley et al. 2017b; D'Ortenzio et al. 2016). This method may provide supporting information for initial macroscopic diagnosis, but may also detect vitamin D deficient individuals without visible macroscopic lesions. Furthermore, assessment of IGD can provide information on the age of vitamin D deficiency onset and the number of deficient periods per individual.

Histological features

Microscopic assessment of bone can provide additional data that may support vitamin D deficiency diagnosis, although most microscopic features are not diagnostic for this deficiency. The cortical bone may show increased numbers of resorption sites, display increased cortical porosity, and may show mineralisation defects adjacent to the cement lines (Brickley and Ives 2008; Mankin 1974). The trabecular bone may display increased resorption, newly formed bone may appear separated from more mature sections, mineralisation defects may be adjacent to cement lines, and if mineralisation occurs the quality of the bone will appear poor (Brickley and Ives 2008; Mankin 1974). Histological analysis of teeth will enable assessment of IGD and may support initial macroscopic and radiological diagnosis. Similar to micro-CT analysis, it can detect affected individuals that do not display clear macroscopic lesions, and provides information on the age of vitamin D deficiency onset and the number of deficient periods per individual.

Etiology of vitamin D deficiency

The majority of individuals with skeletal deformities due to vitamin D deficiency had inadequate exposure to sunlight and/or diets low in vitamin D (Brickley et al. 2014; Mithal et al. 2009). Geographic characteristics, such as latitude and climate, influence the availability of sunlight and the wavelengths of UVB radiation required for the production of vitamin D (290 – 315 nm) (Holick et al. 1981). The Netherlands has a latitude between 50° and 53°N and production of vitamin D during the winter months is expected to be absent since at latitudes above 35°N and below 35°S, there is no production of vitamin D in the winter months (Jablonski and Chaplin 2013; Lee et al. 2008; Webb et al. 1988). In addition, the time of day also can influence the amount of vitamin D that can be produced in the skin, since the angle of sunlight changes during the day and a large number of UV photons are filtered in the atmosphere at oblique angles causing differences in cutaneous vitamin D

Table 1. Hereditary or acquired conditions causing rickets and/or osteomalacia.

Acquired or Inherited condition	Manifestations
Hereditary vitamin D-dependent rickets Type I	Defect in the hydroxylation that occurs in the kidneys to form active vitamin D
	Pseudo-vitamin D deficiency rickets
Hereditary vitamin D-dependent rickets Type II	Mutations in vitamin D receptor gene cause vitamin D resistant rickets
Hereditary vitamin D-depenedent rickets Type III	Resistant to the action of active vitamin D
	Vitamin D deficiency occurs despite normal intake of vitamin D
	Severe skeletal deformities
25-OHase-deficiency rickets	Defect in the hydroxylation that occurs in the liver, thus limiting amount of vitamin D passed to the kidneys
Fibroblast growth factor 23 (FGF23)	Defect in phosphorous homeostasis: failure or excessive production of FGF23
Autosomal dominant hypophosphatemic rickets	Mutation of the FGF23 gene
	Increased levels of phosphorous excretion
	Increased levels of growth hormone
	Decreased absorption of phosphorous from the diet
X-linked hypophosphatemic rickets	Hypophosphatemia and decreased intestinal absorption of calcium and phosphorous
	May increase expression of FGF23 affecting phosphorous metabolism

production during the day (Holick 1994; 2003; 2005b; Holick and Chen 2008). With age, 7-dehydrocholesterol levels decline and less vitamin D can be produced in older compared to younger individuals after the same exposure to sunlight (Holick 2003; Lee et al. 2008). In addition, skin thickness and kidney function decrease with age, markedly affecting vitamin D levels in older individuals (Chapuy and Meunier 1997; Halloran and Portale 1997). Other factors that affect the amount of vitamin D produced in the skin include clothing, spending time indoors, and sunscreen, although the latter will not have affected past populations (Brickley and Ives 2008; Brickley et al. 2014; Holick 1994).

There are a number of congenital or acquired pathological conditions that can cause vitamin D deficiency. Table 1 lists a number of these conditions as described by Berry et al. (2002), Glorieux (1999), Holick (2006), Liberman and Marx (1999), Nield et al. (2006), and Reginato and Coquia (2003), and White and Thakker (2005).

All of these conditions are very rare and therefore, it is unlikely that individuals in archaeological populations were affected by one of these conditions. Thus, it is assumed that bending deformities due to a shortage of vitamin D most likely are the result of insufficient dermal synthesis perhaps combined with suboptimal diets (Brickley et al. 2014; Mays 2008; Mithal et al. 2009).

SECTION 3: SKELETAL COLLECTIONS

For this research, six skeletal collections were selected from different parts of the Netherlands and their location is shown in figure 1 in Section 1. Table 2 provides an overview of the total number of individuals analysed divided into nonadults and adults with a further distinction between males (M) and females (F), site type, and average socioeconomic status.

The first and largest collection comes from Beemster, a predominantly 19th

Table 2. Number of nonadults and adult females and males assessed for vitamin D deficiency with socioeconomic status and site type (rural, urban or psychiatric institution) and size (small vs. large) for each site.

Sites	Nonadults						
Adults	Total Individuals					Average SES	Site type
		F	M	Total			
Beemster	95	100	100	200	295	M – L	Rural
Bloemendaal	0	39	28	67	67	M - L	Psychiatric hospital
Gouda	4	18	23	41	45	H	Small, urban
Rotterdam	3	16	18	34	37	M – L	Large, urban
Roosendaal	15	18	27	45	60	M – L	Small, urban
Hattem	28	47	53	100	128	M – L	Small, urban
TOTAL	145	238	249	487	632		

SES = socioeconomic status, F = female, M = male, M – L = middle to low, H = high.

century rural community in the province of Noord-Holland. The main activities of the inhabitants concerned cattle farming (Falger et al. 2012), and archival data show the individuals buried in this cemetery had a middle to low SES. The collection of Beemster is the largest of the sites and enables vitamin D deficiency assessment of all age groups and both sexes in a rural community from a province typified as urban (De Vries and Van der Woude 1977).

Bloemendaal is the second collection and the skeletal remains come from 19th century Meerenberg psychiatric hospital, where both deceased patients and staff were buried (Vijselaar 1997). This site was selected because of the risk of osteomalacia development was expected to be elevated due to confinement of the patients rather than factors attributed to industrialisation, and provided a unique opportunity to research and present the first data on osteomalacia in the Netherlands.

The third collection consists of individuals from Gouda that come from inside the Sint-Janskerk (St. John's church) from the 17th to 19th centuries. Burial records were available for the majority of individuals and indicated they had a high SES, some of them being regents, mayors and prefects (Van Dasselaar 2015). Generally, it is assumed that individuals with high SES did not experience vitamin D deficiency, as observed in the high SES collections from Alkmaar (Baetsen 2001) and Zutphen (Berk 2007), since their living conditions and diets are expected to be better than those of lower SES. This collection enables assessment of vitamin D deficiency in a high SES community to test this assumption.

Rotterdam, the fourth and smallest collection, was an urban centre in the province of Zuid-Holland, and already in the 17th century important in the sea faring trade (Van der Bent et al. 2011). The skeletal remains come from the cemetery surrounding the Laurenskerk (Laurence church) that are dated to the 17th century, and their SES is suggested to be middle to low. The analysis of vitamin D deficiency in the skeletal remains from this urban centre dating to the Golden Age improves our understanding of the influence of urbanisation, increasing prosperity, and other economic and political changes on vitamin D deficiency development.

The fifth skeletal collection, Roosendaal, comes from a cemetery surrounding the Sint -Janskerk (St. John's church) from the 17th to 19th centuries. This small urban centre in the province of Noord-Brabant was strategically positioned between the larger cities of Dordrecht and 's-Hertogenbosch, and its main activities were agriculture and a small-scale textile industry (Van Gastel 1995). Historic sources suggest the population buried outside the church consisted of individuals with a middle to low SES, although the majority are postulated to have been poor (Van Gastel 1995). The collection of Roosendaal enables assessment of vitamin D deficiency prevalence in a small urban centre from one of the poorer provinces that was typified as rural traditional (De Vries and Van der Woude 1977).

Hattem is the last collection. Historic sources report Hattem to have been a small, prosperous town during the 16th century as part of the Hanseatic League, but a number of attacks of the Spanish Army at the end of this century depleted Hattem's resources and destroyed large parts of the town (Sypkens Smit 1964). Several periods of French occupation in the 17th and 18th centuries caused further impoverishment (Sypkens Smit 1964). Hattem's main activities consisted of agriculture and the transportation of goods by ship such as peat (Koridon 1985; Scheper 1984). The individuals buried outside the Andreaskerk (Andrew's church) in the 17th to 19th centuries are expected to have had a middle to low SES. Hattem is a larger collection from the rural traditional area (De Vries and Van der Woude 1977) that further improves our understanding of vitamin D deficiency development in this part of the Netherlands.

Section 4. Sub-questions and dissertation organisation

The main research question is divided into three sub-questions that will be answered by determining vitamin D deficiency prevalence in six Dutch communities from the 17th to 19th centuries. These sites were selected based on differences in settlement type (rural vs. urban, including Bloemendaal from a psychiatric hospital), location (provinces of Gelderland, Noord- and Zuid-Holland, and Noord-Brabant), all SES groups (high vs. middle to low), all age groups, and both sexes. In this way, the influence of industrialisation on sociocultural practices (e.g. SES, clothing, and gendered activities) related to vitamin D deficiency development in these six communities can be assessed, which will provide a more complete understanding of vitamin D deficiency prevalence in the Netherlands and improve our understanding of the process of industrialisation in the Netherlands.

Sub-question 1: How did differences in population aggregation affect vitamin D deficiency prevalence in 17th to 19th century Netherlands?

Differences in population size, living conditions, activities, and availability of foods are likely to affect vitamin D deficiency frequency. Factors such as air pollution and tall buildings blocking the sunlight are commonly considered to be the main cause for high vitamin D deficiency prevalence (Baetsen 2001; Holick 2003; Maat et al. 2002). However, other factors are likely to be at play as demonstrated by several researchers for modern (Van der Meer et al. 2006; Underwood and Margetts 1987; Yassin and Lubad 2010) and archaeological populations (Giuffra et al. 2015; Palkovich 2012; Pētersone-Gordina et al. 2013). By examining communities from both rural and urban locations, changes in urban (factory) and rural (farming) industrialisation on vitamin D levels can be most effectively compared and contrasted. Combined with information from historic sources, the impact of settlement size, various activities, and the availability of foods can be assessed which will aid in understanding regional variation of industrialisation and its influence on the population, as will be demonstrated in Chapters 2, 4, and 5.

Sub-question 2: How is vitamin D deficiency prevalence influenced by age, sex, and gender in 17th to 19th century Netherlands?

Vitamin D deficiency prevalence between various age and sex groups will be compared. Differences in age-related prevalences will enhance our knowledge of behavioural patterns in various stages of life. Information on the effect of industrialisation on specific age groups is limited, in particular information on nonadults is virtually lacking from the historical record (Wintle 2000). Determining differences in age-related vitamin D deficiency prevalence will enhance our understanding of changes in behaviour and activity throughout life and will aid in decreasing the paucity of information on nonadults. In addition, differences in vitamin D deficiency prevalence that can be attributed to sex and gendered roles will provide information on traditions and community norms. This way, changes in gender-related behaviours will be informative on the effect of industrialisation on community life. Chapters 3 and 4 show the impact of gender-related activities on the prevalence of vitamin D deficiency in several rural and urban sites in post-Medieval Netherlands. The influence of age on the prevalence of vitamin D deficiency will be shown in Chapters 2, 4, and 5. In Chapter 6, the impact of other sociocultural practices will be demonstrated in a population from the psychiatric hospital of Meerenberg.

Sub-question 3: : How did socioeconomic status influence vitamin D deficiency prevalence in 17th to 19th century Netherlands?

It is commonly assumed that individuals of high socioeconomic status were less affected by vitamin D deficiency than those of lower socioeconomic status (Baetsen 2001; Maat et al. 2002). However, behavioural patterns, and the availability of foods that can be attributed to these statuses, need to be determined. By combining archival data with the results from osteoarchaeological analysis, socioeconomic status, activity and vitamin D deficiency frequency can be linked, thus testing this assumption and enhancing our understanding of differences in socioeconomic classes in past populations in the Netherlands. The influence of socioeconomic status will be demonstrated in Chapter 4.

Dissertation organisation

In Chapter 2, assessment of 95 nonadults from the rural community of Beemster is discussed. Chapter 3 demonstrates residual rickets prevalence in 200 Beemster adults and Chapter 4 provides an overview of vitamin D deficiency prevalence in five collections: Beemster, Gouda, Rotterdam, Roosendaal, and Hattem. In the study presented in Chapter 5, micro-CT and histological analysis of IGD in teeth is performed, and macroscopic, radiological, and histologic vitamin D detection methods are compared to observe the merits of each. Chapter 6 presents the results of the analysis of the skeletal remains from the Meerenberg psychiatric hospital from Bloemendaal focussing on the improvement of osteomalacia detection. Chapter 7 contains the overarching conclusion in which the main and sub-research questions will be answered.

CONCLUSION

The analysis of vitamin D deficiency in human skeletal remains can provide information on sociocultural practices and other variables related to sunlight exposure in past communities that cannot be obtained from historic sources alone. Although numerous studies describe the economic and political changes in 17th to 19th century Netherlands (De Vries 2000; De Vries and Van der Woude 1977; Mokyr 1976; 2000; Wintle 2000), the effect of important processes, such as industrialisation, on local communities is hard to assess without information about individuals from these past communities. This study intends to do just that and is the first to undertake a large-scale assessment of vitamin D deficiency in Dutch skeletal remains by evaluating vitamin D deficiency prevalence in six 17th to 19th century communities of different settlement size, region, occupation, and SES. Biological and cultural characteristics of individuals from all age groups combined with historic information facilitate a life course perspective to provide a more profound understanding of the range of factors increasing the risk of vitamin D deficiency development, including industrialisation. The use of the recently developed methods of IGD assessment in teeth via micro-CT and histology (Brickley et al. 2017; D'Ortenzio et al. 2016), generate novel data that cannot be obtained from macroscopic and radiographic analysis of bone, such as the age of rickets onset, and the number of vitamin D deficient periods per individual. The data from micro-CT and histological analysis aid in the reconstruction of a more accurate overview of vitamin D deficiency prevalence in 17th to 19th century

Netherlands, and facilitate a more nuanced understanding of vitamin D deficiency development within certain age groups. This study contributes to our understanding of the transformation that Dutch communities underwent in this period of significant economic, political, and social change via macroscopic, radiographic, and histologic assessment of vitamin D deficiency prevalence.

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