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Research article

Gender-related vitamin D deficiency in a Dutch 19th century farming community

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ABSTRACT

The most common cause of vitamin D deficiency is inadequate dermal exposure to sunlight. Residual rickets is nonadult vitamin D deficiency still evident in an adult individual, whereas osteomalacia occurs in adulthood. Previous research on the Beemster population, a 19th century rural community in the Netherlands, identified rickets in 30.4% of the nonadults between the ages of two and four years (n = 7/23). Because the sex of these nonadults was not known it was not possible to determine if there were differences between boys and girls. To overcome this gap in our knowledge, the aim of this paper is to determine if there are gender related differences in vitamin D deficiency in the Beemster skeletal collection, based on adults with residual rickets and osteomalacia. Out of 200 adults (100 females; 100 males) no cases of osteomalacia were detected. However, there were 29 cases of residual rickets (14.5%), with 21 of those cases in females (21.0%; 21/100). A complex interplay of multiple factors is proposed to have affected vitamin D levels in nonadults, including sociocultural variables such as gender-based labour norms. This research highlights the importance of continuing to explore gender-based health differences in past populations.

1. Introduction

Limited access to sunlight due to narrow streets and tall buildings, air pollution, and overcrowding, as can be observed in historical populations, are commonly considered to be important contributing factors to the prevalence of vitamin D deficiency (Brickley et al., 2007; Maat et al., 2002; Mays et al., 2006). However, other aspects, such as habitual activities and sociocultural practices that influence sunlight exposure (i.e. time spent indoors or covering clothing), have a large impact on the amount of vitamin D that can be synthesized in the skin. Therefore, the frequency of vitamin D deficiency may provide information about sociocultural practices, as noted in modern (van der Meer et al., 2006; Miyako et al., 2005; Underwood and Margetts 1987; Yassin and Lubbad, 2010) and archaeological populations (Brickley et al., 2014; Giuffra et al., 2015; Palkovich 2012). Most Dutch studies focusing on vitamin D deficiency concentrate on urban populations (Baetsen 2001; Maat et al., 1998; Maat et al., 2002). Little research has been performed on vitamin D deficiency in rural populations from the Netherlands (Veselka et al., 2015) and research on the influence of sociocultural habits on the occurrence of vitamin D deficiency in either urban or rural settlements is lacking.

A recent study on a 19th century rural population from Beemster, the Netherlands, reported a high prevalence of vitamin D deficiency in individuals under the age of four years (Veselka et al., 2015). The high occurrence was partly attributed to sociocultural habits, such as prolonged swaddling, suboptimal weaning foods, and concealing clothing. In addition, a gender-based division in activities was postulated as a potential factor contributing to vitamin D deficiency in girls who may have been required to more often assist with indoor tasks (Veselka et al., 2015). This would predispose girls to developing rickets. However, due to the inaccuracy of current macroscopic methods for sex estimation in nonadults, this hypothesis could not be tested on the basis of the nonadult data alone.

Another way to assess the influence of sociocultural habits, especially the gendered division of labour, on the risk of developing rickets in the Beemster population, is to assess residual rickets, whereby remnant bending deformities of nonadult rickets are studied in adults. Commonly observed residual rickets features include bending deformities of the lower limbs. It is also useful to examine osteomalacia, which is vitamin D deficiency that occurs in adolescents and adults (Brickley et al., 2010), as it may reveal gender differences in vitamin D deficiency in the adult Beemster community. Osteomalacia is evident as pseudofractures in specific parts of the skeleton and, in severe cases, buckling and bending deformities of certain parts of the skeleton

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(Brickley and Ives, 2008: 127–129).

Therefore, the aim of this paper is firstly to determine if there are gender differences in vitamin D deficiency in the Beemster skeletal collection. The two ways of assessing this are via residual rickets as a marker for the impact of vitamin D deficiency in nonadults and osteomalacia as a marker for adults. Secondly, with these data a life course approach is applied to assess the impact of sociocultural habits on disease levels in the sexes and various age groups within this rural population. This research will provide information on whether gender-based differences in activities increased the Beemster female risk of developing vitamin D deficiency.

2. Materials and methods

The sample for this research comes from Middenbeemster, a cemetery in Beemster which is situated in the province of North-Holland, the Netherlands, and dates mostly to the 19th century. The sample consisted of 200 adult individuals, 100 females and 100 males, with ages ranging from 18 to 50+ years. This rural population is comprised of individuals with various occupations mainly related to cattle farming (Falger et al., 2012).

Age-at-death was estimated by assessing changes to the pubic symphysis (Suchey and Brooks, 1990), auricular surface (Buckberry and Chamberlain, 2002), and sternal rib ends (Isçan et al., 1984), evaluating the degree of cranial suture closure (Meindl and Lovejoy, 1985), and dental attrition (Maat, 2001). Individuals were placed in the following age categories: early young adult (18–25 years), late young adult (26–35 years), middle adult (36–49 years), old adult (50+ years), or 18+ years if a more narrow age range could not be obtained. Sex was estimated using methods outlined in the Workshop of European Anthropologists (1980) and Buikstra and Ubelaker (1994), assessing the Phenice traits (Phenice, 1969), and a number of metric measurements (McCormick et al., 1991; Stewart, 1979; Steyn and İşcan, 1999). Individuals are categorised as Female (F), Probable Female (PF), Indeterminate (I), Probable Male (PM), and Male (M). In statistical tests, individuals sexed as PM are added to the M category, and the same is done for PF and F; this is done to enlarge the sample size to enable more robust statistical comparisons.

To identify residual rickets, macroscopic changes, as described by Brickley et al. (2010) and Brickley and Ives (2008: 110–111) are evaluated in all skeletons. They consist of remnant deformities of rickets, such as residual bending of the long bones. For a positive diagnosis of residual rickets, clear bending deformities of at least two of the lower limb bones needed to be present. Bowing of only one lower limb bone was diagnosed as possible residual rickets. This may result in a slight underrepresentation of the actual number of affected individuals, but this cautious approach is believed to produce more reliable results.

Although bending deformities of the upper limbs have been reported in cases of rickets (Brickley and Ives, 2008; Mays et al., 2006; Ortner, 2003; Ortner and Mays, 1998) they are rarely used as diagnostic for residual rickets (Baetsen, 2001; Brickley et al., 2010; Ellis, 2010; Maat et al., 2002; Pinhasi et al., 2006). Bowing of the arms due to vitamin D deficiency will develop at an age when nonadults are not yet able to walk and the arms function as the weight bearing long bones during crawling (Mays et al., 2006; Ortner, 2003; Ortner and Mays, 1998). The most common age of rickets onset is between three and 18 months of age (Ortner, 2003; Wagner and Greer, 2008) and the mean age of walking lies between nine and 12 months of age (Clark et al., 1988; Hindley et al., 1966). This implies that the majority of individuals developing rickets can walk rather than crawl at the time of onset of the condition. Thus, bending deformities of the arms are expected to occur less frequently than those of the legs (Brickley et al., 2010; Mays et al., 2006; Ortner and Mays, 1998). Moreover, the arms are used for a large variety of activities (Pearson, 2000; Rhodes and Knüsel, 2005; Stock and Pfeiffer, 2004) which further impairs the distinction between pathological bowing and changes in shape due to activity. Therefore, individuals with bending deformities of the upper limbs were scored as having possible residual rickets. In order to enhance comparison with other skeletal assemblages and improve our knowledge of bending deformities in residual rickets, the location of all the deformities is noted. In addition, the location of the deformities in the long bones of nonadults from this population are added to observe possible differences between rickets and residual rickets deformities.

Macroscopic changes due to osteomalacia, as described by Brickley and Ives (2008: 127–129) and Brickley et al. (2005), are evaluated in all skeletons, and included diffuse porosity and fine pitting of the cortical surface of the cranium, vertebral bodies that show biconcave compression or are wedge shaped, scoliosis or kyphosis, lateral straightening of rib shafts, rib neck angulation, folding of ilia, obstruction of the pelvic inlet, extreme angulation of the sacrum, anterolateral bending of femoral shafts, *coxa vara* of femoral necks, knock-knee angulation of the femur, increased curvature of the scapular blade, and the presence of Looser's zones or pseudofractures, which are strongly diagnostic for osteomalacia (Ives and Brickley, 2014; Brickley and Ives, 2008: 127–129; Brickley et al., 2007). Looser's zones can be present in specific parts of the skeleton, such as in the scapular spines, pubic rami, ribs and femoral necks, and are a frequently encountered clinical trait (Bhan et al., 2012; Mankin, 1974; Ortner, 2003: 399; Vigorita, 1999; Whyte and Thakker, 2005). Macroscopically, pseudofractures will be visible as minor fissures of the cortex while radiographically they will be present as a radiolucent area (Berry et al., 2002; Mays, 2008: 218; Parfitt, 1990: 345; Waldron, 2009: 130). However, pseudofractures do not always develop and their absence in vitaminh D deficient individuals is not uncommon (Berry et al., 2002; Brickley and Ives, 2008; Brickley et al., 2007; Whyte and Thakker, 2005). In addition, it is possible that some pseudofractures will only be visible radiographically (Berry et al., 2002) which may lead to a underrepresentation of the actual number of pseudofractures when only macroscopic analyses are applied. To minimize this possibility, radiographs were taken of the scapular spines and lateral borders of all individuals that presented other features which may be related to osteomalacia ($n = 9$). This area was chosen because pseudofractures in the scapulae are frequently encountered in archaeological cases of adult vitamin D deficiency (Brickley et al., 2007; Ives and Brickley, 2014). Radiographs were taken with a hand-held Nomad Pro (60 kV, 2.5 μA, exposure from 0.10–0.20 s).

It should be kept in mind that the manifestation of osteomalacia is highly variable between individuals, caused mainly by the age of onset of the vitamin D deficiency and its duration. The later in life the deficiency occurs, the more likely the manifestations will resemble lesions that can be attributed to age-related osteoporosis (Parfitt, 1990: 341). The previously reported relatively high rickets prevalence in the Beemster collection could be indicative of an elevated risk of developing more severe manifestations of vitamin D deficiency in adulthood, enabling its better recognition. However, osteomalacia needs to be chronic for diagnostic lesions to develop and recognition of, in particular, the earlier stages of this disease in an archaeological skeleton is difficult (Brickely and Ives, 2008; Brickley et al., 2007; Ortner, 2003; Waldron, 2009). In this study, a conclusive diagnosis of osteomalacia requires pseudofractures and/or multiple macroscopic changes to be present, such as multiple vertebral bodies showing biconcave compression, anterolateral bending of the femoral shafts, and obstruction of the pelvic inlet.

Since a number of macroscopic changes can be attributed to both residual rickets and osteomalacia, additional radiological analysis of cases with (possible) residual rickets and possible osteomalacia needed to be undertaken. The fifth lumbar vertebra is ideal for this because it has a high bone turnover rate (Brickley and Ives, 2008; Schamall et al., 2003) and will display the effects of vitamin D deficiency earlier than many other parts of the skeleton. Due to remodeling, radiological evidence of residual rickets will most likely be obliterated, whereas in osteomalacia the trabeculae will show a radial orientation, and the vertebrae will have decreased trabecular bone density (Schamall et al., 2003). Schamall et al. (2003) describe trabecular organisation in osteomalacic individuals as irregularly arranged with a heterogeneous appearance. Forty-one individuals were diagnosed with residual rickets, possible residual rickets, or showed non-diagnostic lesions that might be attributed to osteomalacia, of which 22 had the fifth lumbar vertebra available for CT-scanning. In addition, five lumbar vertebrae of individuals without any macroscopic lesions of the skeletons were used as a control sample. The individuals were divided into the aforementioned age categories to take the effect of age on trabecular bone structure into account. Ct scans were performed on a Philips Brilliance 64 scanner (Philips Medical Systems Best) set at 199 mAs and 120 kV with a slice thickness of 1 mm. Since some vertebrae contained a large amount of soil and/or were taphonomically damaged, the quantitative and qualitative information on trabecular bone density that can be calculated is limited. Therefore, trabecular bone density was not measured. Rather, the trabecular organisation and structure are evaluated and scored as 'regular' or 'disorganised'.

To assess whether differences in observed and expected results between sexes and age categories were statistically significant, a Pearson's χ^2-test and a Mann-Whitney *U* test, respectively, are performed. In this way, the null-hypothesis, that there is no difference between females and males nor age categories, is tested. The results of these analyses are assessed to determine whether there is a significant difference between men and women in the occurrence and age-of-onset of vitamin D diseases in the rural population of Beemster.

3. Results

3.1. Residual rickets

A total of 29 individuals displayed evidence of residual rickets. Three additional individuals were diagnosed with having possible residual rickets due to bending deformities of only one lower limb bone or bowing of the upper limb bones. Table 1 presents an overview of the location of bending deformities per sex and the statistical significance of the observed differences in females and males. The data relating to the bending deformities of the nonadults from this population are added, including the results of the statistical analyses, to offer a more thorough life course approach.

The affected femora in this study display anterolateral bending of the proximal third of the shaft. The tibiae displayed either lateral bending of the proximal part, as observed in Fig. 1, or posterior bowing of the distal end. A number of individuals displayed bowing of both upper and lower limbs (12.5%; 4/32). No male displayed bending deformities of any of the upper limbs. However, the difference between females (n = 7) and males (n = 0) displaying bending deformities of any of the upper limbs did not reach statistical significance (Fisher's exact test p = 0.077).

Fig. 1. Bending of tibiae and fibulae individual S307V0567 (Veselka, 2014).

In the nonadults, the most frequently bowed long bones are the humeri (37.5%; 3/8). The next most frequently observed bending deformities are in the rest of the combinations mentioned in Table 1, although no case of bending deformities of just the femora or just the fibulae are observed. The difference in the frequency of bending deformities per location is not statistically significant, partly due to the small sample size, as shown in Table 1.

The frequency of residual rickets is not affected by age since the difference between the number of affected and unaffected individuals within each age category is not statistically significant, although this is partly due to small sample size. Twenty-one females and eight males displayed bending deformities of two or more lower limb bones. The difference between the number of affected females and males is statistically significant (χ^2 = 6.989, p = 0.008). There is no statistically significant difference in the distribution of affected and possibly affected individuals by age-at-death (Mann-Whitney U = 89.000, p = 0.524).

3.2. Osteomalacia

None of the individuals in the sample are diagnosed with definitive osteomalacia since pseudofractures were not macroscopically nor radiologically evident. Several individuals did display non-diagnostic lesions, such as biconcave compression of a single vertebra or non-congenital scoliosis. The organisation of the trabeculae did not appear irregular, heterogeneous or disorganised in any of the 22 L5 vertebrae.

4. Discussion

4.1. Differential diagnosis

Several pathological conditions can cause bending deformities of

Table 1
Frequency of affected bones in adults individuals with residual rickets and possible residual rickets per sex, with nonadult rickets data for comparison.

Affected bones[a]	F (n = 23)	M (n = 9)	Mann-Whitney U	p-value	Total adults (n = 32)	Nonadults (n = 9)	χ^2	p-value
Femur and tibia	26.1% (6/23)	0.0%	72,000	0.086	18.8% (6/32)	22.2% (2/9)	2778	0.096
Femur, tibia, and fibula	21.7% (5/23)	11.1% (1/9)	92,000	0.133	18.8% (6/32)	25.0% (2/8)	2778	0.096
Femur	17.4% (4/23)	22.2% (2/9)	98,500	0.976	18.8% (6/32)	0.0%	–	–
Tibia	8.7% (2/23)	33.3% (3/9)	75,000	0.101	15.6% (5/32)	22.2% (2/9)	2778	0.096
Tibia and fibula	8.7% (2/23)	11.1% (1/9)	97,000	0.865	9.3% (3/32)	25.0% (2/8)	2778	0.096
Fibula	8.7% (2/23)	22.2% (2/9)	97,880	0.865	12.5% (4/32)	0.0%	–	–
Radius	17.4% (4/23)	0.0%	81,000	0.118	12.5% (4/32)	25.0% (2/8)	2000	0.157
Ulna	13.0% (3/23)	0.0%	90,000	0.358	9.3% (3/32)	25.0% (2/8)	2000	0.157
Humerus	13.0% (3/23)	0.0%	85,500	0.252	9.3% (3/32)	37.5% (3/8)	0,500	0.480

[a] Individuals were counted per affected bone not distinguishing between unilateral or bilateral. All long bones from the affected and possibly affected adult individuals were present for analysis. F = female, M = male.

the long bones in childhood, such as Blount's disease, congenital bowing, infantile cortical hyperostosis, metaphyseal chondrodysplasia, osteogenesis imperfecta, trauma, and treponemal diseases (Bleck, 1982; Brickley and Ives, 2008; Cheema et al., 2003; Silverman, 1985). In addition, some degree of physiological bowing is commonly observed in children and falls within the range of what would be considered 'normal' bowing (Bleck, 1982). When interpreting bowing deformities of the long bones, other conditions needed to be ruled out for the diagnosis to be residual rickets. Most of the other causes of physiological bending deformities, as well as congenital bowing, would not persist throughout life and would occur at other locations, such as the femoral neck (Bleck, 1982; Cheema et al., 2003). All affected femora in this study displayed anterolateral bending of the proximal third of the shaft and differ from the other bending deformities commonly observed in children. The tibiae of the affected individuals either showed lateral bending of the proximal end or posterior bowing of the distal third portion, thus ruling out Blount's disease which produces a sharp lateral bend of the proximal tibia and includes the joint (Jain et al., 2002). Infantile cortical hyperostosis is rare and can cause bending deformities of the long bones in childhood, but is a disease which usually resolves itself within six to nine months (Brickley and Ives, 2008; Caffey, 1956). Metaphyseal chondrodysplasia, osteogenesis imperfecta, and treponemal diseases will display other lesions besides bowing of the long bones thus enabling the distinction between these pathological conditions and residual rickets (Brickley and Ives, 2008; Ortner, 2003; Waldron, 2009). Bending due to trauma can most of the time be distinguished quite easily from other causes of bending and is not the cause of the bending deformities observed in the Beemster individuals.

Therefore, the observed bowing of the lower limbs in the Beemster adults can be confidently interpreted as remnant bending due to childhood rickets. The frequency of bowing in the various lower limb bones is similar to the residual rickets bending deformities observed by Brickley et al. (2010) in the collection of St. Martin's from Birmingham, UK, but some Beemster adults also displayed bending deformities of the humerus, radius, and ulna. These deformities might also be attributed to residual rickets and could be indicative of cyclical or ongoing vitamin D deficiency. A nonadult would acquire vitamin D deficiency at a crawling age whereby the arms would be the weight bearing bones. If the disease endured or came back at an age when this individual was able to walk, the legs would bend as well. Bending of upper and lower limbs, as noted in Table 1, suggest multiple periods of or ongoing vitamin D deficiency. However, the shape of the adult humeri is more difficult to interpret as a marker of vitamin D deficiency as a greater variety of activities are performed with the arms and greater differences in upper arm musculature are expected. This will obscure recognition of residual upper limb bending deformities. However, although deformities of the arms as a result of vitamin D deficiency are less common and changes in shape are more difficult to recognize and interpret, they should be considered more often as a possible indication of residual rickets.

No macroscopically evident pseudofractures were present and radiographic Looser's zones were not observed in the scapular spines nor the lateral borders, hence no cases of osteomalacia were diagnosed. Several individuals did display non-diagnostic lesions that can be due to osteomalacia, such as scoliosis or concave compression of the vertebral bodies. However, as pointed out by Brickley and Ives (2008) and Brickley et al. (2007), other pathological conditions can cause loss of vertebral body height, biconcave compression of the vertebral bodies, and scoliosis/kyphosis, and these skeletal deformities need to be accompanied by other lesions for the diagnosis to be osteomalacia.

The CT-scans taken from the fifth lumbar vertebrae were inconclusive for osteomalacia. Unfortunately, several lumbar vertebrae contained soil particles and taphonomic damage could have caused a decrease in trabecular bone density. Therefore, only trabecular organisation was assessed but none of the individuals presented with an irregular or disorganised structure of the trabeculae. Since the macroscopic features could not provide a definitive osteomalacia diagnosis and the radiographs and CT-scans did not provide additional evidence of adult vitamin D deficiency, the observed skeletal lesions cannot be attributed to osteomalacia.

4.2. Sociocultural practices affecting vitamin D levels

Several factors can be responsible for the occurrence of a prolonged shortage of vitamin D. These include geographic and climatological characteristics, such as latitude and available solar hours, but also sociocultural habits related to sunlight exposure and diet (Brickley et al., 2014; Giuffra et al., 2015; Palkovich, 2012). A way to assess the influence of these sociocultural habits is by evaluating vitamin D deficiency prevalence. Previous research indicated that the high percentage of childhood rickets in the rural population of Beemster was most likely caused by a multitude of factors, including sociocultural habits related to sunlight exposure, such as type of clothing and time spent indoors (Veselka et al., 2015).

Dietary practices may also have contributed to infant vitamin D deficiency via maladaptive breastfeeding and weaning practices. Recent stable isotope research of the Beemster nonadults, showed relatively short periods of breastfeeding, on the order of a few weeks to months, and some infants appear not to have been breastfed at all (Waters-Rist and Hoogland, 2017). Rather, it is likely that these young infants were fed raw (i.e. unpasteurised) cow's milk. Cow's milk is very different from human breastmilk and predisposes infants to gastrointestinal bleeding, intestinal blockages, bacterial infection, reduced immune function, gastric symptoms (vomiting, diarrhea), breathing difficulties, and iron deficiency anemia (Butte et al., 2002; Haug et al., 2016; Sullivan, 1993; Thompkinson and Kharb, 2007). In regards to vitamin D, neither breastmilk nor cow's milk are very good sources of it, but the vitamin D in cow's milk becomes less bioavailable when the infant is suffering from the conditions listed above. Therefore, the infant feeding practices of this community may have been an important contributing factor in infants and children developing vitamin D deficiencies (Waters-Rist and Hoogland, 2017).

Clothing is commonly region specific and often the result of community norms and traditions (de Leeuw, 1920). Furthermore, the type of clothing worn can be influenced by socioeconomic status and sex. During the 19th century, Dutch nonadults and adults dressed similarly, exposing little to no skin, as shown in Fig. 2. Although this picture shows Beemster school children in their best clothes (Beemster inhabitant, Mr. T. Molenaar: pers. comm.), it is postulated that clothes worn everyday would resemble the ones worn on specials occasions in covering about the same amount of skin.

Covering clothing would substantially decrease dermal synthesis of vitamin D. However, if adults exposed their face, hands, and arms every

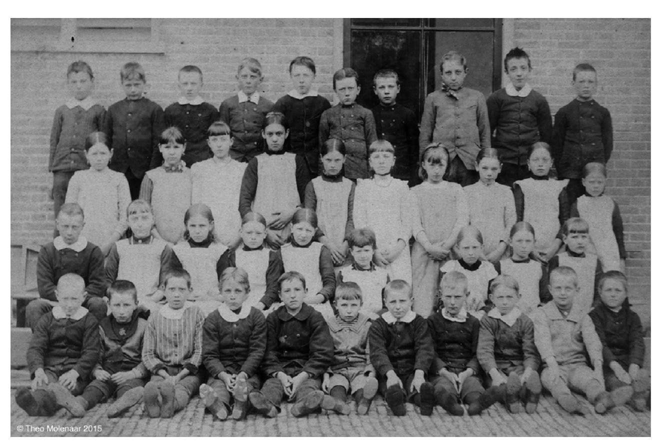

Fig. 2. Beemster school children from the 19th century (Photograph: courtesy of Mr. T. Molenaar, inhabitant of Beemster).

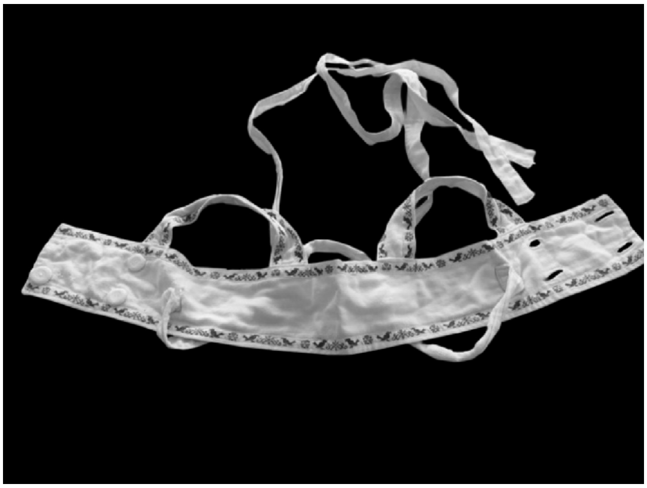

Fig. 3. Early 20th century tree harness (Photograph: courtesy of Mrs. A.Vis-Best, inhabitant of Beemster).

day during the late spring and summer months, vitamin D levels should have been adequate (Brickley and Ives, 2008: 77; Holick, 2005). Infants that were fully dressed (without a hat) would need two hours of sunlight exposure in these months (Pettifor and Daniels, 1997: 665). Yet, the Beemster is an area with many canals and houses would have been surrounded by water. Constant danger of drowning would have kept young children inside. On occasions, these children were allowed to play outside, but would have been tied to a tree for a short period of time to prevent them from drowning while their mother or grandmother performed activities in and around the house (Beemster inhabitants Mr. K.C. Visser and Mrs. A. Vis-Best, pers. comm.). Fig. 3 displays one of these 'tree harnesses'. Thus, just because ample sunlight was available in spring and summer months in this rural region, it does not mean the nonadults had access to it. Clearly many did not.

Indoor activities or activities in the shade combined with concealing clothing would further increase the risk of developing vitamin D deficiency. This would imply equal risk of developing rickets for boys and girls at least up to the age of five to six years, when children were expected to help with daily tasks. Most of the Beemster inhabitants performed activities involving cattle farming, such as herding, milking, churning butter, and making cheese (Falger et al., 2012). Typically, the men worked in the fields while women performed work in and around the house, such as spinning, sawing, laundry, churning butter, making cheese, and tending to the children (van Cruyningen, 2015; Falger et al., 2012; van Nederveen Meerkerk, 2015; Palmer et al., 2016). Up to the 19th century, this division of labour started early in life, whereby children from the age of six years, and sometimes even younger, were put to work (Brugmans, 1929: 93; Schenkeveld, 2008). Common activities for boys in cattle farming communities included herding and milking the cows, whereas girls would knit, sow, help their mothers or grandmothers with house chores, and tend to younger brothers and sisters (Schenkeveld, 2008: 38, 50, 53).

Residual rickets was significantly more frequently observed in the Beemster females than males, which suggests female nonadults received less sunlight exposure than male nonadults. Gendered division of labour wherein older boys (6+ years) spent more time in the fields is proposed to have enabled more of them to overcome a vitamin D deficiency they might have developed during their early years of life. Fewer females were able to overcome the deficiency, being involved in tasks that kept them indoors or closer to home and farm building that may have shaded their outdoor work. Some of these females may even have experienced additional bouts of vitamin D deficiency as they grew.

An alternative explanation for the finding that significantly more females than males had residual rickets must be considered. This pattern would result if more nonadult males with vitamin D deficiency died, causing more adult females with bending deformities to be part of the analyzed sample. If indeed nonadult males experienced a greater frailty and the risk of developing rickets was about the same for female and male nonadults up the age of six years, more male than female nonadults under the age of six years are expected to be buried in the Beemster cemetery. However, archival data of the Beemster cemetery have shown that the age-at-death distribution of male and female nonadults is not statistically significant ($U = 492{,}000$; $p = 0.821$).Therefore, nonadult males and females are postulated to have comparable frailty. In addition, vitamin D deficiency is rarely fatal (Brickley et al., 2010). Taking into account that the diet was similar for girls and boys (Waters-Rist and Hoogland, 2017) and that the properties of the skin needed to synthesize vitamin D do not differ substantially between males and females, this strongly suggests that gender related differences in activities were a key reason for the higher frequency of residual rickets in females.

Although the relatively high rickets and residual rickets prevalence in this population would suggest a high prevalence of osteomalacia (Brickley et al., 2014), no definitive case of adult vitamin D deficiency was observed. Several individuals displayed non-diagnostic lesions that failed to meet the criteria for a diagnosis of osteomalacia. Manifestations of adult vitamin D deficiency often are more subtle and severe manifestations of this disease are rarely found in the archaeological record (Brickley et al., 2007; Ives and Brickley, 2014; Ortner, 2003; Waldron, 2009). While the lack of definitive cases of adult vitamin D deficiency in the Beemster sample may suggest that gender related differences in activities were absent in adulthood, this is considered unlikely. Most likely, a large part of the reason for osteomalacia not being detected can be attributed to its subtle, non-diagnostic osseous changes.

Indeed, in most populations of this region and time, including the Beemster, a rigid gender- related labour division was the norm (van Cruyningen, 2015; van Nederveen Meerkerk, 2015; van Poppel et al., 2009). Importantly, however, it has been noted that at times, women were needed to work in the fields together with the men (van Cruyningen, 2015; Falger et al., 2012; Schenkeveld, 2008). In such scenarios, it was the girls that were tasked with tending to the home and younger children together with the grandmothers (Schenkeveld, 2008; Beemster inhabitants Mrs. M. de Reus-Kilsdonk, Mr. K.C. Visser and Mrs. A. Vis-Best, pers. comm.), thereby continuing their time spent mostly indoors. Maybe these events contributed to adult females having an adequate or only slightly low level of vitamin D.

Several researchers have studied gender-based differences in activity using musculoskeletal markers (e.g. Eshed et al., 2004; Palmer et al., 2016; Villotte et al., 2010) and disease (e.g. Agarwal, 2012; Sofaer Deverenski, 2000; Weiss and Jurmain, 2007). As this paper has shown, vitamin D deficiency prevalence can also be used to assess gender-based differences in activity. Although historical and contemporary sources contain information on various activities in the past, women and children are often invisible in these sources (van Cruyningen, 2015; Dekker, 2015; van Poppel et al., 2009; van Nederveen Meerkerk, 2015). This research on vitamin D deficiency prevalence in the Beemster enhances our knowledge of gender related differences in activities in this population and the impact of this division on various stages in life, and provides more information on the past lives of women and children in rural areas.

5. Conclusion

Besides geographic and climatological characteristics, sociocultural habits, such as gender- related differences in activity that affect the amount of time spent outdoors, can influence vitamin D levels. Therefore, vitamin D deficiency prevalence can be informative about the impact of these habits on various age groups. In addition, it can enhance our knowledge about the past lives of women and children, who are often invisible in historical records. The prevalence of residual rickets in the rural Beemster population showed that female nonadults were more frequently affected by vitamin D deficiency than male nonadults. Although the residual rickets prevalence strongly suggests a gender-related division in activities contributed to higher female vitamin D deficiency in childhood, the impact nor the existence of this division in adulthood is clear. Methods to better detect non-severe cases of osteomalacia in archaeological skeletal remains are needed.

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