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RESEARCH ARTICLE

Coming of age in the Netherlands: An osteological assessment of puberty in a rural Dutch post-medieval community

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Abstract

Objectives: The objective of this study is to apply pubertal stage estimation methods to a sample from a rural community: the post-medieval Dutch skeletal collection from Middenbeemster. Puberty is a key developmental period involving transition to physical adulthood with broad societal relevance through its impact on fertility, morbidity, and mortality.

Materials and methods: Individuals (n = 55), including 27 of known sex and age-at-death, between the ages of 8 and 25 years were assessed for six skeletal markers indicative of pubertal growth spurt. Recent novel osteoarchaeological methods from Shapland and Lewis are used to reconstruct the timing and duration of pubertal stages.

Results: Pubertal acceleration occurred earlier in females (10.38 years, n = 8) than males (13.30 years, n = 6), whereas maturation occurred later in males (21.36 years, n = 11) than females (19.30 years, n = 5). Onset appears earlier and completion later compared to other archaeological skeletal samples with osteoarchaeological evidence of puberty. Age shortly after menarche was reconstructed at 20.45 years, substantially later than historic records and bioarchaeological research reports suggest.

Conclusion: This early onset and late completion caused a "stretch" of the overall duration of puberty compared to other collections, especially of the last three stages. This prolonged development is reflected in historically known social expectations for the Netherlands, for example, that marriage and children should not occur before about 22–23 years of age. Increasing the range of past peoples with puberty stage reconstruction will permit more insightful interpretations of the biological and cultural patterns of this important life stage.

KEYWORDS

adolescence, osteoarchaeology, post-medieval, puberty, the Netherlands

1 | INTRODUCTION

Adolescence, which is responsible for the physical and psychological changes leading to adulthood, is among the most important developmental stages a human goes through in life. According to the World Health Organization (1993), it occurs between the ages of 10 to 24 years. Puberty, an essential phase within adolescence, produces sexual maturation, and is a key factor in population fertility (Lewis, Shapland, & Watts, 2016a, 2016b). In addition, adolescence is typically associated with pronounced cultural changes in identity, partially attributable to the development of secondary sexual traits during puberty. Much of our understanding of the biological and cultural

facets of adolescence in past populations comes from literary sources that focus on the cultural conceptualizations of different life stages. These conceptualizations may differ among populations in many ways including the recognition, number, timing, and duration of different life stages and the culturally defined roles and behaviors associated with each (Thewissen, 2004; Van Poppel, 1992). With recent osteological methods to estimate pubertal timing (Shapland & Lewis, 2013, 2014), we can explore this important life stage in past peoples without written records. With such records, we can compare the osteological and literary results to gain better understanding of the myriad of biological and cultural changes that occur during adolescence, and their variation within and between past populations.

Since these puberty estimation methods have been introduced to osteoarchaeology, several studies have been published. These focus on Roman and medieval England (Arthur, Gowland, & Redfern, 2016; Lewis et al., 2016a, 2016b; Shapland, Lewis, & Watts, 2015), early modern Portugal (Henderson & Padez, 2017) and a Muslim osteological sample from Spain (Doe, Pérez, Cambra-Moo, Martín, & González Martín, 2019). Most of these communities lived in urban settlements and showed frequent pubertal delay compared to historic ranges and

FIGURE 1 Location of the Middenbeemster excavation (red churchyard symbol) on a crop of the ESRI world street map of the Netherlands

modern standards (Arthur et al., 2016; Doe et al., 2019; Henderson & Padez, 2017; Lewis et al., 2016a, 2016b; Shapland et al., 2015). Factors explaining such a delay in urban environments include pollution, strenuous physical work, and population density aiding the spread of chronic disease (tuberculosis and other lung diseases specifically; Lewis et al., 2016a, 2016b; Shapland & Lewis, 2013; Shapland et al., 2015). These findings are congruent with the well-established understanding, based on modern populations, that poor health can cause delayed puberty and sexual maturation (Berk, 2003; Lewis, 2007). Yet, rural and urban communities typically experience a different pattern of health stressors, which may influence pubertal timing and thus growth and development during adolescence.

To contribute to the growing body of osteoarchaeological puberty research, this study applies pubertal stage estimation methods to a sample from a large, rural, predominately 19th-century Dutch skeletal collection from the village of Middenbeemster (Figure 1) with archival records. We analyze individuals between 8 and 25 years in order to capture both early and late maturation changes and to accommodate osteologically estimated age ranges. As a rural community has not yet been assessed using puberty estimation methods, and scant puberty data exist for Dutch skeletal collections, this study will provide important new insights about pubertal development and delay in the recent past.

2 | MATERIALS

Over 450 individual interments were discovered at the Middenbeemster cemetery (Hakvoort, 2013; Lemmers, Schats, Hoogland, & Waters-Rist, 2013), mostly dating between AD1829 and 1866 (Griffioen, 2011; Griffioen, Lemmers, Schats, Waters-Rist, & Hoogland, 2012). The collection is very well preserved and most skeletons are complete. Of 75 individuals between the ages of 8 and 25 years, 55 could be assessed for three or more pubertal stage estimation markers and were included in this study. Two types of archival records are available for the Middenbeemster cemetery: (a) a cemetery ledger containing names, ages-at-death, lineages, marriages and occupations for a large portion of the collection; and (b) a post-medieval military archive detailing height, disease and abnormalities for most males (Waters-Rist & Hoogland, 2013). Archival records stating age-at-death and sex were available for 27 of the 55 individuals (49.1%) and were only used after all data were collected. These records showed that one individual died at 26 years of age. This individual was kept in the study due to notable pubertal delay. The collection is currently housed at the Laboratory for Human Osteoarchaeology, Faculty of Archaeology, Leiden University, The Netherlands.

Post-Medieval Dutch rural villages had fewer inhabitants (<2000 individuals) spread out over a wider area compared to towns and cities. The Beemster polder (low-lying land reclaimed from the sea) has a surface area over 7,000 ha and a population of 2,681 inhabitants in 1828 and 3,770 in 1870 (Archiefgroep Historisch Genootschap Beemster and Hoogland, 2017), the majority of whom were involved in dairy farming. Compared to residents of more urbanized areas, Beemster citizens likely suffered less from communicable infectious diseases (especially respiratory conditions) and ill health due to air, ground, and water pollution from factories (Schats, 2016; Walter & DeWitte, 2017). Parasitic infection due to inadequate sanitation and unhygienic conditions, more common in large, densely populated cities, was probably also less prevalent (Mitchell, 2015). Yet, while the Netherlands was a highly urbanized country by 1800 (Bairoch & Goertz, 1986) city sizes were generally smaller than in other western European countries (e.g., United Kingdom, France; de Vries, 1984). Thus, urban–rural differences in health may not have been as pronounced as in countries with large cities (Schats, 2016). Finally, occupations and thus common types of physical activity varied between city and country; osteoarchaeological research has found markers of high levels of manual labor in men and women in the Middenbbemster collection (Chilcote, 2018; Palmer, Hoogland, & Waters-Rist, 2016; Saers et al., 2017).

2.1 | Historic background

It is necessary to establish the norms and variability of pubertal development for a population, and a sociohistorical context of its implications, to assess if an individual had delayed onset or completion, and if that had social implications. Archival and medical sources from the late 19th -early 20th centuries suggest an age-at-menarche of 14–16 years, with puberty beginning around 12–14 years for girls (Braun, 1864; D'Espine 1835 in Ploss & Bartels, 1918; Bolk, 1923; Kellermann-Slotemaker, 1924; Tilt, 1862; Touw, 1926; Van Rhyn, 1925; Van Ussel, 1982; Zeeman, 1869). For boys, such sources suggest the entire pubertal phase falls between 14 and 19 years with the height of physical and psychological changes—"the transitional phase"—occurring around 15 years of age (Blommaert, 1843; Faust, 1792; Gunning, 1918; Schreber, 1862; Van den Eerenbeemt, 1935; Van Ussel, 1982). This anecdotal information cannot, unfortunately, be directly linked to modern medical terms such as peak height velocity (PHV). Nonetheless, it suggests when visual and behavioral changes were likely to arise (12–14 years for girls and 14–19 years for boys), when menarche was expected to happen (14–16 years), and possibly when boys entered PHV (15 years). Based on these data, we can set an expectation that peak physical changes (represented by pubertal stage 3 for boys; and menarche for girls) occurred in both females and males around 15 years of age.

Social adulthood can hint toward "physical readiness" for certain adult roles. Historical archival data from Middenbeemster specifically allow us to determine that the average marital age was 27.5 years for males (n = 168) and 25.8 years for females (n = 168), with two males from this historic sample marrying at 19 years or younger (~1.2%), compared to 10 females (~6%; based on DTB-boeken Beemster, 1829 to 1866; WA-GB, NL-PmWA, n.d.). Although laws allowed marriage at the age of 18 years for men and 15 years for women *if* the parents provided permission (Van Poppel, 1992), social rules and medical beliefs implied marriage should occur only in one's mid- to late

twenties (Conférence du Code Civil, 1805; Hofstee, 1981; Van Poppel, 1992; Verwijs, 1878). Additionally, the average age of first-child for women in late 19th-century Netherlands, hinting to sexual maturation, was between 25.5 and 26 years (Van Gaalen & Van Poppel, 2007). Moreover, the marital contracts of Middenbeemster refer to 22 years old as minors, and 23 years old as adults (WA-GB, NL-PmWA). This suggests there is a biological/natural argument behind the "appropriate" age of marriage.

Delay in the development of secondary sexual traits and menarche was often explained through "poor blood preparation" (Braun, 1864; Ootmar, 1923). The most commonly listed conditions for women are excessive vaginal secretion, chronic uterine infection, hydremia, the underdevelopment or lack of uterus and/or ovaria, obstruction of the uterine cavity or the cervix, stenosis of the vagina, and work-related chemicals (Clarys, 1894). For men—for whom first ejaculation, behavioral changes, pubic hair and increase in muscularity were key in recognizing puberty—strenuous physical work, poor nutrition, hygiene and country-life are mentioned (Daignan 1786 in Van Ussel, 1982). Historic records for Beemster show that 56.3% of men worked on farms and 6.7% worked as laborers (WA-GB, NL-PmWA). Conditions that could affect both sexes include chlorosis ("green sickness"), rickets, tuberculosis/scrofula ("King's Evil"), cancer, colds, mood disorders, stomach-, lung-, and nosebleeds, and acute diseases (Braun, 1864; Daignan 1786 in Van Ussel, 1982; Frisch, 1983; Ootmar, 1923).

More direct historic records mention cholera epidemics in Beemster in 1832, 1849, 1854, and 1866 (Kurpershoek, 2012); and although not recorded for Beemster specifically, across the country typhus, measles, Scarlett fever, diphtheria, whooping cough, and croup caused 12 to 60% of deaths between 1866 and 1879 (Hofstee, 1981). None of these diseases are, however, visible in skeletal remains. Diseases that can be found in the skeleton and are known from historic records and analyses of the Middenbeemster collection, including rickets, scurvy, tuberculosis, syphilis, and scoliosis. Additionally, various skeletal markers can hint toward general physiological stress from disease or malnutrition, including stunted growth and non-specific stress markers (including cribra orbitalia, cribra femora, and enamel hypoplasia), or hard physical labor (including osteoarthritis, Schmorls' nodes, and degenerative disc disease at a young age). Finally, different regions of the Netherlands, Beemster included, experienced various crop and livestock failures over the course of the 19th century, with 1846 to 1847 being particularly hard due to the potato blight and wheat and rye failures (Hofstee, 1981). Food shortages, of varying severity and duration, would have been a common cause of malnutrition and physiological stress for all but the wealthy.

3 | METHODS

Age-at-death estimation for individuals <18 years-old was based mainly on dental formation and eruption (Moorrees, Fanning, & Hunt, 1963; Ubelaker, 1987) and complemented by epiphyseal fusion methods of the vertebrae, sacral segments, humerus, radius, ulna, os coxa, and occipital bone for 3–12 years old, plus clavicle, scapula, femur, tibia, fibula, calcaneus, and spheno-occipital synchondrosis for 13–17 years olds (Schaefer, Black, & Scheuer, 2009). Age-at-death estimation for 18–26 year old was based on dental formation of the M3 specifically (Ubelaker, 1987; Moorrees et al., 1963; M3 eruption is not evaluated due to its large range of variation; e.g., Hillson, 1996), several late fusing epiphyses (spheno-occipital synchondrosis, medial clavicle, first and second sacral vertebrae, ischium, and sternal segments; Schaefer et al., 2009), pubic symphysis morphology (Brooks & Suchey, 1990), sternal rib end morphology (İşcan & Loth, 1986; İşcan, Loth, & Scheuerman, 1987; İşcan, Loth, & Wright, 1984; Yoder, Ubelaker, & Powell, 2001), dental wear (Maat, 2001), and cranial suture closure (Meindl & Lovejoy, 1985). These late adolescent aging methods are in order of most to least accurate and reliable. Heavier reliance was put upon methods that are most accurate and reliable. No individuals in this study were aged based only on the less reliable methods such as sternal rib morphology, dental wear, or cranial suture closure.

Despite debate about the reliability of sexing methods on non-adults (Sutter, 2003), such analysis is necessary for an accurate understanding of puberty results. The use of 27 known-sex individuals in this sample, and the application of previously tested—and considered accurate (between 72 and 85%; Bergmans, 2018; Brinkman, 2014; Falys, Schutkowski, & Weston, 2005; Sutter, 2003)—methods for the estimation of sex, should limit the extent and impact of inaccurate estimates. Sex is only estimated in individuals over 10 years of age (following procedures set out by Shapland & Lewis, 2013, 2014; see Table 1 for a list of the methods). Sex estimation accuracy will be calculated by comparing osteological and archival sex.

Pubertal stage estimation methods are based on research by Shapland and Lewis (2013, 2014) and include ossification of the hamate hook, development of the mandibular canine root, fusion of the distal radial epiphysis, ossification and fusion of the iliac crest, fusion of the epiphyses of the hand phalanges, and the development of the cervical vertebrae. Results will be compared to (a) estimations of pubertal stages from Dutch historic medical literature, (b) pubertal stage timing of the largest adolescent cohort currently published (i.e., Lewis et al., 2016a, 2016b); (c) other smaller and urban osteoarchaeology collections (i.e., Arthur et al., 2016; Doe et al., 2019; Henderson & Padez, 2017); and (d) modern Dutch adolescent growth spurt timing.

The small sample size for several puberty stages precludes us from estimating "normal age ranges" for the Middenbeemster sample. As a result, we use the age ranges of puberty stages produced by the large Medieval English sample analyzed by Lewis et al. (2016a, 2016b) for comparison, and will term this the "expected range" in the remainder of the article. This range is shown in Table 2. An age that falls outside of this expected range by 1 year or more is indicative of early or late development (following protocols by Lewis et al., 2016b). Categorizing an individual as having early or late development is intended to imply the direction of variation in the average age of pubertal stages in Middenbeemster relative to the expected range (Lewis et al., 2016a, 2016b). We do calculate the average age associated with

TABLE 1 Sex estimation methods used in this study ordered per age of applicability following method guidelines and procedures set out by Shapland and Lewis (2013, 2014)

Sexing methods	Age of application	References
Mandibular morphology	11–17 years old	Sutter, 2003
Pelvic traits		Ferembach, Schwidetzky, & Stloukal, 1980; Schutkowski, 1993
Distal humerus		Falys et al., 2005; Rogers, 2009
Foramen magnum		Brinkman, 2014; De Vito & Saunders, 1990; Macaluso Jr., 2011; Morgan, 2011; Veroni, Nikitovic, & Schillaci, 2010
Mandibular canine		
WEA pelvic traits	15+ years	Ferembach et al., 1980
Phenice traits	16+ years	Phenice, 1969
Pubic bone shape		Phenice, 1969
Acetabulum size/location		Schwartz, 2007
Ischial spine protrusion		Maat, Mastwijk, & Van der Velde, 1997
Sacral curvature	18+ years	Schwartz, 2007
Sacral breadth		Byers, 2008
Cranial methods (WEA)[a]		Ferembach et al., 1980
Additional cranial methods[b]		LoHO, 2018
Metric methods[c]		Bainbridge & Genovés-Tarazaga, 1956; LoHO, 2018; McCormick, Stewart, & Greene, 1991; Stewart, 1979; Steyn & İşcan, 1999

[a]Sharpness of the supraorbital margin, extension of the zygomatic arch (beyond the external auditory meatus), thickness of the inferior margin of the mandibular horizontal ramus, the outward flaring of the gonial angle and the acuteness of the gonial angle.
[b]Workshop of European Anthropologists.
[c]Metric methods of the clavicle, scapula, humerus, and femur.

puberty stages for the Middenbeemster sample, but treat the results tentatively in cases where the value is based on only a few individuals (see Section 4.3.).

It is important to determine if individuals suffered from diseases or conditions that could have stunted or delayed growth to such an extent that pubertal timing could be affected. Pathological conditions are assessed macroscopically and with low (×10) magnification. An overview of the skeletal changes per pathology used for diagnosis can be found in Table S1.

An intraobserver agreement analysis of 12 individuals is performed using Pearson's correlation and Cohen's Kappa. Any age- or sex-related differences will be statistically assessed using Chi-square analyses and paired *t*-tests. Pubertal stage scoring will be presented using descriptive statistics and the coefficient of determination (R^2). Glass's delta and Hedges' *G* quantify whether sex can be considered a determining factor in average age per pubertal stage. Both analyses are adaptations to Cohen's *D*, the former correcting for statistically different *SD*s between groups; and the latter for small sample sizes ($n < 20$). Groups consisting of one individual cannot be used in these analyses because the calculation makes use of the standard error of the mean (*SEM*) within a group. The results reflect by how many *SD*s the average of one group deviates from another (Ellis, 2010).

4 | RESULTS

4.1 | Applicability and repeatability

Twelve (~22% of the sample) randomly selected individuals were re-assessed for pubertal stage estimation 2 weeks after initial data collection. The high values for the Pearson's *R* and Cohen's Kappa tests indicate that the majority of the markers were scored consistently (see Table 3).

4.2 | Demography

Of the 55 individuals included in the study, 47 could be assigned an osteologically estimated sex. Final sex for a total of 28 individuals (~51%) is dependent on only osteological estimates, and 27 (including three individuals aged below 10 years) could be assigned a sex through archival records. The archival records include 15 females and 12 males. Combined with osteological sex data, this results in 24 females, 24 males, 2 indeterminates, and 5 unassessed individuals (aged <10 years and lacking archival records). For eight individuals aged 10–15 years old, osteological sex, and archival sex could be

TABLE 2 Summary of the different pubertal stages, the age range of their attainment, their relationship to the completion of adolescent growth, and the highlights occurring during these phases, based on Lewis et al. (2016a) and Shapland and Lewis (2013, 2014)

Stage	Age range (years), male and female combined	Name	% Adolescent growth remaining	Highlights
Stage 0	<10	Prepubertal	100%	Adrenarche, Pubarche
Stage 1	10–12	Initiation	80–100%	Pubertal onset, Gonadarche
Stage 2	10–13	Acceleration	65–85%	Increased skeletal growth
Stage 3	11–15	Transition	25–65%	Peak height velocity (PHV), breast growth; sexual maturation boys
Stage 4	15–17	Deceleration	10–25%	Menarche[a]/sexual maturation for girls
Stage 5[b]	15–17	Maturation	5–10%	Skeletal growth completing
Stage 6	16–22	Completion	0–5%	Physical adulthood (skeletal/soft tissue)

[a]Menarche essentially occurs within pubertal stage 4, but cannot be equated to the entire phase. The passing of menarche has its own focused and unique hormonal shift that lasts shorter than the entire deceleration phase (Tanner, 1989).
[b]Stage 5, or the maturation stage, is identified as a separate stage in clinical, medical and pediatric research (Chertkow, 1980; Grave & Brown, 1976; Hägg & Taranger, 1982; Hewitt & Archeson, 1961). It is identifiable as a discrete pubertal stage in skeletal remains but has the same age range as stage 4 because that was the result derived from the skeletal collections used to create the method (Lewis et al., 2016a, p. 54).

TABLE 3 Availability of maturation markers in the Middenbeemster sample (*n*) and comparison of their reliability

Maturation method	*n* individuals with marker present	R^2 pubertal stage and age	Cohen's kappa		Pearson's *R*	
			K	Strength of agreement	*R*	Strength of correlation
Canine mineralization	47	0.6874	0.667	Substantial	0.920	92.0%
Hamate hook	37	0.318	0.172	Slight	0.868	86.8%
Phalangeal fusion	49	0.769	0.551	Moderate	0.935	93.5%
Iliac crest	54	0.723	0.697	Substantial	0.957	95.7%
Radial fusion	53	0.761	0.551	Moderate	0.918	91.8%
Vertebral development	48	0.717	0.577	Moderate	0.872	87.2%
Overall stage	55	0.734	0.474	Moderate	0.926	92.6%

Note: Table includes correlation between average age at pubertal stage and age-at-death estimation/archival age and Cohen's Kappa and Pearson's *R* results for intraobserver agreement. The strength of the agreement is based on Landis and Koch (1977).

compared. Only 50% (*n* = 4) had congruent results, the other four representing two females and two males that were incorrectly sexed. Given the small sample size, we will not put undue confidence on this low accuracy result but will keep the potential of incorrect sex estimates in mind when interpreting results. Sex estimation is more accurate in older individuals, with only two out of 19 individuals (10.5%) aged ≥16 years being sexed incorrectly. For the combined group of 10–26 years old, 77.8% (21/27) had congruent archival and osteological sex results.

While the sexes are equally represented in the sample, the distribution of the sexes among the age categories is uneven at a statistically significant level (χ^2 = 8.140, df = 2, *n* = 48, *p* = .017).[1] Fifty-three individuals could be assigned a dental age-at-death, the remaining two a skeletal age. For 27 individuals, osteological age estimates could be replaced with archival information. For a summary of the demographic results, see Table 4.

4.3 | Pubertal stage

All 55 individuals could be assigned a pubertal stage. For the number of individuals per marker, see Table 4. Figure 2 shows the distribution of these pubertal stages per age group and sex and Figure 3 for the pubertal stages per single-value age. The reconstruction of average ages of the different pubertal stages in Middenbeemster can be seen in Table 5. Menarche is associated with fusion of the distal phalangeal epiphyses of the second finger specifically (other fingers are also indicative) and iliac crest ossification (Lewis et al., 2016a, 2016b; Shapland & Lewis, 2014). This sample lacks females with these criteria preventing the exact estimation of age-at-menarche. However, 11 females had complete or partial iliac crest fusion with fully fused phalangeal epiphyses upon which we can estimate the average age closely after menarche. These individuals range from 16 to 26 years with a mean of 20.45 years.

4.4 | Developmental timing

Using our approach of suggesting the presence of early, normal, or late development (see Section 3) seven individuals (~12.7%) are considered to be early, 22 (40.0%) show late pubertal timing, and 26 (~47.3%) are believed to have experienced development in line with the expected norm. The distribution of pubertal stages among the age categories shows that early development is most frequent in the younger individuals (six out of seven ≤13 years) and late development in the older individuals (18 out of 22 ≥18 years). Moreover, the onset of pubertal development is either early or normal, while its completion is normal or late (see Figure 4a).

Assessing the relationship between pubertal stages and sex reveals that more males (n = 13; ~54%) than females (n = 7; ~29%) show late development, while more females (n = 3; 12.5%) than males (n = 1; ~4.1%) show early development (Figure 4b). This unequal distribution of early, normal and late development among the sexes is statistically significant (χ^2 = 5.882; df = 2; p = .053, n = 51). Additionally, the correlation between age-at-death and maturation stage per sex shows that there is a slightly stronger correlation between the age-at-death and pubertal stage for females (R^2 = 0.7212) than for males (R^2 = 0.6523). This correlation also shows a larger scatter for males indicating a wider range of ages per pubertal stage and vice versa. Glass's delta and Hedge's G (Table 5) results show that there is a medium to large effect of sex on average age per stage.

Table 6 shows the average age of pubertal stages for Middenbeemster compared to the "expected norm" (Lewis et al., 2016a, 2016b). Based on the sexes combined, paired-sample t-tests reveal the latter three pubertal stages at Middenbeemster occur at a later age than the in the English sample (see Table 6 for statistics). Moreover, the average Middenbeenster male age of sexual maturity, represented by PHV, is 18 years which is 3 years later than suggested by historic sources although not statistically significant due a large age-scatter for males (t = 1.964; df = 2; p = .188), and girls show the first evidence for the post-menarche period approximately 5.5 years later than indicated by historic sources (t = 5.957; df = 10; p = .00014). Despite the small sample size of some stages, these results show that Middenbeemster had unique pubertal timing.

TABLE 4 Demographic results for the sample (n = 55)

	Number of individuals				
Age (years)	Male	Female	Indeter.	Not sexed	Total
8	-	-	-	1	1
9	-	3	-	4	7
10	1	2	-	-	3
11	1	1	-	-	2
12	-	4	-	-	4
13	1	-	-	-	1
14	-	-	1	-	1
15	4	-	-	-	4
16	1	1	1	-	3
17	-	2	-	-	2
18	1	-	-	-	1
19	3	1	-	-	4
20	3	1	-	-	4
21	-	3	-	-	3
22	1	-	-	-	1
23	1	1	-	-	2
24	2	-	-	-	2
25	1	2	-	-	3
26	-	1	-	-	1
18–25	4	2	-	-	6
Total	24	24	2	5	55

Note: Individuals <10 years cannot be osteologically assessed for sex; if sex for this category is provided, it is derived from archival records.

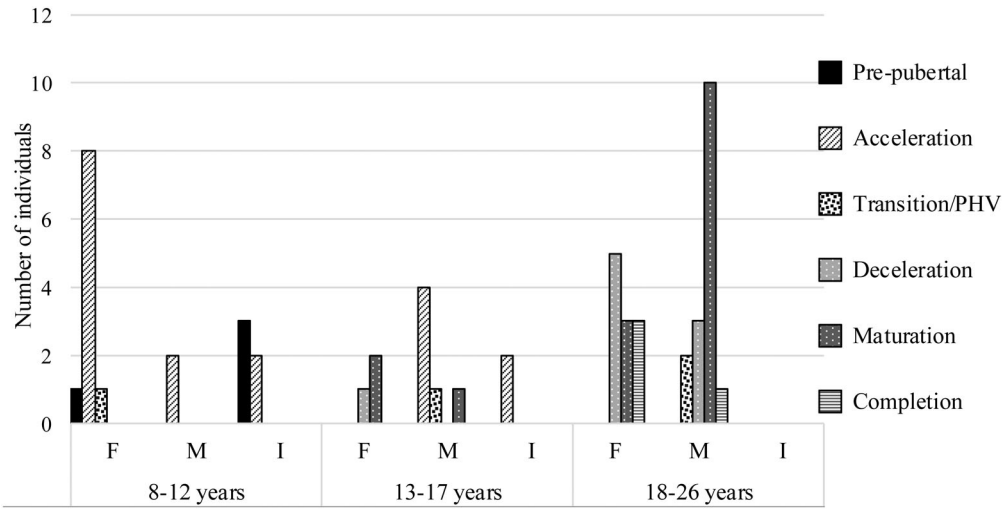

FIGURE 2 The pubertal stages per age groups, including all 55 individuals. Age-at-death from archival records combined with estimated age-at-death

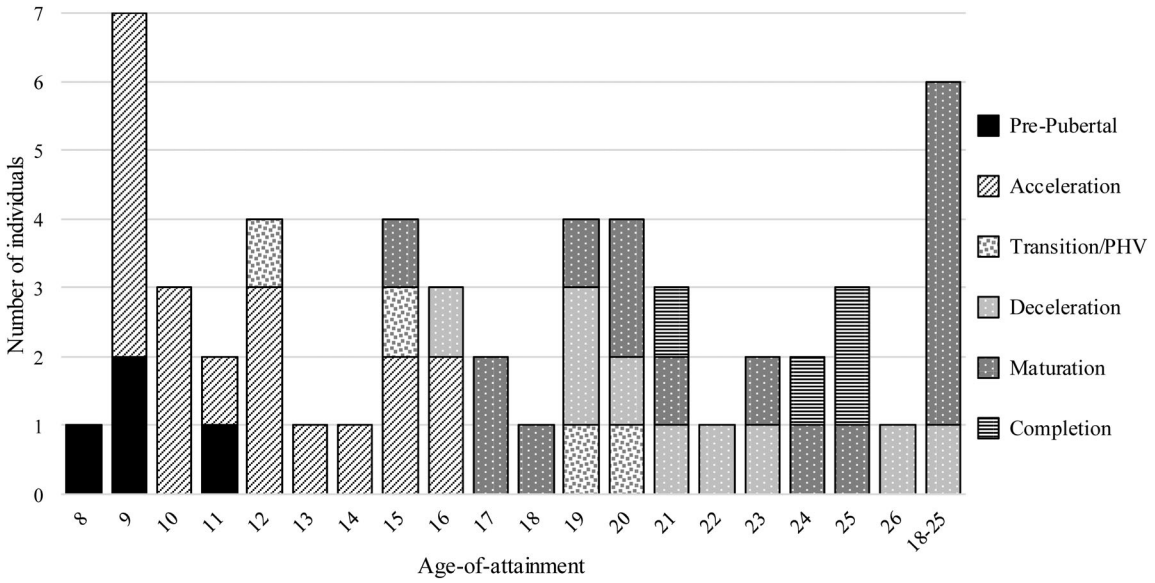

FIGURE 3 The pubertal stages per single-value age-at-death. Sexes combined, including all 55 individuals

TABLE 5 Average age in years and standard error of mean (*SEM*) per stage, for girls and boys separately and the sexes combined, with and without removal of individuals with late development[a]

	Female			Male			Sexes combined—All individuals (*n* = 55)				Sexes combined—Late individuals removed (*n* = 33)					
	n	Age	*SEM*	*n*	Age	*SEM*	*n*	Age	*SEM*	Age range MB	*n*	Age	*SEM*	Age range MB	Glass's delta	Hedge's G
Stage 1	1	11.00	-	0	-	-	4	9.25	0.63	8–11	4	9.25	0.63	8–11	2.10	1.49
Stage 2	8	10.38	0.50	6	13.33	0.99	18	11.70	0.60	9–16	14	10.71	0.50	9–15	-	-
Stage 3	1	12.00	-	3	18.00	1.53	4	16.50	1.85	12–20	2	13.50	1.50	12–15	-	-
Stage 4	6	21.42	1.37	3	20.00	1.00	9	20.90	0.95	16–26	2	19.25	3.25	16–22.5	0.48	0.53
Stage 5	5	19.30	1.09	11	21.36	0.87	16	20.70	0.71	15–25	10	19.85	0.94	15–22.5	0.85	0.77
Stage 6	3	23.67	1.33	1	24.00	-	4	23.75	0.95	21–25	1	21.00	-	21	-	-

Note: Glass's delta and Hedge's *G* for effect size show the strength of the effect (in this cases sex): 0–0.2 = small effect; 0.21–0.5 = medium effect; 0.51–0.8 = large effect. When no value is given, it indicates that this indicates the value could not be calculated (each group requires more than one individual).
[a]For all values above: individuals that could not be assigned a more accurate age than 18–25 years are included in these average ages as having an age of 22.5 years. This includes one female in stage 4, one female in stage 5 and four males in stage 5.

4.5 | Pathology

Of the 55 individuals, 37 (∼67.3%) have pathological lesions associated with either specific diseases (*n* = 4, ∼7.3%), non-specific stress episodes (*n* = 22, 40.0%), or both (*n* = 11, 20.0%), that could have potentially affected growth. The 33 individuals with non-specific stress markers have the following: enamel hypoplasia (*n* = 19/55), cribra orbitalia (*n* = 14/55), and/or cribra femora (*n* = 13/55). Table 7 provides prevalence rates and compares the pubertal stage timing of those with (termed "affected") and without (termed "unaffected") these diseases and stress markers against the expected norm (Lewis et al., 2016a, 2016b), and the average values with one *SD* from Middenbeemster.

The third to sixth pubertal stages contain at least one "affected" individual with some level of late development. Sixteen of the "affected" individuals (∼29.1%) are identified as late, 10 of which (∼18.2%) have an age greater than 3 years beyond the expected range (Table 7). The group of "unaffected" individuals (*n* = 8) contains six cases of pubertal lateness, four of which have an age that falls greater than 3 years outside of the expected range. This results in 22 (40.0%) "late" individuals, 14 (∼25.5%) of which are late by more than 3 years.

Hard physical labor could have impacted growth and development. This category is not treated as a pathology or stress marker but is shown in Table 7 to assess if it is associated with pubertal delay. Of the sixteen individuals (∼29.1%) with these signs, seven are late, five

of which show a lateness of 3 years of more. Contrarily, one shows early development.

5 | DISCUSSION

This research provides the first application of pubertal stage estimation methods to a Dutch rural skeletal collection and is one of few studies with access to archival records on age-at-death, sex, profession, and marital contracts.

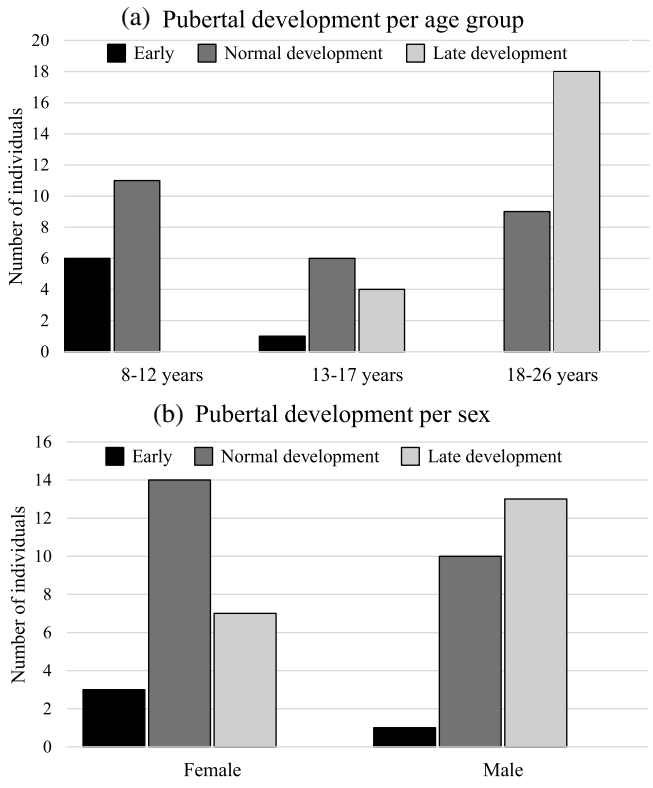

FIGURE 4 Distribution of early, normal, and late pubertal development per age group (a) for the whole sample (n = 55); and per sex (=48)

5.1 | Reliability

The correlation (R^2) between pubertal stage and age offers insight into the potential reliability of pubertal markers. Cohen's Kappa and Pearson R are used here to assess the consistency in scores between multiple tests by one observer. Results of all three comparisons are listed in Table 3. The hamate has the lowest repeatability score of all maturation markers and a low correlation with age. Possibly, this reflects that the hamate is the least represented maturation marker (n = 37), or that Middenbeemster shows a different developmental sequence for the hamate. More research, including larger scale intra- and interobserver error tests, is needed to understand the impact of this effect on pubertal stage estimation for Middenbeemster, and possibly other skeletal collections.

5.2 | Representativeness of sample

A noteworthy problem in this study is selective mortality and hidden heterogeneity (Wood, Milner, Harpending, & Weiss, 1992). As archaeology reconstructs health based on the skeletal remains of individuals who died, caution must be taken when interpreting the results and comparing it to data from living populations. As this study works with the largest possible subsample of adolescents in the Middenbeemster collection (~73% of all individuals aged 8–25 years) and has complemented osteological demographic data with archival records and palaeopathological data with historic research, the impact of hidden heterogeneity is attempted to be minimized. Moreover, some of these early-death individuals will represent cases of sudden death, which are not influenced by selective mortality (Doe et al., 2019). Thus, despite small sample size possibly influencing results, this collection is considered as representative of the 8–25-year-old cohort of Middenbeemster as could be achieved and is argued to roughly approximate true developmental data.

5.3 | Pubertal development

Figure 5 (designed by Doe et al., 2019) shows a comparison of Middenbeemster average ages for each stage to those of previously

TABLE 6 One-sample t-test comparing the average age of pubertal stages between the "expected norm" of a Medieval English sample (Lewis et al., 2016a, 2016b) and Middenbeemster

	Average age (years) for medieval English cohort (males and females combined)	Middenbeemster					
		n	Years	SD	t	df	p
Stage 1	10	4	9.3	1.26	−1.192	3	.319
Stage 2	12	18	11.7	2.56	−0.460	17	.651
Stage 3	14	4	16.5	3.70	1.353	3	.269
Stage 4	16	9	20.9	2.88	5.156	8	*.001*
Stage 5	16	16	20.7	2.85	6.619	15	*.000008*
Stage 6	19	4	23.8	1.89	5.019	3	*.015*

Note: Those in italics show a significant deviation from the expected norm.

TABLE 7 The number (*n*) of individuals per disease, stress marker, and signs of hard physical labor, and their average age per maturation stage

			Pathology														Other		Unaffected	
	Age range (years) of medieval English cohort	Age range (years) of MB[a]	*n* Rickets	Mean age	*n* Scurvy	Mean age	*n* Tuberculosis	Mean age	*n* Syphilis	Mean age	*n* Scoliosis	Mean age	*n* Stunted growth	Mean age	*n* Non-specific stress markers	Mean age	*n* Hard physical work	Mean age	*n*	Mean age
Stage 1	10–12	8.0–10.5	1	9.0	0	-	0	-	0	-	0	-	3	9.7	4	9.3	0	-	0	-
Stage 2	10–13	9.2–14.3	3	9.3	1	10.0	1	12.0	0	-	0	-	6	11.7	13	12.0	0	-	3	12.3
Stage 3	11–15	12.8–20.2	0	-	0	-	1	20.0	0	-	0	-	0	-	3	15.7	0	-	1	19.0
Stage 4	15–17	17.2–22.4	3	23.2	2	22.5	0	-	0	-	2	22.0	1	16.0	5	21.1	2	24.0	2	19.5
Stage 5	15–17	17.9–23.6	0	-	0	-	2	19.0	1	22.5	0	-	2	16.5	6	19.3	11	20.3	2	24.0
Stage 6	16–22	21.9–25.6	0	-	0	-	0	-	0	-	0	-	0	-	2	25.0	3	23.3	0	-

Note: 23 individuals suffer from multiple conditions and are thus represented multiple times in this table. Values that are underlined indicate a mean age that falls outside of the bioarchaeological norm as established in previous research. MB stands for Middenbeemster.

[a]Calculated as one *SD* below and above the mean (sexes combined).

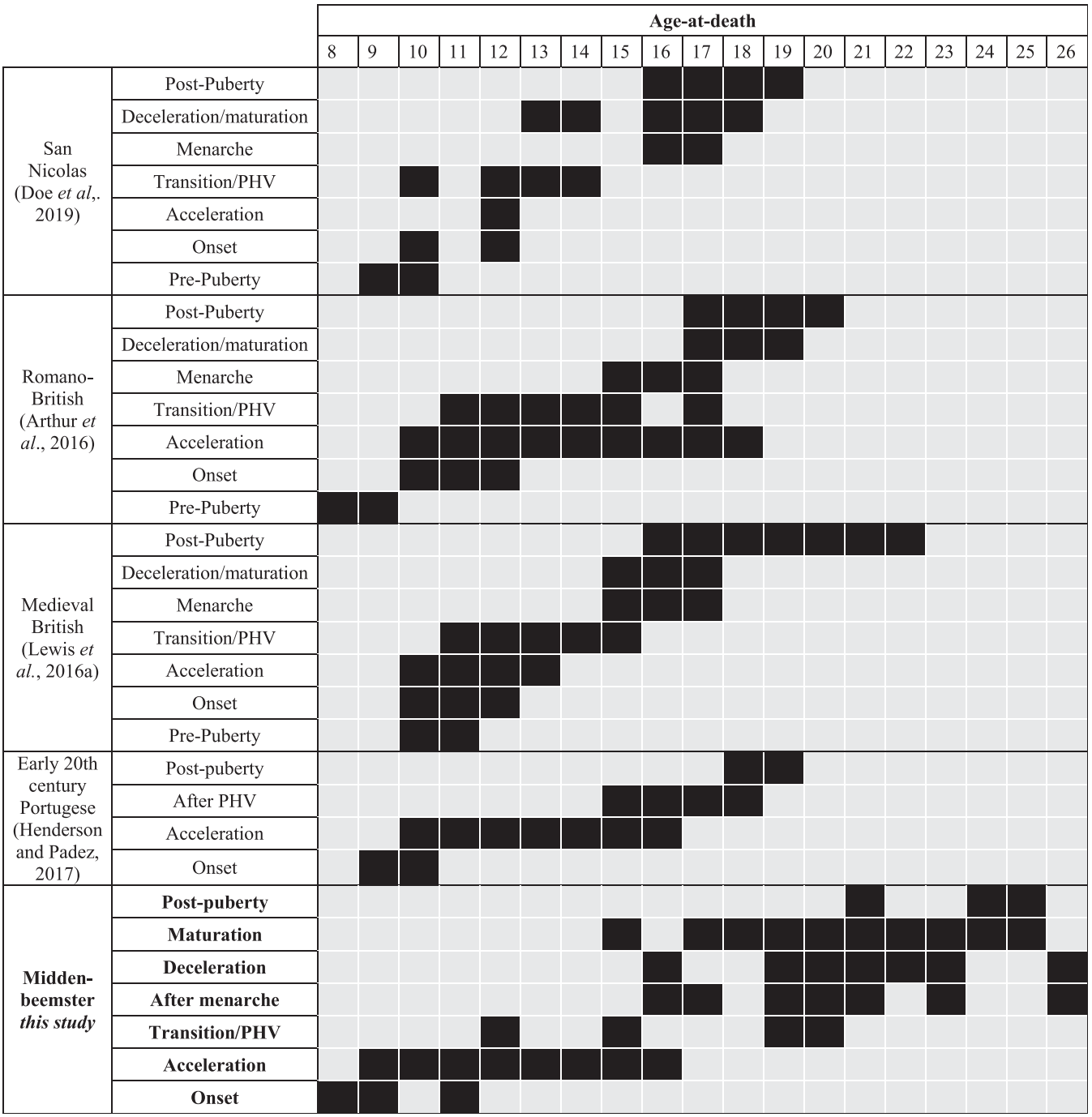

FIGURE 5 Ages-at-death per pubertal stages for previously published bioarchaeological research and Middenbeemster (bottom). Figure augmented from Table 5 of Doe et al., 2019, p. 550. Reproduced with permission of Springer Nature

published skeletal samples. Table 5 further shows the average ages per pubertal stage for Middenbeemster. Pubertal onset of ~9.25 years in Middenbeemster falls within the lower range of the age-of-onset in other geographical and temporal samples, ranging from 9 to 12 years (Arthur et al., 2016; Doe et al., 2019; Henderson & Padez, 2017; Lewis et al., 2016a, 2016b).

Acceleration also reflects a similar average age as was found in most previous studies (Doe et al., 2019; Henderson & Padez, 2017; Lewis et al., 2016a, 2016b), although Roman Britain shows a much wider range of 9–18 years (Arthur et al., 2016). Five of the individuals from this stage are 9 years of age, and as such show pubertal acceleration earlier than has been identified in some previous studies (Henderson & Padez, 2017; Lewis et al., 2016a, 2016b; Shapland et al., 2015; Shapland & Lewis, 2013, 2014). Whether Middenbeemster shows a significantly earlier onset of puberty than other samples cannot be properly assessed because most studies only

assess individuals from the age of 10 years (Lewis et al., 2016a, 2016b; Shapland & Lewis, 2013, 2014). Although Doe et al. (2019, p. 544) do include 9-years-olds, the majority of the individuals of this age were classified as pre-pubescent and thus show a different pattern from Middenbeemster.

The timing of PHV has shown quite some variation in previous studies, ranging from 14 to 15 years on average (Arthur et al., 2016; Doe et al., 2019; Henderson & Padez, 2017), to between 12 and 18 years (Lewis et al., 2016a, 2016b). This stage is represented by four individuals in Middenbeemster, aged 12, 15, 19 and 20 years, reflecting a similarly wide range of ages as found in other collections (Arthur et al., 2016; Doe et al., 2019). Moreover, Lewis et al. (2016b) showed that the pathology-affected group lagged behind in PHV compared to their non-affected peers. Possibly, this pattern of a wide age range thus reflects that PHV is a stage easily disturbed by physiological stress. PHV for males specifically, when they are believed to have experienced spermarche, occurred on average at 18.0 years. This number is only based on three individuals, however, and thus may not reflect the true average age for all Middenbeemster inhabitants.

The latter three pubertal stages all occur at a relatively late age compared to the "expected norm," although a prolonged duration of completion was also found in a large English cohort (see Table 5 and Figure 5; Lewis et al., 2016b). Nonetheless, Medieval English deceleration/maturation (stages 4 and 5) occurred between 15 and 17 years, whereas 80% (20/25) of individuals in these stages in Middenbeemster range from 19 to 26 years (overall range: 15–26 years equaling a span of 11 years). Moreover, deceleration/maturation shows a "tighter" age distribution, spanning 2 to 6 years, in Roman Britain (Arthur et al., 2016), 20th-century Portugal (Henderson & Padez, 2017) and early medieval Spain (Doe et al., 2019).

Overall, it appears that in Middenbeemster the earliest three stages occur slightly earlier while the latter three stages occur much later. Nonetheless, the age range of each stage show a similar spread of ages, albeit less pronounced, as found in previous studies, indicating that a "stretch" of pubertal development, independent of the stage, was common in the past. It must be noted here that when the late individuals are excluded, the average age per stage drops notably (Table 5), although the stages still have higher average ages than other studies.

This slower physical development for Middenbeemster is alluded to in historical records, which imply a late age of cultural maturation—marking social adulthood and thus the right to marry, start a household, a family, and so forth. (Hofstee, 1981; Van Poppel, 1992; Verwijs, 1878; WA-GB, NL-PmWA). This "age-at-adulthood" of 22–23 years is similar to the osteological age of sexual maturation for Middenbeemster (19.9 years, sexes combined). Thus, although historical records suggest menarche occurred around 15 years of age—placing fertility a year later (Zhang et al., 2008)—full-scale, social adulthood is not reached until 22–23 years of age. The extensive allotted time period for sexual maturation and complete adulthood in historical records (~7 years) implies that "stretched" pubertal development may have been frequent and "normal" enough for it to play a role in the cultural age-of-adulthood in Middenbeemster, and possibly the Netherlands as a whole. Similar cultural patterns have been found in English collections (Lewis et al., 2016a).

The fact that this "prolonged" adolescence was found in the majority of the previous studies (e.g., Arthur et al., 2016; Doe et al., 2019; Henderson & Padez, 2017; Lewis et al., 2016b), whereas it is not as common, or as extreme, in modern societies (Abreu & Kaiser, 2016), does imply that physiological stress in the past may have influenced development. For example, modern clinical literature suggests that pubertal initiation to completion (sexual maturity) takes 3–4 years on average (Abreu & Kaiser, 2016). In Middenbeemster, the duration for girls from initiation (n = 1) to sexual maturity (early postmenarche; n = 11) is 9.45 years, and for boys from acceleration (n = 6; no males in onset/initiation stage) to PHV (n = 3) is 4.67 years (sex differences are discussed in Section 5.4.).

The post-menarchael age reconstructed for Middenbeemster (20.45 years on average, range: 16–26 years) suggests menarche occurred much later than would be expected from historic and bioarchaeological data. Previous studies report menarche at 15–18 years (Arthur et al., 2016; Doe et al., 2019; Henderson & Padez, 2017; Lewis et al., 2016b). Middenbeemster's late menarcheal age more closely resembles that which is reported for professional athletes, of up to 19–20 years (Frisch, 1983; Frisch, 1985; Frisch, Wyshak, & Vincent, 1980; Maline, 1983). This late development is attributed to intense physical exercise, reduced body weight, lower fat percentage, and psychological stress (Calthorpe, Brage, & Ong, 2019; Dušek, 2001; Frisch, 1985; Frisch et al., 1980; Torstveit & Sundgot-Borgen, 2005). Moreover, for rural populations in developing countries, age-at-menarche of up to 18.5 years has been reported (Zegeye, Megabiaw, & Mulu, 2009), largely attributed to low socioeconomic class, poor nutrition and hygiene, and vigorous physical activity (Dambhare, Wagh, & Dudhe, 2012; Zegeye et al., 2009), especially compared to urban peers (Dambhare et al., 2012; Ikaraoha et al., 2005; Lin et al., 1992; Zegeye et al., 2009). This reflects the strong influence of physical strain and healthy BMI on normal pubertal development. For Middenbeemster, this pattern of late development may thus be an effect of food shortages and hard physical work in the countryside.

Moreover, a study from 1923 reports an average menarcheal age of 15.25 years for women born *before* 1880, with ~28% obtaining menarche at ≥17 years, and all ages ranging from 10 to 23 years. In women born between 1897 and 1906, menarche occurred at 13.75 years, with ~2% obtaining menarche at ≥17 years, with ages ranging from 9 to 18 years (Bolk, 1923). Midenbeemster's menarcheal age thus shows considerable similarity to Dutch women born before 1880, substantiating that it is not uncommon for the Netherlands to show stretched development in the past.

5.4 | Sex-dependent differences

The majority of late individuals are male—as was found in Lewis et al., 2016b—whereas a larger portion of early developers are female. Effect size statistics showed medium to large effects of sex on

average age per stage. Moreover, the female adolescent period takes almost 5 years longer than that of males. The possible low accuracy (i.e., 50%) of sex estimation in the 10–15 years old may be affecting these data, but this is less likely for the older, ≥16 year-old individuals for whom sex estimation appears much more accurate (i.e., 89.5%). Thus, sex-based data for the latter pubertal stages are likely reliable. Sex-dependent differences have also been found in many previous osteoarchaeological studies (Arthur et al., 2016; Doe et al., 2019; Henderson & Padez, 2017; Shapland & Lewis, 2013). Girls preceding boys in their development is congruent with historical and modern biological knowledge. Currently, no standard average ranges for the sexes are available (as they are for some aging methods, for example: Brooks & Suchey, 1990), and comparisons between different sites has occurred largely based on sex-combined ages (e.g., Doe et al., 2019). Possibly, future research can focus on developing such standards based on the accumulating amount of developmental data for different collections.

Several other causes for variable development can be recognized. Modern biomedical research has shown that many factors interplay with pubertal development, including genetic predisposition, epigenetics, idiosyncratic differences, psychology, physiology, and health and disease (Hochberg & Belsky, 2013; Louis et al., 2008; Sypek, Benson, Spanner, & Williams, 2016). This could explain why the correlation between health and development does not appear to be stronger when gleaned from osteological analyses. Moreover, there is a lack of knowledge about male development, with existing studies focusing mostly on non-European populations (e.g., Lee, Pabayo, & Kawachi, 2016; Song, Ma, Wang, Lau, & Agardh, 2015) or overweight children (e.g., De Leonibus et al., 2013). Additionally, biological and medical literature has shown that puberty, especially in girls, can be expedited due to psychological stress, and to a lesser extent due to physical stress (Hochberg & Belsky, 2013; Louis et al., 2008; Proos & Gustafsson, 2012). If puberty can be both delayed and expedited due to physiological stress, caution must be taken when interpreting the results (Hochberg & Belsky, 2013; Louis et al., 2008; Proos & Gustafsson, 2012).

5.5 | Effect of disease/non-specific stress

Table 7 shows that the effect of disease, non-specific stress, and hard physical labor on pubertal timing is largest in the latter three stages of development. There does not appear to be a clear link between early, normal, or delayed development and any specific pathological condition, but rather, common among all individuals. However, the high number of pathologically "affected" individuals *and* high number of seemingly "unaffected" individuals with an age that falls more than 3 years beyond the "expected range," suggests that the extent of delay is not strongly linked to pathological lesions visible in the skeleton, possibly reflecting hidden heterogeneity. This conclusion might be impacted by small sample size. PHV and completion were previously found to be substantially impacted by pathology (Lewis et al., 2016b, p. 8). In the current study, PHV (n = 4) contains one late developer; and completion (n = 4) three late developers. The uneven distribution of individuals among pathological conditions and the high number of "affected" individuals, make an analysis of these results difficult. However, the commonality of such conditions might indicate that (a) specific and non-specific physiological stress was prevalent in Middenbeemster; (b) hard physical labor during adolescence was common in this rural community; and/or (c) these late average ages reflect the general pattern of Middenbeemster, or the Netherlands as a whole, "normally" having stretched pubertal development. Based on historic data, the latter two appear likely.

In addition, six out of 10 "unaffected" individuals show pubertal delay and 29 out of 45 "affected" individuals do not show pubertal delay. This lack of a relationship between pathology and pubertal delay, while late pubertal completion is common and pathological conditions are frequent, might support the notion that physical stress was more common in the past than it is today. It might even be argued that pubertal developmental timing based on past peoples should not *exclude* "affected" individuals, as their late development may be "normal," or common. A pattern of stretched pubertal developmental timing could additionally hint toward signs of physical stress otherwise not recognizable; thus functioning as a non-specific sign of physiological stress. If all individuals were to be excluded prior to further analysis, such patterns might remain unnoticed. Moreover, all results should be considered within the framework of selective mortality and hidden heterogeneity and because puberty is highly sensitive to physiological stress, a difference between the living (represented in historic and modern medical records) and the dead (the archaeological sample) can be expected.

6 | CONCLUSION

The study of pubertal development in osteoarchaeological remains is important because of its potential to provide insight into key biological, cultural, and social changes. This study was the first to estimate pubertal development in a Dutch and a rural community from the post-medieval period. The results show that Middenbeemster females appear to have experienced pubertal onset at an earlier-than-average age, while its completion in males is later than expected compared to previous archaeological research from other regions, and medical data from modern-day the Netherlands. In both sexes, sexual maturation occurs late in comparison to published studies. This pattern is congruent with historic records, implying a fairly late marital and reproductive age, and thus late social "adulthood." Historic medical descriptions support the idea that hard physical work or pathology in the countryside may delay pubertal onset and completion. Reconstructing past pubertal development and its deviations from normality, at an individual and population level, improves our understanding of an important yet understudied phase of life that yields information about key biological and cultural phenomena.

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AUTHOR CONTRIBUTIONS

Alette Blom: Conceptualization; data curation; formal analysis; investigation; methodology; project administration; resources; visualization; writing-original draft. **Rachel Schats:** Conceptualization; resources; supervision; validation; visualization; writing-original draft; writing-review and editing. **Menno Hoogland:** Data curation; resources. **Andrea Waters-Rist:** Conceptualization; data curation; resources; supervision; validation; visualization; writing-original draft; writing-review and editing.

CONFLICT OF INTEREST

The authors of this publication declare that there is no financial or non-financial conflict of interest.

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ENDNOTE

[1] One Chi-square assumption was violated: two of the cells had an expected count of less than five individuals. The data do not lend themselves to a Fisher test because they are not presentable in a 2 by 2 table.

DATA AVAILABILITY STATEMENT

Data availability statement: The data that support the findings of this study cannot be made available Open Access due to privacy or ethical restrictions: the archives contain personal data from individuals with living relatives. The data can be made available on request to the Laboratory for Human Osteoarchaeology, Leiden University, The Netherlands.

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of this article.

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