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The Effects of Urban Living on Child, Infant, and Maternal Health: A Comparative Study of Linear Enamel Hypoplasia Between Two Dutch Postmedieval Populations

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ABSTRACT

Substantial research has been done assessing health inequalities between rural and urban contexts in the low countries; however, fewer studies have considered the effect of urban living on non-adults. Because dental enamel does not remodel, recording the time of dental stress insults in both deciduous and permanent teeth allows for the analysis of episodes of stress, including those occurring during the fetal period. Thus, through the analysis of dental stress markers, we can provide information about child, infant, and maternal health inequalities between urban and rural contexts. To do this, we recorded the frequency and age at formation of linear enamel hypoplasia in both permanent and deciduous teeth of 177 individuals between 0 and 35 years of age from two Dutch postmedieval sites; 64 from the city of Arnhem (1650–1829 CE) and 113 from the rural cemetery of Middenbeemster (1623–1867 CE). Results from this research reveal that urban living during Dutch postmedieval times had a negative impact specifically on infants and their gestating mothers, as deciduous teeth from urban Arnhem presented a significantly higher frequency of LEH compared with their rural counterparts ($p = 0.009$). However, no significant difference was found on permanent teeth between sites ($p = 0.868$), showing that during the following years of life (3–6), urban life did not appear to have a greater negative impact compared with rural life.

1 | Introduction

With rapid urbanization during the late medieval and postmedieval periods, European societies experienced structural changes that deeply affected their general living conditions, including people's health. According to historical sources, in the territory now the Netherlands, cities were characterized by being densely populated with poor sanitization systems, resulting in the spread of infectious diseases, particularly felt by individuals of lower socioeconomic status (Coomans 2018; Lucassen and Willems 2011; van Poppel 2018; Wintle 2000). Through the osteoarchaeological data presented in this research, supplemented by historical sources, we offer a unique approach to how Dutch people (including infants, children, and pregnant women) experienced the early urban phenomenon in terms of health and lifestyle.

Substantial research has been done to determine health status in European postmedieval populations by comparing skeletal stress markers of individuals living in urban and rural contexts (see DeWitte and Betsinger 2020). Although many examples exist of urban living being detrimental for medieval and

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postmedieval communities (e.g., Betsinger et al. 2020; Krenz-Niedbała and Łukasik 2020; Lewis, Murphy and Wiltshire 2003; Walter and DeWitte 2017), the evidence from the Netherlands reveals a more nuanced picture that is yet to be fully understood. Specifically for Dutch medieval and postmedieval collections, some studies have shown similar health conditions for urban and rural individuals (Casna et al. 2021; Schats 2016), whereas others highlight the variability of health patterns depending on factors such as socioeconomic status, sex, or age at death (Casna et al. 2023; Morgan 2021; Orfanou 2018).

However, most of these rural–urban health inequality studies in Dutch populations have focused on adult skeletal remains, often excluding non-adults and leaving out valuable information about individuals who died during early life stages (infancy and childhood). In addition, studying health conditions of young individuals from an osteoarchaeological perspective can reveal significant understandings about the mother–infant nexus, as the first years of life, including the fetal period, are majorly influenced by maternal health (Capra et al. 2013). Thus, any sign of stress or disease in the youngest individuals (death included) could represent physiological stressful events experienced by gestating mothers (Gowland and Halcrow 2020).

Because permanent teeth form during the first years of life and do not remodel afterwards, dental stress markers have been thoroughly recorded in archaeology as an indicator of childhood stress, as any disruption remains marked permanently on the tooth's enamel. Linear enamel hypoplasia (LEH) is the most common dental stress indicator, described as a furrow-like defect visible to the naked eye, caused by disrupted enamel secretion during tooth development (Goodman and Rose 1991; Hillson 1996). LEH is associated (but not exclusive) to various stressors, such as infectious diseases, nutritional deficiencies, and breastfeeding or weaning stress (Bereczki et al. 2018; Nikiforuk and Fraser 1981). Thus, it is considered a nonspecific stress indicator (Goodman and Rose 1991; Hillson 1996). When observed in deciduous teeth, LEH can be directly linked to the prenatal period and early postnatal life, as formation times of the prenatal dentition range between 144 days before birth to 388 days after birth (Birch and Dean 2014). Therefore, the mother–infant nexus can be explored through deciduous LEH (Halcrow et al. 2020). Some examples of research conducted on this topic on postmedieval and modern European populations include those by Ogden, Pinhasi, and White (2007) and López-Lázaro (2022).

In terms of urban–rural health inequalities, several studies have analyzed LEH in permanent teeth to assess childhood developmental disruptions in medieval and postmedieval European populations (e.g., Hanson and Miller 1997, King, Humphrey, and Hillson 2005, Miszkiewicz 2015, Palubeckaitė, Jankauskas, and Boldsen 2002). Although some research has focused on analyzing childhood stress in Dutch medieval and postmedieval populations through LEH (Casna and Schrader 2024; Fernández Sánchez 2017; Schats 2016), none of them have analyzed deciduous LEH; thus, no osteological information is available on the stress experiences of infancy, childhood, and gestating motherhood during the Dutch early urban phenomenon.

Therefore, by analyzing and comparing age at formation and frequency of LEH on permanent and deciduous teeth from adult and non-adult individuals of a low status urban site (Arnhem), and a rural farming community (Middenbeemster), we assessed the impact of urban living on childhood, and the mother–infant nexus in the Netherlands during postmedieval times.

2 | Materials and Methods

For this study, 177 individuals were analyzed, 64 from an urban context, and 113 from a rural cemetery (Figure 1). The urban collection of individuals originates from the city of Arnhem (1650 to 1829 CE) while the rural collection comes from the Middenbeemster countryside (1623 to 1867 CE). These contexts were selected for comparison due to their similar temporalities, and their well-documented sociocultural contexts.

2.1 | Site Description and Archaeological Context

2.1.1 | Arnhem

During the 17th and 19th centuries, Arnhem experienced a major urbanization event. In the late 17th century, the city went from a small leather and beer production economy to the establishment of major industries, including textiles, footwear, and tobacco. This economical shift attracted many workers, leading to a major population expansion (Klep 2009; Roessingh 1979). Between 1795 and 1850 alone, Arnhem doubled its population going from 10,080 inhabitants in 1795, to around 20,000 during the 1850s (de Vries 1984).

In 2017, the northern side of St. Eusebius Church's cemetery was excavated as part of the renovations in the city center. The

FIGURE 1 | Map of the provinces in which Arnhem and Middenbeemster are located in the current territory of the Netherlands. [Colour figure can be viewed at wileyonlinelibrary.com]

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burials found here were associated with lower socioeconomic status, as this section was designated for people that could not afford to be buried elsewhere (Baetsen et al. 2018). Two archaeological phases were identified: the first one dating from 1350 to 1650 and the second one dating from 1650 to 1829 (Baetsen et al. 2018). The individuals from this sample come from the latter period, representing working class people from the 17th–19th centuries.

2.1.2 | Middenbeemster

Middenbeemster is a small town located in Northern Holland in the Beemster Polder, created in the beginning of the 17th century after draining the Beemster Lake (Falger, Beemsterboer-Köhne, and Kölker 2012). The inhabitants of Middenbeemster were dedicated to agricultural and livestock activities, specifically dairy farming (Liagre, Hoogland, and Schrader 2022). By 1840, the Beemster community comprised 2971 people, from middle to lower socioeconomic classes (Falger, Beemsterboer-Köhne, and Kölker 2012).

The church's 2011 renovation prompted an archaeology project to preserve the cemetery's historical and cultural value. The excavation identified two different phases: the early one dating between 1638 and 1829 and the latter one from 1829 to 1867 (van Spelde and Hoogland 2018). The individuals from this research correspond to both phases, thus representing a rural population ranging from the 17th to the 19th centuries.

2.2 | Sample

The individuals from this sample correspond to different age-at-death groups, ranging from infants to late young adults according to the categories established by Buikstra and Ubelaker (1994) (see Table 1). The individuals were selected based on the near-completion of crown development in deciduous and/or permanent teeth so that the total number of lesions on each tooth were visible (Hassett 2014). Individuals who died as fetuses and perinates were not considered for this research, because at these stages, deciduous crowns are not fully developed (Birch and Dean 2014). Middle and old adults (35+ year olds) were excluded from this study due to high degrees of dental wear and dental caries in these collections that affected the visibility of enamel defects.

Because teeth can be lost in archaeological contexts, to avoid having individuals with contrasting number of teeth that could skew the data, dental analyses were performed based on the number of teeth rather than on an individual level. Teeth were divided into permanent and deciduous, as non-adults can have both types. A total of 3592 teeth were analyzed; 1292 from the Arnhem collection and 2300 from Middenbeemster.

2.3 | Estimation of Age at Death

For non-adults, age at death was determined using dental eruption of deciduous and permanent teeth (Moorrees, Fanning, and Hunt 1963; Ubelaker 1989), dental and root measurements (Demirjian, Goldstein, and Tanner 1973; Liversidge, Dean, and Molleson 1993), and skeletal features like epiphyseal closure and long bone length (Maresh 1955; Schaefer et al. 2009; Scheuer and Black 2000). For adults, it was estimated using morphometric features of the pubic symphysis, auricular surface, sternal rib end (Buikstra and Ubelaker 1994; Işcan, Loth, and Wright 1984), cranial suture closure (Meindl and Lovejoy 1985), and dental attrition (Maat 2001).

2.4 | Recording Frequency and Location of LEH

To examine dental defects, all permanent and deciduous teeth were sided and divided by type (lower and upper incisors, canines, premolars, and molars). The number of LEH insults was recorded in all available teeth and identified based on Goodman and Rose (1990) in the following way: teeth were gently cleaned

TABLE 1 | Sample distribution.

	Arnhem (urban)			Middenbeemster (rural)		
Age at death (years)	**No. individuals**	**No. deciduous teeth**	**No. permanent teeth**	**No. individuals**	**No. deciduous teeth**	**No. permanent teeth**
Infant (0.8–3)	19	226	0	34	413	8
Child (4–6)	5	68	12	5	49	51
Juvenile (7–12)	2	28	16	14	73	298
Adolescent (13–18)	12	0	316	6	0	148
Early young adult (18–25)	10	0	249	21	0	524
Late young adult (25–35)	16	0	377	33	0	736
Total	64	322	970	113	535	1765

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to allow for better visibility; then, the buccal (or labial) tooth surface was examined under daylight at an oblique angle using a 10× magnifying glass and LED light. Defects were identified by inspecting the surface with a toothpick or fingernail, requiring at least two-thirds of the crown to be visible to score LEH, and lesions to be present in more than one tooth per individual to discard focal lesions.

The location of enamel defects on permanent and deciduous teeth was measured using a digital sliding caliper (accuracy: 0.01 mm) to determine the distance from the cemento-enamel junction (CEJ) to the midpoint of the defect, reflecting the average time of formation (Blakey and Armelagos 1985; Goodman and Rose 1990). Due to time constraints, inter- and intra-observer errors were not recorded; however, random side-by-side observations were conducted to ensure consistency and accuracy.

Although macroscopic methods have proven to provide a lower estimation of LEH lesions compared with microscopic methods (Cares Henriquez and Oxenham 2019; Hassett 2014; Hillson 1996), when based on histological data of enamel growth rates, they remain a relevant and practical alternative, particularly for large sample sizes such as the one presented in this study (Dąbrowski et al. 2021; O'Donnell and Moes 2021).

2.5 | Establishing the Age at Formation of LEH

2.5.1 | Permanent Teeth

The chronology of LEH lesions in permanent teeth was determined following the methodology established by Reid and Dean (2000), which divides the height of each tooth into deciles, calculating the age at formation of each of these equal sections into years. Therefore, the total crown length of each tooth divided by 10 provides the distance corresponding to a specific age range. The measurement distance from the CEJ to the hypoplastic lesion is matched with the correspondent age interval to determine the age at formation of LEH. Only the northern European estimates and crown heights were used, as the individuals analyzed for this research are biologically closer to this population. Because this method only provides information about the chronological age formation of molars and anterior teeth, the premolars were excluded from this part of the analysis.

2.5.2 | Deciduous Teeth

To date, no decile chart method has been developed for macroscopic study of LEH on deciduous teeth. However, histological information on the percentage of crown completion times before and after birth are available (Birch and Dean 2014), as well as average deciduous crown heights for northern European populations (Liversidge, Dean, and Molleson 1993). With this information, we were able to calculate the prenatal and postnatal average crown heights for each tooth (see Table S2). Like in permanent teeth, the distance from the CEJ to the LEH was measured and matched to the period of formation (either prenatal or postnatal).

TABLE 2 | Frequency of LEH on permanent teeth (anterior and posterior) per site and age-at-death categories.

Permanent teeth										
	Arnhem (urban)					Middenbeemster (rural)				
Age at death (years)	Total Anterior teeth	Anterior teeth w/ LEH	Total Posterior Teeth	Posterior teeth w/ LEH	Total No. teeth w/ LEH	Total Anterior teeth	Anterior teeth w/ LEH	Total Posterior Teeth	Posterior teeth w/ LEH	Total No. teeth w/ LEH
Infant (0.8–3)	0	0 (0%)	0	0 (0%)	0 (0%)	5	3 (60%)	3	3 (100%)	6 (75%)
Child (4–6)	5	5 (100%)	7	7 (100%)	12 (100%)	17	5 (29%)	34	12 (35%)	17 (33%)
Juvenile (7–12)	9	3 (33%)	7	3 (43%)	6 (38%)	127	71 (56%)	171	59 (35%)	130 (44%)
Adolescent (13–18)	131	100 (76%)	185	62 (34%)	162 (51%)	62	43 (69%)	86	30 (35%)	73 (49%)
Early young adult (18–25)	95	84 (88%)	154	78 (51%)	162 (65%)	212	181 (85%)	312	170 (54%)	351 (67%)
Late young adult (25–35)	156	102 (65%)	221	109 (49%)	211 (56%)	300	239 (80%)	436	196 (45%)	435 (59%)
Total	396	294 (74%)	574	259 (45%)	553 (57%)	723	542 (75%)	1042	470 (45%)	1012 (57%)

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3 | Results

3.1 | Frequency of LEH on Permanent and Deciduous Teeth

The results presented here focus on the frequency of LEH on anterior and posterior teeth, organized by site and age-at-death category. For detailed data on LEH per individual or per tooth type, please refer to Tables S1, S5, and S6.

3.1.1 | Permanent Teeth

The frequency of total LEH on permanent teeth of Arnhem and Middenbeemster is equal (57% in both sites, 1012/1765 Middenbeemster, 553/970 Arnhem) and does not vary significantly (χ^2 [1, N 2735] = 0.027, p = 0.868; Table S3). These data are shown in Table 2, and can be visualized in Figure 2.

3.1.2 | Deciduous Teeth

The urban site of Arnhem presents a higher frequency of LEH in deciduous teeth (17% 54/322) compared with the rural site of Middenbeemster (11% 57/535). This difference is statistically significant (χ^2 [1, N = 857] = 6.669, p = 0.009; Table S3). These data are shown in Table 3 and can be visualized in Figure 3.

3.2 | Age at Formation of LEH

3.2.1 | Permanent Teeth

Results indicate a similar distribution of LEH age-at-insult between both sites (Table 4). Because the samples are not normally distributed according to Levene's test (f = 5.484, p = 0.027), a Mann–Whitney U test was applied showing no significant difference between both samples (z = −1.282, p = 0.201).

3.2.2 | Deciduous Teeth

Although the χ^2 test does not show a statistically significant relationship between site and age at formation of LEH (χ^2 [1, N = 1] = 2.56, p = 0.109; Table S4), the absolute frequencies show that in both locations, the majority of lesions occurred during the prenatal period (Table 5).

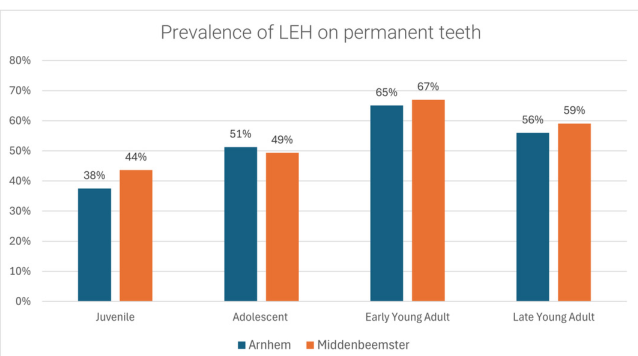

FIGURE 2 | Frequency of LEH on permanent teeth per site and age-at-death category. [Colour figure can be viewed at wileyonlinelibrary.com]

4 | Discussion

4.1 | Child Health

The data of LEH in permanent teeth show an equal frequency of lesions in Arnhem and Middenbeemster. This suggests that growing up in the Netherlands during postmedieval times represented high levels of physiological stress for children, regardless of whether they lived in the countryside or in the city. Similar results have been found in Dutch medieval populations, with equal LEH rates between rural and urban sites (Fernández Sánchez 2017; Schats 2016). Because the etiology of enamel hypoplasia is multifactorial, the sources of stress may vary depending on the environment or circumstances. Regarding infectious diseases, in urban sites, physiological stress may have been related to the spread of airborne pathogens due to conglomerate living spaces, and air pollution, as accounted by historic documents and osteological studies focused on maxillary sinusitis (Casna et al. 2021; Casna, Davies-Barrett, and Schrader 2024; Wintle 2000). Meanwhile, in rural areas, children may have predominately suffered from gastroenteric infectious diseases due to constant contact with zoonotic pathogens related to cattle and polluted water bodies (Smith et al. 2004; Wintle 2000). This shows how despite experiencing contrasting lifestyles and being exposed to different sources of stress, rural and urban individuals may still exhibit similar outcomes.

Nonetheless, similar stressors may have been present in both environments, affecting both populations. Such is the case of malnourishment and nutritional deficiencies, as LEH has also been attributed to a lack of calcium and vitamins A and D (Beckett et al. 2022; Nikiforuk and Fraser 1981; Tapalaga et al. 2023). The Arnhem sample shows skeletal signs of nutritional stress in 15 juvenile individuals, including the presence of cribra orbitalia, porotic hyperostosis, and vitamin D deficiency (Baetsen et al. 2018), whereas in rural Middenbeemster, Veselka, Hoogland, and Waters-Rist (2015) noted rickets in 13.6% of the infants and children (ages 0 to 6 years). This shows that vitamin D deficiency was not uncommon in urban and rural areas and could be a potential cause of LEH lesions in children in both sites.

Regarding the age at formation of LEH in permanent teeth, the results from this research present an equal distribution between Arnhem and Middenbeemster with a higher incidence between 2 and 3 years of age. Although some scholars have theorized elevated LEH rates during these years to be linked to post-weaning stress (Blakey, Leslie, and Reidy 1994; Goodman and Armelagos 1989; Moggi-Cecchi, Pacciani, and Pinto-Cisternas 1994), isotopic analyses have shown that in Middenbeemster infants either breastfed for brief periods of time or were not breastfed at all (Waters-Rist, de Groot, and Hoogland 2022). Because during the first years of life individuals are the most vulnerable (Gowland and Halcrow 2020), in this specific population LEH seems to be related to physiological stressors, such as infectious diseases,

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TABLE 3 | Frequency of LEH on deciduous teeth (anterior and posterior) per site and age-at-death categories.

Deciduous teeth										
	Arnhem (urban)					Middenbeemster (rural)				
Age at death (years)	Total Anterior teeth	Anterior teeth w/ LEH	Total Posterior Teeth	Posterior teeth w/ LEH	Total No. teeth w/ LEH	Total Anterior teeth	Anterior teeth w/ LEH	Total Posterior Teeth	Posterior teeth w/ LEH	Total No. teeth w/ LEH
Infant (0.8–3)	138	32 (23%)	88	13 (15%)	45 (20%)	240	25 (10%)	173	21 (12%)	46 (11%)
Child (4–6)	37	2 (5%)	31	5 (16%)	7 (10%)	27	3 (11%)	22	3 (14%)	6 (12%)
Juvenile (7–12)	16	2 (13%)	12	0 (0%)	2 (7%)	23	4 (17%)	50	1 (2%)	5 (7%)
Adolescent (13–18)	0	0 (0%)	0	0 (0%)	0 (0%)	0	0 (0%)	0	0 (0%)	0 (0%)
Early young adult (18–25)	0	0 (0%)	0	0 (0%)	0 (0%)	0	0 (0%)	0	0 (0%)	0 (0%)
Late young adult (25–35)	0	0 (0%)	0	0 (0%)	0 (0%)	0	0 (0%)	0	0 (0%)	0 (0%)
Total	191	36 (19%)	131	18 (14%)	54 (17%)	290	32 (11%)	245	25 (10%)	57 (11%)

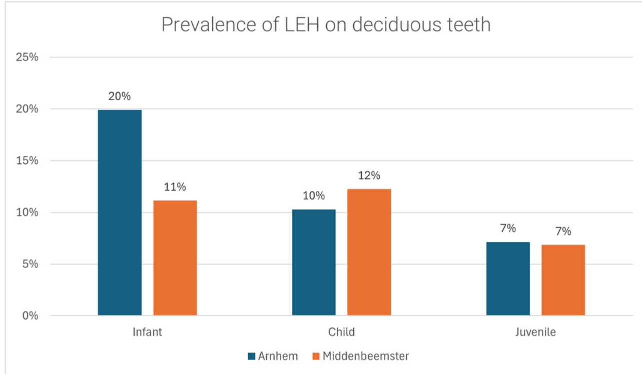

FIGURE 3 | Frequency of LEH on deciduous teeth per site and age-at-death category. [Colour figure can be viewed at wileyonlinelibrary.com]

TABLE 4 | Number of LEH lesions on permanent teeth divided by chronological age-of-insult.

	Arnhem		Middenbeemster	
Age range (years)	# LEH	Frequency	# LEH	Frequency
1.0–1.4	1	0%	0	0%
1.5–1.9	10	2%	27	3%
2.0–2.4	61	10%	125	11%
2.5–2.9	137	23%	282	26%
3.0–3.4	88	15%	170	16%
3.5–3.9	96	16%	179	16%
4.0–4.4	61	10%	89	8%
4.5–4.9	61	10%	92	8%
5.0–5.4	22	4%	65	6%
5.5–5.9	16	3%	28	3%
6.0–6.4	8	1%	2	0%
9.4–9.9	0	0%	1	0%
10.0–10.4	8	1%	17	2%
10.5–11.0	17	3%	23	2%

metabolic conditions or nutritional deficiencies, rather than to weaning stress. However, it is worth considering that these results might be influenced by the underrepresentation of LEH due to the limitations of macroscopic methods, as well as the potential higher susceptibility of mid-crown regions to develop LEH (Goodman and Armelagos 1985; Hassett 2014).

4.2 | Infant and Maternal Health

The frequency of LEH in deciduous teeth is significantly higher in Arnhem than in Middenbeemster (17% vs. 11%). The higher rates of LEH lesions appearing only in deciduous teeth (formed between 4 months in utero and 1 year of age) suggest that infants

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TABLE 5 | Number and frequency of LEH insults on deciduous teeth divided by chronological age-of-insult (during the prenatal or postnatal period).

	Arnhem (urban)		Middenbeemster (rural)	
Period of formation	**# LEH insults**	**Frequency**	**# LEH insults**	**Frequency**
Prenatal	31	57.4%	41	71.9%
Postnatal	23	42.6%	16	29.1%
Total	54	100%	57	100%

living in Dutch cities during the postmedieval period were more vulnerable to physiological stress than their rural counterparts.

Just as with permanent teeth, deciduous LEH can be related to the multiple environmental, infectious, and nutritional stressors previously discussed. However, because the primary dentition develops from early pregnancy to 1 year after birth, enamel hypoplasia in deciduous teeth can directly relate to maternal and infant stress (Lacruz et al. 2017; López-Lázaro et al. 2022; Temple 2020).

Because most lesions on deciduous teeth were produced during the prenatal period in both sites, we can attribute this to poor maternal health in rural and urban settings. According to the Developmental Origins of Health and Disease Hypothesis (DOHaD), the first 1000 days after conception are critical to an individual's health, and any disruption in development during this stage could have detrimental effects later in life (Barker 2007; Gamble and Bentley 2022). This is confirmed by the prenatal and postnatal frequencies of LEH lesions in deciduous teeth, demonstrating how early exposure to physiological stress during gestation or after birth can result in premature death (Armelagos et al. 2009).

The higher rates of LEH in deciduous teeth, specifically for Arnhem individuals who died during infancy, along with most LEH lesions linked to the intrauterine period, suggest that urban environments were tougher for infants and gestating mothers in the Dutch postmedieval period. This could be due to the different lifestyles experienced by pregnant women in urban and rural environments. According to historical sources, it was common in the cities for women working in the textile industry to work long shifts of 12 to 20 h in deplorable conditions, constantly exposed to toxic chemicals in unheated, damp, and dark mills (Wintle 2000). These poor working conditions must have repercussed in the physiological health of pregnant women from Arnhem and their offspring.

In addition, LEH development in deciduous teeth has been linked to even mild degrees of maternal vitamin D insufficiency during pregnancy (Beckett et al. 2022; Reed et al. 2017; Tapalaga et al. 2023). Because of their living and working conditions, it is highly possible that women in cities were not receiving enough sun exposure, contrary to women working in rural environments who were likely to receive sunlight in their hands and face, which would have been enough to avoid vitamin D insufficiency (Veselka et al. 2018). Other sources of vitamin D that can be found in animal foodstuffs such as salmon, herring, fish oil, beef offal, and egg yolk, all of which could have been present in the Dutch urban and rural diets (Waters-Rist and Hoogland 2018). However, the low socioeconomic status of the Arnhem women analyzed in this study could have prevented them from frequently consuming these types of foods (Wintle 2000). In sum, maternal stress due to constant exposure to infectious diseases along with mild vitamin D deficiency related to deplorable living and working conditions could be an explanation for higher rates of deciduous LEH in Arnhem infants.

4.3 | Limitations

Even though this study has shown that recording LEH in permanent and deciduous teeth can provide valuable insights into the health and lifestyles of children, infants, and pregnant mothers from rural and urban settings of the Dutch postmedieval era, certain limitations must be acknowledged.

Due to its nonspecific etiological origin, the recording of enamel hypoplasia alone cannot identify the cause of physiological stress, which may lead to similar outcomes in populations affected by different stressors, such as Arnhem and Middenbeemster. A multiproxy approach, including skeletal stress markers like cribra orbitalia and porotic hyperostosis, can better identify causes of physiological stress, such as nutritional deficiencies (Betsinger et al. 2020). However, these conditions are difficult to observe in non-adults due to high levels of diagenetic damage from bone porosity, whereas teeth are usually well-preserved (Manifold 2015). Dental markers, unlike other skeletal stress markers, offer insights into early life stages in both adults and non-adults. Due to time restraints other dental pathologies such as periodontal disease, dental caries and antemortem tooth loss were not recorded; however, we acknowledge that studying these pathologies would provide further insight into the possible causes of physiological stress in these populations, and we recommend their inclusion in future research. We observed several caries on the buccal surface of deciduous teeth that may be associated to LEH lesions (Cook and Buikstra 1979; Halcrow et al. 2013); thus, we recommend future research to analyze both the presence and location of caries when assessing LEH.

Another limitation of this research is encompassed by the osteological paradox. Because stress markers in bones and teeth take longer to develop than those in soft tissues, these markers could be signs of resiliency, rather than frailty, as individuals with visible skeletal manifestations of stress were able to survive these episodes for longer periods of time, compared with those who might have died before developing them

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(Buikstra and DeWitte 2019; Wood et al. 1992). DeWitte and Stojanowski (2015) recommend looking into age-categorical data to deeper understand skeletal patterns in terms of resiliency and survivorship. Although for permanent teeth, our data show higher frequencies of LEH in older individuals compared with younger ones, our sample size was significantly reduced when divided by age-at-death categories, particularly for non-adults, which hindered our ability to interpret the data in such way.

Because macroscopic methods have proven to underscore lesions on the occlusal part of the tooth, this could result in an underrepresentation of lesions occurring earlier in life for both Arnhem and Middenbeemster (Hassett 2014; Hillson 2014). Moreover, although in this research we compared biologically similar populations, we acknowledge that inter- and intra-population variability such as genetic and environmental tendencies to develop LEH could be factors influencing the results and should be further investigated (Lawrence et al. 2021).

5 | Conclusion

Through osteoarchaeological data, this research provides unique insights into how the transition to urban life affected people's health in Dutch postmedieval society, particularly children, infants, and gestating women. Notably, we found significantly higher frequencies of deciduous LEH in urban individuals, as well as high frequencies of LEH formed in utero, demonstrating that for infants and gestating mothers, urban living had detrimental effects.

However, for children (3–6 years old), urban life did not appear to have a greater negative impact compared with rural life because the frequency and age at formation of LEH on permanent teeth have shown that non-adults living in urban environments were equally stressed than non-adults growing up in rural settings. This confirms the complexity of interpreting LEH data, as manifestations of skeletal stress can be strikingly similar between urban and rural populations, which can be explained by shared stressors affecting both environments and potentially different stressors leading to the same skeletal outcomes. This research marks the first comprehensive investigation into the maternal–infant nexus in the Netherlands during postmedieval times.

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Ethics Statement

During this project, the guidelines suggested in the "Codes of Ethics and Practice (2019)" from the British Association for Biological Anthropology and Osteoarcheology were followed. No destructive analyses were made, and photographic material was kept to a minimum.

Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

The data that support the findings of this study are available from the corresponding author (O.C.) upon reasonable request.

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