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Early childhood diets in medieval and Post-Medieval Pälkäne, Finland: Insights from stable isotope analysis

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ABSTRACT

Early childhood nutrition is crucial for long-term health, yet little is known about breastfeeding and weaning practices in medieval and post-medieval Finland. This study investigates early childhood dietary histories of six individuals buried at St. Michael's Church in Pälkäne (13th–19th centuries CE) using stable isotope ($\delta^{13}C$ and $\delta^{15}N$) analyses of dentin collagen from first permanent molars. These isotopic profiles reveal that all individuals were initially breastfed, but the duration and nature of weaning practices varied. Three medieval individuals (13th century) exhibited prolonged breastfeeding periods of approximately two years or more, consistent with broader European medieval norms. In contrast, two post-medieval children (late 18th–early 19th centuries) were weaned significantly earlier, around their first birthday, possibly reflecting social and economic shifts in dietary practices. Evidence of stress markers, such as enamel hypoplasia and isotopic shifts, suggests that weaning-related malnutrition or disease influenced some individuals' health and survival. Notably, differences in $\delta^{15}N$ values point to variations in weaning foods compared to average post-weaning diets, with one medieval individual's profile suggesting the possible inclusion of C_4 plants, possibly Chenopodium album, in the weaning diet.

1. Introduction

Early childhood nutrition lays the foundation for health in later life. In Medieval and Post-Medieval Finland (c. 13th–19th centuries CE), society was predominantly agrarian, with communities relying on farming and fishing (e.g., Taavitsainen 2005; Lahtinen 2017; Lahtinen & Salmi 2018; Maaranen 2002: 104–105; Lõugas & Bläuer, 2020). Family units were often closely knit, and breastfeeding was likely a natural part of infant care, as breast milk provides essential nutrition and immune protection during an infant's early months. However, little is known about early childhood dietary practices, including the prevalence and duration of breastfeeding or the nature of weaning foods and customs, as there are no written sources that would provide detailed accounts of these practices. Consequently, archaeological research and stable isotope analyses are crucial for investigating this topic (see Väre et al. 2023; Väre et al 2022a; Väre et al. 2022b).

Early childhood diets in the past can be studied using the stable isotope ratios of carbon ($\delta^{13}C$) and nitrogen ($\delta^{15}N$) in tissues formed during that period. Over the past decade, numerous studies have explored this topic among various archaeological populations (e.g., Eerkens et al. 2011; Beaumont & Montgomery 2016; Laffranchi et al. 2018; Lee et al. 2020; Drtikolová Kaupová et al. 2024). Determining whether early life began with breast milk consumption, as is typical for mammalian species, relies on observing the trophic enrichment of heavier isotopes in the tissues of consumers, i.e., breastfed infants. Breastfeeding practices, however, are shaped by multiple factors, including a woman's milk production, cultural preferences, habits, and even societal recommendations.

In exclusively breastfed infants, $\delta^{15}N$ values are elevated by approximately 2–3 ‰ and $\delta^{13}C$ values by around 1 ‰ compared to the nursing woman (Fogel et al. 1989; Fuller et al. 2006). During weaning, as the proportion of breast milk in the diet decreases, the fraction of heavier isotopes in the developing dentin also diminishes. Once breastfeeding ceases entirely, the δ-values reach the approximate level measured in the tissues of the nursing woman, assuming the weaned child consumes an isotopically similar diet (e.g., Fogel et al. 1989;

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Fig. 1. Location of Pälkäne, and the ruin of St Michael's church.

Eerkens et al. 2011; Beaumont et al. 2013).

The isotope composition of collagen of inert dentin primarily reflects the protein component of nutrition, revealing the (healthy) individual's trophic position during dentin formation. It can also offer information about the individual's physiological condition (Ambrose & Norr 1993; Fernandes et al. 2012), as changes in δ-values may indicate shifts in condition. For example, starvation leads to an enrichment of ^{15}N atoms in developing tissues due to the recycling of amino acid nitrogen. Similarly, the utilization of stored lipids, which are low in ^{13}C, may result in a depletion of δ^{13}C values, although this effect is not consistently observed (e.g., Neuberger et al. 2013; Mekota et al. 2006; 2009; Doi et al. 2017).

The development of first permanent molars (M1) begins around the time of birth, with dentin growth proceeding from the dentinoenamel junction towards the root. The crown forms over the first three years of life, while root apex typically completes development by around nine years of age (AlQahtani et al. 2010). Changes in the proportion of dietary protein can be traced by analyzing the dentin in successive, transversally cut segments. These anatomical landmarks provide reference points for estimating the approximate developmental period of each segment. Due to the pattern of dentin growth, the temporal resolution is higher in segments cut from the earliest-forming parts of the crown—specifically, the cusps and the dentin immediately beneath the dentinoenamel junction. whereas growth in the root segments increasingly overlaps, leading to a rolling average of values (Eerkens et al. 2011; Beaumont and Montgomery 2016; Beaumont et al. 2018).

This article reconstructs the early childhood (life)histories of three medieval (13th century CE) and three post-medieval (17th–19th century CE) individuals buried at St Michael's Church in Pälkäne, Finland (Fig. 1), providing insights into their nutrition and physical state. In autumn 2022, 17 graves were excavated from the site. Six of the individuals had relatively well-preserved first molars that were suitable for studying historic breastfeeding practices. These individuals represent different periods and had different ages at death, suggesting that isotopic analyses may reveal varied childhood conditions. For those who died during childhood, some isotope values may indicate adverse conditions, such as malnutrition or disease, rather than diet alone.

Table 1
The individuals in this study.

Grave	Osteological sex determination (Kuha 2023)	Age estimation (Kuha 2023)	Dating (Moilanen 2023)	Additional information
H2	n/a	Adult	Late 13th century	Linear enamel hypoplasia
H6	Female	Young adult	Mid-13th century	
H9	Female	Adult	Early 13th century	
*H*11	Female	Adult	17th century	
H15	n/a	Child 2–3 years	Early 19th century	Possibly low socioeconomic class
H16	n/a	Child 9–12 years	Late 18th century	Possibly low socioeconomic class

2. Materials and methods

2.1. Graves at St. Michael's Church, Pälkäne

The six studied individuals, along with their osteological age and sex, and the dating of their graves, are presented in Table 1. All individuals were found at the site currently known as the St Michael's Church (Rauniokirkko). The now-abandoned and ruined church was constructed between 1495 and 1505, though a church or chapel existed at the site as early as the 14th century (Hiekkanen 2007: 319–321, 2020: 408). The site was used as a cemetery even earlier, with the oldest graves radiocarbon dated to the 13th century (Mikkola & Vuoristo 2004: 5–6; Moilanen 2023: 63, 69). Christianity became firmly established in the region during the 13th and 14th centuries with the founding of the first parishes (Hiekkanen 2020: 408). The medieval graves included in this study (H2, H6, and H9) likely represent members of the general, early Christian rural population. This population primarily consisted of free farmers, as Finland did not experience feudalism or the highly stratified class systems typical of Central Europe or the Baltic countries.

The Reformation in the 16th century brought significant changes to Finland's religious, social, and cultural landscape. The growth of towns and the expansion of trade networks further contributed to increasing

Table 2
Results of the $\delta^{13}C$ and $\delta^{15}N$ analyses of the M1 segments of archaeological individuals excavated from Pälkäne. The estimates of developmental periods for each 1 mm segment were calculated based on the distances between dentinoenamel and cementoenamel junctions and apex. For H15, who was a child, the age-estimates were modified after Eerkens et al. (2011) as the tooth was not fully developed.

Grave	Estimated crown height	Estimated length	Mid-point of the age of formation in years	$\delta^{13}C$ (VPDB)	$\delta^{15}N$ (AIR)	Additional information
H9	5,3 mm	21 mm	0,5*	−20,8	15,2	Dietary information: 0,3–4,7 yrs
			0,8	−21,1	14,2	
			1,4	−21,3	13,1	
			2,0	−21,7	11,9	
			2,5	−22,1	11,1	
			3,1	−22,3	11	
			3,4	−22,3	11,3	
			3,8	−22,2	10,7	
			4,1	−22,3	11	
			4,5	−22,4	11	
H6	4,7 mm	16,5 mm	0,5*	−20,9	13,3	Dietary information: 0,3–5,6 yrs
			1,0	−21,1	12	
			1,6	−21,2	10,6	
			2,2	−21,6	9,5	
			2,9	−21,9	9	
			3,4	−22	8,6	
			3,9	−21,9	8,7	
			4,4	−21,8	8,4	
			4,9	−21,5	8,2	
			5,4	−22,4	8,1	
H2	4,1 mm	18,5 mm	**			Linear enamel hypoplasia Dietary information: 0,7–5,4 yrs
			1,1	−21,4	11,9	
			1,8	−21,3	9,7	
			2,6	−21,3	9,1	
			3,1	−21,2	9,2	
			3,5	−21,5	9	
			3,9	−21,6	7,5	
			4,3	−21,7	7,8	
			4,7	−21,6	7,7	
			5,2			
*H*11	4,5 mm	16,5 mm	0,5*	−20	12,3	Dietary information: 0,3–5,8 yrs
			1,0	−20,4	11,1	
			1,7	−20,8	9,9	
			2,3	−20,6	9,6	
			3,0	−20,3	9,2	
			3,5	−20,3	9,3	
			4,0	−20,1	9,3	
			4,5	−20,1	9,4	
			5,0	−20,2	9,5	
			5,5	−20,2	10,3	
H16	5,0 mm	18,5 mm (no apical closure)	0,3	−20,3	11,2	Possibly low socio-economic class Dietary information: birth − 5,2 yrs
			0,9	−20,3	10,2	
			1,5	−20,4	9,6	
			2,1	−20,7	9,9	
			2,7	−21,2	10	
			3,2	−21	10	
			3,7	−21	9,4	
			4,1	−20,8	9,2	
			4,6	−20,8	9,1	
			5,0	−20,6	9	
H15	n/a	n/a	0,3	−19,4	14,6	Possibly low socioeconomic class Dietary information: birth − 2,3 yrs
			0,8	−20,1	13	
			1,4	−20,5	11	
			2,0	−20,5	11,6	

social stratification, even within rural communities. Social status became a determining factor in grave placement, and individuals of higher socioeconomic standing were typically buried either inside the church or on its south side (e.g., Paavola 1998: 36). In contrast, burials on the church's northern side were often associated with individuals from lower socioeconomic groups (Rimpiläinen, 1971: 72). Thus, the two chronologically youngest burials in this study (H15 and H16) are likely to represent members of the lower socioeconomic class.

2.2. Sample preparation and stable isotope analysis

The first permanent molars of six individuals from Pälkäne were sufficiently preserved for the early childhood dietary analysis using the 1 mm sectioning method introduced by Beaumont et al. (2013). Two of these individuals had died during childhood, while the remaining four had reached adulthood (Table 1). In the adult individuals, both the occlusal enamel and underlying dentin were significantly worn (Table 2), resulting in the loss of information about their nutrition during the earliest months of life. Additionally, incomplete root preservation further reduced the accuracy of estimating developmental timing based on anatomical landmarks. Dental wear may have led to the formation of tertiary dentin while secondary dentin, which forms around the pulp chamber as an individual ages, also complicates the analysis of early childhood diets (Arana-Chavez & Massa, 2004; Smith et al., 2012; Meinl et al., 2007). This later-formed tissue reflects the diet at the time of its formation, potentially obscuring earlier dietary signals.

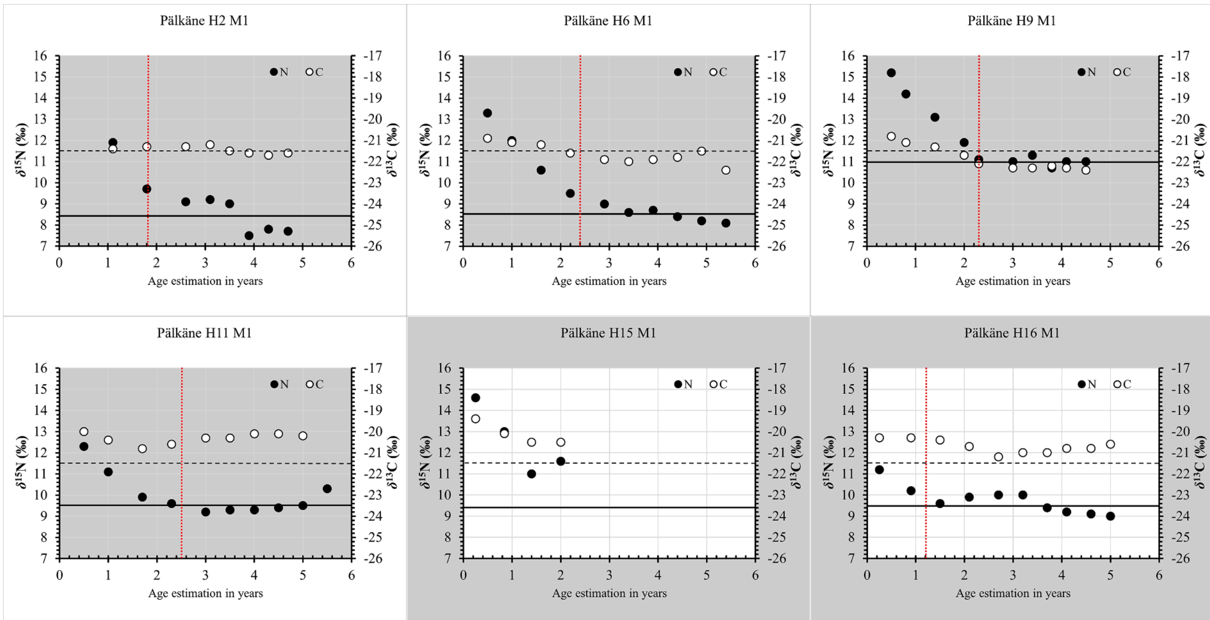

Fig. 2. The early childhood dietary profiles of six individuals from Pälkäne. The mean δ^{13}C (−21.5 ‰) from the last two dentin samples of the adults in this study and the mean post-weaning δ^{15}N values by the WEAN tool are presented as solid (δ^{15}N) and dashed (δ^{13}C) lines, respectively. The weaning age estimates by WEAN tool have been indicated in red dash lines. Individuals surviving into adulthood are coloured white, and individuals who died in childhood (H15, H16) gray.

The discoloured dentin was carefully removed during sample preparation to avoid inclusion of degraded collagen in samples (cr. Czermak et al. 2019).

Although establishing a precise developmental timeline may not be possible, the sequence of dietary changes can still be examined. Thus, to assess early childhood diets, profiles illustrating the development of both δ values were created. Weaning ages (i.e., the cessation of breastfeeding) were estimated by identifying the point at which δ^{15}N values plateaued and approached the average post-weaning δ^{15}N level, indicating a dietary shift to foods more consistent with those consumed by the rest of the family. The behaviour of δ^{13}C values was also visually examined to support this assessment. Additionally, the recently developed WEAN tool (Ganiatsou et al. 2023), which estimates weaning ages based on δ^{15}N values in dentin collagen, was employed to refine and validate the visual examination. The tool can also be used to estimate the largest isotopic offset, helping to determine whether the difference between the first and later values is more likely attributed to breastfeeding or influenced by factors such as physiological stress (cf. King et al. 2018; Craig-Atkins et al. 2018).

Following the protocol outlined by Beaumont et al. (2013), the mechanically brushed first molars (M1s) were vertically bisected using a diamond wheel cutter and ultrasonicated in ultrapure water. Loose enamel was carefully removed from the tooth halves, which were then submerged in 0.5 M HCl at room temperature for up to a week and subsequently rinsed with ultrapure water. The demineralized tooth halves were sliced into parallel horizontal segments of 1 mm. Our isotope analysis was limited to the first ten segments, as the temporal resolution of the root segments becomes increasingly blurred (Tsutaya 2020). As can be inferred from the timeline of tooth developmental stages (AlQahtani et al. 2010), ten millimeters capture dietary information for the individuals from Pälkäne up to approximately 5 to 6 years of age, depending on tooth length. These segments were surged in pH 3 (0.001 M) HCl solution in individual microcentrifuge tubes and gelatinized at 70 °C for 24 h. After this, the samples were centrifuged, frozen, and lyophilized. Dry collagen (0.800–1.000 mg) was then weighed into tin capsules. Dentin collagen samples were analyzed in duplicate whenever possible to ensure data reliability.

The analyses were conducted at the Nuclear Research Department, Center for Physical Sciences and Technology, Vilnius, Lithuania, using a Flash EA 1112 series Elemental analyzer connected to a Delta V Advantage Isotope Ratio Mass Spectrometer (IRMS) via a ConFlo III interface (Thermo, Bremen, Germany). The Elemental analyzer consists of oxidation and reduction furnaces, a chromatographic column (PoraPlot Q), a water absorption column, and a TCD detector. Stable carbon and nitrogen isotopic compositions were determined using a Thermo Delta V continuous flow isotope ratio mass spectrometer coupled to a Thermo FlashEA1112 elemental analyzer. Stable carbon and nitrogen isotopic compositions were calibrated relative to the VPDB and AIR scales using USGS24 and IAEA-600. Precision (u(Rw)) was determined to be ± 0.24 ‰ for δ^{13}C and ± 0.34 ‰ δ^{15}N on the basis of repeated measurements of calibration standards and sample replicates. Accuracy or systematic error (u(bias)) was determined to be ± 0.12 for both δ^{13}C and δ^{15}N on the basis of the difference between the observed and known δ values of the check standards. The total analytical uncertainty was estimated to be ± 0.26 ‰ for δ^{13}C and ± 0.36 for δ^{15}N.

3. Results

A total of 93 dentin collagen samples from the first permanent molars of 6 individuals were analyzed for δ^{13}C and δ^{15}N values. Of these, 91 samples met the following collagen quality control criteria and were included in the analysis: atomic C:N ratios between 3.2 and 3.3 (cf. DeNiro 1985), C% between 34.0–43.6 % and N% between 12.0–15.4 % (cf. Ambrose 1990; van Klinken 1999). These quality indicators are detailed in the Supplementary Material. Caffeine IAEA-600 (δ^{15}N=+1‰; δ^{13}C = -27.77 ‰) and Graphite USGS24 (δ^{13}C = -16.05 ‰) were used as secondary reference materials; the analytical precision was 0.1 ‰ for δ^{13}C and 0.15 ‰ for the δ^{15}N.

The δ^{13}C values ranged from –22.4 ‰ to −19.4 ‰ (mean −21.1 ± 0.7 ‰) and the δ^{15}N values from 7.5 ‰ to 15.2 ‰ (mean 10.2 ± 1.7 ‰). The δ^{13}C values for the first segments that are primarily influenced by breastfeeding ranged from −20.49 ‰ to −19.4 ‰ (n = 5, mean −20.3 ± 0.6 ‰) and the δ^{15}N values from 11.2 ‰ to 15.2 ‰ (n = 5, mean 13.3 ± 1.6 ‰). In contrast, the values from the last two segments, which reflect the diet between approximate ages of four and six, were notably lower: –22.4 ‰ and −20.1 ‰ (mean −21.1 ± 0.8 ‰) for δ^{13}C and 7.7 ‰ –22.4

Table 3
Interpretation of the results.

Grave	Most likely weaning age based on visual observation	Most likely weaning age based on WEAN (Ganiatsou et al. 2023)	Interpretation
H9 (early 13th century)	Information about the individual's diet during the first couple of months of life is missing due to dental wear; this has been noted in the age estimations (Table 2). The δ^{15}N value in the first segment shows a + 5.8 ‰ elevation compared to the mean post-weaning diet, indicating an initial period of exclusive breastfeeding. In the second segment, the δ^{15}N values begin to decline, suggesting that the weaning process likely started a little after six months of age. Weaning may have continued until after the individual's second birthday, as the δ^{15}N values stabilize only in the fifth segment.	The most likely weaning age, estimated at 2.3 years, aligns well with a visual interpretation of the dietary profile. The covarying δ^{13}C values further support this interpretation.	The offset of 4.2 ‰ between the values of the first and sixth segments (according to WEAN tool, the estimated δ^{15}N value difference is 3.6 ‰), exceeds the typical elevation caused by breastfeeding (e.g., Fuller et al. 2006). The mother's diet could have been richer in δ^{15}N than the average post-weaning food, and after infancy, this individual's diet also appears to have been relatively protein-rich compared to the other individuals in the study (mean post-weaning δ^{15}N value from WEAN: 11.0 ‰ vs. the average of 9.4 ‰).. However, significantly higher elevations in the first M1 dentin samples of breastfed individuals, beyond what is typically expected, could also result from a combined influence of physiological stress and breastfeeding (King et al. 2018; Craig-Atkins et al. 2018).
H6 (mid-13th century)	Information about the individual's diet during the first couple of months of life is missing due to dental wear. The δ^{15}N value in the first segment is + 4.8 ‰ higher than the individual's mean post-weaning δ^{15}N value, indicating that exclusive breastfeeding was still ongoing around the six-month mark when the segment formed, and weaning beginning slightly later. The δ^{15}N values stabilize at the sixth segment. This suggests that breastfeeding likely continued beyond the second birthday.	The most likely weaning age is 2.4 years. While the changes in δ^{13}C values are subtle, their simultaneous decline with the δ^{15}N values supports the interpretation that these patterns reflect breastfeeding followed by weaning.	The weaning process for this individual appears to have been gradual. The notable difference of 4.7 ‰ (or estimated δ^{15}N value difference of 4.0 ‰ with WEAN) between the δ^{15}N value in the first and the sixth segments suggests that the weaning foods contained fewer ^{15}N atoms than the mother's diet during breastfeeding. However, the possible effect of nutritional stress implied by the larger than usual isotopic offset could also be considered (King et al. 2018; Craig-Atkins et al. 2018). After the breastfeeding period, the individual's diet appears to have been predominantly plant-based.
H2 (late 13th century)	The δ^{15}N values for the first segment are unavailable, but the second segment shows a significant increase in δ^{15}N value, suggesting an initial period of exclusive breastfeeding, though its duration cannot be determined. The δ^{15}N values continue to decline until stabilizing after the individual's second birthday, indicating a weaning process that likely lasted until the end of the second year. However, the proportion of breast milk in the diet likely began to decrease months earlier.	The WEAN tool suggests a weaning age of 1.8 years; however, caution should be applied in interpreting the results when the earliest values are missing. Nevertheless, as the derivative for this individual was negative, we are inclined to trust the analysis.	The δ^{13}C values remain stable throughout most of the observation period, even slightly increasing over time. This is not necessarily unusual (Craig-Atkins et al. 2018). As suggested by Dupras et al. (2001), such a pattern may result from the inclusion of weaning foods with higher ^{13}C values, such as C_4-plants, compared to the nursing woman's diet. Millet, a common C_4-plant in the Baltic region during the late medieval period, has not been documented in Finland in the 13th century (Grabowski 2011; Pollmann 2014; Etu-Sihvola et al. 2022). However, plants in the Chenopodiaceae family, which include several C_4-plants (Pyankov et al. 2010) and some C_3– C_4 intermediate types (Yorimitsu et al. 2019), may offer an explanation. For example, *Chenopodium album* is commonly found in Finland in Late Iron Age and Early Medieval contexts and is known to have been used as a flour additive/ supplement (Lempiäinen-Avci, 2022: 290–291). This individual's teeth also exhibit enamel hypoplasia (Kuha 2023), which can indicate nutritional or physiological stress during early childhood (see King et al. 2005; White et al. 2012: 455). Based on the location of the transverse lines, such stress may have occurred between the ages of 2 and 4 years (Dąbrowski et al., 2021), potentially linking it to weaning-related challenges. Additionally, a pronounced decline in the δ^{15}N values during this period may reflect a dietary shift toward more plant-based nutrition.
*H*11 (17th century)	Information about the individual's diet during the first couple of months of life is missing due to dental wear. The initially elevated δ^{15}N value implies that exclusive breastfeeding was ongoing when the dentin in the first segment formed, around six months of age. The δ^{15}N values stabilize and reach the post-weaning level by the fourth or fifth segment, indicating that breastfeeding likely continued until at least the child's second birthday, possibly even longer. However, the proportion of breast milk in the diet may have started to decrease significantly soon after the first year.	A relatively late weaning age of 2.5 years	The δ^{15}N value difference is 3.1 ‰ between the first and fifth segments but the expected difference of 2.9 ‰ by WEAN points toward breastfeeding as the cause of the δ^{15}N value elevation during early months. The gradual decline in δ^{13}C values is consistent with breast milk consumption during infancy, with a noticeable shift occurring around the time of presumed weaning.
H16 (Late 18th century)	The δ^{15}N values decline from + 1.7 ‰ above the mean post-weaning level in the first segment and reach the level in the third. This suggests that this individual was breastfed – possibly exclusively –	A weaning age as early as 1.15 years	This individual died in mid-childhood (Table 1). Although it is unclear whether the relatively short breastfeeding period directly contributed to their early death, it may have influenced their long-term

(*continued on next page*)

Table 3 (*continued*)

Grave	Most likely weaning age based on visual observation	Most likely weaning age based on WEAN (Ganiatsou et al. 2023)	Interpretation
	during their first months of life. Weaning likely began early and cessation of breastfeeding occurred soon after their first birthday.		health and susceptibility to illness. The isotopic profile also shows a pattern around 2 to 3 years of age that may indicate a period of malnutrition. This is reflected in the enrichment of ^{15}N and depletion of ^{13}N atoms in developing tissues, likely caused by the recycling of amino acid nitrogen and the utilization of stored lipids during metabolic stress (see e.g., Neuberger et al. 2013; Mekota et al. 2006; 2009).
H15 (Early 19th century)	This individual, who died during their early childhood (Table 1), likely experienced an initial period of exclusive breastfeeding during the formation of the first segment, corresponding to approximately the first six months of life. A decline of 3.5 ‰ in $\delta^{15}N$ values from the first to the third segment, where the lowest value is observed, suggests that breastfeeding ceased or was significantly reduced shortly after the first birthday.	The analysis with the WEAN tool was impossible for this individual.	The $\delta^{15}N$ values rise again in the fourth segment, which formed shortly before the individual's death. As with the higher than 3 ‰ $\delta^{15}N$ value offset between the first and the third segment, this re-elevation may reflect increased systemic stress in the months leading up to death. Elevated $\delta^{15}N$ values in incremental tissues are often linked to physiological stress (Neuberger et al. 2013). Alternatively, the increase might indicate that breast milk consumption was resumed to support recovery from a chronic condition (cf. Wood et al. 1992). Historically, breast milk was sometimes considered medicinal, even for adults (Wickes 1953; Olai 2008 [1578]: 29, 69). On the other hand, according to folklore, the death of a fully breastfed child was believed to pose a danger to the mother, which may have led to weak or sickly children being given water in addition to, or instead of, breast milk (Paulaharju 1924: 40).

‰ and −20.2 ‰ (mean −21.3 ± 0.9 ‰) for $\delta^{13}C$ and 7.7 ‰ and 11.0 ‰ (n = 9, mean 9.3 ± 1.2 ‰). These lower values suggest that breast milk consumption did not influence the δ-values of later stages. The average values of duplicate samples were used for analyses and are presented in Table 2.

The $\delta^{15}N$ values in the earliest-forming first segments of the M1s (n = 5) ranged from + 4.8 to + 1.7 ‰ above the individual's mean post-weaning $\delta^{15}N$ values calculated by the WEAN tool. These values reflect the later childhood diets that possibly correspond to the family diet. The extent of the offset aligns with expectations for exclusively breastfed infants and their mothers (Fogel et al. 1989; Fuller et al. 2006; Howcroft 2013; Herrscher et al. 2017). Deviations from expected values (2–3 ‰) may arise from individual physiological differences or variations in maternal or post-weaning diet. Due to the extensive dental wear affecting both enamel and dentin on occlusal surfaces, the first segment of most individuals was less than 1 mm in thickness, resulting in the loss of information about nutrition during the earliest months of life. Consequently, the values measured in the first segments primarily reflect dietary patterns during the latter part of the first six months. Dental wear has been considered in sampling and the age estimation of the samples (Table 2).

The WEAN tool provided estimated weaning ages for five of the individuals, as the derivatives calculated by the tool to assess the inclination of the values were all negative. Negative derivatives indicate a decreasing trend over time, consistent with breastfeeding, whereas positive derivatives would suggest an absence of breastfeeding (Ganiatsou et al. 2023). These estimations are presented in the discussion. As the program requires profiles with at least five values for evaluation (Ganiatsou et al. 2023), it was not possible to estimate the weaning age of individual H15 with this method.

The early childhood dietary profiles are presented in Fig. 2. The estimated midpoints of development for each sample are plotted from left to right on the horizontal axis. The developmental ages of each sample are assigned based on the average time of initiation of crown development of M1 at birth, and the developmental ages of relevant anatomical landmarks (CEJ, apex) as approximated by AlQahtani et al. (2010). This is with the exception of individual H15, whose samples were aged according to modification of the method suggested by Eerkens et al. (2011). Due to variation in tooth development between individuals, the ages are approximate, which makes the age estimates for weaning less comparable. The $\delta^{15}N$ and $\delta^{13}C$ values, which reflect the average diet during the development of each segment, are plotted on the vertical axes. The individual mean post-weaning $\delta^{15}N$ values calculated by WEAN and the average $\delta^{13}C$ values from the last two segments of adults (n = 5, −21.5 ‰) are shown as horizontal reference lines. For H15, the average of the post-weaning $\delta^{15}N$ values of other individuals is used. The weaning age estimation by WEAN is presented as a vertical line.

4. Discussion

Recent advancements in mass spectrometry and dentin sampling techniques have significantly improved the precision of estimating developmental ages for dentin micro-samples. Czermak et al. (2018, 2020) and Curtis et al. (2022) have introduced sampling methods, such as using biopsy punches and cutting along dentin growth lines, to improve the accuracy of temporal representativity of the dentin stable isotope values (cf. Cheung et al. 2022). While these approaches offer greater accuracy, they are technically complex and require specialized laboratory tools, which were unavailable for this study. Additionally, the preservation of skeletal material in Finland is often poor due to acidic soils, limiting the stable isotope analyses of older human remains. For these reasons, we used the traditional method in which the studied samples are larger.

This study aimed to observe the early childhood dietary histories of individuals who lived in medieval and post-medieval Finland. While the small sample size hinders drawing broad conclusions about past diets, these findings provide valuable insights into a little-known aspect of life in medieval Finland. Such studies are particularly challenging due to the poor preservation of unburnt bones in Finnish soil (see Moilanen, 2021: 31–32), which limits the availability of suitable material for analysis. Of the 17 excavated individuals, only six had sufficiently well-preserved first molars for inclusion in this study. Despite these limitations, the data offer a rare glimpse into early childhood nutrition during this period.

The early childhood dietary profiles indicate that all six individuals were initially breastfed, though the duration of their weaning periods varied (Table 3). After weaning, dietary protein was likely

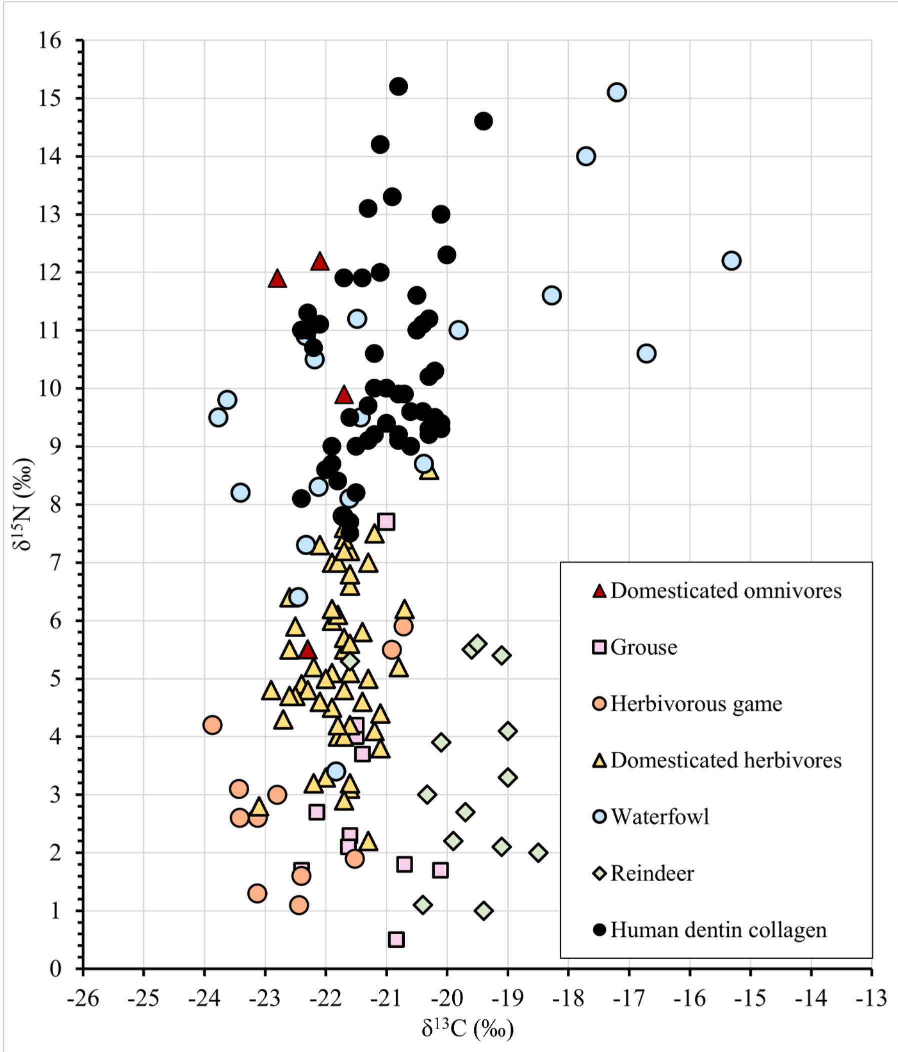

Fig. 3. The dentin serial values within the local food web, reconstructed utilising the bone collagen stable isotope values measured in Finnish archaeological (Iron Age to Post-Medieval Period) or ecological (modern) animal remains collected from the dIANA database (Bläuer et al. 2016; Etu-Sihvola et al. 2019; Lahtinen & Salmi 2019). The annual correction factors introduced by McCarroll and Loader (2004) were added to the modern δ^{13}C values to make them correspond to the pre-industrial era values.

predominantly sourced from farm animals. The relatively low values measured in the ninth and tenth segments of the studied individuals (δ^{13}C −21.3 ± 0.9 ‰; δ^{15}N 9.3 ± 1.2 ‰; Fig. 3) suggest limited reliance on aquatic species, which typically exhibit higher values due to the complexity of trophic relations in such environments (e.g. Katzenberg 1989). In particular, the δ^{15}N values are unusually low compared to contemporary archaeological samples from Finland (for example, Eura Luistari and Ii Hamina), likely reflecting differences in the dietary use of aquatic and semi-aquatic species (see Etu-Sihvola 2022; Väre et al. 2022a; Lahtinen & Salmi 2019). Each grave is presented in Table 3 chronologically, from the oldest to the youngest.

To summarise the findings presented in Table 3, all three individuals from the 13th century and one from the 17th century appear to have been breastfed for approximately two years, possibly even longer. Only H16 and H15, both of whom died in childhood, were breastfed for a shorter duration, with exclusive breastfeeding lasting six months and weaning occurring around their first birthday.

Written sources on breastfeeding practices in Finland are scarce, especially those extending beyond the past few centuries. Even in more recent centuries, breastfeeding customs varied significantly across regions and time periods. These practices were shaped not only by broader societal trends but also by individual and personal circumstances. In medieval Europe, the church actively promoted breastfeeding, and a 13th-century Norwegian law book specifically recommended it for newborns (Thorvaldsen 2008). Mothers were generally expected to breastfeed their infants, as inspired by the Virgin Mary, although members of the elite often employed wet nurses (Mocholí Martínez 2023). Breastfeeding was regarded as beneficial for both health and moral development, with the belief that it could shape a child's character (van der Lugt 2019). Stable isotope analyses on medieval individuals indicate that the duration of breastfeeding varied, with cessation commonly occurring between the third and fourth year of life (Bourbou et al. 2013; Burt 2013).

Occasionally, women may have refrained from breastfeeding due to economic pressure or cultural influences that deemed breastfeeding undesirable, leading to the adoption of artificial feeding methods (Thorvaldsen 2008). In the Early Modern Period, weaning very young infants was particularly common among the Nordic bourgeoisie. In rural areas, breastfeeding often ended early because mothers were required to work in the fields during the summer months (Turpeinen 1987). Infants from lower socio-economic classes in the coastal town of Rauma, Finland, around the turn of the 19th century were typically breastfed for approximately six months, followed by a weaning process that continued until the end of the second year of life (Väre et al. 2022b).

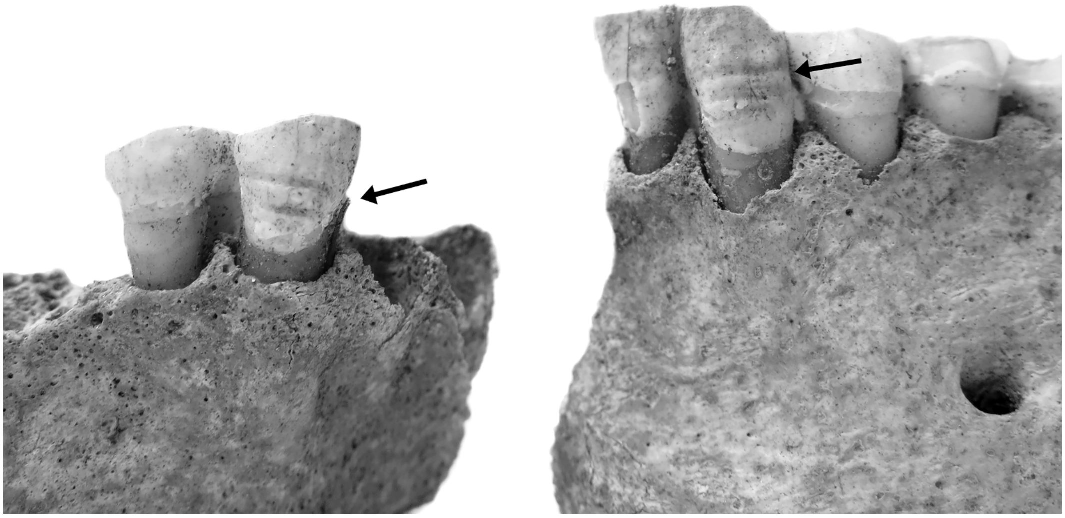

Fig. 4. Linear Enamel Hypoplasia in the lower canines of individual H2.

This breastfeeding duration is shorter than that observed in most individuals in this study, though it aligns with the profile of H2.

The introduction of artificial feeding methods contributed to a decline in breastfeeding rates despite efforts to promote its benefits. In Finland, infant mortality remained high until the late 19th century, partly due to unhygienic conditions and harmful feeding practices. Substituting breast milk with animal milk was sometimes linked to this high mortality. Babies were often fed animal milk using cow horns fitted with leather teats, which were unhygienic and prone to contamination with harmful bacteria, exposing infants to infections (Brändström 1984; Turpeinen 1987). While breastfeeding likely improved child survival rates, the relationship is not straightforward. Individual H15 was one of several 2–3-year-old children who died in Pälkäne between 1810 and 1841. Parish records from Pälkäne (NAF 1711–1908) indicate that 21.5 % of children in this age group succumbed to intestinal ailments during the period. However, whether H15 was among these cases remains uncertain, as such acute infections would hardly have left evidence in the individual's isotopic profile (Craig-Atkins 2018). The causes of infant mortality vary; for example, the study by Nenko et al. (2021) found that in historical Finland, children with a younger sibling born less than 24 months later faced a higher risk of death. Therefore, the early cessation of breastfeeding seen in H15′s profile (Fig. 2) could also be related to the birth of a younger sibling.

5. Conclusion

All six individuals were likely exclusively breastfed during infancy, though the duration of their weaning periods varied. Two individuals from the 13th century (H9, H6) and one from the 17th century (*H*11) were breastfed for approximately two years, consistent with medieval European norms. For one medieval individual (H2), the duration of exclusive breastfeeding remains uncertain due to severe dental wear that obscures data from their earliest months. However, weaning appears to have ended around the second birthday. In contrast, the two individuals who died during childhood (H15 and H16) in the late 18th and early 19th centuries had significantly shorter breastfeeding periods, likely ending around their first birthday. In the harsh conditions of the past, this relatively brief breastfeeding duration may have impacted their survival. For H16, the rapid weaning may have contributed to weakened health, while the isotopic profile of H15, who was approximately 2.5 years old at death, indicates increased systemic stress in the months preceding their death.

The isotopic values of the medieval individuals (H9, H6, H2) suggest that their weaning diets differed from their post-weaning/nursing womens' diets, although the effect of malnutrition should also be considered. For individuals H9 and H6, the protein sources in their weaning foods may have been distinct from those consumed by their mothers. In the case of H2, the weaning diet may have included ^{13}C-rich sources. Especially H2 shows evidence of nutritional or physiological stress during early childhood, as indicated by linear enamel hypoplasia (Fig. 4) observed in their canines. This stress may be linked to challenges associated with the weaning process.

Although the small sample size limits broad generalizations, the observed differences may still hold significance. With a larger dataset, it would be possible to investigate factors such as the influence of the baby's sex on the duration of breastfeeding and to identify broader temporal trends in breastfeeding practices. Our findings contribute valuable insights into past diets in Finland, where the poor preservation of skeletal material in archaeological contexts often limits the scope of biochemical analyses.

CRediT authorship contribution statement

Tiina Väre: Writing – review & editing, Writing – original draft, Visualization, Methodology, Investigation, Formal analysis. **Ulla Nordfors:** Writing – review & editing, Writing – original draft, Visualization, Project administration, Investigation, Conceptualization.

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jasrep.2025.105113.

Data availability

Data is available in the article.

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