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Breastfeeding in low-income families of the turn of the 19th-century town of Rauma, Southwestern Finland, according to stable isotope analyses of archaeological teeth

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ABSTRACT

We explore breastfeeding practices among low-income families in the late 18th to early 19th-century town of Rauma in Southwestern Finland. The breastfeeding practices in the area of the current nation of Finland (at the time belonging to first Sweden and then Russia) had been under debate. While in certain regions artificial infant feeding was common and was linked to high infant mortality, breastfeeding was also known to be practiced in certain regions of Finland. To explore this, we analyzed the $\delta^{15}N$ and $\delta^{13}C$ values in collagen of horizontally cut dentin segments of permanent first molars (M1; n = 7) collected from 19th century human skeletal remains from the deconsecrated Holy Trinity churchyard excavated in 2016. The resulting isotopic profiles were similarly patterned across the seven individuals. The emerging pattern revealed a period of exclusive breastfeeding during approximately the first six months of life, followed by weaning until the latter half of the second year. We further investigated diet during mid-childhood by comparing the stable isotope ratios in collagen of the M1 and premolar roots. This comparison suggested that the mid-childhood diets may have contained more plant-based foods than those consumed earlier in childhood.

1. Introduction

Based on population statistics from mid-18th-century Sweden it was evident that certain regions of the kingdom were afflicted by remarkably high infant mortality (Rabbe 1844; Halila 1954, 640; Brändström 1984, 46–51; Turpeinen 1987; Jutikkala 1994, 151). The state officials connected the problem to the regionally diverse infant feeding practices as the mortality rate was most devastating in areas where breastfeeding was substituted by artificial infant feeding, while the lowest rates prevailed in areas where breastfeeding was customarily practiced (Brändström 1984, 158, 186–187; Jutikkala 1994, 99; Turpeinen 1979; 1987). Particularly, in the province of Ostrobothnia in the current nation state of Finland which, until 1809, was an integral part of Sweden known as Österland (EN Eastland, later in this paper Finland), cow horns filled with animal milk were a common replacement for breastfeeding (Turpeinen 1987; Rabbe 1844). In 1809, Finland was annexed by the Russian Empire but the regional division in breastfeeding practices persisted for much longer.

One of the regions where breastfeeding had traditionally been preferred over artificial infant feeding was Southwestern Finland (Turpeinen 1987). This paper explores how infants in one of the local towns, Rauma (Fig. 1), were fed. To do so, we have analyzed the nitrogen ($\delta^{15}N$) and carbon ($\delta^{13}C$) stable isotope ratios in sections of dentin from the permanent first molars (M1) of seven archaeological individuals. All of them were estimated to have died in their young or mid-adulthood during the late 18th century and early 19th century which means that they were infants during the decades around the turn of the prior century. Additionally, their skeletal remains were excavated from the northern side of the churchyard, where the less valued and cheaper burial plots were located, which indicates that they, or their families, were of lower socioeconomic status. (Uotila & Lehto 2016, 4, 71.).

Stable isotope analysis of either human tooth dentin or bone collagen is an established method for evaluating infant feeding practices among archaeological/historical populations and has been widely used in bioarcheological studies around the world (*e.g.*, Fogel et al. 1989; Fuller et al. 2006; Eerkens et al. 2011; Lidén et al 2012; Howcroft et al., 2012;

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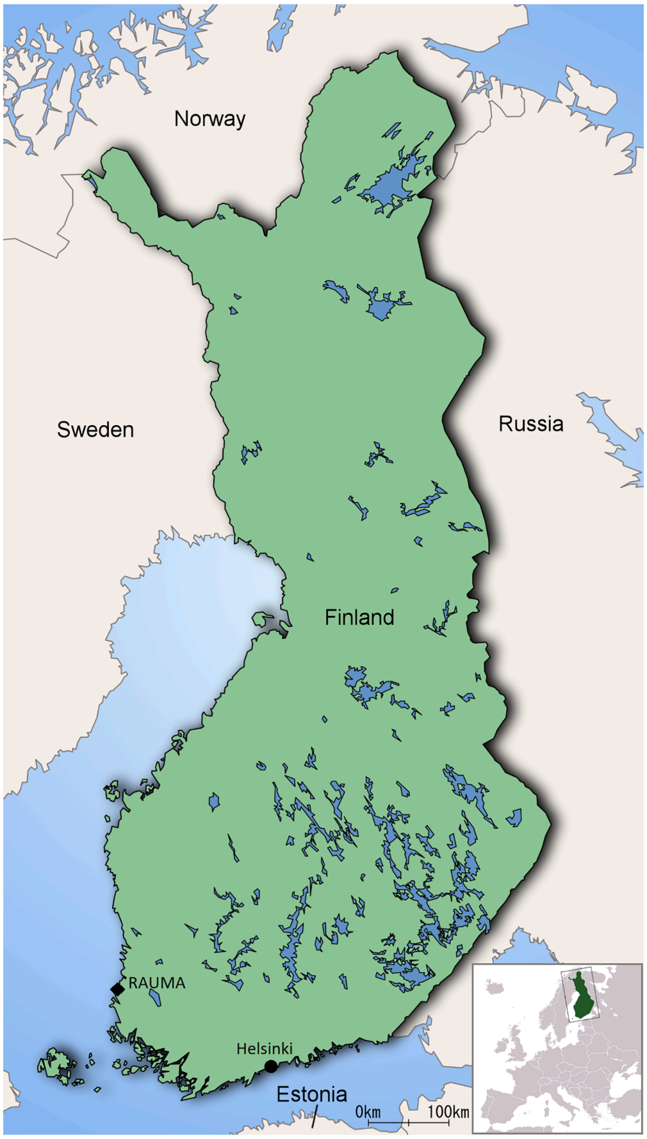

Fig. 1. The present-day nation of Finland was a part of the Kingdom of Sweden until 1809. This is when it was surrendered to the Russian Empire when and became the Grand Duchy of Finland before gaining independence in 1917. The town of Rauma is indicated in the map. Map: Public domain, Wikimedia Commons, modified by Tiina Väre.

Howcroft et al., 2012b; Howcroft et al., 2014; Howcroft et al., 2015; Beaumont et al. 2013; Beaumont et al. 2015; Tsutaya and Yoneda 2015). In addition, we compare the stable isotope values measured in M1 dentin collagen, representing the post-weaning period diets, to the corresponding values from the cervical region of second premolars (PM2) of the same subjects (Väre et al., 2022a), representing their mid-childhood diets.

2. Background

2.1. Artificial feeding and benefits of breastfeeding

In the past artificial infant feeding was a significant contributor to infant mortality and continues to play a role in the ability of mothers and infants to resist disease (Fildes 1998). In certain regions of Finland, unhygienic cow horns filled with animal milk were commonly used as a premodern alternative for a baby bottle. The suitability and digestibility of cow's milk for human infants depends on the mode of preparation and delivery. Cow's milk contains more protein, but less lactose and iron than human milk and has been associated with increased risk of anemia and gastrointestinal blood loss when offered to infants without prior heat-treatment or additional nutritional supplementation (World Health Organization, 2005). The Dietary Guidelines for Americans advise against providing infants younger than 12 months of age with cow's milk (U.S. Department of Agriculture and U.S. Department of Health and Human Services., 2020). Prior to the mid-19th century, higher infant mortality rates in Europe were associated the transmissibility of microbial pathogens in unpasteurized animal milk and unhygienic dairying practices (Currier & Widness 2018).

In Finland, various gastrointestinal conditions caused a substantial portion of the early modern infant mortality (Halila 1954, 640; Turpeinen 1987; Jutikkala 1994). In fact, between the areas where infants were artificially fed and those where breastfeeding was traditionally practiced a clear distinction in infant mortality rate prevailed painting the picture of the latter in much more favorable light (Brändström 1984, 158, 186–187; Turpeinen 1987). On the other hand, with respect to the presumed economic status and surroundings of the individuals studied in this article, it has been suggested that pragmatic reasons may have necessitated resorting to exclusive breastfeeding amongst the poorest residents in urban environments as logistics and expenses restricted their access to supplemental animal milk (Rabbe 1844; Brändström 1984, 84, 124; Turpeinen 1987; Jutikkala 1994, 99, 149).

Currently the comprehensive effects of human milk consumption in infancy on long-term health, and thus, the entire lifespan are well known. The exclusive consumption of human milk for the first six months provides substantial protection against infectious diseases as it profoundly impacts the formation and functionality of the infant's immune system (Bridgman et al. 2016; Kumar et al. 2016). It has been demonstrated to significantly lower infant mortality caused by diarrhea (e.g., Victora et al. 1987). Additionally, a long breastfeeding period may have a preventive effect against afflictions emerging later in life such as allergies, inflammatory bowel disease as well as other autoimmune diseases, and even certain neoplastic conditions (Hanson 1998; 1999; Jakaitis & Denning 2014; Victora et al. 2016; Jackson & Nazar 2006; Bener et al. 2008).

2.2. Archaeological and historical context

Rauma is located in the southwest corner of Finland, approximately 250 km northwest of Helsinki (Fig. 1). Founded in CE 1442, it functioned as a center for trade for a largely rural population with links to other harbors in the kingdom of Sweden, including Stockholm (Bläuer et al. 2019). *Pyhän kolminaisuuden kirkko* (EN The Holy Trinity church) was constructed out of stone in the late 15th century but burned down in 1640. The churchyard had been used for burials between the late-14th century and its closing in 1853 when the last recorded burial occurred, apart from the period of 1790–1810 (Hiekkanen 2007, 253). In 2015 and 2016, excavations were carried out in the churchyard to make way for public works. The skeletons of 116 individuals were recovered at this time (Uotila and Lehto 2016). The seven individuals analyzed in this study were recovered from the northern side of the churchyard, which was mainly used in the late 18th and early 19th century, presumably by the lower socioeconomic classes of townspeople as it contained inexpensive burials sites (Uotila & Lehto 2016; Lähteenoja 1939). Most skeletons were nearly completely preserved (Uotila and Lehto 2016).

At the turn-of-the-19th-century, Rauma was a small but rapidly growing harbor town. Its population was small, only 1400–1500, and was not strongly hierarchical and wealth was nearly equally distributed. (Bläuer et al. 2019; Lähteenoja 1939, 276–278.) The subsistence economy was centered on the cultivation of crops such as potatoes, but residents also accessed the resources of the brackish Baltic Sea via the harbor (Lähteenoja 1939). Ongoing isotope analyses of the subjects of this study and some other individuals from the same population showed rather high $\delta^{15}N$ values in the bone and dentin collagen for example in comparison to the values measured in Fennoscandian cattle data summarized in Oinonen et al. (2020). This suggests that their diets probably consisted of fish in addition to foodstuffs of terrestrial origin – likely either plant products from manured fields or products of animals feeding off these plants (Väre et al., 2022a; Fig. 2.).

2.3. Stable isotope analysis and archaeological studies of breastfeeding

The isotopic composition of bone and tooth collagen is directly related to the isotopic composition of food, and more specifically, to dietary protein (Ambrose and Norr 1993; Fernandes et al. 2012). Stable carbon isotope ratios vary with the source of primary production in a particular food web and can be used to assess relative contributions of marine and terrestrial foods or between C_3 and C_4 photosynthetic pathways (Chisholm et al., 1982; O'Leary 1981). Stable nitrogen isotope values can be used to distinguish among trophic levels as they are known to increase by + 3‰ to + 5 ‰ with increasing trophic level (Minagawa & Wada 1984; Bocherens & Drucker 2003).

Stable nitrogen isotope composition can also vary with nutritional and health status, or due to growth related factors (D'Ortenzio et al., 2015; Fuller et al. 2005; Neuberger et al. 2013; Warinner & Tuross 2010; Webb et al. 2015; Webb et al., 2016). Incidences of nutritional or physiological stress in infants and their gestational parents have been identified in dentin isotope profiles as rising $\delta^{15}N$ values paired with falling $\delta^{13}C$ values (Beaumont et al. 2015; Craig-Atkins et al. 2018; King et al. 2018; O'Donoghue et al. 2021). This may be related to the isotopic effect of tissue catabolism; recycling of amino acids is associated with tissue enrichment in ^{15}N while the use of body lipids as an energy source may deplete tissues in ^{13}C although the $\delta^{13}C$ values have been observed to both increase and decrease under nutritional stress (Lidén and Angerbjörn, 1999; Mekota et al. 2006; Neuberger et al. 2013; Doi et al. 2017).

The application of stable isotope analysis to archaeological infant feeding studies was developed in the late 20th century using incrementally growing tissues, such as hair and fingernails, of modern human mother-infant dyads (Fogel et al. 1989; Fuller et al. 2006). During the following decades, a number of studies has demonstrated that exclusive breastfeeding produces higher $\delta^{15}N$ (~+2-3‰) and $\delta^{13}C$ (~+1‰) values in simultaneously growing tissues of infants relative to their mothers, and that with the introduction of supplementary foods, both isotope ratios in infant tissues usually decline (e.g., Eerkens et al. 2011; de Luca et al. 2012; Beaumont et al. 2013; Howcroft 2013; Fahy et al. 2014). This pattern is not observed in tissues of formula-fed infants who had more similar isotopic values to their mothers (Fuller et al. 2006). Similar studies have since been conducted on archaeological human remains using the dentin in deciduous and permanent molars. The primary dentin in human teeth develops incrementally and once formed is chemically inert, effectively preserving a record of childhood diet (Hillson, 2005). Teeth develop according to a known pattern throughout childhood; the crown of first permanent molar (M1) is formed approximately during the first three years of life, which is usually the timeframe for both breastfeeding and weaning (AlQahtani et al. 2010; Hillson 1996; Howcroft 2013). By comparing the isotopic composition of horizontally cut segments of dentin, age-related changes in diet and, in some cases, physiological stress during their developmental period can be retrospectively identified (Beaumont et al. 2013; Beaumont et al., 2016).

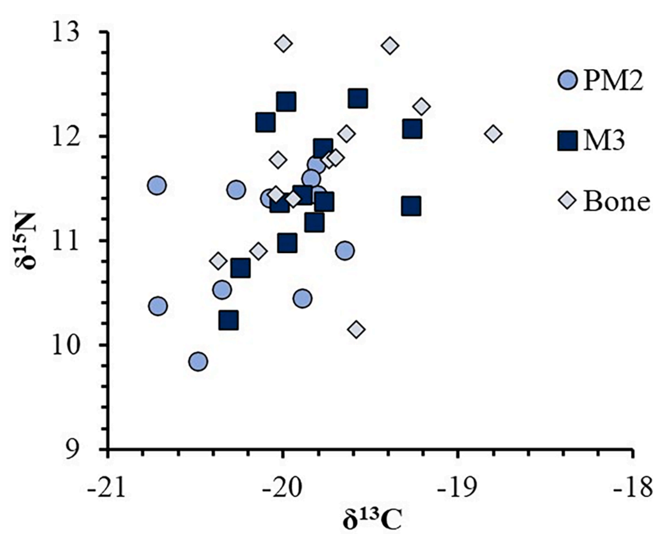

Fig. 2. The $\delta^{13}C$ and $\delta^{15}N$ values measured in PM2 collagen representing the mid-childhood diet ($\delta^{13}C$ −20.1 ± 0.4‰; $\delta^{15}N$ + 11.0 ± 0.6‰, n = 12), M3 collagen representing the adolescence diet ($\delta^{13}C$ −19.9 ± 0.3‰; $\delta^{15}N$ + 11.5 ± 0.6‰, n = 13), and bone collagen representing the average diet of several years prior to death ($\delta^{13}C$ −19.7 ± 0.4‰; $\delta^{15}N$ + 11.7 ± 0.8‰, n = 13) in Rauma. The $\delta^{15}N$ values in the population are at a quite high level perhaps resulting from consumption of aquatic species and animal-dung manuring of fields while the $\delta^{13}C$ values are typical for terrestrial C_3 plant or brackish and freshwater environments (Väre et al., 2022a).

3. Materials

The seven individuals selected for analyses (Table 1) were excavated in 2016 from the Holy Trinity churchyard of Rauma, Southwestern Finland (Uotila & Lehto 2016; Liira 2016; Fig. 1). The selected permanent first molars could be either maxillary or mandibular and from either side of the dentition as only slight differences are observed in the development schedules between these locations (Hillson 1996, 123). The stable isotope ratios were analyzed only for the first ten sections closest to the occlusal surface. Due to the development pattern of dentin, the temporal resolution in these segments, representing the growth during the first years of infancy, is rather good (Beaumont et al. 2018). However, as cutting proceeds toward the apex, the segments increasingly contain mixed signals from other periods as the dentin in roots does not grow vertically – but rather diagonally relative to the occlusal surface (cf. Fig. 2 in Eerkens et al. 2011; Tsutaya 2020). This blurs the chronology of the changes when comparing parallelly cut horizontal segments. Thus, it was reasoned better to focus on the values representing the typical breastfeeding period in infancy and to exclude the

Table 1
Individuals selected for analyses excavated from the Holy Trinity churchyard in Rauma. The osteological and paleopathological observations are according to the osteological report by Liira (2016). The biological sex estimations of RH122 and RH166 were reaffirmed by the analyses of amelogenin sequences in enamel (Väre et al. In prep.b).

Burial	Sex	Age	Height	Pathological findings	Other
RH122	F	Adult	c. 163 cm	Woven bone: lower long bones	Most bones preserved, hair present
RH151	F	Adult (young)	c. 152 cm	Caries in most tooth	Most bones preserved but fragmentary
RH166	M	Adult (young)	c. 183 cm	Woven bone: pelvis, lower long bones, bones of the foot	Most bones preserved
RH196	F	Adult (young)	c. 156 cm	Cribra Orbitalia (unilateral), Schmorl's nodes	Most bones preserved
RH200	M	Adult (young)	c. 171 cm	Endocranial lytic changes: Frontalis	Most bones preserved
RH202	F	Adult (young)	c. 155 cm	Periondontitis, Cribra orbitalia, lumbar osteophytes	Most bones preserved
RH208	F	Adult (young)	c. 147 cm		Most bones preserved

segments near the apex that represent the most recent growth. To determine the ages for interindividual comparison, we followed the previous work of Eerkens et al. (2011) and Beaumont & Montgomery (2015) estimating each segment having formed during an approximate period of 6 months.

The osteological age estimations have previously been conducted by osteologist Anne-Mari Liira (2016), who determined all the individuals were adults (18–44 years of age). As the burials excavated in 2016 date to the first half of the 19th century (prior to 1853), then the adult individuals included in this study were infants in the early 19th or late 18th century. None of the subjects died at an advanced age (Table 1) and all of the sampled teeth were unworn and free of secondary dentin that accrues with age which could obscure or alter the childhood dietary signatures. Unfortunately, finding first molars completely free of caries was challenging. The studied molars of RH122 (dental neck), RH208 (occlusal surface) presented with caries or enamel discoloration (RH166). We analyzed the halves of each tooth that were free of caries, but such lesions may induce tertiary dentin formation that time-averages the stable isotope signals. Nevertheless, the isotope profiles were similar between teeth with and without carious lesions thus any tertiary dentin did not significantly obscure the childhood dietary values.

4. Methods

4.1. Collagen extraction

The dentin samples were prepared at the Archaeological Research Laboratory, Stockholm University, and at the Faculty of Medicine, University of Oulu. The collagen extraction was performed according to the method 2 as described by Beaumont and colleagues (2013). The teeth were brushed free of macroscopic debris and bisected in vertical halves using a diamond wheel cutter. The tooth halves were then ultrasonicated in ultrapure water. All easily detachable enamel was manually removed, and the teeth were demineralized in 0.5 M hydrochloric acid (HCl). The samples were kept in room temperature for 1 to 2 weeks and the acid was refreshed when the sample ceased reacting. The demineralized teeth were rinsed with ultrapure water and sliced with a surgical scalpel in parallel horizontal sections of 1 mm with the aid of a ruler, beginning from the crown and proceeding to root tip. The dentin sections were placed in microcentrifuge tubes (Eppendorf) and gelatinized in a pH 3 (0.001 M) HCl solution at 70 °C for 24 h. Next, the samples were centrifuged, frozen, and lyophilized.

Additional samples from the cervical region of premolar dentition were prepared in order to compare mid-childhood diet with the weaning and post-weaning diets of infants. The collagen extraction of the ground samples was performed according to a modified Longin (1971) method introduced by Brown et al. (1988) where the samples go through ultrafiltration in the final step before lyophilization. These results were previously published by Väre and colleagues (2022a).

4.2. Stable isotope analyses

Analyses were conducted at the Nuclear Research Department, Center for Physical Sciences and Technology, Vilnius, Lithuania. Dentin collagen samples of 0.8 to 1 mg were weighed into tin capsules and flash combusted in a Flash EA 1112 series Elemental analyzer that was connected to the Delta V Advantage Isotope Ratio Mass Spectrometer (IRMS) via ConFlo III interface (all Thermo, Bremen, Germany). Isotope ratios were calculated according to the equation: $\delta X(‰) = [(R_{sample}/R_{standard})\text{-}1] \times 1000$ where X equals the isotope ratio of interest (*e.g.*, $^{13}C/^{12}C$ or $^{15}N/^{14}N$) and R the isotope ratio of either the sample or a standard and the resulting delta value expressed using permil (‰) units. The delta values were calibrated relative to the international scales for carbon (V-PDB) or nitrogen (AIR) using the following standards: Caffeine IAEA-600 ($\delta^{15}N$ = +1‰; $\delta^{13}C$ = –27.77‰), USGS24 ($\delta^{13}C$ = –16.05‰) and IAEA-NO-3 ($\delta^{15}N$ = +4.7‰). The analytical precision was 0.1‰ for both $\delta^{15}N$ and $\delta^{13}C$. One sample, RH122_1, was weighed out and analyzed in a smaller quantity (0.4 mg), but this still produced a measurable peak for nitrogen.

4.3. Identification of breastfeeding status and weaning process

After Katzenberg et al. (1996) we define weaning as a process that begins with the supplementation of human milk with complementary foods and ends with the cessation of lactation. Following from Jay (2009) we deemed an individual to be exclusively breastfed if they had $\delta^{15}N_{dentin}$ values that were elevated by + 2‰ to + 3‰ relative to the average bone collagen stable isotope ratios from adult females recovered from the Holy Trinity churchyard (Väre et al., 2022a). The onset of the weaning process was identified as the point at which $\delta^{15}N_{dentin}$ values began to decline and the cessation of lactation as the point where $\delta^{15}N_{dentin}$ values stabilized.

5. Results and discussions

Carbon and nitrogen stable isotope ratios were obtained from collagen of 59 sections of M1 dentin of seven individuals and are presented with collagen quality indicators in Table 2. The atomic C:N ratios calculated for the analyzed samples ranged from 2.9 to 3.3 and fell within the acceptable ranges for well-preserved Type 1 collagen (DeNiro 1985; van Klinken 1999; Guiry et al., 2020). The weight % of carbon and nitrogen, ranging between 33.4% and 47.3% and 12.4%–17.3%, respectively, were consistent with published ranges for modern bone collagen (Ambrose 1990). One sample produced high weight % of carbon and nitrogen that fell outside published parameters, likely due to an analytical error, and was not included in the subsequent analysis.

5.1. Exclusive breastfeeding and duration of the weaning process

Across the seven individuals, the $\delta^{13}C_{dentin}$ values ranged from –20.8‰ to –19.0‰ (mean –19.9 ± 0.4‰, n = 60) and the $\delta^{15}N_{dentin}$ values ranged from + 10.4‰ to + 15.2‰ (mean + 12.2 ± 1.2‰, n = 60). The average $\delta^{15}N_{dentin}$ of the first M1 increments was + 14.4 ± 0.5‰ while the latest forming increments had an average of + 11.8 ± 0.9‰. The isotopic profiles followed broadly similar patterns across all individuals. The $\delta^{15}N$ values in earliest forming increment of the M1s ranged from + 2.0 to + 3.4‰ above the average female bone collagen $\delta^{15}N$ value at + 11.8‰, consistent with established expectations for exclusively breastfed infants (Fogel et al. 1989; Fuller et al. 2006; Howcroft 2013).

The isotope profiles in all the studied molars were similar and showed a marked decrease in $\delta^{15}N$ values between the first and fourth increments from the occlusal surface (Fig. 3). Using a 1 mm sampling protocol, the fourth to fifth increments of the first permanent molar typically correspond approximately to 2 years of age (Beaumont et al. 2021; Beaumont et al. 2014). This suggests that supplementary foods may have been introduced approximately after the first six months of life and that weaning was completed by 2 years of age or even a little earlier. After this the changes are much less rapid or large and not as systematically unidirectional. In case of RH151, the enrichment in both ^{13}C and ^{15}N later in childhood is likely related to consummation of different foods after weaning, compared to the other individuals.

In the dentin segments formed after the breastfeeding period, both the $\delta^{13}C$ and $\delta^{15}N$ values should approach those of the average adult female bulk bone collagen values assuming all family members were consuming similar foods (Fuller et al. 2006). The $\delta^{15}N$ values of three individuals, RAU.RH151, 200 and 202, all fall below the average female bone collagen value by 0.4‰ to 0.6‰. This minor difference is likely due to maternal (or wetnurse) dietary or physiological variation that caused isotopic deviation from the average female bone collagen values and subsequently influenced infant isotopic values (cf. Beaumont et al.

Table 2
Stable isotope values and collagen quality indicators of incrementally sampled dentin from permanent first molars. Additionally, the previously published bulk dentin values from second premolars (Väre et al., 2022a) are presented. Section numbering begins at the occlusal surface and proceeds toward the root. *) Excluded values **) sample was contamined before analysis.

Individual	Sex	Tooth	Section (mm)	δ^{13}C (‰)	δ^{15}N (‰)	%C	%N	Atomic C:N
RH166	M	M1	0–1					
			1–2	−19.6	13.9	40.54	14.88	3.2
			2–3	−19.8	12.5	42.22	15.61	3.2
			3–4	−19.7	12.3	39.83	14.63	3.2
			4–5	−19.6	12.6	42.80	15.63	3.2
			5–6	−19.5	12.5	36.67	13.39	3.2
		PM2	N/A	−19.8	11.5	39.95	14.62	3.2
RH122	F	M1	0–1	−19.2	15.2	41.84	14.98	3.3
			1–2	−19.2	14.5	45.55	16.70	3.2
			2–3*	−19.5	13.4	50.94	18.64	3.2
			3–4	−19.6	12.7	45.39	16.59	3.2
			4–5	−19.6	12.8	47.33	17.33	3.2
			5–6	−19.6	12.9	45.41	16.63	3.2
			6–7	−19.6	12.9	46.13	16.88	3.2
			7–8	−19.6	12.8	45.83	16.73	3.2
			8–9	−19.9	12.4	44.83	16.31	3.2
			9–10	−20.0	12.2	45.07	16.49	3.2
		PM2	N/A	−20.3	11.6	38.76	14.27	3.2
RH151	F	M1	0–1	−19.5	14.3	33.45	12.41	3.2
			1–2	−19.7	13.2	43.56	15.99	3.3
			2–3	−19.9	12.0	41.78	15.29	3.2
			3–4	−20.0	11.5	41.99	15.45	3.2
			4–5	−19.9	11.6	42.25	15.59	3.2
			5–6	−19.9	11.4	38.73	14.27	3.3
			6–7**					
			7–8	−19.0	13.1	38.35	14.20	3.2
		PM2	N/A	−20.4	10.5	38.99	14.32	3.2
RH208	F	M1	0–1	−19.2	14.7	44.74	16.46	3.2
			1–2	−19.1	13.6	45.39	16.75	3.2
			2–3	−19.5	12.9	45.11	16.67	3.2
			3–4	−20.0	11.7	45.80	17.23	3.3
			4–5	−19.8	11.7	44.12	16.58	3.2
			5–6	−19.9	11.7	44.38	16.63	3.2
			6–7	−19.9	11.5	44.01	16.34	3.2
			7–8	−20.0	11.6	45.26	16.82	3.2
			8–9	−19.9	11.7	46.47	17.26	3.2
			9–10	−19.8	11.8	44.53	16.57	3.1
		PM2	N/A	−19.9	10.5	36.83	14.93	2.9
RH196	F	M1	0–1	−19.5	14.5	42.47	15.20	3.3
			1–2	−19.9	13.8	44.43	15.95	3.2
			2–3	−20.3	11.8	42.81	15.32	3.3
			3–4	−20.4	10.8	43.88	15.73	3.3
			4–5	−20.4	10.8	43.28	15.51	3.3
			5–6	−20.2	10.4	43.57	15.87	3.2
			6–7	−20.1	10.7	40.95	14.95	3.2
			7–8	−19.9	10.8	44.30	16.25	3.2
		PM2	N/A	−20.5	9.9	37.59	14.46	3.0
RH200	M	M1	0–1	−20.1	14.0	41.22	14.65	3.3
			1–2	−20.5	12.5	36.35	13.23	3.2
			2–3	−20.6	11.4	36.25	13.26	3.2
			3–4	−20.7	10.9	39.36	14.33	3.2
			4–5	−20.8	11.0	42.04	15.29	3.2
			5–6	−20.5	11.1	41.52	14.96	3.2
			6–7	−20.4	11.1	42.34	15.31	3.2
			7–8	−20.4	11.3	42.17	15.21	3.2
			8–9	−20.6	11.2	35.01	12.60	3.2
			9–10	−20.6	11.2	42.16	15.24	3.2
		PM2	N/A	−20.7	10.4	38.49	13.94	3.2
RH202	F	M1	0–1	−20.0	13.8	40.51	14.51	3.3
			1–2	−20.1	12.6	42.35	15.31	3.2
			2–3	−20.3	11.2	44.28	15.86	3.3
			3–4	−20.4	10.9	41.28	14.86	3.2
			4–5	−20.1	11.1	38.35	13.86	3.2
			5–6	−20.0	10.8	40.43	14.55	3.2
			6–7	−20.0	10.9	42.16	15.18	3.2
			7–8	−20.0	10.9	41.91	15.05	3.2
			8–9	−20.0	11.2	43.84	15.75	3.2
			9–10	−20.0	11.0	41.41	14.76	3.3
		PM2	N/A	−20.7	11.0	29.90*	9.82*	3.6

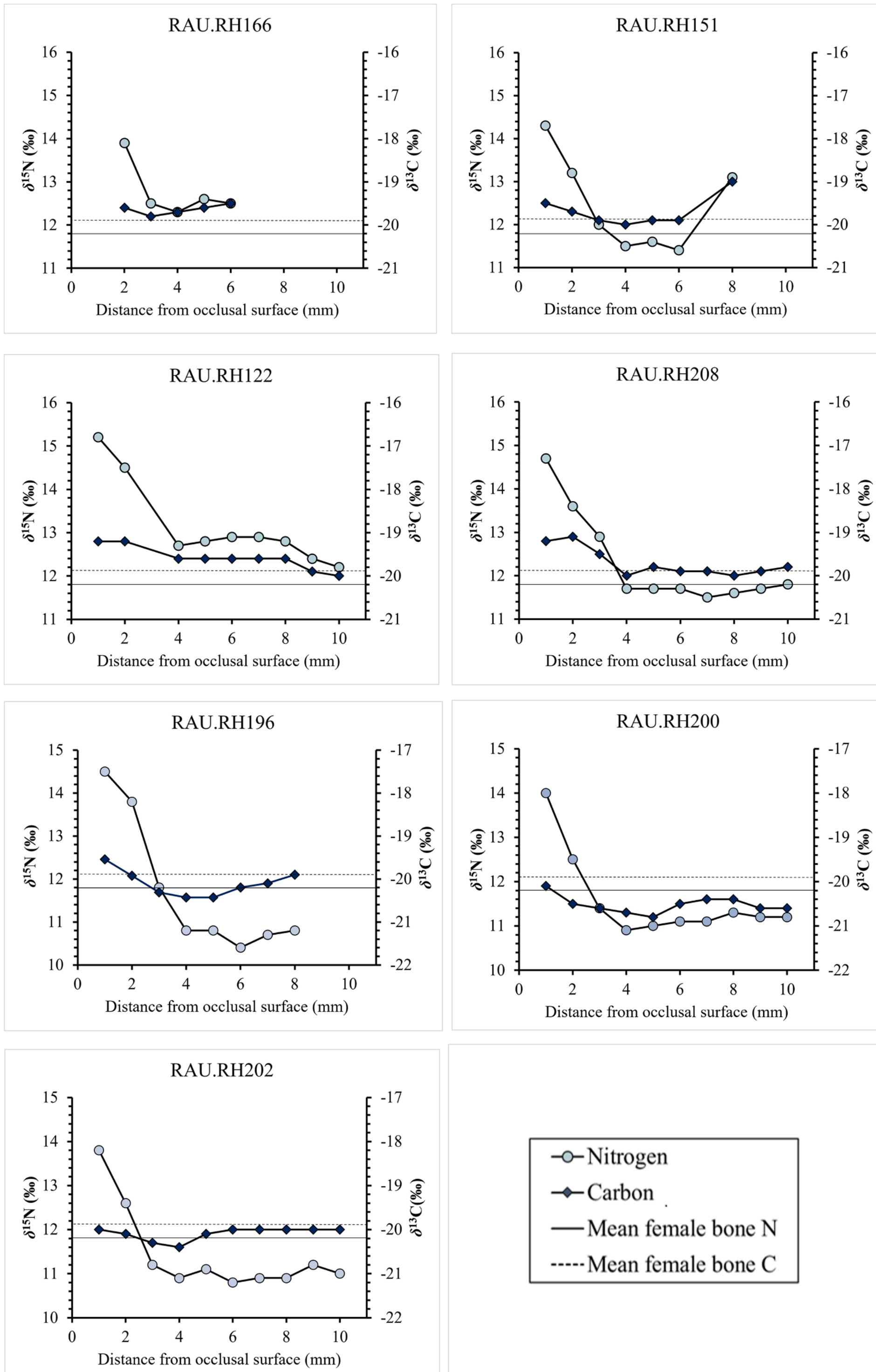

Fig. 3. Sampling distance in millimeters from top of the crown is plotted on the horizontal axis and both the δ^{13}C (circles) and δ^{15}N (diamonds) values on vertical axes. The mean δ^{13}C (–19.9‰) and δ^{15}N (+11.8‰) from the bulk bone collagen of seven adult females from Rauma (data from Väre et al., 2022a) are presented as solid (δ^{15}N) and dotted (δ^{13}C) lines, respectively, and they represent the average diet of mothers in the population.

2015). This may explain why the difference between the female mean collagen δ^{15}N value and that of the first dentin segment of one individual, RAU.RH122, at 3.4‰, is slightly larger than expected, although even the possible effect of analytical imprecision should be considered.

Some differences in weaning pattern may be observed: for example, as demonstrated by the isotope signals of the third section, RH166 or RH202 probably no longer consumed notable amounts of human milk during the first half of the second year while for at least RH208 and RH196 the process of weaning likely was more gradual.

These results correspond relatively well to the current recommendation of exclusive breastfeeding for the first six months, after which time human milk alone no longer serves as a sufficient source of nutrition and introduction of new foods alongside continued breastfeeding becomes necessary until the infant reaches 2 years of age (World Health Organization, 2015). Secondly, these results are in accordance with the hypothesis based on historical documentation that breastfeeding was common in Southwestern Finland. They could even fit together with the idea that often the poorest inhabitants of towns resorted to breastfeeding out of necessity as acquiring animal milk from farms could be too expensive (e.g., Rabbe 1844; Brändström 1984, 84, 124; Turpeinen 1987, 320; Jutikkala 1994, 99, 149). The results also suggests that women's socioeconomic roles in Rauma allowed for a period of exclusive breastfeeding and gradual weaning process which was not always the case in urban contexts in other regions of Northern Europe (Fildes 1988) or, for instance, in the Ostrobothnian countryside (Turpeinen 1987). This pilot study was comprised of seven individuals and almost certainly does not capture the full extent of variation present in infant feeding practices in 18th and 19th century Southwestern Finland. Nevertheless, the similarity of the pattern for all the studied individuals suggests that adhering to the mentioned schedule of infant feeding in Rauma region may have been common – at least among the low-income families.

5.2. Other considerations

In this study, none of the studied M1s exhibited opposing covariation of the values marked by rising δ^{15}N and falling δ^{13}C values, which has been interpreted as famine pattern (Beaumont et al., 2016). Instead, the patterns in the isotopic values over the chronologically organized increments can be attributed to an initial period of exclusive breastfeeding followed by the introduction of complementary foods. In fact, the material is inherently biased in this respect. All the subjects had reached adulthood and we know that breastfeeding is one fundament of infant survival and even a factor of lifelong health (*e.g.*, Hanson 1998; 1999; Jakaitis & Denning 2014; Victora et al. 1987; 2016; Jackson & Nazar 2006; Bener et al. 2008). Particularly, survival of an infant through severe nutritional stress, lasting for the duration of development of several millimeters of dentin, would be improbable (cf. Pearson 1980 on malnutrition and infant mortality). This implies a trophic level shift and not physiological stress during early infancy as the most likely explanation for the elevated δ^{15}N values in the first dentin increments: starvation or chronic health impediment during the first months could obviously have deterred survival. In studies addressing breastfeeding customs at a population level by comparing isotope composition in bones of children who died at different ages or utilizing the pattern of variation of isotope signals in deciduous teeth of dead children, interpreting high δ^{15}N values as sign of physiological stress may be considered more plausible.

While this method does allow infant feeding practices to be estimated, it does not allow us to determine who provided human milk to the infant. At least since Antiquity until the Early Modern period, breastfeeding was habitually avoided by many women in Europe and employing a wetnurse has a long history (Wickes 1953; Fildes 1986; 1988.). Even so, in Finland, a wetnurse was likely a relative rarity, although their use has been mentioned as a preferable option over artificial feeding by some scholars and physicians (Lönnroth 1981 [1838/1856], 38; Turpeinen 1987). The section of the churchyard, where the subjects had been buried, comprised of inexpensive burial sites, and was likely mostly utilized by the townspeople of low socioeconomic status. This makes it more likely that the gestational parents, instead of paid wetnurses, were providing human milk. Some type of fostering system may, however, have been possible at least if the mother was seriously ill or died.

5.3. Diet in childhood

We also compared the stable isotope ratios of M1 root dentin collagen formed after the weaning period to collagen from cervical region of PM2 representing mid-childhood of these same individuals (data from Väre et al., 2022a). The latest forming M1 segments of the seven individuals that were measured in this study variously corresponded approximately to ages of 3 to 5.5 years (cf. Eerkens et al. 2011). The crown of PM2 is completed at approximately six to seven years of age (Hillson 1996; AlQahtani et al. 2010), which means that a sample drilled just below the crown represents the mixed signals of the growth from approximately the subsequent year.

The $\delta^{13}C_{dentin}$ values from the PM2s of the studied individuals ranged from –20.7‰ to –19.8‰ (mean –20.3 ± 0.4‰, n = 6) and the $\delta^{15}N_{dentin}$ values from + 9.9‰ to + 11.6‰ (mean + 10.7 ± 0.7‰, n = 6) (Väre et al., 2022a; Table 2). The $\delta^{13}C_{dentin}$ values of the latest forming analyzed M1 increments ranged between –20.6‰ and –19.0‰ (mean –19.8‰±0.5‰, n = 7) and the $\delta^{15}N_{dentin}$ values between + 10.8‰ and + 13.1‰ (mean + 11.8 ± 0.9‰ n = 7). Thus, in Rauma, the mid-childhood diets (PM2 cervical region) of these subjects do not resemble those they had consumed in early childhood (M1 root; Fig. 4).

As judged particularly by the consistently higher δ^{15}N in the earlier forming samples, it seems plausible that animal protein, most likely in the form of animal milk – a common dish during weaning – was served to younger children, while plant-based foods instead were served to older children. The higher stable isotope values in early childhood may also result from consumption of omnivorous species (pigs and chickens) and their secondary products, or to contributions from aquatic protein sources. Perhaps, the very young children were given a privileged access to better sources of protein than older children. However, if we assume an offset of approximately + 1‰ for carbon and + 3-5‰ for nitrogen (Bocherens & Drucker 2003), then at –19.8 ± 0.5‰ and + 11.8 ± 0.9‰, the post-weaning δ^{13}C and δ^{15}N values of the M1s are high relative to archaeological Fennoscandian cattle, sheep/goats and horses which have average δ^{13}C and δ^{15}N values of –22.0 ± 0.6‰ and + 5.5 ± 0.5‰, respectively (data summarized in Oinonen et al. 2020).

When comparing the isotope compositions of tissues developed during different phases of growth the plausible influence of differing metabolic conditions on their formation needs to be discussed. Anabolic states achieved during periods of growth, such as during pregnancy or puberty, are known to result in a reduced enrichment in ^{15}N (*e.g.*, Millard 2000; Fuller et al. 2004). Current understanding, however, is that if such decline occurs, it would be to a rather diminutive degree (*e.g.*, Ponsard & Averbuch 1999; Waters-Rist & Katzenberg 2010; Nitsch et al. 2011). Rather than assume that some children experienced a positive nitrogen balance and thus lower δ^{15}N values relating to a growth spurt in mid-childhood, the more likely explanation for the systematically higher δ^{15}N values during early childhood would be differing diets.

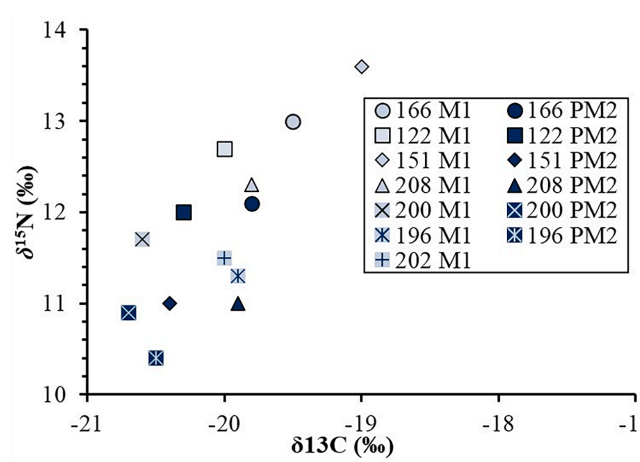

Fig. 4. A comparison of the δ^{13}C and δ^{15}N values of M1 root segments (light symbols), representing the post-weaning diet of early childhood, with the isotopic composition of premolar (PM2) root segments just below the cementoenamel junction from the same individuals (dark symbols), representing mid-childhood diet. The collagen quality in the PM2 sample of RH202 was substandard and could not be included (Väre et al., 2022a).

6. Conclusion

We explored whether breastfeeding was the preferred infant feeding method among the low-income part of the population in the town of Rauma in Southwestern Finland in the late 18th to early 19th century. The historical record implies that in certain regions breastfeeding was traditionally practiced while in others artificial infant feeding was favored. Breastfeeding practices were examined by analyzing the nitrogen and carbon stable isotope ratios in incrementally sampled dentin from the permanent first molars of seven individuals from the part of the cemetery of the Holy Trinity church used during the late 18th and early 19th centuries mainly by the low-income population of Rauma.

The results demonstrated that all individuals experienced a period of exclusive breastfeeding followed by the cessation of lactation by the age of approximately 2 years. Despite the small sample size, the similarity of the pattern for all the subjects indicates that the results may represent the typical breastfeeding practices among the turn of the 19th-century low-income families in Rauma. This supports the prior understanding of breastfeeding being the most utilized method of infant feeding in the area at the time. Nevertheless, at the dawn of the modern era, mothers of low-income families in Rauma seem to have been able to adhere to long breastfeeding periods; perhaps as a result of long traditions or even due to the lack of resources enabling use of animal milk. Their schedule of infant feeding was quite consistent with what is currently considered ideal long before global official recommendations based on modern medical science.

There also was a clear distinction between the subjects' postweaning diet in the early childhood and their diets during mid-childhood. The latter was comparatively depleted in ^{15}N, which could be explained by the younger children's diets containing greater amount of animal protein (including secondary products such as milk and eggs) while the diets of older children could have been more plant-based.

Ethical Statement

The destructive sampling of human remains was permitted by the Finnish Heritage Agency (MV/62/05.04.01.02/2016). The skeletal remains utilized in this study were handled with respect. The information concerning these once living people was handled anonymously and identifying these individuals was not possible.

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CRediT authorship contribution statement

Tiina Väre: Conceptualization, Funding acquisition, Investigation, Data curation, Methodology, Formal analysis, Writing – original draft, Writing – review & editing. **Alison J.T. Harris:** Methodology, Investigation, Formal analysis, Writing – original draft, Writing – review & editing. **Mikko Finnilä:** Resources, Writing – review & editing. **Kerstin Lidén:** Resources, Writing – review & editing.

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