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Comparing childhood and adulthood diets in a Viking Age population from the Lejasbitēni cemetery, Latvia: a pilot study

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ABSTRACT

This study examines childhood and adulthood diets in selected individuals from the Iron Age Lejasbitēni cemetery population in Latvia (7th–10th centuries CE). Bone samples for isotope analysis were collected from 12 adult individuals; six had previously available isotope data from M1 root dentine. Bone samples from two non-adult individuals of the chronologically later Liv culture were included for preliminary comparison. Results showed that the Lejasbitēni bone carbon ($\delta^{13}C$) and nitrogen ($\delta^{15}N$) values were among the lowest in the region, suggesting a diet dominated by terrestrial C_3-based resources with low-trophic-level animal protein. Unlike dentine data, bone $\delta^{15}N$ values were not significantly different between gender groups, indicating a more homogeneous adulthood diet. Higher bone $\delta^{15}N$ values were not always consistent with rich grave inventories, suggesting no clear correlation between social status and diet. Comparison of bone and dentine values revealed a statistically significant shift towards lower $\delta^{15}N$ and higher $\delta^{13}C$ values in adulthood compared to childhood, indicating significant dietary change across the life course. Four out of five individuals with usable isotope data from both tissues showed a decrease in $\delta^{15}N$ values, and all five showed an increase in $\delta^{13}C$ values between childhood (dentine) and adulthood (bone), respectively. These results represent only a small group, and further research is necessary to explore childhood-to-adulthood dietary transitions and links between access to resources and grave goods in the Lejasbitēni population.

KEYWORDS
archaeology, burial customs, gender, age, life course, dietary isotopes, social status.

Introduction

This research focuses on childhood and adulthood diets in selected adult individuals from the Lejasbitēni cemetery population in Latvia (7th–10th centuries CE). Lejasbitēni is one of the few completely excavated Iron Age cemeteries in Latvia. It was located near the modern-day town of Aizkraukle on the right bank of the River Daugava, approximately 90 m from the river (Fig. 1). In 1961–1964, due to the construction of the Pļaviņas hydroelectric plant, the Lejasbitēni cemetery was excavated, uncovering 453 burials. The excavation was led by Vladislavs Urtāns, and it has been dated to the 3rd–10th centuries CE according to archaeological artefacts (Urtāns 1965). The area was permanently flooded after the excavation.

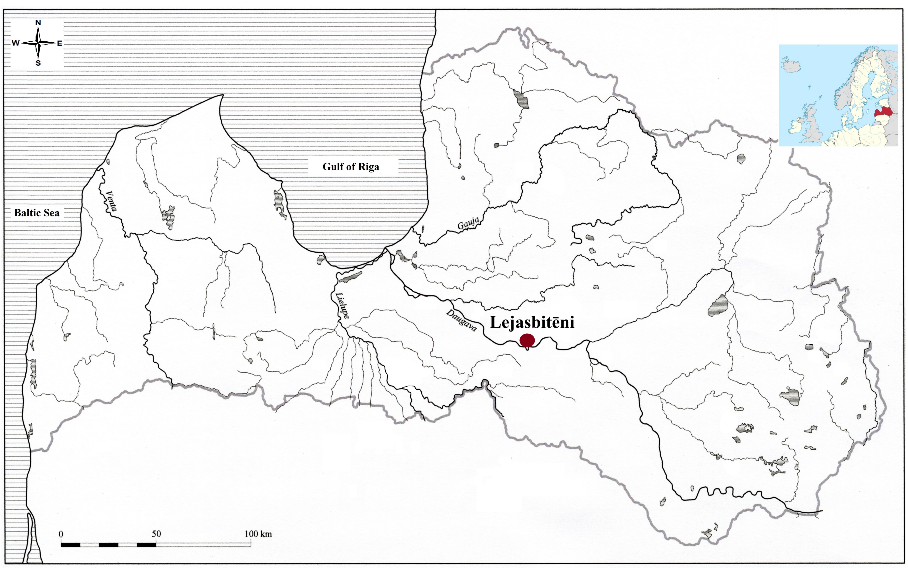

FIG. 1. Map of Latvia showing the location of the Lejasbitēni cemetery. The map in the upper right corner shows the geographic location of Latvia. Maps by Antonija Vilcāne.

The chronology of the Lejasbitēni cemetery corresponds to the second half of the Middle and Late Iron Age in Latvia (Vasks 2018, 28–38), partly overlapping with the period conventionally known as the Viking Age in Scandinavia and neighboring regions (c. 750–1050 CE; Brink & Price 2008). During this period, several Baltic peoples lived in the territory of modern-day Latvia (Vilcāne 2018, 59–84).

The history of the Aizkraukle region suggests that this territory was inhabited by both ancient Baltic peoples (Semigallians, Selonians, and Latgalians) and Baltic Finnic peoples – the predecessors of the Liv culture (Atgāzis 2001). The first burials from the 3rd–5th centuries CE at the Lejasbitēni cemetery may have been interred in several small burial mounds. These have been completely flattened due to anthropogenic activities, and only separate archaeological finds have helped to identify the destroyed graves (Urtāns 1965).

During the 6th–7th centuries CE, the dead were interred in graves organised in a semi-circular pattern around the first burial mounds. Although the grave orientation was thus variable, it was always inverted between male and female gender individuals (Fig. 2). From the 8th century CE onwards, as the cemetery grew, the graves were organised in rows, which were particularly pronounced in the 9th–10th centuries CE. During this period, the characteristic Latgalian inverted grave orientation of the two gender groups was established, with males and females buried with their heads to the east and west, respectively. At Lejasbitēni, there are burials with grave goods characteristic of Selonian and Latgalian cultures (Atgāzis 2001). Calibrated ^{14}C dates suggest that the Lejasbitēni cemetery was predominantly used during the 7th–10th centuries CE, between 610 and 980 cal. CE, with a 68.3% probability (Pētersone-Gordina et al. 2022).

In the western part of the cemetery, there were Liv burials from the end of the 10th to the beginning of the 11th century CE (Fig. 2). The Liv burials in the Lejasbitēni cemetery are distinguished by the cremation rite for adult females, which is atypical of Latgalian practice; grave goods (jewellery, pottery, etc.) characteristically associated with the Liv culture; and their peripheral spatial position, consistent with a later episode of burial activity (Urtāns 1965). Lejasbitēni is geographically the easternmost known area of Liv burials in the Daugava basin (Urtāns 1965). Archaeological data suggest that Liv cemeteries appeared by the River Daugava only in the 10th century CE, and none are known in this area in the centuries before (Mugurēvičs 2006; Vasks 2018).

Although rich in archaeological material, the Lejasbitēni cemetery offers very limited potential for osteological analysis. This is because skeletal remains from this cemetery were collected based on the selection of what were then considered the most informative skeletal elements, which were

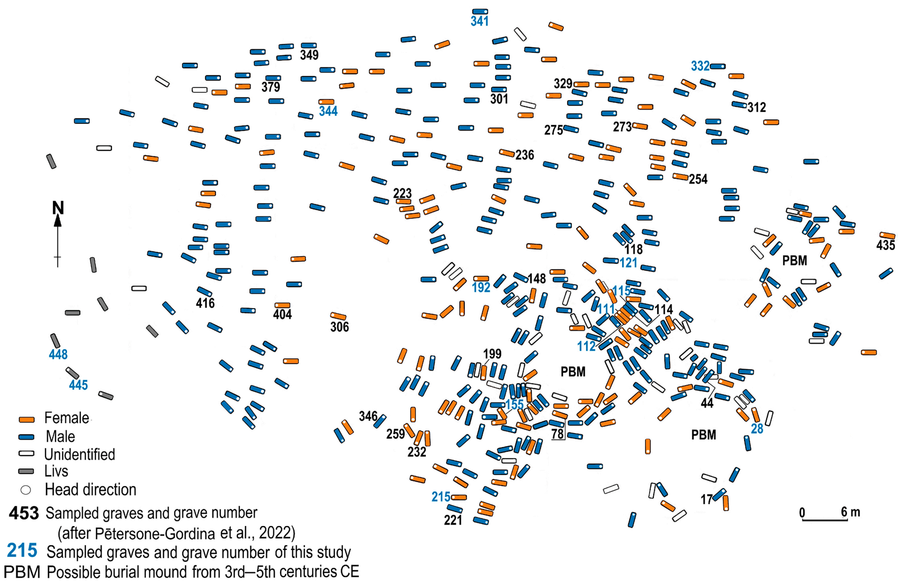

FIG. 2. Plan of the Lejasbitēni cemetery showing burials by gender and burials sampled for isotope analysis, redrawn and supplemented by Vilcāne from Urtāns (1970, 69; fig. 5). The oldest burials in the cemetery are concentrated around the three burial mounds (PBM).

almost exclusively crania and mandibles, including teeth, and occasionally, long bones. Since thorough osteological and palaeopathological analysis of this cemetery population is not possible, most information has so far been obtained through alternative means, including stable isotope, ancient DNA, and amelogenin peptide analyses (Pētersone-Gordina et al. 2022; Ķimsis et al. 2023).

Due to the incomplete nature of the skeletal remains, it has not been possible to estimate biological sex in all adult individuals by osteological analysis. For this reason, throughout this study all individuals will be referred to according to their gender as expressed by grave goods and grave orientation, unless specified otherwise. This approach does not imply that there were only two gender categories in the Lejasbitēni population and accepts that gender might have been a complex concept, as has been pointed out previously (Arnold 2006, 138–140; Moen 2019).

The current pilot study builds on previously acquired archaeological and isotopic evidence from the Lejasbitēni cemetery, which explored whether and how the advance of the Viking Age in Europe might have affected the diet of the Lejasbitēni people of different genders and social statuses, according to grave goods and burial ritual (Pētersone-Gordina et al. 2022). Dentine from the first permanent molar root, representing the age range between three and ten years (Dean & Scandrett 1995; Beaumont & Montgomery 2016), was mainly used for dietary isotope analysis, thus limiting the information to childhood in non-adults as well as adults (Pētersone-Gordina et al. 2022). It should be noted that bulk dentine analysis integrates isotopic signals over the entire root formation period, thereby averaging short-term dietary fluctuations, including weaning-period stress events (Beaumont & Montgomery 2016; Beaumont et al. 2018). In individuals who died in childhood, the age at death may fall within this formation window, and values may represent a partial rather than complete developmental period.

The aim of the current pilot study is to explore dietary change across the life course in selected adult male and female gender individuals from the Lejasbitēni population by comparing stable carbon and nitrogen isotope data from bone collagen (reflecting adulthood diet) with previously published dentine isotope data (reflecting childhood diet), using data from the same individuals where possible. The following objectives support this aim:

1. To identify and characterise dietary changes across the transition from childhood to adulthood in the Lejasbitēni population;
2. To assess whether the gender-related dietary differences previously documented in childhood are also present in adulthood;
3. To explore whether social status, as expressed by grave goods, correlates with access to dietary resources.

To place the Lejasbitēni bone isotope data in its broader regional context, the results will be compared with published isotope data from broadly contemporary archaeological populations across the eastern Baltic and the wider region.

Stable carbon and nitrogen isotope analysis

Stable carbon ($\delta^{13}C$) and nitrogen ($\delta^{15}N$) isotope analysis has become a useful and reliable tool for reconstructing diet in archaeological populations. Information about diet can be obtained by measuring $\delta^{13}C$ and $\delta^{15}N$ values in collagen (Schoeninger et al. 1983), as the body records dietary signals during the deposition of new bone and other body tissues (Fuller et al. 2006; D'Ortenzio et al. 2015). Bone is often used to obtain a dietary average for an individual, but its turnover rate varies considerably depending on the skeletal element and the health, nutrition, activity, and age of the individual (Hedges et al. 2007; Fahy et al. 2017). Thus, to enable comparability, it is important to sample the same skeletal element in all individuals where possible (Beaumont 2020). In contrast, analysing dentine provides information about childhood diet, as teeth form at specific ages and primary dentine, once formed, does not remodel (Dean & Scandrett 1995), locking in dietary information from the period of tooth formation (Fuller et al. 2003; Beaumont and Montgomery 2016). While bone can cease to grow in response to physiological stress (Beaumont et al. 2018; Beaumont 2020), dentine keeps forming even during undernutrition (Elamin & Liversidge 2013) and can record factors such as breastfeeding, weaning, in-utero stress, and periods of dietary deficiency (Beaumont & Montgomery 2016; Beaumont et al. 2018; King et al. 2018; Crowder et al. 2019).

$\delta^{13}C$ analysis can be used to detect the presence of plants with different photosynthetic pathways in the diet: C_3 and C_4 plants. C_3 plants (including crops such as wheat, rye, and oats) grow worldwide and have yielded values between –35‰ and –20‰, while C_4 plants (e.g. millet) mainly originate from warm, arid regions and have produced values between –14‰ and –9‰ (Katzenberg 2008, 423). In regions where diets are dominated by C_3 plants, such as northern Europe, $\delta^{13}C$ analysis can detect the contribution of marine resources, which have $\delta^{13}C$ values between –17.0‰ and –5.0‰ (Schoeninger & DeNiro 1984). Freshwater resources are more difficult to determine in human populations using bulk collagen $\delta^{13}C$ and $\delta^{15}N$ isotope analysis because of overlap with a terrestrial C_3 plant-based diet, including herbivores and omnivores consuming these resources. It has been suggested that lower $\delta^{13}C$ values in combination with higher $\delta^{15}N$ values might indicate the consumption of freshwater resources (Müldner & Richards 2005; Ottalagano & Loponte 2017; Eriksson et al. 2018), although some studies have shown that this might not always be the case, as freshwater resources can have wider-than-expected isotopic ranges (Guiry 2019; Etu-Sihvola et al. 2022). In consumer tissues, $\delta^{13}C$ values are higher than in the diet, by around 1‰ in flesh and by 5‰ in skeletal tissues (Schoeninger & DeNiro 1984; Bocherens & Drucker 2003).

$\delta^{15}N$ analysis provides information about the sources of protein in the diet and shows the individual's position in the food chain, or their trophic level (Hedges & Reynard 2007). Organisms at higher trophic levels (e.g. omnivores and carnivores) typically have higher $\delta^{15}N$ values than those at lower levels (e.g. herbivores), which translates into higher or lower $\delta^{15}N$ values, respectively, in human populations consuming these resources. In archaeological populations, individuals or population groups with higher bone collagen $\delta^{15}N$ values compared to the rest of the population have been used as indicators of diets with a higher proportion of animal protein and thus, potentially, higher social status (e.g. Müldner & Richards 2005; Reitsema 2013). However, this relationship is not universal and must be evaluated on a case-by-case basis. During breastfeeding, a baby occupies one trophic level above their mother or wet nurse (Fogel et al. 1989). In skeletal tissue, a dietary shift to a higher trophic level will be expressed as an increase of 2–5‰ (ibid.). Values of $\delta^{15}N$ can also increase during episodes of physiological or nutritional stress (Mekota et al. 2006; Reitsema & McIlvaine 2014). As mentioned above, several studies have detected short-term dietary changes and episodes of nutritional stress by analysing increments of dentine in archaeological populations (e.g. Beaumont & Montgomery 2016; Beaumont et al. 2018; King et al. 2018; Crowder et al. 2019; DeWitte et al. 2025).

Materials and methods

The gender of the individuals at Lejasbitēni had been estimated previously by grave goods and orientation. In total, there were 230 adult males, 103 adult females, and 10 adult individuals for whom it was not possible to estimate gender; and 46 non-adult males, 46 non-adult females, as well as six non-adult individuals for whom gender estimation was not possible (Pētersone-Gordina et al. 2022). Biological sex estimation in adult individuals used in this analysis was based on morphological characteristics of the skull (as described in Buikstra & Ubelaker 1994), since no pelvic bones were present. Throughout this study, 'gender' refers to the archaeologically attributed category based on the typology of grave goods and burial orientation (Arnold 2006; Moen 2019), while 'biological sex' refers to estimates derived from osteological morphology (Buikstra & Ubelaker 1994) or molecular analysis.

To understand what resources the Lejasbitēni human population might have relied on, previously published local archaeological faunal $\delta^{13}C$ and $\delta^{15}N$ values were used as a guide (Gunnarssone et al. 2020).

The primary focus of this study was to explore adulthood diet in individuals with available childhood data from dentine, and this was possible for six individuals (three females and three males; Table 1). Seven adult individuals (including one with available dentine data, LB28) were selected based on grave inventories or mortuary rituals that could be indicative of a particular social status. These comprised five female burials (LB28, LB111, LB112, LB155, and LB215) that contained an axe in their grave inventory; a richly furnished male burial (LB341); and another male burial (LB115). One of the female burials (LB215) contained an axe with a decorative bronze strip wound around the handle. Only 30 such axes (four of them in female gender burials) have been found in the territory of Latvia, mainly in the Latgalian and Selonian territories (Gerhards et al. 2024). The assessment of social status followed the established tradition in Latvian Iron Age archaeology, in which the richness and rarity of grave goods serve as the primary criteria for status attribution (Gerhards 2002; Gerhards et al. 2024). No formal quantitative scoring system was applied; individuals were classified as richly furnished based on items rare in the Lejasbitēni assemblage (Pētersone-Gordina et al. 2022). By selecting individuals with rich or unusual grave inventories, we intended to explore any potential status-related differences in diet within this small group.

Finally, two non-adult individuals thought to date from the 11th century CE Liv culture from the periphery of the cemetery were sampled to complement the dataset from the Lejasbitēni cemetery. The reason for their inclusion was to provide a point of dietary comparison with the chronologically earlier and ethnically distinct Lejasbitēni population. Since the Liv adult individuals at Lejasbitēni were cremated, bone collagen isotope analysis of adults from this group is not possible, meaning that the non-adults represent the only available biological material from this population at the site. Moreover, there are currently no isotope data from any other Liv population in Latvia that could be used for comparison. These results are discussed separately in Subsection 'Adulthood and childhood diet at Lejasbitēni' and are not included in the primary statistical analyses.

In total, dietary isotope analysis was carried out on bone samples from 12 adult individuals (seven females and five males; Table 1) and two non-adults. Poor preservation of skeletal material and the lack of post-cranial bones prevented the sampling of fragments from the same bone, with the selected samples including femora and hand phalanges, but mostly different bones of the skull (Table 1). Because of the selection of bone samples with differential turnover rates in this study, we acknowledge that the data obtained from this assemblage might not be comparable with respect to the time of life represented by the data. While this sample selection strategy is extremely limited in terms of population-level analysis, it provides valuable individual data from the people buried in the Lejasbitēni cemetery.

The documentation of the excavations, as well as all artefacts, is curated and is available for scientific research at the National History Museum of Latvia. The skeletal material from Lejasbitēni is curated at the Repository of Bioarchaeological Material, Institute of Latvian History, University of Latvia.

For the stable isotope analysis, bone samples were cleaned and abraded to a depth of >100 μm using a tungsten carbide dental drill. Collagen extraction was carried out using the method of O'Connell & Hedges (1999), briefly summarised here: unpowdered bone and dentine samples (c. 400 mg) were demineralised in refrigerated 0.5M HCl for several weeks and then thoroughly washed in Millipore Alpha Q water before gelatinisation in a pH 3 solution of HCl at 70 °C for 48 hours. The samples were then Ezee-filtered, frozen, and freeze-dried before being sent to the University of Bradford for analysis. At Bradford, samples and reference material (c. 0.3–0.5 mg) were weighed into tin capsules and introduced to the EA IsoLink™ via a MAS 200 autosampler (Thermo Fisher Scientific), alongside a pulse of oxygen to aid combustion. The combusted gases were then carried in a helium stream over a single quartz reactor column containing combustion catalysts (silvered cobaltous oxide and chromium oxide) and a reduction phase of high-purity copper wires to produce N_2, CO_2, and water. Water was removed using a water trap (magnesium perchlorate). The resulting gases were then separated on a GC column held at a constant temperature of 40 °C and were then transferred to a DELTA V™ Advantage isotope ratio mass spectrometer via a ConFlo IV Universal interface, where they were ionised and accelerated. Gas species of different masses were separated in a magnetic field, then simultaneously measured on a Faraday cup universal collector array. Analysis was based on monitoring of m/z 28 and 29 for N_2, then m/z 44, 45, and 46 for CO_2.

The results were calibrated against both internal and international standards that were run at the same time as the samples. The samples were batch processed, and standards were run at the start and end of the sequence to check for drift. One duplicate was run for every ten samples. Only one sample (LB112; Table 1) from this batch of samples was analysed in duplicate. The internal lab standards used for carbon and nitrogen isotopes were Bovine Liver ($\delta^{13}C_{v\text{-}PDB}$ = –21.59; $\delta^{15}N_{v\text{-}AIR}$ = +7.65) and Fish Gel ($\delta^{13}C_{v\text{-}PDB}$ = –15.52; $\delta^{15}N_{v\text{-}AIR}$ = +14.25). These in-house standards are calibrated against and traceable to inter-laboratory comparison standards distributed by the International Atomic Energy Agency (IAEA) with internationally accepted values: IAEA 600 ($\delta^{13}C_{v\text{-}PDB}$ = –27.77; $\delta^{15}N_{v\text{-}AIR}$ = +1), IAEA CH3 ($\delta^{13}C_{v\text{-}PDB}$ = –24.72), IAEA N1 ($\delta^{15}N_{v\text{-}AIR}$ = +0.40), and IAEA N2 ($\delta^{15}N_{v\text{-}AIR}$ = +20.41). The analytical error for carbon and nitrogen isotopes is $\leq$ 0.2‰.

Bone and comparative dentine samples from previous research were processed using an identical collagen extraction protocol (O'Connell & Hedges 1999) at the same laboratory (Durham University). The mass spectrometric analysis of the previous dentine samples was, however, performed at Durham University, while the bone samples from this study were analysed at the University of Bradford. Both laboratories use continuous-flow isotope ratio mass spectrometry and are calibrated against the same international standards (IAEA). The expected inter-laboratory variability for well-calibrated facilities is typically $\leq$ 0.2‰ for both $\delta^{13}C$ and $\delta^{15}N$, which is within the analytical error reported in both studies and is considerably smaller than the observed differences between dentine and bone values. Collagen quality indicators (carbon and nitrogen content, atomic C:N ratio) for both tissue types fall within accepted ranges (DeNiro 1985) and are reported in Table 1. The observed isotopic differences between bone and dentine are therefore attributed to genuine biological differences reflecting distinct tissue formation periods, rather than methodological artefacts (Szpak et al. 2017; Roberts et al. 2018).

Because of the small sample size, a two-tailed t-test was used to calculate statistical differences between adult male and female $\delta^{15}N$ and $\delta^{13}C$ values. The same test was applied to calculate differences between adulthood and childhood diets using results from the previous dietary analysis from dentine.

Both results were then confirmed with a non-parametric Mann–Whitney U-test. A Wilcoxon signed-rank test was applied to calculate the differences between dentine and bone values in the five individuals with both sets of data available.

Results

The results of the dietary stable isotope analysis are presented in Table 1 and Fig. 3. Sample LB114 had an atomic C:N ratio (4.8) outside the acceptable range (2.9–3.6; DeNiro 1985) and was not included in further analysis. The bone sample of individual LB112 was measured in duplicate, and for further analysis, the mean δ^{15}N‰ and δ^{13}C‰ values of the two measurements were used (9.03‰ and –21.70‰, respectively). The Liv burials are reported at the bottom of Table 1.

The mean, minimum, and maximum δ^{15}N (‰) and δ^{13}C (‰) values for all the other samples are presented in Table 2.

There were no statistically significant differences in δ^{15}N values between the adult males ($N = 4$, $M = 9.4$‰, $SD = 0.8$‰) and females ($N = 7$, $M = 9.0$‰, $SD = 0.4$‰) from the Lejasbitēni group, although the sample size for males was very small ($t(9) = –0.96$, $p = 0.360$, Cohen's $d = 0.60$). Likewise, the differences in δ^{13}C values between males ($M = –21.7$‰, $SD = 0.1$‰) and females ($M = –21.8$‰, $SD = 0.3$‰) were not significant ($t(9) = 0.70$, $p = 0.504$, Cohen's $d = 0.44$). The lack of significance was confirmed by a Mann–Whitney U-test for δ^{15}N values ($U = 10$, $p = 0.450$) and δ^{13}C values ($U = 9$, $p = 0.345$). The Liv non-adults were excluded from this comparison, as they belong to a different archaeological population group.

Comparative analysis revealed that the results from adult bone samples were significantly different from the dentine samples in this population, both in terms of their δ^{15}N values ($N = 12$, $M = 8.9$‰ and $N = 29$, $M = 9.9$‰, respectively, $t(38) = –3.00$, $p = 0.005$, Cohen's $d = 1.06$) and δ^{13}C values ($M = –21.8$‰ and $M = –22.7$‰, respectively, $t(38) = 6.30$, $p < 0.001$, Cohen's $d = 2.23$). The significant differences were confirmed by the Mann–Whitney U-test ($U = 58.50$, $p = 0.002$ for δ^{15}N values and $U = 10.00$, $p < 0.001$ for δ^{13}C values).

Four of the five adult individuals for whom childhood (dentine) and adulthood (bone) dietary data were available showed a shift from higher to lower δ^{15}N values, respectively, while the male gender individual from burial 332 had a slightly lower dentine δ^{15}N value than bone δ^{15}N value (10.3‰ and 10.5‰, respectively; Fig. 4). The shift from lower to higher δ^{13}C values in dentine compared to bone, however, was the same in all five individuals. The difference between bone and dentine in this small group was calculated with

TABLE 1. Individuals selected from the Lejasbitēni population and results of carbon and nitrogen stable isotope analysis

Burial No.	Gender	Age	Grave orientation (head first)	Sample type	$\delta^{15}N_{V\text{-}AIR}$ (‰)	$\delta^{13}C_{V\text{-}PDB}$ (‰)	%N	%C	C/N
LB28*^	F	20–25	NW–SE	Femur	8.7	–22.2	13.3	39.7	3.5
				M^1 dentine	9.3	–22.7	15.3	41.2	3.2
LB111^	F	>40	NW–SE	Parietal	9.2	–21.7	13.9	39.0	3.3
LB112a^	F	18+	NW–SE	Mandible	9.0	–21.8	13.4	37.9	3.3
LB112b^					9.0	–21.6	13.5	38.1	3.3
~~LB114*~~	~~M~~	~~>30~~	~~SE–NW~~	~~Parietal~~	~~5.9~~	~~–23.2~~	~~0.7~~	~~2.8~~	~~4.8~~
				M^1 dentine	9.6	–22.7	15.6	42.9	3.2
LB115	M		SE–NW	Frontal	8.8	–21.9	6.3	18.4	3.4
LB155^	F	16–18	NW–SE	Hand phalanx	8.8	–21.6	11.8	34.4	3.4
LB199*	F	25–30	SW–NE	Mandible	8.6	–21.9	12.6	35.9	3.3
				M_1 dentine	8.8	–22.6	15.0	42.9	3.2
LB215^	F	>30	W–E	Hand phalanx	9.2	–21.4	13.9	38.8	3.2
LB221*	M	45–50	E–W	Mandible	9.2	–21.6	8.0	23.5	3.4
				M^1 dentine	9.3	–22.2	15.5	43.1	3.2
LB332*	M	55–65	E–W	Zygomatic	10.5	–21.7	12.8	36.9	3.4
				M_1 dentine	11.4	–22.0	15.5	42.8	3.2
LB341	M	30–35	E–W	Femur	9.0	–21.6	13.3	38.7	3.4
LB344*	F	45–50	W–E	Parietal	9.8	–21.9	12.3	36.6	3.5
				M_1 dentine	10.0	–23.2	15.5	42.7	3.2
LB445**	M	10–11	NW–SE	Parietal	10.2	–21.5	13.7	38.9	3.3
LB448**	M	7–8	NW–SE	Parietal	10.1	–21.5	14.1	39.8	3.3

* Individuals with available carbon and nitrogen isotope data from dentine (Pētersone-Gordina et al. 2022); ** Liv culture non-adult individuals; ^ – axe in grave inventory; %N – nitrogen content; %C – carbon content; C/N – atomic C:N ratio; M^1 – maxillary first molar; M_1 – mandibular first molar

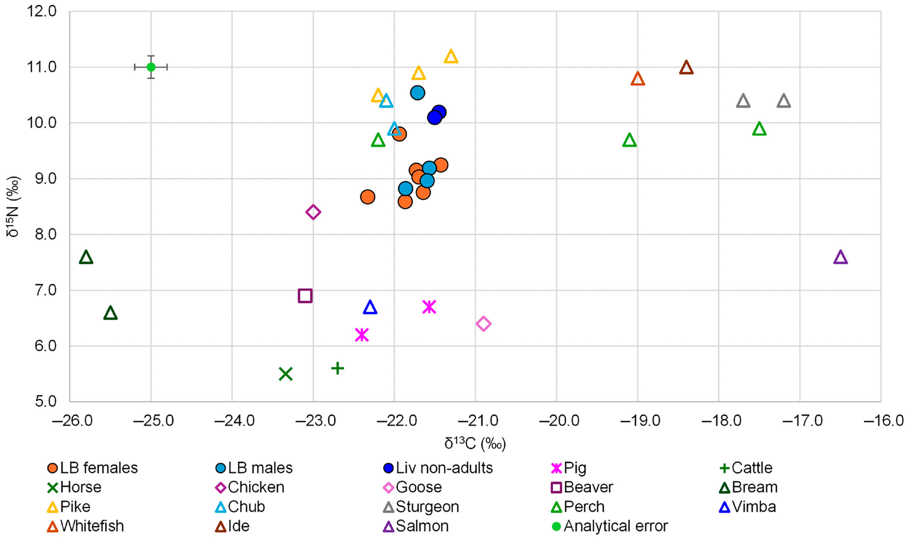

FIG. 3. Lejasbitēni (LB) male and female, and Liv non-adult isotope bone values obtained during this study (see Table 1 for bone elements sampled), along with previously published faunal data from Gunnarssone et al. (2020), including domestic animals (two pigs, a cow, and a horse), birds (a chicken and a goose), a beaver from Aizkraukle, and several freshwater (bream, chub, and pike), freshwater/brackish (perch, whitefish, and ide), migratory (vimba and sturgeon), and marine Baltic (salmon) fish from Daugmale, with both archaeological sites (Aizkraukle and Daugmale) located next to the River Daugava. Analytical error ($\leq$ 0.2‰) is shown in the upper left corner of the graph.

a Wilcoxon signed-rank test and proved to be statistically significant both in terms of $\delta^{15}N$ values ($N = 5$, $M = 9.4$‰ (bone) and $M = 9.8$‰ (dentine), $W = 0.00$, $p = 0.043$) and $\delta^{13}C$ values ($M = –21.9$‰ (bone) and $M = –22.5$‰ (dentine), $W = 0.00$, $p = 0.043$).

When compared within the same gender groups, the difference between the mean dentine and bone $\delta^{15}N$ values was more pronounced in males (1.1‰, 10.4‰, and 9.4‰, respectively) than in females (0.4‰, 9.4‰, and 9.0‰, respectively). In fact, the mean male bone $\delta^{15}N$ value was almost identical to the mean female dentine $\delta^{15}N$ value. With regard to $\delta^{13}C$ values, the difference between the mean dentine and bone values in males was 0.8‰ (–22.5‰ and –21.7‰, respectively), while in females it was 1.0‰ (–22.8‰ and –21.8‰, respectively), reaching one trophic level (Fig. 4). Female bone $\delta^{15}N$ values were not significantly lower than dentine values when calculated by a t-test ($N = 7$, $M = 9.0$‰ and $N = 15$, $M = 9.4$‰, respectively, $t(20) = –2.03$, $p = 0.056$, Cohen's $d = 0.93$), but the difference was significant by Mann–Whitney U-test ($U = 24.50$, $p = 0.048$), while male bone values were significantly lower than dentine values according to both tests ($N = 4$, $M = 9.4$‰ and $N = 14$, $M = 10.4$‰, $t(16) = –2.78$, $p = 0.014$, Cohen's

TABLE 2. Mean, standard deviation, minimum, and maximum $\delta^{15}N$ and $\delta^{13}C$ values for Lejasbitēni bone samples from adult individuals and previously published dentine samples

Gender	Sample size	Mean		Standard deviation		Minimum		Maximum	
		$\delta^{15}N$ (‰)	$\delta^{13}C$ (‰)	$\delta^{15}N$ (‰)	$\delta^{13}C$ (‰)	$\delta^{15}N$ (‰)	$\delta^{13}C$ (‰)	$\delta^{15}N$ (‰)	$\delta^{13}C$ (‰)
Bone (adulthood values)									
Male	4	9.4	–21.7	0.8	0.1	8.8	–21.9	10.5	–21.6
Female	7	9.0	–21.8	0.4	0.3	8.6	–22.3	9.8	–21.4
Overall	11	9.3	–21.7	0.6	0.2	8.6	–22.3	10.5	–21.4
Dentine (childhood values)*									
Male	14	10.4	–22.5	0.6	0.4	9.3	–23.2	11.5	–22.0
Female	15	9.4	–22.8	0.4	0.5	8.8	–23.6	10.0	–21.7
Overall	29	9.9	–22.7	0.7	0.5	8.8	–23.6	11.5	–21.7

* Data from Pētersone-Gordina et al. (2022)

$d = 1.57$ and $U = 8.00$, $p = 0.034$). In contrast, the $\delta^{13}C$ values were significantly higher in bone than dentine samples both in males, according to both statistical tests ($N = 4$, $M = –21.7$‰ and $N = 14$, $M = –22.5$‰, respectively, $t(16) = 4.26$, $p < 0.001$, Cohen's $d = 2.42$ and $U = 0.00$, $p = 0.003$) and females ($N = 7$, $M = –21.8$‰ and $N = 15$, $M = –22.8$‰, respectively, $t(20) = 5.30$, $p < 0.001$, Cohen's $d = 2.43$ and $U = 4.00$, $p < 0.001$) (Fig. 4).

Discussion

ADULTHOOD AND CHILDHOOD DIET AT LEJASBITĒNI

Bone values in the Lejasbitēni adult population are characterised by comparatively low $\delta^{13}C$ and $\delta^{15}N$ values, which point to a diet mainly comprising terrestrial resources based on C_3 crops and a small proportion of domestic animal proteins such as meat and dairy. In particular, the $\delta^{13}C$ and $\delta^{15}N$ values for the cow and horse were, respectively, 1.1‰ and 3.3‰ lower than the mean human bone values, indicative of a trophic-level shift. The inclusion of some aquatic resources cannot be ruled out, based on the highly variable $\delta^{13}C$ and $\delta^{15}N$ values of local fish, as shown by previously published values from Latvia (Gunnarssone et al. 2020; Fig. 3). To understand whether aquatic resources were indeed used in the Lejasbitēni population, and how

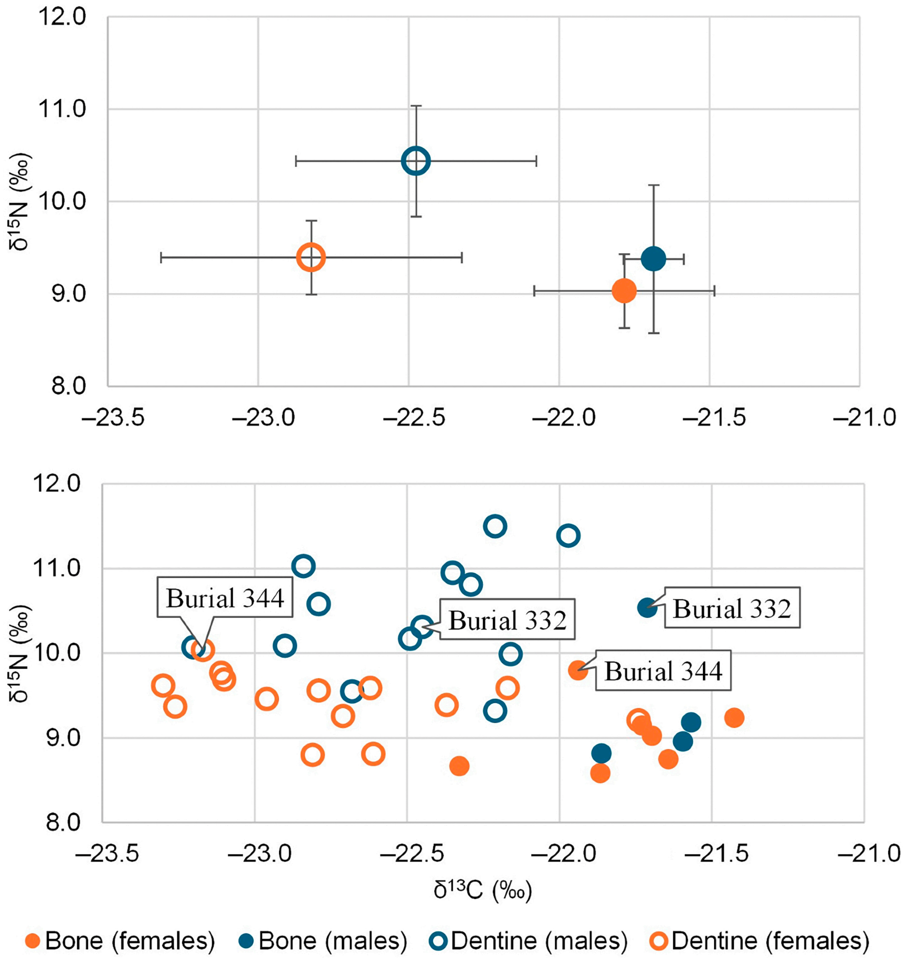

FIG. 4. Lejasbitēni male and female mean dentine and bone values ± 1 SD (upper graph) and individual bone and dentine values (lower graph).

important they were as a resource, compound-specific isotope analysis is necessary.

To identify differences in childhood and adulthood diets, the values obtained from bone during this study were compared with previously acquired dentine values, testing for statistical differences between the two sets of results (Fig. 4). Overall, the bone $\delta^{15}N$ values were significantly lower and $\delta^{13}C$ values significantly higher compared with those from dentine. In the two gender groups, the difference between bone and dentine $\delta^{15}N$ values was more pronounced in males than in females, while the difference between bone and dentine $\delta^{13}C$ values was pronounced in both gender groups. The same trend was observed in the five adult individuals for whom both sets of data were available, with the exception of the male gender individual from burial 332, whose dentine and bone $\delta^{15}N$ values remained similarly high, while the bone $\delta^{13}C$ value demonstrated a similar shift to that observed in other individuals from this group.

The key finding of the previous study about childhood diet in this population was that during the Viking Age, male gender non-adults had significantly higher $\delta^{15}N$ values and thus likely access to sources of higher-trophic-level protein compared with female gender non-adults, indicating that the source of protein in the diet during childhood was linked to gender. Since the human $\delta^{13}C$ values from dentine were similar to those of the domestic fauna, without demonstrating a trophic-level shift of 1‰, it was suggested that dietary sources with lower $\delta^{13}C$ values, such as freshwater organisms, were present in non-adults' diets. However, no childhood dietary differences were observed between individuals of different social status within the same gender group (Pētersone-Gordina et al. 2022).

The present study has demonstrated that, unlike in dentine, there were no statistically significant differences in either $\delta^{15}N$ or $\delta^{13}C$ bone values between gender groups, suggesting that in adulthood, both gender groups had access to similar sources of protein.

The isotopic trajectories from dentine to bone therefore suggest that the dietary differentiation observed in childhood did not persist into adulthood, and that individuals of both gender groups converged on a broadly similar diet dominated by terrestrial domesticated animals. This pattern may reflect a change in the subsistence resources available or consumed across the life course, or alternatively a relaxation of gender-based dietary distinctions, as individuals transitioned from childhood to adulthood. The transition to the adulthood diet was especially pronounced in male gender individuals, who appear to have had access to higher-trophic-level protein during childhood. Because the sample size is so small, it is possible that isotope analysis of bone in more individuals from this population, and preferably from individuals with already available dentine isotope values, will reveal more variation in the transition from childhood to adulthood diet.

Regarding the potential link between social status and diet, the highest bone $\delta^{15}N$ values were observed in individuals LB332 (a male) and LB344 (a female) (Fig. 4). Individual LB344 had the highest dentine $\delta^{15}N$ value among the tested female gender individuals, and the bone value was also the highest in the female gender group. Individual LB332 had a close-to-mean dentine $\delta^{15}N$ value, but the highest bone $\delta^{15}N$ value in the male gender group and overall (Fig. 4). Both individuals had richly furnished graves. In contrast, five female gender individuals who were buried with an axe (burials LB28, LB111, LB112, LB155, and LB215) and the richly furnished male burial LB341 all had close-to-mean $\delta^{15}N$ and $\delta^{13}C$ values, which formed a cluster with most other analysed individual values (Fig. 4). The lack of a clear pattern suggests that in this group of adult individuals, social status as expressed by grave goods might not have been related to access to resources. To test whether any individuals with higher or lower isotope values might have been non-local, including from a neighbouring community, incremental dentine $\delta^{13}C$ and $\delta^{15}N$ and enamel strontium isotope analyses would be necessary.

As to why there were significant dietary differences observed between the gender groups in childhood, but not in adulthood in the Lejasbitēni population, the demographic profile might provide a clue. In this cemetery, the number of male gender burials is twice that of female gender, and the number of adult burials far exceeds that of non-adults (Pētersone-Gordina et al. 2022). Such deviation from the expected demographic profile of a living population is commonplace in most Latgalian cemeteries from the 7th–10th centuries CE. Researchers have suggested that these common burial places were only reserved for individuals with a particular social status (Gerhards 2002). In this pilot study, dietary isotope analysis included five females who were buried with an axe, which is a very rare item in female gender burials (Table 1; Fig. 5). There were no statistically significant differences in bone isotope values between the Lejasbitēni females who had an axe in their grave inventory ($N = 5$) and males ($N = 4$), either in their $\delta^{15}N$ values ($M = 9.0‰$ and $M = 9.4‰$, respectively, $t = -1.11$, $p = 0.304$, Cohen's $d = 0.74$) or $\delta^{13}C$ values ($M = -21.7‰$ and $M = -21.7‰$, $t = -0.30$, $p = 0.771$, Cohen's $d = 0.20$). Due to the insufficient dietary isotope data from other female gender individuals in the cemetery, however, it is not clear whether the currently observed lack of adulthood dietary differences between gender groups applied only to selected individuals or to the whole adult population at Lejasbitēni. This will be explored in an upcoming study.

Finally, comparison between the mean bone values of the two Liv non-adults and the previously published Lejasbitēni dentine values suggests dietary differences between the two groups. Their mean bone $\delta^{15}N$ value (10.1‰) fell between the mean male (10.4‰) and female gender (9.4‰) Lejasbitēni dentine values, although both differences were below 1‰ and thus considerably short of one trophic level. The mean Liv bone $\delta^{13}C$ value (–21.5‰) was 1.0‰ and 1.3‰ higher than the mean male and female Lejasbitēni dentine values (–22.5‰ and –22.8‰, respectively), a difference equivalent to approximately one trophic level. The combination of $\delta^{15}N$ values broadly comparable to the Lejasbitēni population but notably higher $\delta^{13}C$ values suggests that the Liv non-adults had access to a different protein source, such as freshwater resources or terrestrial animals with different isotopic baselines, rather than simply consuming more or less protein overall. However, given the sample size of only two individuals, these observations are preliminary and should be interpreted with caution.

FIG. 5. Grave inventory of female gender burial LB215 from the Lejasbitēni cemetery. The artefacts are stored in the National History Museum of Latvia (LNVM A11912). Photo by Antonija Vilcāne.

COMPARISON OF THE LEJASBITĒNI BONE AND DENTINE ISOTOPE DATA WITH OTHER LOCAL AND REGIONAL SITES

To place the Lejasbitēni isotope data in a wider context, it is necessary to compare them with broadly contemporary local and regional archaeological populations. The mean Lejasbitēni bone $\delta^{15}N$ value (9.3‰) is slightly higher than that from the contemporary Čunkāni-Dreņģeri cemetery from Zemgale (N = 29, M = 8.9‰; Pētersone-Gordina et al. 2023), and slightly lower than that of the rural 13th–15th-century Siksali site in Estonia (N = 16, M = 9.6‰; Aguraiuja-Lätti & Malve 2023); the Siksali population is thought to have retained Iron Age traditions well into the medieval period (Valk & Laul 2014), and according to the interpretation of recent isotopic data, its diet was based almost entirely on terrestrial resources (Aguraiuja-Lätti & Malve 2023). The mean Lejasbitēni bone $\delta^{15}N$ value is also comparable with the mean bone value of the Estonian Iron Age population of Kukruse (N = 10, M = 10.0‰), where pottery lipid compound-specific stable isotope analysis

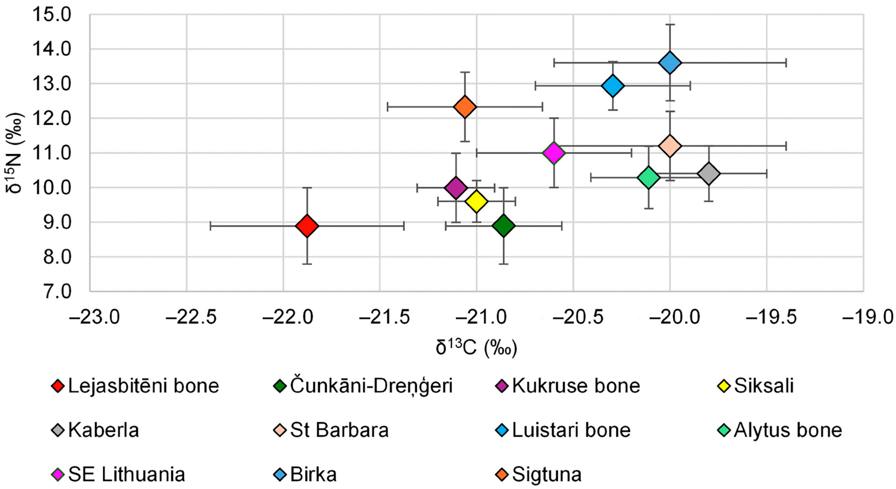

FIG. 6. Lejasbitēni bone values against the mean bone values ± 1 SD of comparative sites in Čunkāni-Dreņģeri, Latvia (N = 29, 7th–11th centuries CE; Pētersone-Gordina et al. 2023); Alytus, Lithuania (N = 35, 14th–18th centuries CE; Whitmore et al. 2019), three barrow sites in SE Lithuania (N = 3, 3rd–5th centuries CE; Bliujienė et al. 2020); Kukruse (N = 10, 12th–13th centuries CE; Oras et al. 2018), Siksali (N = 16, 13th–15th centuries CE; Aguraiuja-Lätti & Malve 2023), Kaberla (N = 29, 12th–16th centuries CE; Aguraiuja-Lätti & Lõugas 2019), and St Barbara, Estonia (N = 30, 12th–16th centuries CE; ibid.); Luistari, Finland (N = 23, 7th–11th centuries CE; Etu-Sihvola et al. 2022); Birka (N = 19, 8th–9th centuries CE; Linderholm et al. 2008) and Sigtuna, Sweden (N = 76, 12th–14th centuries CE; Kjellström et al. 2009).

(CSIA) detected evidence for aquatic (marine and freshwater) resource use in ceramic vessel contents (Oras et al. 2018); the elevated mean bone $\delta^{15}N$ value (10.0‰) is broadly consistent with this inference, though the CSIA evidence derives from ceramic vessels rather than human tissues directly.

In other regional archaeological sites with mainly C_3 food-chain diets, the mean bone $\delta^{15}N$ values were higher, including those from Alytus, Lithuania (N = 35, M = 10.3‰; Whitmore et al. 2019) and three barrow sites from SE Lithuania (N = 3, M = 11.0‰; Bliujienė et al. 2020), and the Estonian sites of Kaberla (N = 29, M = 10.4‰; Aguraiuja-Lätti & Lõugas 2019) and St Barbara (N = 30, M = 11.2‰; ibid.). In broadly contemporary sites further afield, with diets likely comprising a higher proportion of aquatic resources, bone $\delta^{15}N$ values were higher still, for example, in the Finnish site of Luistari (N = 23, M = 12.0‰; Etu-Sihvola et al. 2022), and the Swedish sites of Birka (N = 19, M = 13.6‰; Linderholm et al. 2008) and Sigtuna (N = 76, M = 12.33‰; Kjellström et al. 2009) (Fig. 6).

In contrast, the mean $\delta^{13}C$ values in all comparative sites used in this study were higher than those at Lejasbitēni (–21.9‰), including those from the contemporary Čunkāni-Dreņģeri cemetery (–20.9‰; Pētersone-Gordina et al. 2023), as well as the Estonian sites of Siksali (–21.0‰; Aguraiuja-Lätti & Malve 2023) and Kukruse (–21.1‰; Oras et al. 2018), and also that from the Swedish site of Sigtuna (−21.1‰; Kjellström et al. 2009), although the difference with these sites was less than 1‰. In all other comparative sites, the mean $\delta^{13}C$ bone values were at least 1‰ higher than those at Lejasbitēni. Altogether, the lower mean $\delta^{15}N$ and $\delta^{13}C$ values in the Lejasbitēni individuals compared with most other populations likely indicate that they mainly relied on low-trophic-level protein and insignificant amounts of marine or brackish-water fish. The possible explanations for the exceptionally low mean $\delta^{13}C$ value at Lejasbitēni (–21.9‰) are as follows: (1) the canopy effect, whereby domestic cattle grazed in forested areas – ancient and modern wild herbivores foraging under a closed canopy have yielded lower $\delta^{13}C$ values than those grazing in open areas (e.g. Drucker et al. 2008); (2) the complete absence of C_4 resources (notably millet), consistent with the very low values observed, as millet consumption typically raises $\delta^{13}C$ above −20‰ (Katzenberg 2008; Danielisova et al. 2025); and (3) unusual local faunal isotope baselines reflecting specific ecological conditions in the Daugava floodplain environment. To explore this possibility, a systematic isotopic study of contemporary local domestic fauna is necessary.

Three regional sites had available data from both dentine and bone, including Kukruse in Estonia (Oras et al. 2018), Luistari in Finland (Etu-Sihvola et al. 2022), and Alytus in Lithuania (Whitmore et al. 2019). Further afield, data were available from Mikulčice, the Czech Republic (9th–10th centuries CE; Jílková et al. 2019), and Solt-Tételhegy, Hungary (13th century CE; Gugora et al. 2018). These comparative populations revealed a wide variety of childhood and adulthood diets, rather than specific trends. Differences between childhood and adulthood diets were observed in all comparative populations except for the mean dentine and bone $\delta^{15}N$ values in Alytus, which were almost identical (Whitmore et al. 2019), and the observed differences were dependent on the type of tooth sampled, geographic location, and available resources (e.g. diets dominated by C_3 and C_4 plants, terrestrial and/or aquatic resources), the local traditions of weaning, as well as factors such as social status and biological sex, among many others. To understand what factors might have influenced the shift from childhood to adulthood diet at Lejasbitēni, more data are necessary from the rest of the population, as the current results are based only on selected individuals.

Conclusions

This pilot study has achieved its aim of comparing childhood and adulthood diets in selected individuals from the Lejasbitēni population. Comparison of bone collagen isotope data obtained during this study with previously published dentine isotope data revealed a statistically significant shift towards lower $\delta^{15}N$ and higher $\delta^{13}C$ values in adulthood, indicating a change in the trophic level of animal protein consumed and a diet more clearly dominated by domesticated terrestrial animals across the life course in the Lejasbitēni population. Unlike dentine data, bone $\delta^{15}N$ values were not significantly different between gender groups, suggesting a more homogeneous diet in adulthood. This may reflect the fact that this cemetery was reserved for individuals of a particular social status, as supported by the highly uneven ratio of adult male to female gender burials.

Higher bone $\delta^{15}N$ values were not always consistent with rich grave inventories, suggesting that social status as expressed by grave goods did not clearly correlate with access to dietary resources in this group. The low $\delta^{13}C$ and $\delta^{15}N$ bone values place Lejasbitēni among the lowest in the wider region, consistent with a diet based primarily on C_3 terrestrial resources with no detectable marine contribution. Preliminary isotope data from two Liv culture non-adults buried at the periphery of the cemetery suggest dietary differences from the main Lejasbitēni population, though the very small sample size precludes firm conclusions.

As this study is based on a small and selected group of individuals, further research is necessary to establish whether these patterns apply to the broader Lejasbitēni population and to clarify the relationship between life-course dietary change, gender, and social status.

DATA AVAILABILITY STATEMENT

All data are included within the paper.

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Lapse- ja täiskasvanuea toitumise võrdlus Läti viikingiaegse Lejasbitēni kalmistu populatsioonis: pilootuuring

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RESÜMEE

Pilootuuringu eesmärk oli uurida toitumise muutusi elukaare jooksul valitud täiskasvanud indiviididel Lejasbitēni kalmistult (Läti, 7.–10. saj pKr), võrreldes luukollageeni stabiilsete süsiniku- ($\delta^{13}C$) ja lämmastikuisotoopide ($\delta^{15}N$) väärtusi, mis peegeldavad täiskasvanuea toitumist, varem avaldatud esimese jäävpurihamba dentiini isotoopandmetega, mis kajastavad lapsepõlve toitumist. Lisaks oli eesmärk hinnata sooga seotud toitumiserinevuste püsimist täiskasvanueas ning uurida võimalikke seoseid sotsiaalse staatuse (mida väljendavad hauapanused) ja ressurssidele juurdepääsu vahel.

Luukollageen eraldati 12 täiskasvanud indiviidilt ja kahelt liivi kultuuri mittetäiskasvanud indiviidilt, kasutades standardset demineraliseerimise ja želatiniseerimise protokolli. Isotoopsuhted määrati pidevvoolu-isotoopsuhte massispektromeetria abil ning andmeid analüüsiti t-testide, Manni-Whitney U-testide ja Wilcoxoni astakmärgitestide abil.

Uuringu peamised tulemused näitavad, et Lejasbitēni täiskasvanuea toitumist iseloomustasid suhteliselt madalad $\delta^{13}C$ ja $\delta^{15}N$ väärtused luukollageenis, mis paigutab selle populatsiooni Baltikumi laiemas kontekstis madalaimate hulka ning viitab maismaa C_3-taimedel põhinevate ressursside domineerimisele ja loomse valgu suhteliselt vähesele osakaalule toidus.

Statistiliselt oluline nihe lapsepõlvest täiskasvanuikka madalamate $\delta^{15}N$ ja kõrgemate $\delta^{13}C$ väärtuste suunas tuvastati kogu valimis (vastavalt $p = 0{,}005$ ja $p < 0{,}001$) ning sama tendents kinnitati ka viiel indiviidil, kelle kohta olid andmed mõlemast koest. Erinevalt lapsepõlvest, mil meessoost indiviididel esinesid naissoost indiviididega võrreldes märksa kõrgemad $\delta^{15}N$ väärtused, ei ilmnenud täiskasvanueas statistiliselt olulisi soopõhiseid isotoopilisi erinevusi, mis viitab täiskasvanute toitumise suuremale homogeensusele.

Kõrgemad $\delta^{15}N$ väärtused luukollageenis ei korreleerunud järjekindlalt rikkalikumate hauapanustega, mistõttu selget seost sotsiaalse staatuse ja toiduressurssidele juurdepääsu vahel ei ilmnenud. Kahe liivi kultuuri mittetäiskasvanud indiviidi esialgsed isotoopandmed viitasid erinevustele võrreldes Lejasbitēni põhipopulatsiooniga, eriti $\delta^{13}C$ väärtuste osas, kuid väga väikese valimi tõttu jäävad järeldused esialgseks.

Autorid rõhutavad, et kuna uuring põhineb väikesel ja sihipäraselt valitud indiviidide rühmal, on vajalikud edasised isotoopuuringud Lejasbitēni ülejäänud populatsiooni kohta, et kinnitada täheldatud mustreid ning täpsustada toitumise muutuste, soo ja sotsiaalse staatuse vahelisi seoseid elukaare jooksul.