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Babes, bones, and isotopes: a stable isotope investigation on non-adults from Aventicum, Roman Switzerland (1st-3rd c. CE)

RUNNING TITLE: INFANT DIET, HEALTH AND STABLE ISOTOPES

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Abstract

The study of infant feeding practices in archaeological populations can aid in the understanding of cultural attitudes towards dietary choices and how specific circumstances experienced by mothers and their offspring influence childhood health and survivorship. Breastfeeding and weaning patterns have received increased interest in Roman bioarchaeology, especially through the application of stable isotopic investigation of nitrogen ($\delta^{15}N$) and carbon ($\delta^{13}C$) values. This study presents the stable isotopic results of the first Roman bone sample analyzed from Switzerland (30 non-adults and 9 females), allowing us an unprecedented insight into health and diet at the site of Aventicum/Avenches, the capital city of the territory of *Helvetii* in Roman times (1st-3rd c. AD). The fact that the majority of the non-adult samples subject to stable isotope analysis were perinates, highlights the complex relationship between their $\delta^{15}N$ and $\delta^{13}C$ values and those of adult females, as different factors, including variation of fetal and maternal stable isotope values, the possible effects of intrauterine growth, as well as maternal/fetal disease and/or nutritional stress (e.g. nutritional deficiencies such as scurvy, parasitic infections, such as malaria), could have influenced the observed elevated $\delta^{15}N$ values.

Keywords: perinatal, stable isotopes, nitrogen isotopes, maternal/fetal stress

INTRODUCTION

The study of infant feeding practices in archaeological populations can aid in the understanding of how diet affects childhood health and survivorship. Human breastmilk –in particular colostrum, the milk produced in the first three-four days postpartum– contains numerous nutrients for infant growth and immunological development, but after the age of six months, breastmilk alone cannot meet the nutritional needs of the infant and supplementary foods are necessary to maintain growth (Lawrence and Lawrence, 2016). The weaning process (when breastmilk in the infant's diet is supplemented with other foods, finally to be replaced with them), is a critical period related to infant mortality and morbidity, since the introduction of supplementary foods can expose infants to pathogens and nutritional stress at a time when its immune system is under development (Goodman and Armelagos, 1989; Katzenberg et al., 1996; Herring et al., 1998; Fairgrieve and Molto 2000; Wheeler 2012; Bourbou, 2014). Infant feeding practices are also culturally determined, and their study reveals attitudes towards specific dietary choices in a given population (Fildes, 1986; Sellen and Smay, 2001; Leeming et al., 2013; Kendall, 2016; Mays et al., 2017; Halcrow et al., 2018a).

These practices have received increased interest in Roman bioarchaeology, especially through the application of stable isotopic investigation (Dupras et al., 2001; Prowse et al., 2004, 2005, 2008; Dupras and Tocheri, 2007; Fuller et al., 2006a; Redfern et al., 2012, 2018; Eerkens et al., 2018; small non-adult samples are also analyzed by Keenleyside et al., 2009; Rutgers et al., 2009; Killgrove and Tykot, 2013, 2018). To date, no large-scale stable isotopic studies have examined infant feeding practices in Roman populations from Switzerland, but a pilot study of 11 non-adults and two females from Roman Petinesca (Switzerland) combines tooth histology (presence of a neonatal line) and stable nitrogen and carbon values in order to clarify a breastfeeding signal and birth survival (Lösch et al., 2013, Siebke et al., 2019). Here we investigate breastfeeding and weaning patterns through stable isotope analysis of nitrogen ($\delta^{15}N$) and carbon ($\delta^{13}C$) ratios from bone samples of 30 non-adults ranging from perinatal to 12-13 years of age, at Aventicum/Avenches (1^{st}-3^{rd} c. CE). This work provides an unprecedented insight into Roman infant feeding practices in Switzerland, also setting the stage for future studies.

2. METHODOLOGY OF STABLE ISOTOPE RATIO ANALYSIS

Stable isotope analysis of nitrogen ($\delta^{15}N$) and carbon ($\delta^{13}C$) values of bones and/or teeth have greatly contributed to the study of breastfeeding and weaning patterns in past populations. The analysis is based on the shifts in infant tissues $\delta^{15}N$ and $\delta^{13}C$ values that typically occur at the onset and termination of breastfeeding (Tsutaya and Yoneda, 2015). Observations showed that infant $\delta^{15}N$ values rise rapidly with the onset of breastfeeding, reaching a plateau roughly one trophic level (~2-3‰) above the mother's tissue value (Fogel et al., 1989; Fuller et al., 2006b). As the introduction of supplementary foods begins, the values decline, falling to a level similar to the mother's after nursing has stopped completely (Jay, 2009). A similar, subtler, effect (~1‰) is present for $\delta^{13}C$ and this can be used to better understand the timing of the introduction of solid foods (Fuller et al., 2006b). However, it

needs to be highlighted that $\delta^{15}N$ and $\delta^{13}C$ isotopic ratios can only serve as indicators of weaning timespan and not as an absolute point of time, since those who died in childhood represent those who did not survive (Wood et al., 1998; Richards et al., 2002; Beaumont et al., 2015; Reynard and Tuross, 2015: Craig-Atkins et al., 2018).

3. ARCHAEOLOGICAL CONTEXT: THE CHILDREN OF AVENTICUM

The territory of *Helvetii* was integrated into the Roman Empire in 15 BCE and Aventicum (nowadays Avenches) served as its capital city. Aventicum was built in the heart of the Swiss plateau, between Jura and the Alps (Figure 1). It became a Roman colony under the rule of Emperor Vespasian (71-72 CE), enjoying prosperity during the 2nd century CE, before its progressive decline after the middle of the 3rd century CE (de Pury-Gysel, 2011, 2012). During the last decades, intensive rescue excavations revealed the rich funerary past of Aventicum with the discovery of extended cemeteries, dating from the 1st to the 3rd centuries CE. Non-adult burials (including those of perinates) were found scattered among those of adults. Independently of their age, non-adults were placed in a supine or lateral position, usually in simple pits or in wooden coffins within pits and without a specific orientation. Further, the archaeology of Aventicum has provided rich material evidence on the lives of children such as clay and glass vessels including feeding bottles deposited in their burials, funerary inscriptions (Frei-Stolba and Bielman, 1996), clay figurines in the motif of *dea nutrix* (Dasen, 1997). The non-adults under study are derived from the cemeteries of "En Chaplix", "Les Tourbières", "Sur Fourches", and "À la Montagne" (for an overview, see Bourbou, 2018).

3.1. Roman infant feeding practices

There is no documentary evidence for infant feeding strategies referring specifically to Roman Switzerland, but exists from the Mediterranean regions of the Roman world. For example, Soranus' *Gynecology*, (2nd c. CE), discuss in detail such dietary recommendations (Dasen, 2015). Breastmilk was considered the ideal food, but it was recommended to avoid colostrum, as maternal milk during the first 20 days, coming from a disturbed body, was not good. The newborn should not be fed for as long as two days and rather moderately boiled honey should be given. Foods, such as butter or southernwood (*Artemisia abrotanum*) with butter, were thought heavy for the stomach and should be avoided in the first days of life (Temkin, 1991, 88–89). Weaning was considered a fairly crucial step in the child's life and thus it should have been a gradual process. The introduction of solid foods was not recommended before the age of six months, but at that age the child's body was ready to receive solid food, such as fine crumbles soaked in hydromel, milk, grape must or wine with honey. Later, gruel made on the basis of wheat groats, a soft-boiled egg, or some delicate bread soaked in wine mixed with water, could be given (Temkin, 1991, 117-118).

Nevertheless, any attempt to reconstruct infant feeding in the past is not completely based on documentary evidence alone, since they are usually discussing the best practice rather than the common practice, and are socially selective towards the upper class. Furthermore, spatial and regional differences in child care within the diverse communities incorporated in the Roman Empire must have existed, including local customs or specific

circumstances experienced by mothers and their offspring. The application of stable isotope analysis on Roman infant feeding practices have suggested temporal and spatial variation, underscoring the importance of childhood diets as a complex interaction of social, cultural and health factors. In Roman Britain, for example, supplementary foods (broadly preparations made of cereals) were introduced by six months of age (or by the age of one and a half years at Queenford Farm), and gradually, children have been fully weaned by the age of four years (e.g. Fuller et al., 2006a; Redfern et al., 2012, 2018). In Italy, the largest stable isotopic study by Prowse and colleagues (2004, 2005, 2008) for the site of Isola Sacra, indicated that supplementary foods were introduced by the end of the first year and that weaning was completed by two-two and a half years of age. The analysis of smaller samples from elsewhere in Italy, tentatively suggested that children between two-three years old were still breastfed but were probably weaned shortly after (e.g. Rutgers et al. 2009; Killgrove and Tykot, 2013, 2018). Similarly, the small sample analyzed from Leptiminus (Tunisia) demonstrated that introduction of solid foods began before the age of two years and that weaning was completed by the age of three years (Keenleyside et al., 2009). These analyses have also suggested regionally specific weaning diets: low in marine resources at Dorset (Redfern et al., 2012), with a significant input of C_4 plant-derived protein at Sudan (Eerkens et al., 2018), on goat and/or cow's milk at Egypt (Dupras et al., 2001; see also Fairgrieve and Molto 2000), or rich in carbohydrates at Isola Sacra (Prowse et al., 2008).

4. MATERIALS AND METHODS

4.1. Sample selection

The skeletal collection under study included 93 non-adults, previously studied by the first author (Bourbou, 2018). Age-at-death was estimated based on standards for deciduous and permanent tooth formation (Moorrees et al., 1963a, 1963b; Smith, 1991), and by measuring the diaphyseal lengths of the limb bones and/or the development of cranial elements (Scheuer and Black, 2000; Table 1). There was no attempt to determine the sex of non-adults (contra Arthur et al., 2016). Based on the availability of sufficient bone for analysis (3-5g), 81 non-adult samples, ranging from <37 weeks gestation to 12-13 years old, were collected from diaphyseal long bone fragments and the pars petrosa, (for the selection of pars petrosa, see Jørkov et al., 2009; for differences in bones turnover rates see Beaumont et al., 2018). Diaphyseal long bone fragments from 16 adult females were also subject to stable isotope ratio analysis. Sex determination (using the available morphological features of the cranium and the pelvis) and age estimation (using pubic symphysis, auricular surface morphology, and dental wear), were recorded according to standard methodology as cited in Buikstra and Ubelaker (1994). In order to interpret the trophic context for the human isotope data, 27 faunal bone samples from burials and disposal pits recovered in the cemeteries under study, were analyzed.

4.2. Collagen preparation

The extraction of bone collagen was performed using a modified acid-base extraction method after Ambrose (1990, 1993), DeNiro (1985), and Longin (1971). The bones were

mechanically cleaned and treated in an ultrasound bath with distilled water (ddH_2O). The samples were then dried and ground to powder. For each sample, 500mg ± 3mg of bone powder was weighed. The samples were treated with 10ml of 1M hydrochloric acid (HCl) for 20min at room temperature. Samples were washed with ddH_2O until neutralized and 10ml of 0.125M Sodium hydroxide (NaOH) was added to the solution, which then was left for incubation (20h) at room temperature. The samples were washed with ddH_2O until neutralization and 10ml of 0.001M HCl was added and placed in a 90°C water bath for 10-17h allowing solubilisation of the collagen. The solubilised collagen was filtered and freeze-dried. The solid collagen was sent for analysis to Isolab, Germany. The data are a mean of three measurements taken from each sample, expressed in δ-notation per mil (‰). The standards used are Vienna Pee Dee Belemnite, (VPDB) for carbon and Ambient Inhalable Reservoir, (AIR) for nitrogen. Internal analytical errors were recorded as 0.1‰ for $\delta^{13}C$ and 0.2‰ for $\delta^{15}N$ and descriptive statistics were performed with Microsoft Excel.

5. RESULTS

The results of the carbon and nitrogen isotope analysis for non-adults, females and the fauna are listed in Tables 2, 3 and 4, respectively. Collagen integrity was determined from three criteria: a) percentage weight yield of collagen (Brock et al., 2010); b) C:N ratio of bone collagen (DeNiro, 1985; van Klinken, 1999); and c) total bone collagen %C and %N (Ambrose,1990). Fifty-one non-adult, seven female, and 17 faunal samples provided insufficient or no collagen, which may be due to taphonomic factors. The collagen average yield of 3.5 ± 2.2 wt% (1sd) obtained for the rest of the non-adult samples (n= 30) indicate that they had good preservation. Same with the average yields of the female (3.5 ± 2.6 wt%; n=9), and the faunal (3.5 ± 2.0 wt%; n=10) samples. Samples with lower percentage have no atypical values in other criteria (e.g. all molar C:N ratios were between 3.1 and 3.6). Similarly, the carbon (39.6 ± 4.5 wt% C) and nitrogen (14.0 ± 1.7 wt% N) contents indicate that collagen obtained from the 30 non-adults was well preserved. The carbon and nitrogen contents of the females were 43.5 ± 2.2 wt% C and 15.9 ± 0.8 wt% N, and of faunal remains of 43.1 ± 2.0 wt% C and 15.4 ± 0.9 wt% N.

5.1. Animal data

We consider the animals as local, representing livestock specimen. The herbivores have a mean of -21.9 ± 0.4‰ for $\delta^{13}C$ and 5.5 ±1.0‰ for $\delta^{15}N$ and the omnivores of -20.5 ± 0.9‰ for $\delta^{13}C$ and 6.8 ±1.3‰ for $\delta^{15}N$. Concerning the herbivores, the two horses have the most $\delta^{13}C$ depleted values, even of all animals studied. The four pigs have similar $\delta^{13}C$ values but a large range in $\delta^{15}N$ values. They could have consumed human refuse, something observed at other Roman sites (e.g. Rissech et al., 2016). The single dog has $\delta^{13}C$ of -20.3 and $\delta^{15}N$ of 8.3 reflecting an omnivorous diet, while the single chicken analyzed had the higher $\delta^{13}C$ values (-19.2‰) in the faunal sample. Both animals could have consumed human refuse as well. In general, there is a relative small trophic level of $\Delta^{15}N$=1.3‰ ($\Delta^{13}C$=1.4‰) between herbivores and omnivores observable.

5.2 Human data

The $\delta^{15}N$ results of the non-adults range from 7.8‰ to 12.5‰ (mean ± SD= 10.8 ± 1.0‰) and the $\delta^{13}C$ values range from -20.5‰ to -18.7‰ (mean ± SD= -19.5 ± 0.5‰). The females show means of -19.1 ± 0.8‰ for $\delta^{13}C$ and 9.7 ± 0.7‰ for $\delta^{15}N$. The diet at Aventicum was at large based on a terrestrial C_3 ecosystem. However, the $\Delta^{15}N$ between omnivores and adult females amounts 2.9‰ ($\Delta^{13}C$=1.4‰), between herbivores and adult females even 4.2‰ ($\Delta^{13}C$=2.8‰). These data imply that the humans must have a diet sufficient of animal proteins in general. Female, #F3 shows the highest $\delta^{13}C$ value of -17.4‰ in the overall adult sample, but without ^{15}N enrichment that would suggest the consumption of marine protein. Alternative explanations are a diet with regular consumption of low-trophic level marine protein or C_4 plants (e.g. millet). Nevertheless, while the enrichment in $\delta^{13}C$ may be related to diet, it could also reflect environmental variation ($\delta^{13}C$ values of C_3 plants are relatively enriched in regions with warmer climates, van Klinken et al., 2000), thus a non-local origin cannot be excluded for #F3. Some females (#F1, F14, F15, F16) show a combination of high $\delta^{15}N$ ratios and a terrestrial C_3-signal. Several nutritional habits can be suggested, such as the consumption of a relatively large proportion of animal protein, or freshwater resources (e.g. Müldner and Richards, 2007; Rutgers et al., 2009).

All data are plotted in Figure 2, the non-adults separated in age including the female average, in Figures 3 and 4. It is assumed that children still breastfeeding or who had been recently weaned would demonstrate isotope values enriched to those of the average adult female of around 1‰ in $\delta^{13}C$ and 2-3‰ in $\delta^{15}N$. Nearly all non-adults have elevated $\delta^{15}N$ values compared to the adult female mean but only a few of them have values which reach the expected ca. 2–3‰ increase, indicative of a breastfeeding signal in relevant studies (e.g. Fuller et al., 2006b). The majority of non-adult individuals aged around birth to one and a half years have $\delta^{13}C$ values (-19.4 ± 0.5‰) and $\delta^{15}N$ values (10.8 ± 0.9‰) within the standard deviation of the female mean, and do not present the indicated trophic increase of nursing. Although it is not possible to estimate if the weaning process was variable and/or gradual, individual #74 (three years old) still shows elevated $\delta^{15}N$ values (12.5‰). Most probably, shortly after the age of three years breastfeeding ceased, as $\delta^{13}C$ and $\delta^{15}N$ values suggest for non-adults aged around four years. Weaning diet could have been largely based on C_3 terrestrial foods with little animal protein (cf. #19, ca. four years old: $\delta^{13}C$ of -20.2‰ and $\delta^{15}N$ of 8.5‰), while the $\delta^{13}C$ and $\delta^{15}N$ values of older non-adults fall within the adult range (cf. #77, around 12 years old: $\delta^{13}C$ of -19.6‰ and $\delta^{15}N$ of 10.5‰) most probably suggestive of a diet with some freshwater fish and/or animal protein.

6. DISCUSSION

The isotopic investigation of the Aventicum sample adds to the corpus of studies, which broadly acknowledge breastfeeding and weaning patterns as attested in the textual evidence but also express –as expected in such a culturally diverse Empire– that local customs or specific circumstances experienced by mothers and their offspring must have played an important role (Craig-Atkins et al., 2018). The fact that in most Aventicum individuals aged between birth to one and a half years the elevated $\delta^{15}N$ values, in comparison with the female mean, do not reach the expected ca. 2–3‰ trophic level increase

indicative of nursing, calls for further investigation (Siebke et al., 2019). A reasonable explanation for the lack of a breastfeeding signal in these individuals could have been that they were not breastfed or that they did not live long enough for the signal to be observed in their bone collagen (Katzenberg, 1993; Richards et al., 2002; Fuller et al., 2006b; Jay et al., 2008; Kinaston et al., 2009; Redfern, 2018; Siebke et al. 2019). For example, individuals #1, #4, #8 and #16 had less chances to survive long beyond birth due to their prematurity (<37 weeks gestation) and thus breastfed, but three of them show elevated $\delta^{15}N$ values ranging from 10.2‰ to 11.1‰ (Aly et al., 2005; Siebke et al., 2019). Further, the recording of unexpected high or low $\delta^{15}N$ values in perinatal bone collagen could indicate an in utero value (cf. #20, fullterm; the $\delta^{15}N$ value of 7.8‰ may be registering a low maternal in utero value), or that these perinates might have been nursed by a woman with lower than average $\delta^{15}N$ diet herself (Beaumont et al., 2015). Female #F3, who had the lowest nitrogen isotope value in the sample (8.3‰), if she were to breastfeed, possibly the trophic level increase of consuming her breastmilk would have been invisible in a perinate. A preterm (#1) has a $\delta^{15}N$ value of 9.7‰, similar to the adult female mean, possibly also recording a maternal in utero value. This individual also exhibited subperiosteal new bone formation on endocranial and ectocranial surfaces; although such skeletal features may be present during normal growth, a systematic pathology (e.g. scurvy, infection), already affecting the individual in utero cannot be ruled out (Bourbou, 2018).

Natural variation of stable isotope ratios between the mother and the in utero fetus due to the positive nitrogen balance caused by pregnancy and the developing fetus (e.g. the last twelve weeks in utero are considered to be a period of rapid bone growth), may result in an enrichment of $\delta^{15}N$ values. It is still poorly understood if different stages of pregnancy or protein metabolism in the mother-fetus pair affect the $\delta^{15}N$ values of fetal bone collagen, and thus, it is difficult to figure out whether the elevated $\delta^{15}N$ values are reflecting the stage of pregnancy or another irrelative factor (Fuller et al., 2004, 2005, 2006b; Jørkov et al., 2008; Derbyshire, 2011). Clinical studies have demonstrated that due to rapid growth, bone turnover in fetuses, infants and children is significantly higher in comparison with adults (Bollen, 2000; Lapillonne et al., 2000; Yang and Grey, 2006), as well as that variations in turnover rates exist for different bones (Sealy et al., 1995; Parfitt, 2002). Although the exact rate of bone turnover is not known, observations by Richards et al. (2002) on elevated $\delta^{15}N$ and $\delta^{13}C$ values in very young infants, suggested that breastmilk protein can be rapidly incorporated into collagen.

Disease stress has been also suggested as a possible etiology of elevated $\delta^{15}N$ values in infant tissues (Katzenberg, 1999; Katzenberg and Lovell, 1999; Kinaston et al., 2009; Beaumont et al., 2013). Although it is unknown to what extent endogenous factors can affect the $\delta^{15}N$ and $\delta^{13}C$ values of the growing fetus, disease processes have been argued to affect human $\delta^{15}N$ values (e.g. White and Armelagos, 1997; Katzenberg and Lovell, 1999; Olsen et al., 2014; D'Ortenzio et al., 2015). Lesions observed in cranial and post-cranial skeletal elements of individuals #2, #9 (fullterms) and #3 (birth to 1 month), were possibly suggestive of neonatal scurvy as a result of undernourished pregnant or lactating women, since the only source of vitamin C for these individuals would have been maternal, either via placenta or breastmilk (Bourbou, 2018). Thus, it is likely that maternal nutritional stress have influenced the elevated $\delta^{15}N$ values seen in these individuals, ranging from 10.1‰ to 11.5‰. Isotopic

variation, as a result of in utero stress, can be also caused by parasitic infections such as malaria. Although numerous infectious conditions can be spread via the placenta to the fetus during pregnancy malaria is one of the most common parasitic infections of pregnant women in the world resulting in serious complications for both the pregnant woman and the fetus (Brabin et al., 2004; Smith-Guzmán, 2015; Lewis, 2018 WHO, 2019). Environmental specifics in Aventicum (near a marshy region, possibly subject to floods), provide indirect evidence for the presence of malaria at the site (Bourbou, 2018), which could have affected fetal growth and perinatal survival, as well as being a possible reason of the elevated $\delta^{15}N$ values.

Thus, the possibility that the elevated $\delta^{15}N$ values of the Aventicum non-adults aged between birth to one and a half years old are a mixture of natural variation in stable isotope ratios between the mothers and their fetuses, the possible effects of poor intrauterine growth or of maternal/fetal disease and/or nutritional stress, cannot be excluded (Gowland, 2015; Halcrow et al., 2018b).

7. CONCLUSIONS

This paper presents the stable isotopic carbon and nitrogen ratios of non-adult (n=30), female (n=9) and faunal samples (n=10) from Roman Switzerland, allowing an unprecedented insight into infant diet and health at Aventicum. Although non-adults under study have lived at different times since the cemeteries were in use from the 1st-3rd CE and infant feeding practices may have not been static over this time frame, the study has found that breastmilk played an important dietary role up to the third year of life, and that weaning must have occurred shortly after. Weaning diet could have been largely based on C_3 terrestrial foods with little animal protein, while the $\delta^{13}C$ and $\delta^{15}N$ values of older non-adults fall within the adult range, indicating consumption of a similar to the adult diet. According to the trophic levels between animals and adult females, it seems that the Aventicum population consumed in general quite sufficient animal protein. The fact that the majority of the samples subject to stable isotope analysis were perinates highlighted the complex relationship between their $\delta^{15}N$ and $\delta^{13}C$ values and those of adult females, as different factors, including variation of fetal and maternal stable isotope ratios, the possible effects of intrauterine growth, as well as maternal/fetal disease stress and/or nutritional stress (e.g. nutritional deficiencies such as scurvy, parasitic infections, such as malaria), could have influenced the observed elevated $\delta^{15}N$ values.

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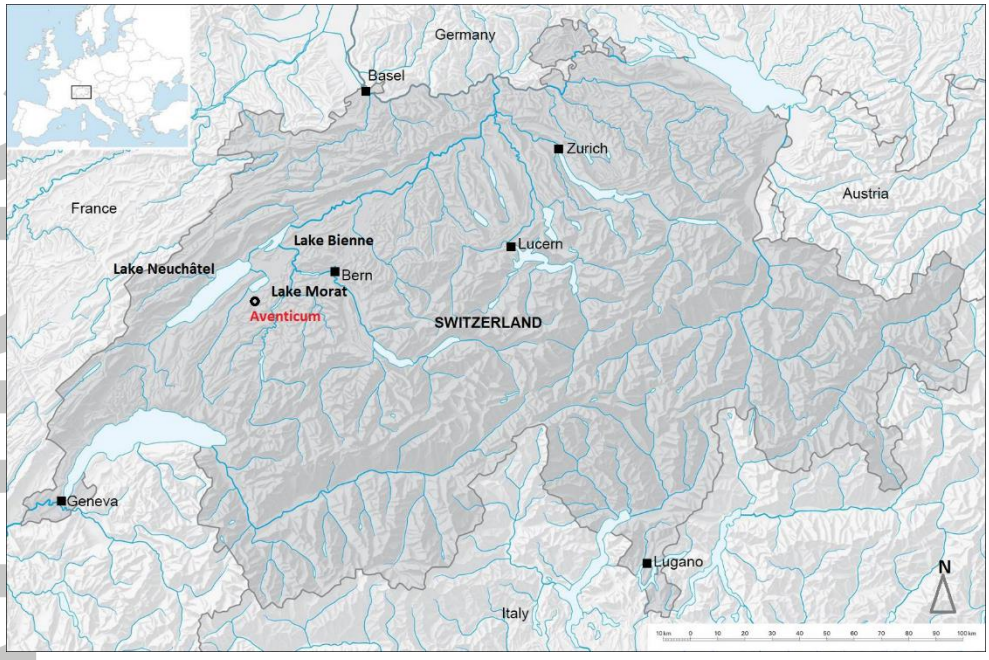

Figure 1. Map of Switzerland showing the location of Aventicum (https://www.swisstopo.ch).

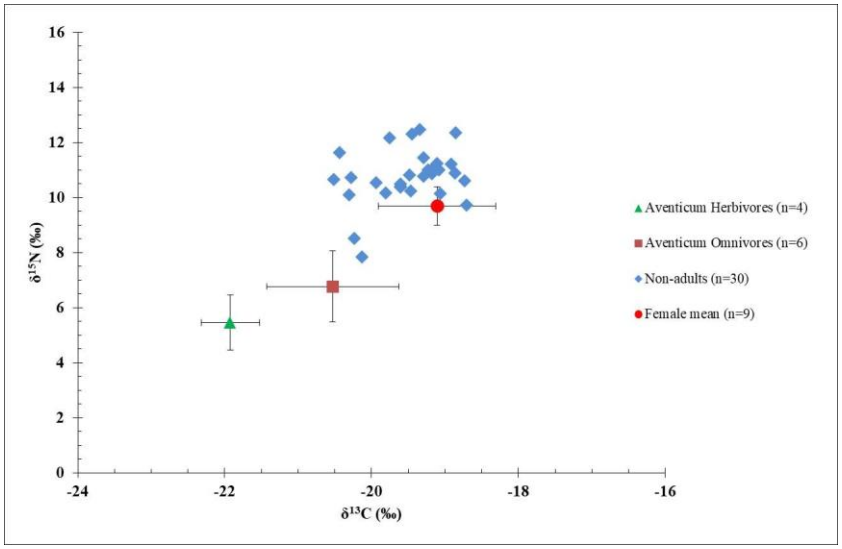

Figure 2. Scatter plot of δ15N and δ13C results of bone samples from Aventicum.

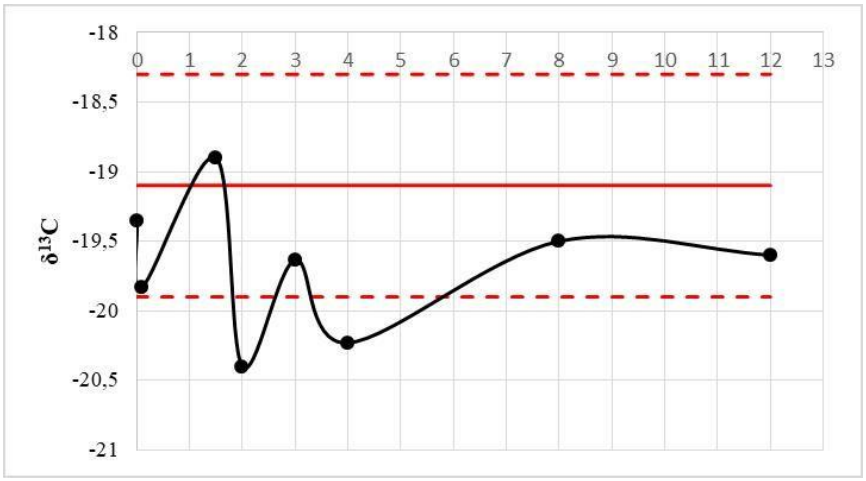

Figure 3. Plot of non-adult mean δ13C values at estimated age at death and female mean (straight line) including standard deviation (dashed line).

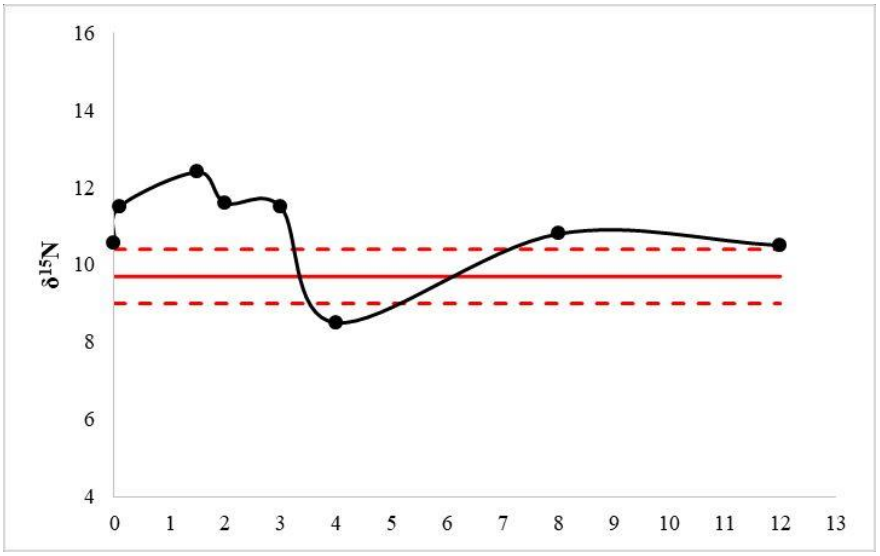

Figure 4. Plot of non-adult mean δ15N values at estimated age at death and female mean (straight line) including standard deviation (dashed line).

Table 1. Non-adult human skeletal collections under study, samples used for stable isotope ratio analysis and samples with sufficient collagen quality.

Cemetery/Date	**non-adults studied**	**Preterm**	**Fullterm**	**Perinate**	**Infant**	**Infant I**	**Infant II**	**Infant III**	**Adolescent**	**samples for isotopic analysis[1]**	**samples with sufficient collagen quality**
À la Montagne (1st c. CE)	22	4	14	-	2	-	1	1	-	22	22
Sur Fourches (end of the 1st-3rd? c. CE)	21	1	16	1	3	-	-	-	-	19	3
En Chaplix (end of the 1st-middle of the 3rd c. CE)	18	-	-	4	4	2	4	2	2	14	5
Les Tourbières (middle 2nd-3rd? c. CE)	32	-	10	16	1	-	-	2	3	26	0
TOTAL	93	5	40	21	10	2	5	5	5	81	30

Note: Definitions of the applied age categories (adapted after Bourbou, 2018, 125, Table 1): **Preterm:** from <37 weeks gestation; **Fullterm:** from 37- 42 weeks gestation; **Perinate:** <42 weeks gestation; **Infant:** birth-1 year; Infant I: *ca.* 1-2 years; **Infant II:** *ca.* 2-7 years; **Infant III:** *ca.*7-14 years; **Adolescent:** *ca.*14-17 years.

[1] For age distribution of the sample subject to stable isotopic analysis, see Table 2.

Table 2. Isotopic results and sample information for all non-adults analyzed from the Aventicum site (Switzerland).

Sample no.	Burial/Skel. no.	Sampled bone	Age (weeks, months & years)	Age in years (average)	Collagen Yield %	δ13C (‰)	δ15N (‰)	C:N	%C	%N
#1	ALM-St.196/002	pars petrosa	preterm	0	1.7	-18.7	9.71	3.2	42.4	15.4
#2	ALM-St.120/014	pars petrosa	fullterm	0	1.2	-19.08	11	3.1	35.8	13.6
#3	ALM-St.165/016	pars petrosa	birth-1 month	0.1	2.6	-20.3	10.08	3.5	39.5	13.0
#4	ALM-St. 117/017	pars petrosa	preterm	0	6.5	-18.86	10.88	3.3	36.9	13.1
#5	ALM-St. 131/018	pars petrosa	fullterm	0	1.6	-18.91	11.2	3.2	44.9	16.2
#6	ALM-St. 131/018a	pars petrosa	fullterm	0	2.9	-19.29	11.43	3.3	45.6	16.2
#7	ALM-St. 147/019	pars petrosa	fullterm	0	6.7	-19.29	10.77	3.3	39.9	14.3
#8	ALM-St.154/020	pars petrosa	preterm	0	4.6	-19.14	11.07	3.3	44.8	15.8
#9	ALM-St.182/ 022	pars petrosa	fullterm	0	3.7	-19.1	11.24	3.2	39.5	14.3
#10	ALM-St.132/023	pars petrosa	fullterm	0	1.3	-18.73	10.61	3.2	42.3	15.3
#11	ALM-St.146/034	pars petrosa	fullterm	0	2.2	-19.17	10.85	3.3	42.7	15.1
#12	ALM-St. 106/036	pars petrosa	fullterm	0	3.4	-19.06	10.14	3.3	39.3	14.1
#13	ALM-St. 112/037	pars petrosa	fullterm	0	5.6	-19.18	11	3.2	39.7	14.3
#14	ALM-St. 164/038	pars petrosa	fullterm	0	1.5	-19.23	10.99	3.3	44.2	15.6
#15	ALM-St. 230/039	pars petrosa	fullterm	0	5.1	-19.8	10.17	3.3	41.2	14.6
#16	ALM-St. 161/040	pars petrosa	preterm	0	5.7	-19.46	10.24	3.3	39.7	14.0
#17	ALM-St. 125/041	pars petrosa	birth-1 month	0.1	2.7	-19.75	12.15	3.4	43.5	15.1
#18	ALM-St. 122/042	pars petrosa	fullterm	0	5.5	-20.27	10.72	3.6	40.2	13.1
#19	ALM-St. 150/003	cranial fragment (occipital)	ca. 4 years	4	3.5	-20.23	8.51	3.3	43.5	15.5
#20	ALM-St. 133/021	femur	fullterm	0	8.1	-20.13	7.84	3.2	46.3	17.0
#21	ALM-St. 143/035	femur	fullterm	0	4.7	-19.6	10.4	3.3	35.9	12.8
#22	ALM-St. 160/004	humerus	ca. 8 years	8	0.5	-19.48	10.82	3.2	34.7	12.7
#24	SF-St. 23/007	pars petrosa	1-2 months after birth	0.1	2.8	-19.44	12.31	3.5	44.5	14.7
#35	SF-St. 54/030	pars petrosa	fullterm	0	0.4	-19.6	10.36	3.3	32.1	11.4
#39	SF-St. 34/006	femur	fullterm	0	0.6	-20.51	10.65	3.5	32.2	10.6
#70	ECH-St.14/079	pars petrosa	3 years ± 12 months	3	1.3	-19.93	10.52	3.5	33.1	11.2
#71	ECH-St.110b/080	long bone shaft	18 months ± 6 months	1.5	8.4	-18.85	12.35	3.2	43.9	16.1
#73	ECH-St.349/074	pars petrosa	2 years ± 8 months	2	2.9	-20.4	11.6	3.4	34.9	12.0
#74	ECH-St.64b/072	pars petrosa	ca. 3 years	3	5.0	-19.3	12.5	3.4	31.7	11.0
#77	ECH-St.212/087	pars petrosa	12 years ± 36 months	12	1.5	-19.6	10.5	3.2	34.2	12.6
#76	ECH-St.88/073	pars petrosa	4 years ± 12 months	insufficient collagen						
#23	SF-St. 37/005	pars petrosa	fullterm	no collagen yield						
#25	SF-St. 19/008	pars petrosa	perinate	no collagen yield						
#26	SF-St. 29/010	pars petrosa	fullterm	no collagen yield						
#27	SF-St. 32/011	pars petrosa	preterm	no collagen yield						
#28	SF-St. 61/012	pars petrosa	fullterm	no collagen yield						
#29	SF-T3/013	pars petrosa	fullterm	no collagen yield						
#30	SF-St. 46/024	pars petrosa	fullterm	no collagen yield						
#31	SF-St. 49/025	pars petrosa	fullterm	no collagen yield						
#32	SF-St. 48/027	pars petrosa	fullterm	no collagen yield						
#33	SF-St. 47/028	pars petrosa	fullterm	no collagen yield						
#34	SF-St. 43/029	pars petrosa	fullterm	no collagen yield						
#36	SF-St. 53/031	pars petrosa	fullterm	no collagen yield						
#37	SF-St. 45/032	pars petrosa	6 months ± 3 months	no collagen yield						
#38	SF-St. 58/033	pars petrosa	fullterm	no collagen yield						
#40	SF-St. 52/026	tibia	fullterm	no collagen yield						
#41	SF-St. 41/009	humerus	birth-1 month	no collagen yield						
#42	LT-St.108/043	pars petrosa	fullterm	no collagen yield						
#43	LT-St.58/046	pars petrosa	fullterm	no collagen yield						
#44	LT-St.219/051	pars petrosa	perinate	no collagen yield						

#45	LT-St.179/052	pars petrosa	fullterm	no collagen yield
#46	LT-St.185/053	pars petrosa	fullterm	no collagen yield
#47	LT-St.257/054	pars petrosa	perinate	no collagen yield
#48	LT-St.213/055	pars petrosa	perinate	no collagen yield
#49	LT-St.150/057	pars petrosa	fullterm	no collagen yield
#50	LT-St.156/058	pars petrosa	fullterm	no collagen yield
#51	LT-St.9/059	pars petrosa	6 months ± 3 months	no collagen yield
#52	LT-St.61/060	pars petrosa	perinate	no collagen yield
#53	LT-St.230/061	pars petrosa	perinate	no collagen yield
#54	LT-St.128/062	pars petrosa	perinate	no collagen yield
#55	LT-St.197/063	humerus	perinate	no collagen yield
#56	LT-St.243/064	pars petrosa	perinate	no collagen yield
#57	LT-St.171/065	pars petrosa	fullterm	no collagen yield
#58	LT-St.241/066	pars petrosa	perinate	no collagen yield
#59	LT-St.193/067	pars petrosa	fullterm	no collagen yield
#60	LT-St.196/068	pars petrosa	perinate	no collagen yield
#61	LT-St.125/045	pars petrosa	fullterm	no collagen yield
#62	LT-St.153/091	pars petrosa	perinate	no collagen yield
#63	LT-St.158/084	pars petrosa	9 years ± 24 months	no collagen yield
#64	LT-St.268/085	pars petrosa	8 years ± 24 months	no collagen yield
#65	ECH-St.387/001	pars petrosa	perinate	no collagen yield
#66	ECH-St.175/069	pars petrosa	6 months ± 3 months	no collagen yield
#67	ECH-St.202/070	pars petrosa	perinate	no collagen yield
#68	ECH-St.370/076	pars petrosa	birth ± 2 months	no collagen yield
#69	ECH-St.63/078	pars petrosa	perinate	no collagen yield
#72	ECH-St.48/081	long bone shaft	1 year ± 4 months	no collagen yield
#75	ECH-St.119/075	pars petrosa	3 years ± 14 months	no collagen yield
#78	ECH-St.319/088	pars petrosa	12 years ± 36 months	no collagen yield
#79	LT-St.157/082	pars petrosa	15-16 years	no collagen yield
#80	LT-St.223/083	pars petrosa	15 years ± 36 months	no collagen yield
#81	LT-St.237/238/086	pars petrosa	15 years ± 36 months	no collagen yield

Note: Sample #76 highlighted in grey has bad C:N and is not used for discussion.

Table 3. Isotopic results and sample information for all adult females analyzed from the Aventicum site (Switzerland).

Sample no.	Burial/Skel. No.	Sex	Age	Sampled Bone	Collagen Yield %	δ13C (‰)	δ15N (‰)	C:N	%C	%N
#F1	SF-St.28/A003	F	25-35	Femur	9.6	-18.0	10.2	3.2	47.4	17.4
#F2	ALM-St. 101/A007	F	45-50	Femur	2.7	-19.4	9.7	3.2	44.6	16.2
#F3	ALM-St. 177/A005	F	40-50	Femur	2.4	-17.4	8.3	3.2	43.0	15.5
#F4	ALM-St. 156/A002	F	50-60	Femur	2.6	-19.7	9.3	3.3	43.9	15.5
#F5	ALM-St. 148/A006	F	30-40	Femur	2.6	-19.1	9.7	3.1	42.3	16.1
#F6	ALM-St. 128/A001	F	20-25	Femur	3.3	-20.0	9.4	3.2	45.2	16.4
#F14	ECH-St. 55/A019	F	25-35	Femur	0.8	-19.5	10.1	3.2	41.6	15.3
#F15	ECH-St. 236/A020	F	25-35	Femur	5.6	-19.2	10.0	3.2	43.6	16.0
#F16	ECH-St. 198/A021	F	40-50	Femur	2.2	-19.6	10.6	3.2	39.6	14.6
#F7	LT-St. 240/A008	F	25-35	Femur	no collagen yield					
#F8	LT-St. 43/A009	F	adult	Femur	no collagen yield					
#F9	LT-St. 169/A010	F	adult	Femur	no collagen yield					
#F10	LT-St. 30-39/A011	F	20-24	Femur	no collagen yield					
#F11	LT-St. 245/A012	F	40-50	Femur	no collagen yield					
#F12	ECH-St. 155-331/A015	F	18-19	Femur	no collagen yield					
#F13	ECH-St. 75/A018	F	25-35	Humerus	no collagen yield					

Table 4. Isotopic results and sample information for all fauna samples analyzed from the Aventicum site (Switzerland).

Sample no.	Context	Species	Collagen Yield %	δ13C (‰)	δ15N (‰)	C:N	%C	%N
HERBIVORES								
#A20	ALM-K11294/St.81	*Equus ferus dom.*	2.2	-22.2	5.1	3.3	42.7	15.2
#A26	ALM-K11583/St.169	*Equus ferus dom.*	1.3	-22.4	4.6	3.4	39.9	13.6
#A22	ALM-K11558/St.44	*Bos taurus*	3.7	-21.6	5.3	3.2	44.8	16.3
#A24	ALM-K11305/St.96	*Ovis aries/Capra hircus*	2.2	-21.5	6.9	3.3	42.9	15.1
Herbivores δ13C mean ± SD: -21.9 ± 0.4‰; δ15N mean ± SD: 5.5 ±1.0‰								
OMNIVORES								
#A18	ALM-K11361/St. 177	*Sus domestica*	8.3	-20.9	6.8	3.2	43.9	16.0
#A21	ALM-K11557/St.44	*Sus domestica*	3.1	-21.5	5.7	3.2	44.6	16.1
#A23	ALM-K11348/St.157	*Sus domestica*	4.1	-20.2	7.7	3.2	44.8	16.3
#A25	ALM-K11365/St.184	*Sus domestica*	4.6	-21.1	4.9	3.2	40.1	14.5
#A19	ALM-K11360/St. 176	*Galus galus domesticus*	1.8	-19.2	7.2	3.3	41.5	14.8
#A27	ALM-K11356/St.166	*Canis familiaris*	3.8	-20.3	8.3	3.3	45.6	16.2
Omnivores δ13C mean ± SD: -20.5 ± 0.9‰; δ15N mean ± SD: 6.8 ±1.3‰								
#A1	ECH-AV 88/6651.29/St. 58	*Sus domestica*	no collagen yield					
#A2	ECH-AV 91/7914/St. 309	*Equus ferus dom.*	no collagen yield					
#A3	ECH-AV 88/6651.33/St. 58	*Sus domestica*	no collagen yield					
#A4	ECH-AV 88/6651.12/St. 58	*Fulica atra*	no collagen yield					
#A5	ECH-AV 88/6651.12/St. 58	*Bos taurus*	no collagen yield					
#A6	ECH AV 91/7981/St. 359	*Canis familiaris*	no collagen yield					
#A7	ECH AV 91/7929/St. 322	*Canis familiaris*	no collagen yield					
#A8	ECH AV 91/7929/St. 322	*Equus ferus dom.*	no collagen yield					
#A9	ECH AV 91/7929/St. 322	*Bos taurus*	no collagen yield					
#A10	ECH AV 91/7891-G	*Indet.*	no collagen yield					
#A11	ECH AV 91/7929/St. 322	*Bos taurus*	no collagen yield					
#A12	ECH AV 91/7940/St. 332	*Equss ferus dom.*	no collagen yield					
#A13	ECH AV 91/7940/St. 332	*Ovis aries*	no collagen yield					
#A14	ECH AV 91/7940/St. 332	*Ovis aries*	no collagen yield					
#A15	ECH AV 91/7940/St. 332	*Ovis aries/Capra hircus*	no collagen yield					
#A16	ECH AV 91/7940/St. 332	*Indet.*	no collagen yield					
#A17	ECH AV 91/7940/St. 332	*Bos Taurus/Cervus elaphus*	no collagen yield					