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ORIGINAL PAPER

What is on the menu in a Celtic town? Iron Age diet reconstructed at Basel-Gasfabrik, Switzerland

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Abstract The late Iron Age (150–80 BC) proto-urban site of Basel-Gasfabrik, Switzerland, yielded numerous human skeletal remains, with individuals of all ages and both sexes being found in two cemeteries and in various features of the settlement itself. About 200 inhumations and two cremation burials as well as isolated skulls and bones attest to complex mortuary practices. Stable carbon and nitrogen isotope analyses of 90 human, 48 faunal, and seven cereal samples provide a rich database for dietary reconstruction. The results point to a diet that was largely based on C_3 plants with a limited contribution of herbivore or pig meat and/or dairy products. Divergent isotope ratios can be attributed to the consumption of chicken meat/eggs or seasonally available salmon. Moreover, the contribution of C_4 plants, supposedly millet, to human diets is well documented at Basel as well as at other central European Iron Age sites. We found no significant dietary distinctions between males and females. In children, indications for breastfeeding terminate between 1.5 and about 4 years of age, with isotopic differences emerging with regard to the investigated skeletal elements. The stable isotope data from different burial contexts, forms of mortuary practice, and presence or type of funerary objects overlap widely, providing only tentative indications for dietary differentiation within the living population. These findings distinguish Basel-

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Gasfabrik from other Iron Age sites and call for further integrative studies for deciphering the complex mechanisms behind the highly differentiated mortuary practices in the late Iron Age.

Keywords Iron Age · La Tène period · Carbon · Nitrogen · Stable isotope analysis · Collagen · Burial · Diet · Central site

Introduction

The Basel-Gasfabrik site in Switzerland was a major proto-urban Celtic settlement of the late La Tène period (150–80 BC) (Fig. 1). The discovery of archaeological remains in an industrial area of the modern city of Basel in 1911 initiated extensive fieldwork, which continues until today. The excavations revealed a large, well-planned settlement with numerous domestic and economic structures at the left bank of the Rhine river. A distinct characteristic of the site was its manifold burial practices. About 200 inhumations and two cremations were discovered in two cemeteries directly north of the settlement, but numerous human remains were also found in diverse settlement features such as ditches, depressions, settlement pits, and well shafts (Fig. 2). Among the latter are complete and partial skeletons, but also isolated human skulls and bones. The human remains and their depositional contexts provide a rich source of information for studying the treatment of the dead in the La Tène period, which often broke present-day taboos.

An interdisciplinary research project investigates the human remains from Basel-Gasfabrik and their depositional contexts in order to gain insights into the living conditions of the proto-urban population and to identify possible selection criteria for individuals subject to different mortuary practices. It integrates archaeological and scientific investigations including osteological and geoarchaeological as well as aDNA, stable isotope, archaeobotanical, archaeozoological, and statistical analyses. A highly informative way to explore differences within and among specific burial contexts is the evaluation of dietary information using stable carbon and nitrogen isotope analyses ($\delta^{13}C$ and $\delta^{15}N$) of bone collagen (Ambrose 1993; Ambrose et al. 2003; Kellner and Schoeninger 2007). These data reflect dietary composition, but also agricultural practices and the habitats in which staple crops were grown and animals grazed.

C_3 plants with $\delta^{13}C$ values between −35 and −22 ‰ vs. V-PDB (Cerling et al. 1997) dominate the central European vegetation and typically form the base of the food webs in this region. They include staple crops such as barley, spelt, emmer, einkorn, and naked wheat, which have also been identified at Basel-Gasfabrik (Kühn and Iseli 2008). In contrast, millet (*Panicum miliaceum*) follows the C_4 photosynthetic pathway ($\delta^{13}C$ between −12.7 and −11.4 ‰) (Lightfoot et al. 2013) and is also present in the archaeobotanical record of the site. Within the spectrum of C_3 plants, variation occurs due to differences in growing conditions in more canopied or in open habitats and levels of humidity (Diefendorf et al. 2010; Drucker et al. 2008; Kohn 2010). Carbon isotope ratios of macroremains can therefore also indicate the watering status of staple crops (Bogaard et al. 2013; Riehl et al. 2008; Riehl et al. 2014). Due to isotope fractionation, $\delta^{13}C$ values of herbivore collagen are about 5 ‰ higher than those of their plant forage (Ambrose et al. 1997), while the difference in collagen $\delta^{13}C$ between representatives of two adjacent trophic levels is

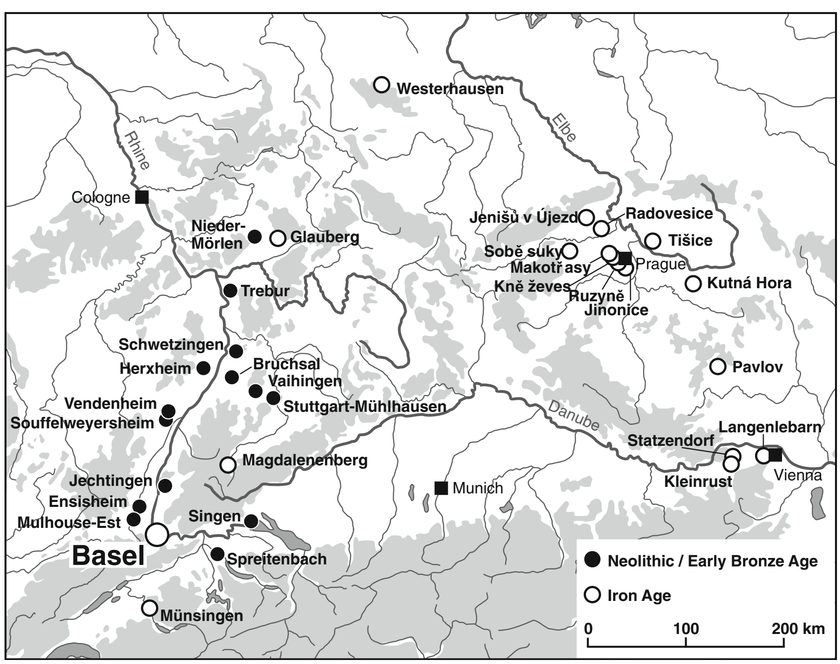


Fig. 1 Map of central Europe showing the location of Basel and other sites used in comparative datasets as listed in Table 2

Fig. 2 The Basel-Gasfabrik site: extension of the settlement and location of cemeteries A and B. *Dots* mark the locations of human skeletal remains in settlement features analyzed in the present study; *shaded areas* delimit excavated versus destroyed zones

0.8 to 1.3 ‰ (average about 1 ‰) (Bocherens and Drucker 2003; Drucker and Henry-Gambier 2005; Lee-Thorp 2008).

Trophic level isotopic enrichment also causes considerable variation in nitrogen isotope ratios and provides the basis for estimating the shares of meat and dairy in the human diet. Delta^{15}N values increase by about 3 to 5 ‰ vs. AIR (Hedges and Reynard 2007) or even by about 6 ‰ per trophic level (O'Connell et al. 2012). Manuring of arable land also raises δ^{15}N values of staple food plants (Bogaard et al. 2007; Fraser et al. 2011; Kanstrup et al. 2011). Consequently, characterizing the growing conditions of staple plants and the isotope ratios of possible foodstuffs is essential for human dietary reconstructions (Bogaard et al. 2013). Such comparative data form the basis for the application of quantitative dietary mixing models, which often use Bayesian statistics and essentially improve data interpretation of stable isotope readings (Fernandes et al. 2014, 2015; Grupe et al. 2015; Phillips and Koch 2002).

The carbon and nitrogen isotope analyses presented in this study were guided by the following questions:

1) *What were the agricultural practices and what was the overall diet of the Iron Age population at Basel-Gasfabrik*? The rich bioarchaeological record, including charred cereal remains and animal bones, provided the foundation for a reconstruction of the human food web at the proto-urban center. The study aims at exploring the shares of animal and plant-derived components, the importance of millet as a C_4 staple crop, and the contribution of other foodstuffs, such as salmon, to the human diet. Comparisons to other Iron Age sites across central Europe as well as to earlier populations in southwest Germany and Switzerland place the data in a diachronic perspective.
2) *How long were typical breastfeeding periods and how variable were weaning ages*? The osteological record includes numerous remains of infant individuals, including fetuses. Because breastmilk is enriched in the heavier ^{13}C but especially in ^{15}N isotopes, nursing is commonly reflected in bone collagen (Fuller et al. 2006a, 2006b). We use stable isotope data of bone collagen to deduce information on the duration of breastfeeding periods and its possible variation within the population.
3) *Do the diverse burial contexts coincide with any grouping according to dietary habits*? The presence of human remains in two cemeteries and in settlement features raises questions regarding the internal social differentiation at the site. Do the different burial contexts represent different subgroups of the population which are also reflected by access to different foodstuffs and distinct dietary habits? Such patterns may reflect specific segments of the living population and contribute to comprehending the mechanisms behind the highly diverse and complex burial practices attested for the middle and late La Tène period all over Europe, and especially at Basel-Gasfabrik.

Material and methods

The investigated human skeletal remains from Basel-Gasfabrik originated from two contemporaneously used cemeteries (A and B) and the adjacent settlement Pichler et al. 2013; Rissanen et al.(2013) (Fig. 2). The bronze and iron fibulae in the graves suggest that both cemeteries were established in the middle and used well into the late La Tène period (ca. 250–80 BC), whereas in the settlement, features of the late La Tène period prevail (ca. 150–80 BC) (Hecht et al. 1999). Ongoing investigations may refine these dates (Pichler et al. forthcoming; Rissanen forthcoming). Both cemetery and settlement burials comprised adult males and females as well as juvenile individuals. In total, the cemeteries contained about 200 inhumations and two cremation burials, while settlement features yielded ca. 30 complete skeletons and several hundred isolated bones, with the skulls alone representing at least 40 individuals. Despite almost continuous archaeological supervision for over a century, it is likely that further human remains disappeared unnoticed during extensive early building activities.

Initial excavations in cemetery A (BGA) in 1915/1917 revealed about 155 graves, to which modern fieldwork added 17 individuals (Rissanen forthcoming). The bones are for the most part highly fragmented and poorly preserved. Because only selected skeletal remains were recovered during the old excavations, a total of 16 individuals from BGA were sampled, including 13 burials from 2006 and remains of three individuals from 1917. Cemetery B (BGB) is situated about 300 m west of BGA. Excavations in 2005/2007 documented 25 graves from which 23 individuals were sampled. Both cemeteries were partially destroyed by later building activities and therefore represent only part of their original burial communities.

At least 11 of the more than 500 settlement pits and two of eight wells yielded single or multiple inhumations (Basel-Gasfabrik settlement, BGS) (Pichler et al. 2013). Especially remarkable is a well (feature 114) containing the skeletons of nine individuals. Moreover, isolated human remains, including about 40 complete or partly preserved skulls, and several hundred isolated bones of the perpendicular skeleton occurred in pits, ditches, shallow depressions, and dark earth deposits (archaeological layers). These features also revealed evidence of about two dozen human fetuses and newborns. In contrast to the gravelly infilling of the graves in the cemeteries, settlement features were in general rich in calcium carbonate, phosphates, and organic material and allowed for better bone preservation (Rentzel 1998, 38 ff.). Among the sampled remains of 51 individuals from BGS were bones of 13 complete and five presumably complete skeletons (uncertainty is due to deficits in the documentation of the old excavations), one partial skeleton, 12 isolated skulls, five isolated jaws, and 15 isolated long bones.

In total, this work reports on collagen stable isotope data of 90 human individuals. They include five fetuses, 20 individuals of the age class infans I (0–6 years), seven individuals of the age class infans II (7–13 years), five juvenile individuals (14–20 years), 13 adult females or possible females (>20 years), 35 adult males or possible males (>20 years), and five adult individuals whose sex could not be determined.

More detailed age categories for the adults are listed in Supplement 1. For complete or partial skeletons, we aimed at sampling ribs, which have a high turnover rate and represent the last few years prior to death (Lamb et al. 2014). However, poor or selective bone preservation repeatedly required choosing alternative samples. In order to avoid multiple sampling of the same individuals for isolated bones, we focused on left humeri ($n = 13$), the skeletal element representing the highest minimum number of individuals (MNIs). These were complemented by five femora which were also used for histological age estimations (Portmann 2015).

In addition to the human skeletal remains, bones of domestic and wild animals and charred cereal grains were analyzed to provide comparison data for different food groups and representatives of several trophic levels and habitats. These samples comprised bones of 48 animals, including five horses (*Equus caballus*), four sheep/goats (*Ovis aries/Capra hircus*), seven cattle (*Bos taurus*), five pigs (*Sus domesticus*), 15 dogs (*Canis familiaris*), four chickens (*Gallus gallus*), a roe deer (*Capreolus capreolus*), a red deer (*Cervus elaphus*), a freshwater fish of the carp family (*Cyprinidae*), and five *Salmonidae* (Supplement 2). The salmons are of special interest because they are anadromous fish who migrated up the Rhine river from the North Sea. Finally, seven samples of charred barley grains (*Hordeum vulgare*) provided an estimate of the baseline values of cereals which, according to archaeobotanical analyses, were the most important staple food of the Celtic population (Kühn and Iseli 2008).

Background information on the applied methods is given in the introduction. The laboratory procedures for osteological investigations and stable isotope analyses are described in Supplement 3. Charred cereal remains underwent an acid-base-acid treatment following (Fraser et al. 2013). Collagen extraction of human and faunal bones was based on Longin (1971) with modifications as described by Knipper et al. (2013) with omission of the ultrafiltration step.

Statistical analyses were conducted using WinSTAT for Microsoft Excel version 2007.1. The Kolmogorov-Smirnov test attested normal distributions for all considered data groups, which were then compared using Student's t tests. Dietary compositions were evaluated using the Bayesian Mixing Model FRUITS (version 2.1; http://sourceforge.net/projects/fruits/ [last access: 05/21/2016]; Fernandes et al. 2014, 2015). Average collagen stable isotope data of barley, herbivores, freshwater fish (*Cyprinidae*), salmon, and chicken were used as baseline estimates for the different elements contributing to human diets. Because millet was probably a significant dietary constituent but charred millet grains were not available for analysis, we used an average $\delta^{13}C$ value for C_4 plants of about −12 ‰ as a proxy for the carbon isotope composition (Cerling et al. 1997) as well as the average $\delta^{15}N$ value of the barley grains. Further modelling parameters including trophic level spacing, collagen-protein, collagen-carbohydrate/lipid spacing, and macronutrient concentrations were adapted from Fernandes et al. (2014, 2015) and listed along with the results in Supplement 4.

Results

Demography

There was a considerable variation in the demographic profiles of individuals from the cemeteries, skeletons from settlement features and individuals represented by isolated bones. The demographic structure and especially the large number of young children interred in the cemeteries corresponded well with models for prehistoric European populations (Bocquet-Appel and Masset 1977; Chamberlain 2006), as, in the modern excavations, 29 out of 48 (i.e., 60 %) of the individuals had died below the age of 14. The individuals deposited in settlement pits and wells, on the other hand, exhibited a skewed age distribution with a prevalence of adults (>20 years of age), while under 14-year olds accounted for only about 20 % (Pichler et al. 2015). This is even more pronounced in the isolated skulls and bones from various settlement features, where under 20-year olds occurred in still smaller numbers. Similar observations were made in the distribution of the sexes: while females and males were present in almost equal numbers among the complete individuals from either settlement (four females, six males) or cemeteries (five females, seven males), male (or probably male) individuals appeared to be more frequent in the isolated bones (15 % male vs. 8 % female specimens) and even more so in the isolated skulls (21 % male vs. 9 % female specimens), even given that more than two thirds of such isolated elements cannot be reliably sexed. At the same time, there were no conspicuous differences in health status among the individuals from specific contexts. Markers of deficiency and physiological stress or dental disease, for example, occurred in roughly similar frequencies in all subsamples. Body height, an additional indicator for the living conditions prevailing during an individuals' youth, appeared quite similar as well (e.g., 1.69 m for males in the settlement vs. 1.70 m in the cemeteries).

Stable isotope data

The stable carbon and nitrogen isotope ratios of human and faunal collagen and barley grains are listed in Supplement 1 and Supplement 2 and are summarized in Table 1. Seven samples of barley grains characterize the most widely consumed staple plant at Basel-Gasfabrik (Kühn and Iseli 2008). Their $\delta^{13}C$ values ranged from −24.5 to −23.3 ‰ (mean −24.0 ± 0.5 ‰), while the $\delta^{15}N$ values appeared highly variable. After accounting for an average increase of $\delta^{15}N$ by

Table 1 Descriptive statistics for major groups of carbon and nitrogen stable isotope data from Basel-Gasfabrik

	N	$\delta^{13}C$ (‰ V-PDB)						$\delta^{15}N$ (‰ AIR)					
		Average	Median	Standard deviation	Range	Minimum	Maximum	Average	Median	Standard deviation	Range	Minimum	Maximum
Human data													
Fetus	5	−18.8	−18.5	0.8	2.2	−20.0	−17.8	−10.6	−10.7	0.4	0.9	−10.1	−11.0
Infans I	20	−18.7	−18.7	0.7	2.1	−19.6	−17.4	−11.1	−11.3	1.2	4.1	−9.1	−13.1
Infans II	7	−19.1	−19.4	1.5	3.9	−20.8	−16.9	−9.3	−9.5	1.3	3.8	−7.4	−11.2
Juvenile	5	−19.3	−19.2	0.7	1.8	−20.2	−18.5	−9.5	−9.6	0.2	0.6	−9.1	−9.7
Female/female?	13	−19.3	−19.2	0.8	2.8	−20.4	−17.6	−9.1	−9.1	0.6	2.4	−7.8	−10.2
Male/male?	35	−19.2	−19.4	1.0	4.9	−20.4	−15.5	−9.1	−9.0	0.9	3.5	−7.7	−11.2
Indet.	5	−18.7	−19.0	2.1	5.4	−20.6	−15.2	−9.2	−9.2	0.6	1.4	−8.6	−10.1
Cemetery A (adult)	8	−19.4	−19.4	0.6	1.8	−20.3	18.6	−9.0	−9.2	0.8	2.1	−8.0	−10.1
Cemetery B (adult)	7	−18.0	−18.5	1.5	4.1	−19.3	−15.2	−9.1	−9.3	0.5	1.4	−8.2	−9.7
Settlement (adult)	38	−19.4	−19.5	1.0	5.1	−20.6	−15.5	−9.2	−9.1	0.8	3.5	−7.7	−11.2
Adult all	53	−19.2	19.4	1.1	5.4	−20.6	−15.2	−9.2	−9.1	0.8	3.5	−7.7	−11.2
Comparative data													
Equus caballus	5	−22.2	−22.1	0.3	0.9	−22.6	−21.7	−5.5	−5.3	0.7	1.9	−4.4	−6.3
Ovis aries/ Capra hircus	4	−21.1	21.2	0.7	1.6	−21.9	−20.2	−7.2	−7.1	0.7	1.4	−6.7	−8.1
Bos taurus	7	−21.3	−21.5	0.4	1.1	−21.8	−20.7	−6.8	−6.8	1.0	2.9	−5.4	8.3
Sus domesticus	5	−21.3	−21.3	0.2	0.5	−21.5	−21.0	−6.3	−6.4	0.6	1.5	−5.4	−6.9
Capreolus capreolus	1	−21.0	−21.0			−21.0	−21.0	−6.3	6.3			−6.3	−6.3
Cervus elaphus	1	−21.0	−21.0			−21.0	−21.0	−6.9	−6.9			−6.9	−6.9
Herbivores (incl. pigs)	23	−21.4	−21.4	0.5	2.4	−22.6	−20.2	−6.5	−6.7	0.9	3.9	−4.4	−8.3
Canis lupus familiaris	15	−19.3	−19.6	1.0	4.0	−20.4	−16.4	−8.9	−8.7	0.7	2.0	−8.1	−10.1
Cyprinidae	1	−21.0	−21.0			−21.0	−21.0	−9.1	−9.1			−9.1	−9.1
Salmonidae	4	−14.0	−14.0	0.2	0.5	−14.3	−13.8	−13.5	−13.6	0.4	0.9	−13.0	−13.9
Gallus gallus domesticus	4	−17.6	−16.8	2.5	5.7	−21.2	−15.4	−8.3	−8.3	0.7	1.4	−7.7	−9.0
Hordeum vulgare	7	−24.0	−24.1	0.5	1.2	−24.5	−23.3	−5.7	−5.4	2.2	5.6	−3.5	−9.1

0.3 ‰ due to charring (Nitsch et al. 2015), the values ranged from 3.5 to 9.4 ‰ (mean 5.7 ± 2.2 ‰).

Despite considerable fragmentation rates of the bones, overall collagen preservation was good. One human sample (BGA 5; 5–8 years) was excluded from further data analysis because of the large offset between the $\delta^{13}C$ and $\delta^{15}N$ values due to an insufficient signal peak in one of the duplicate analyses. An unusually high $\delta^{15}N$ value of 12.7 ‰ was only represented by a single measurement and therefore the authenticity was not ensured. Among the faunal measurements, one salmon bone yielded less than 1 % of collagen and had an atomic C/N ratio of 3.7, therefore not meeting the criteria for good collagen preservation (Ambrose 1990; Klinken 1999). All other samples fell into the suggested thresholds with yields of between 1.1 and 17.9 % of collagen, 11.3 and 17.7 % of N, 30.4 and 47.3 % of C, and atomic C/N ratios of between 3.1 and 3.3.

The carbon and nitrogen isotope ratios of the collagen of the domestic and wild herbivore species including the domesticates horse, sheep/goat, cattle, pigs as well as single samples each of roe deer and red deer overlapped widely between −22.6 and −20.2 ‰ (mean −21.4 ± 0.5 ‰) in $\delta^{13}C$ and between 4.4 and 8.3 ‰ in $\delta^{15}N$ (mean 6.5 ± 0.9 ‰) (Fig. 3). Within this cluster, horses had comparatively low $\delta^{13}C$ and $\delta^{15}N$ values, while both samples of red deer and roe deer plot among the data of the domestic species. In comparison to the herbivorous species, dogs had higher $\delta^{13}C$ values of between −20.4 and −16.4 ‰ (mean −19.3 ± 1.0 ‰) and $\delta^{15}N$ ratios of between 8.1 and 10.1 ‰ (mean 8.9 ± 0.7 ‰). Chickens stood out by their highly variable $\delta^{13}C$ values of between −21.2 and −15.4 ‰ (mean −17.6 ± 2.5 ‰), while their nitrogen isotope ratios ranged from 7.7 and 9.0 ‰ (mean 8.3 ± 0.7 ‰). The single sample of a cyprinid ($\delta^{13}C$ = −21.0 and $\delta^{15}N$ = 9.1 ‰)

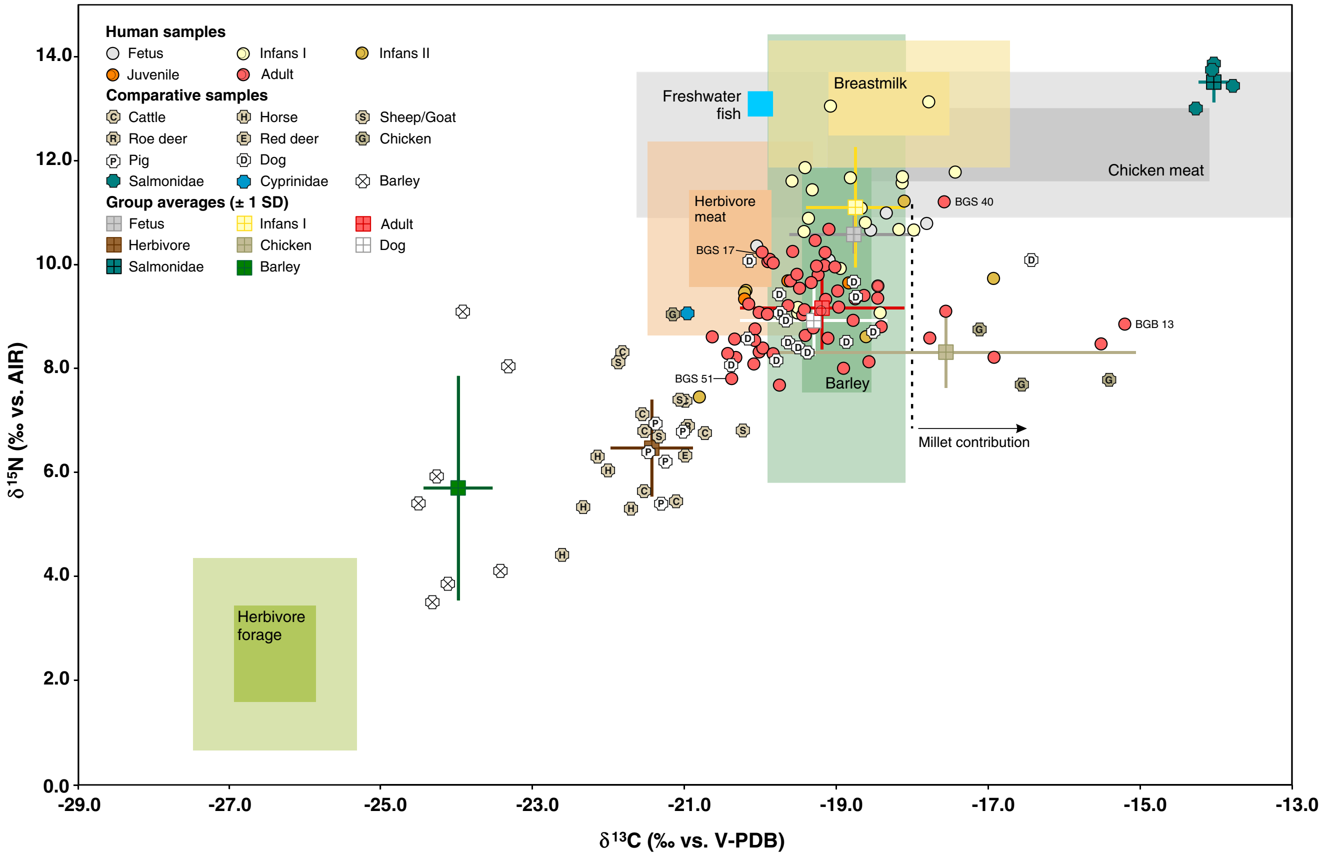


Fig. 3 Stable carbon and nitrogen isotope data of human and faunal skeletal remains as well as barley grains. The *shaded fields* indicate the $\delta^{13}C$ and $\delta^{15}N$ values of the herbivore forage as estimated from the faunal collagen stable isotope data and data ranges one trophic level above different foodstuffs, i.e. barley, herbivore meat, freshwater fish, breastmilk, and chicken meat. Human stable isotope data in these ranges are in agreement with the consumption of these foodstuffs. *Darker shades* indicate one and *lighter shades* indicate two standard deviations from the averages of the respective comparative data. The *labels* highlight individuals for whom the quantitative average dietary composition was modelled using the Bayesian mixing model FRUITS (s. Fig. 4)

represented freshwater fish. In comparison, four samples of salmonids had distinctly elevated $\delta^{13}C$ and $\delta^{15}N$ values averaging −14.0 ± 0.2 and 13.5 ± 0.4 ‰, respectively.

The carbon isotope ratios of the human collagen samples varied widely between −20.8 ‰ (Inf. II) and −15.2 ‰ (mature, sex indet.) as did the nitrogen isotope ratios with values between 7.4 ‰ (Inf. II) and 13.1 ‰ (Inf. I). With mean $\delta^{13}C$ values of −19.2 ± 1.1 ‰ and $\delta^{15}N$ values of 9.2 ± 0.8 ‰, the collagen of the adult human individuals was enriched by 2.2, resp., 2.7 ‰ in comparison to the herbivorous animals, and by 4.8, resp., 3.5 ‰ in comparison to the barley samples. The most prominent age-specific difference among the human individuals occurred between the individuals below the age of 6 and all older age classes. Their collagen was enriched in the heavier isotope by 0.4 ‰ in $\delta^{13}C$ and by 1.9 ‰ in $\delta^{15}N$ in comparison to the adults. The difference was statistically significant for $\delta^{15}N$ ($t(25.9) = 6.91$, $p < 0.001$) and $\delta^{13}C$ ($t(56.4) = 2.12$, $p = 0.038$). The averages of both isotope ratios of the age groups infans II and juvenile (7 to 19 years of age), on the other hand, did not differ significantly from those of the adults ($\delta^{13}C$ inf. II/adult, $t(58) = 0.098$, $p = 0.922$; $\delta^{13}C$ juvenile/adult, $t(57) = -0.160$, $p = 0.874$; $\delta^{15}N$ inf. II/adult, $t(58) = 0.464$, $p = 0.644$); $\delta^{15}N$ juvenile/adult $t(57) = 0.870$, $p = 0.388$).

The difference of the mean carbon and nitrogen isotope ratios between adults of both sexes was negligible with $\delta^{13}C$ values of −19.3 ± 0.8 ‰ for females/probable females and −19.2 ± 1.0 ‰ for males/probable males, and also statistically insignificant ($t(46) = -0.10$, $p = 0.917$). The differences between the mean $\delta^{15}N$ values of 9.1 ± 0.6 ‰ for females/probable females and 9.1 ± 0.9 ‰ for males/probable males were also statistically insignificant ($t(46) = -0.02$, $p = 0.979$). Taking only reliably sexed individuals into account did not noticeably change these results.

Regarding burials in one of the two cemeteries or in the settlement, there were no significant differences in the mean $\delta^{15}N$ values (BGA/BGB, $t(13) = -0.21$, $p = 0.836$; BGA/BGS, $t(45) = 0.48$, $p = 0.631$; BGB/BGS, $t(44) = -0.25$, $p = 0.806$). The average $\delta^{13}C$ values of the burials in cemetery B (−18.0 ± 1.5 ‰) were significantly higher than those in cemetery A (−19.4 ± 0.6 ‰) (BGB/BGA, $t(13) = -2.52$, $p = 0.026$) and the individuals from the settlement

(−19.4 ± 1.0 ‰) (BGB/BGS, $t(44) = 3.22$, $p = 0.002$), while the difference between BGA and BGS was insignificant (BGA/BGS, $t(45) = −0.16$, $p = 0.875$).

Discussion

Characterization of the Iron Age diet at Basel-Gasfabrik

Plant growing conditions and animal husbandry strategies

The botanical and faunal comparison samples inform on the isotopic composition of potential foodstuffs of the investigated community, but also on cereal growing conditions and domestic animal husbandry strategies. The mean $\delta^{13}C$ and $\delta^{15}N$ values of the barley grains (−24.0 and 5.7 ‰, respectively) were noticeably higher than the stable isotope values of the herbivore forage ($\delta^{13}C = −26.4$ ‰, $\delta^{15}N = 2.5$ ‰) as calculated from the collagen data of the animals. Possible reasons for this include about 1–2 ‰ higher $\delta^{13}C$ values in grains compared to leaves and chaff (Merah et al. 2002), contribution of plants from more humid or forested areas to the animals' fodder (Ferrio et al. 2003; Heaton 1999) and chiefly unmanured pastures. These observations underline that estimations of the isotopic composition of human vegetable foodstuffs using faunal collagen stable isotope data may be misleading. They further stress the necessity for direct analyses of both cereal grains and herbivore collagen to characterize the isotopic composition of potential human dietary items (cf. Fraser et al. 2013; Nitsch et al. 2015; Vaiglova et al. 2014).

Appreciating the variation of the isotopic composition of air CO_2 through time (Ferrio et al. 2005) and using a correction factor of $\delta^{13}C_{Air}$ of −6.4 ‰ for the time period between 150 and 80 BC (online resource: web.udl.es/usuaris/x3845331/AIRCO2_LOESS.xls [last access: 05/19/2016]; Ferrio et al. 2005), the $\delta^{13}C$ values of charred barley remains (mean −24.0 ± 0.5 ‰) correspond to $\Delta^{13}C$ values of between 17.3 and 18.5 ‰. $\Delta^{13}C$ values denote isotopic discrimination independent of the isotopic composition of the source CO_2 and enable comparison of archaeological data over time. The average of 18.0 ± 0.5 ‰ found at Basel is typical for barley which was grown under moderately watered conditions (Wallace et al. 2013). This finding is in accordance with the given climatic conditions and coincides well with previously analyzed cereal samples from the Neolithic settlement of Vaihingen in southwest Germany, the most extensive sample set from a site with presumably similar environmental conditions (Fraser et al. 2013).

The $\delta^{15}N$ values of the grains appeared more variable than in previously studied contexts (Fraser et al. 2013; Vaiglova et al. 2014) and point to differing manuring rates of agricultural plots as well as varied growing conditions (Bogaard 2014). In sum, they correspond to medium to high manuring rates (Fraser et al. 2011) and probably reflect the large catchment area of the proto-urban center. This is further supported by comparatively low quantities of threshing waste among the botanical macroremains of the site which point to cereal imports that likely came from surrounding farmsteads and hamlets on fertile loess soils in the nearby Sundgau region (Stopp et al. 1999).

The widely overlapping stable isotope ratios of the different herbivore species did not indicate species-specific foddering strategies, resp. habitat use. In contrast to evidence from Neolithic sites in southwest Germany and Swiss lakeshore settlements, restriction of certain species to specific environments such as shrubby hillsides or soggy floodplains was unlikely (Doppler et al. 2015; Fraser et al. 2013). Slightly lower $\delta^{13}C$ values of horses in comparison to other herbivore species have been noted before (Knipper et al. 2013; Le Huray 2006; Privat et al. 2002; Stevens et al. 2010) and point to metabolic differences between horses and the ruminant species (Hedges 2003) rather than to fodder from woodland habitats. The $\delta^{13}C$ values of the cattle and sheep/goat samples but also of the deer of well above −22 ‰ indicated feeding in open habitats (Doppler et al. 2015; Drucker et al. 2008). Frequent evidence for grassland plants among the botanical remains suggested that hay was used for winter foddering, even though the settlement probably also had its own pastures (Stopp et al. 1999). The fact that hares represented the most frequent wild animal at Basel (Schibler et al. 1999) as well as pollen data further supported the existence of a generally open and intensively exploited landscape (Wick 2015). Moreover, diachronic archaeobotanical observations indicated that a transition from extensive forest pasture to grassland used for both grazing and haymaking had already occurred in the late Bronze Age (Jacomet 1999; Jacomet et al. 2009; Kühn and Heitz 2015).

The stable isotope ratios of the pigs fell well into the range of the typical herbivores and did not hint at notable shares of animal-derived protein. The $\delta^{13}C$ values of three out of four chicken bones pointed to a remarkable contribution of a C_4 plant component, supposedly millet, while the $\delta^{15}N$ values suggested a mixture of plant and animal-derived fodder or to feeding on manured crops. Higher $\delta^{15}N$ values of chickens in comparison to herbivorous species have also been observed in earlier studies (cf. Cheung et al. 2012; Hakenbeck et al. 2010; Knipper et al. 2013). Dogs fed on an omnivorous diet. One individual revealed a noticeable contribution of a C_4 plant or a marine component, such as salmon, an anadromous species that seasonally migrated up the Rhine for spawning, carrying marine isotope signals to inland localities. The stable isotope data of the salmon specimens from Basel are typical for marine fish (Barrett et al. 2011).

Human dietary composition

Human dietary compositions were first evaluated by exploring the average isotopic spacing between the human collagen stable isotope data and those of the studied potential foodstuffs. In a second step, the Bayesian mixing model FRUITS (Food reconstruction using isotopic transferred signals) (Fernandes et al. 2014, 2015) was used for quantitative assessments of the dietary composition. The average differences of the $\delta^{13}C$ and $\delta^{15}N$ values between the barley grains and the human collagen of 4.8 ‰, resp., 3.5 ‰ corresponded closely to the expected trophic level spacing of about 5 ‰ in $\delta^{13}C$ and 4 ‰ in $\delta^{15}N$ between plant food and primary consumers (Ambrose 1993; Hedges and Reynard 2007). The majority of the human data were consistent with a data range that resulted from adding the given estimates for trophic level enrichments to the average values of the barley grains (green shaded area in Fig. 3). This indicated that most of the human individuals largely lived on a diet that was isotopically similar to the analyzed barley samples. In agreement with the archaeobotanical record (Kühn and Iseli 2008), this suggested that cereals constituted the staple food of the human population. Contribution of herbivore and pig meat and/or dairy products to the human diet was also likely, especially for individuals with comparatively high $\delta^{15}N$ and low $\delta^{13}C$ ratios (Fig. 3). The latter seemed to contradict the expected slight enrichment of ^{13}C per trophic level. This was, however, caused by about 2.5 ‰ lower $\delta^{13}C$ values of the herbivore forage in comparison to the barley grains at the base of the human food web, a difference that exceeded the enrichment of 0.8 to 1.2 ‰ per trophic level in simple food chains with an isotopically homogeneous vegetable foundation (Bocherens and Drucker 2003). This finding, again, stressed the importance of independent isotope analyses of both cereal grains and faunal collagen.

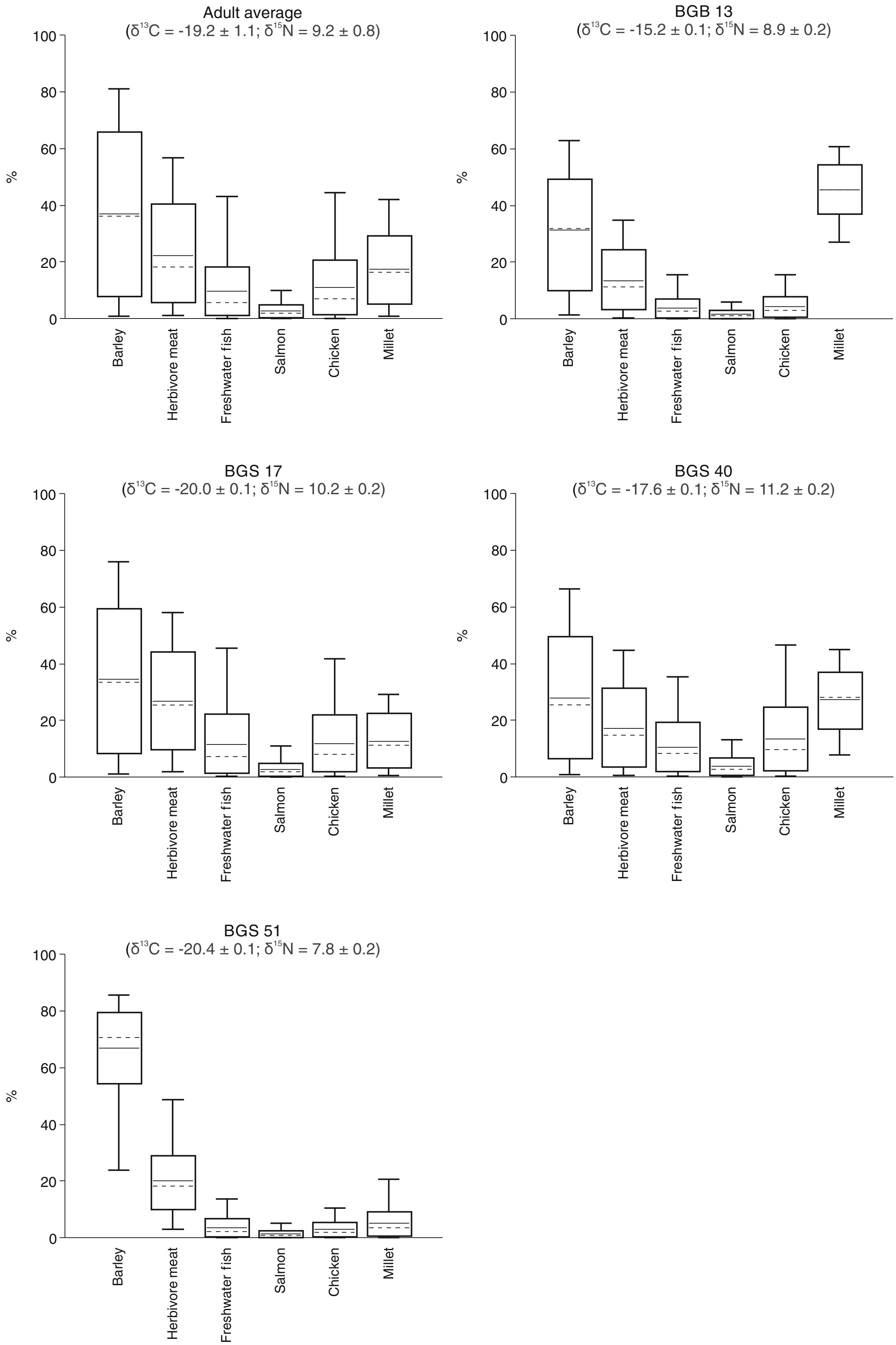
A number of individuals from Basel-Gasfabrik showed $\delta^{13}C$ values that were either below or above those to be expected for a barley-dominated diet (Fig. 3). Regarding the lower values, the estimations for $\delta^{13}C$ of the herbivore forage indicated the presence of C_3 plants with lower $\delta^{13}C$ values than the barley in the dietary catchment of the site. Stable isotope analyses of different cereals and pulses at Neolithic sites (Bogaard et al. 2013, 2014) revealed differences among the crops, even though in the investigated cases wheat species had higher $\delta^{13}C$ values than barley grains and would not explain our observations at Basel. However, pulses, which certainly formed an important part of the Iron Age diet (Jacomet and Jacquat 1999), and leafy vegetables or fruit rarely preserved in the archaeobotanical record (Kühn and Iseli 2008; Stopp et al. 1999), may have contributed carbon with distinctly lower $\delta^{13}C$ values to the human diet, thus producing the observed data.

Six adults (BGB 2, 13, BGS 18, 39, 40, 53), a 7-year-old child (BGA 12), three children between the ages of 2 and 5 (BGA 16, BGB 18, BGS 28), and a fetus (BGA 4) exhibited $\delta^{13}C$ values above the expected range for barley consumers (Fig. 3). For the infants, trophic level enrichment due to the consumption of breast milk (s. below) may have contributed to the elevated values (Fuller et al. 2006a). For the six adults, $\delta^{13}C$ values were also above −18 ‰, which is a widely accepted threshold for C_4 plant contribution to the human diet (Lightfoot et al. 2015). At Basel-Gasfabrik, millet (*P. miliaceum*) consumption presents a likely explanation for these elevated values as this C_4 cereal occurred frequently in the site's archaeobotanical record (Kühn and Iseli 2008) and was considered the second most important cereal after barley (Stopp et al. 1999).

The estimates generated by the Bayesian mixing model FRUITS present relatively large uncertainties. Nonetheless, these confirmed a dominance of plant-derived food in the average Iron Age diet, with barley making up 37.1 ± 24.5 % and millet 17.5 ± 11.2 %, based on the average $\delta^{13}C$ and $\delta^{15}N$ values of the adult individuals from Basel-Gasfabrik (Fig. 4; Suppl. 4). Herbivore meat also contributed noticeably (22.2 ± 15.9 %) to human diets, while chicken, freshwater fish, and the seasonally available salmon were of minor importance. Four exemplary individuals with combinations of either low or high $\delta^{13}C$ and $\delta^{15}N$ values (BGB 13, BGS 17, 40, 51) illustrate the variability in access to different foodstuffs and/or personal dietary preferences. For instance, the data for individual BGB 13 ($\delta^{13}C$ = −15.2 %; $\delta^{15}N$ = 8.9 ‰) translate into a millet contribution of 45.4 ± 8.6 %, which dominates over barley (31.3 ± 17.5 %) and animal-derived foods. A contrary example is represented by individual BGS 51 ($\delta^{13}C$ = −20.4 ‰; $\delta^{15}N$ = 7.8 ‰) attesting to a predominance of C_3 plant-based foodstuffs such as barley (67.0 ± 14.8 %), supplemented by herbivore meat (20.2 ± 11.1 %) and minor contributions of freshwater fish, chicken, and millet. Animal-derived food items (herbivore meat [incl. dairy products], freshwater fish, salmon, chicken/eggs) may have contributed up to half of the dietary intake in such individuals as BGS 17 and BGS 40, who exhibit comparatively high $\delta^{15}N$ values, again demonstrating the wide individual dietary variation among the members of the former population.

Basel-Gasfabrik in a diachronic perspective and Iron Age millet consumption

A comparison of the stable isotope data from Basel with datasets from central European Iron Age sites and those from Neolithic and early Bronze Age sites in southwest Germany and Switzerland revealed their agreement with established chronological and regional trends (Table 2; Fig. 5; sites mapped in Fig. 1). Regarding $\delta^{15}N$, the Basel dataset was below average both in a diachronic and supra-regional perspective. This did, however, not necessarily translate into smaller shares of animal-derived food stuffs since site-specific baselines may have varied, and especially since plant data were available for few sites only.


Adult average
(δ13C = -19.2 ± 1.1; δ15N = 9.2 ± 0.8)
BGB 13
(δ13C = -15.2 ± 0.1; δ15N = 8.9 ± 0.2)
BGS 17
(δ13C = -20.0 ± 0.1; δ15N = 10.2 ± 0.2)
BGS 40
(δ13C = -17.6 ± 0.1; δ15N = 11.2 ± 0.2)
BGS 51
(δ13C = -20.4 ± 0.1; δ15N = 7.8 ± 0.2)
%
0
20
40
60
80
100
Barley
Herbivore meat
Freshwater fish
Salmon
Chicken
Millet

◀ **Fig. 4** Modelled estimates of dietary composition based on the average $\delta^{13}C$ and $\delta^{15}N$ values of the adults from Basel-Gasfabrik and the stable isotope data of selected individuals. The *boxes* represent the 16th and the 84th percentiles (68 % of the data) and the *whiskers* the 2.5th and the 97.5th percentiles (95 % of the data) for the contribution of each food source. The *continuous lines* illustrate averages and the *discontinuous lines* median values

The carbon isotope ratios were more meaningful. In diachronic considerations, the Neolithic and early Bronze Age sites had significantly lower average $\delta^{13}C$ values ($t(30) = -12.31$, $p < 0.001$), and the Basel dataset plotted among the Iron Age sites. This was in agreement with only sporadic evidence for millet in the Neolithic (Bogaard 2011, 37 with further references) and a good representation of the cereal in the archaeobotanical record beginning in the late Bronze Age (Jacomet et al. 2009; Kühn and Heitz 2015). Isotopically, millet consumption is well documented in central Europe. Among the earliest examples is the Hallstatt period burial mound of Magdalenenberg near Villingen (Baden-Württemberg) (Oelze et al. 2012). Consumption of the C_4 cereal increased during the La Tène period (Moghaddam et al. 2016; Knipper et al. 2014; Nehlich et al. 2007; Le Huray 2006; Le Huray and Schutkowski 2005), but C_3 plants continued to dominate the consumed food stuffs of the majority of the investigated populations. Except for the site of Magdalenska gora in Slovenia (Murray and Schoeninger 1988), $\delta^{13}C$ values of above −18 ‰ appeared as outliers among the Iron Age burial communities.

Millet has certain advantages over C_3 cereals including a shorter growing season, lower required work input, relative drought-resistance, and high nutritional values regarding proteins, vitamins, and minerals (Lightfoot et al. 2013). Today, millet is seen as a “low status food.” In prehistoric times, this was not necessarily the case, and other tangible or ascribed material or social characteristics need to be considered to discern high or low social status in an individual, for being identified as a crafts specialist, a migrant, or for any other personal distinctions (Lightfoot et al. 2015; Nitsch et al. 2015). At Basel-Gasfabrik, the individuals with distinct signals for millet consumption included adult males and females as well as juveniles, individuals from both cemeteries and both complete skeletons and isolated bones from various settlement features. Of the three burials from the cemeteries, one contained a fibula (BGA 12), while no grave goods were evidenced for the others (BGB 2, BGB 13). Overall, the picture could hardly have been more heterogeneous and lacked any indication that millet consumption was associated with an easily identified social or economic subgroup of the late Iron Age population.

Prenatal nutrient supply, nursing, and weaning

Due to the trophic enrichment of isotopically heavy carbon and especially nitrogen in breastmilk, infant nursing is commonly reflected in bone collagen (Fuller et al. 2006a, b). At Basel-Gasfabrik, five individuals sampled were premature or stillborn fetuses or newborns, respectively, who had not yet reached a viable age. Their bone samples yielded stable isotope ratios that were on average 0.5 ‰ higher in $\delta^{13}C$ and 1.4 ‰ higher in $\delta^{15}N$ than those of the adult females/probable females (Fig. 6). The $\delta^{15}N$ values of four of the five samples also exceeded the females’ maximum. Because fetuses are completely supplied by their mothers through the placenta, the stable isotope ratios of mothers and infants were expected to be equal at birth (Kinaston et al. 2009; Richards et al. 2002). There is, however, increasing evidence for elevated nitrogen isotope ratios of newborns in comparison to their mothers before any breastmilk consumption, as well as in bones of fetal and perinatal individuals from various archaeological contexts (cf. Fuller et al. 2006b; Nitsch et al. 2011; Pearson et al. 2010; Richards et al. 2002). Sections of dentine collagen of deciduous and permanent first molars that represent the time in utero exhibited variable and often elevated nitrogen isotope ratios in comparison to dentine formed both during the nursing period and after weaning (Beaumont et al. 2015). Furthermore, 239 modern mother-child pairs revealed systematically and significantly elevated $\delta^{15}N$ values of the hair of the newborns by an average of 0.9 ‰ (de Luca et al. 2012). For prehistoric contexts, it has previously been postulated that the elevated $\delta^{15}N$ of fetal bones may reflect nutritional stress or other health-related issues of the mothers, so that the stable isotope composition of maternal blood and tissues may deviate from the live-time average during pregnancy (Beaumont et al. 2015; Kinaston et al. 2009). However, similar observations in modern well-nourished mothers make it more likely that the offsets are due to other non-stress-related physiological causes. Also, high fetal protein turnover may augment ^{15}N retention, leading to elevated $\delta^{15}N$ values in fetal tissues (de Luca et al. 2012). In sum, accumulating evidence suggests that elevated $\delta^{15}N$ values in fetal bone do not provide compelling evidence of life births and nursing.

At Basel-Gasfabrik, 20 infants below 6 years of age yielded on average 0.5 ‰ higher $\delta^{13}C$ and 2.0 ‰ higher $\delta^{15}N$ values as compared to the average values of the females/probable females at the site (Figs. 3 and 6). This represented about half a trophic level and the $\delta^{15}N$ offset was within the expected range for breastfed children of about 2–3 ‰ (Kinaston et al. 2009). Regarding differentiation within the age group, the carbon isotope ratios showed little systematic variation (Fig. 6a). Samples of infants below 1.5 years ($n = 7$) all yielded $\delta^{15}N$ values well above the single standard deviation of the adult females, indicating that breastmilk was the infants main food (Fig. 6b). They were also higher than those of the fetuses, with hardly any overlap between the groups. The $\delta^{15}N$ values of ribs of three individuals around 1.5 years were variable and indicated the cessation of breastfeeding in one and probable continuation of nursing in the other individuals. Among the infants between 2 and 6 years of age, nursing

Table 2 Summary of carbon and nitrogen stable isotope data of pre-Iron Age sites in Switzerland and southwest Germany and Iron Age sites in central Europe for comparison to the dataset from Basel-Gasfabrik

No. of site	Time period		δ13C (‰ V-PDB)				δ15N (‰ AIR)				
		N	Average	SD	Minimum	Maximum	Average	SD	Minimum	Maximum	References
Neolithic and Bronze Age: Switzerland, southwest Germany											
1 Ensisheim	Early Neolithic (LBK)	33	−20.2	0.2	−20.6	−19.8	9.3	0.5	8.4	10.9	Bickle et al. 2013
2 Herxheim	Early Neolithic (LBK)	21	−20.1	0.3	−20.6	−19.6	9.8	1.1	7.8	12.1	Dürrwächter et al. 2006
3 Mulhouse-Est	Early Neolithic (LBK)	8	−20.3	0.1	−20.5	−20.1	10.6	0.6	9.4	11.2	Bickle et al. 2013
4 Nieder-Mörlen	Early Neolithic (LBK)	4	−20.4	0.3	−20.8	−20.1	10.0	0.2	9.7	10.2	Nehlich et al. 2009
5 Schwetzingen	Early Neolithic (LBK)	98	−20.1	0.2	−20.9	−19.6	8.9	0.5	7.6	10.7	Bentley et al. 2013
6 Souffelweyersheim	Early Neolithic (LBK)	6	−20.5	0.5	−21.0	−19.7	10.5	0.6	9.9	11.2	Bickle et al. 2013
7 Stuttgart-Mühlhausen	Early Neolithic (LBK)	41	−20.5	0.2	−21.0	−20.1	9.7	0.5	8.3	10.8	Knipper in press
8 Vaihingen	Early Neolithic (LBK)	26	−20.6	0.3	−21.0	−19.7	9.2	0.4	8.0	10.2	Fraser et al. 2013
9 Vendenheim	Early Neolithic (LBK)	17	−20.2	0.2	−20.5	−19.8	10.5	0.8	8.8	11.7	Bickle et al. 2013
10 Jechtingen	Middle Neolithic (Großgartach, Planig-Friedberg, Rössen)	67	−20.6	0.3	−21.3	−20.1	9.4	0.8	7.9	11.9	Mörseburg et al. 2015
11 Trebur HST	Middle Neolithic (Hinkelstein)	20	−19.8	0.3	−20.6	−19.0	9.8	0.6	8.4	10.7	Dürrwächter et al. 2006
12 Trebur GG	Middle Neolithic (Großgartach)	20	−19.8	0.4	−20.3	−19.3	9.6	0.6	8.5	10.5	Dürrwächter et al. 2006
13 Bruchsal-Aue	Younger Neolithic (Michelsberg)	4	−20.9	0.1	−21.1	−20.8	10.3	0.5	9.9	10.8	Keller et al. 2015
14 Spreitenbach	Final Neolithic	11	−21.0	0.1	−21.3	−20.8	8.7	0.2	8.1	8.9	Knipper et al. 2012
15 Singen	Early Bronze Age	16	−20.3	0.3	−20.8	−19.6	9.6	0.5	8.9	10.5	Kupke 2010
Iron Age: central Europe											
16 Magdalenenberg	Hallstatt (Ha D)	47	−19.7	0.4	−20.9	−18.8	9.6	0.8	7.6	10.9	Oelze et al. 2012
17 Austria (collective series)	Hallstatt	16	−18.6	1.4	−20.1	−14.8	8.9	0.8	7.1	10.1	Le Huray 2006
18 Glauberg	Late Hallstatt/early La Tène	18	−18.4	1.0	−20.0	−16.5	8.9	0.7	7.4	10.8	Knipper et al. 2014
19 Kněževes	Hallstatt/early La Tène	9	−18.7	0.6	−19.7	−18.0	9.5	1.0	7	10.6	Le Huray 2006
20 Münsingen	Early-middle La Tène (Lt A-C)	63	−19.4	0.8	−20.8	−16.8	8.8	0.5	7.6	10.2	Moghaddam et al. in press
21 Jenišův Újezd	Early-middle La Tène (Lt B1a-C1a)	17	−19.0	0.5	−19.8	−18.1	10.2	1.0	8.4	12.4	Le Huray 2006
22 Kutna Horá-Karlov	Early La Tène (Lt B1b-B2a, possibly until the end of Lt C)	37	−18.9	0.6	−19.7	−17.1	10.0	0.6	8.9	11.2	Le Huray and Schutkowski 2005
23 Radovesice 1	Early La Tène (Lt B1b-B2b/C1a transition or beginning of Lt C1b)	27	−18.9	0.5	−19.7	−17.5	9.9	0.6	8.7	11.3	Le Huray and Schutkowski 2005
24 Radovesice 2	Early La Tène (Lt B1b-B2b)	20	−18.8	0.2	−19.2	−18.4	9.4	0.6	8.4	10.5	Le Huray and Schutkowski 2005
25 Tišice	Early La Tène (LT B1b-B2b)	17	−18.6	0.5	−19.7	−18.0	9.7	0.6	8.6	10.7	Le Huray et al. 2006
26 Makotřasy	Early-middle La Tène (Lt B1-LT B2/C1)	17	−18.7	0.7	−20.0	−16.8	9.6	0.5	8.7	10.6	Le Huray et al. 2006
27 Jinonice	Early-middle La Tène (Lt B-C)	56	−18.7	0.8	−20.1	−16.4	10.0	1.0	8.5	13.3	Le Huray et al. 2006
28 Ruzyně-Jiviny	Early-middle La Tène (Lt B-C)	38	−19.1	0.6	−20.4	−17.1	9.9	0.6	8.4	11.4	Le Huray et al. 2006
29 Soběsuky	La Tène	10	−19.0	0.7	−19.9	−17.7	9.6	0.8	8.0	10.6	Le Huray et al. 2006
30 Pavlov-Horní Pole	La Tène	10	−18.8	0.8	−19.9	−17.5	9.9	0.8	8.9	11.1	Le Huray 2006
31 Basel	Middle-late La Tène (Lt C2-D1)	54	−19.2	1.1	−20.6	−15.2	9.2	0.8	7.7	11.2	This study
32 Westerhausen	Pre-Roman Iron Age	16	−18.6	0.5	−19.7	−18.1	9.6	0.7	8.1	10.6	Nehlich et al. 2007

The sites are mapped in Fig. 1

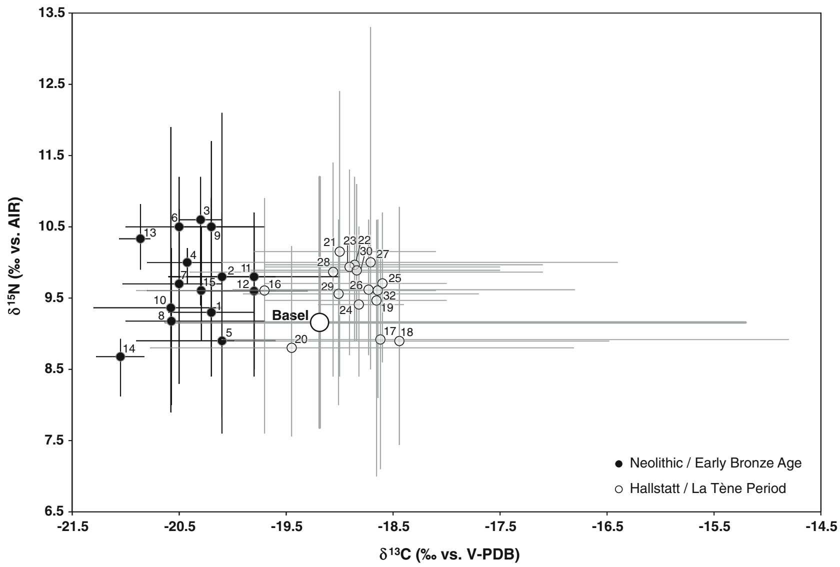


Fig. 5 Averages and minimum and maximum $\delta^{13}C$ and $\delta^{15}N$ values of human collagen at Neolithic and Bronze Age sites in Switzerland and southwest Germany (*black symbols*) and Iron Age sites in central Europe (*white symbols*). The *numbers* correspond to the site numbers listed in Table 2

signals were still detectable in skulls and long bones (n = 6), while lower values in two ribs and a metatarsal bone pointed to the consumption of solid food, similar to that of the adults. The stable isotope data appeared to indicate that some children were still nursing even at 4 or 5 years of age, which seems unusually late (Haydock et al. 2013; Richards et al. 2002; Sellen 2001). This may, however, be due to the specific bones sampled. Despite a child's rapid growth, the skull and long bones have comparatively low turnover rates (Hedges et al. 2007; Knipper 2004) and seemingly retain the isotopic information on breast feeding longer than ribs. This observation is of some significance for the assessment of weaning ages in prehistoric samples. An accumulation of enamel hypoplasias in regions of the tooth crowns that form between 3 and 4 years of age pointed to physiological stress occurring during that period (Rissanen et al. 2013). This time span is largely in agreement with the stable isotope data even though the sampling of different skeletal elements contributes significantly to the observed variation.

Individuals above the age of 6 did not show any systematic differences among samples from skulls, ribs, long bones, and other skeletal elements (Fig. 6b). Children between 7 and 13 years of age exhibited rather variable $\delta^{15}N$ values of between 7.5 and 11.2 ‰ (n = 6). The post-weaning dip of the $\delta^{15}N$, which was recorded repeatedly in previous studies (Nitsch et al. 2011; Richards et al. 2002) and discussed with regard to physiological versus cultural causes (Reitsema and Muir 2015), was not present in the data from Basel-Gasfabrik.

All in all, estimations of the duration of breastfeeding periods and reconstructions of infant diets based on bone samples of children that died prematurely may not be representative of the individuals or population that survived into adulthood. Dietary stress or illness of either the mothers or the infants, or of both, may have shortened or extended nursing periods or initiated isotopic shifts independent of socially prescribed dietary habits or the sheer availability of certain foodstuffs (Beaumont et al. 2015). Moreover, the respective mothers of the children analyzed were not known and isotopic offsets could therefore not be assessed directly.

Internal differentiation of the Basel-Gasfabrik population

Basel-Gasfabrik is among the few sites of the late La Tène period with evidence for a multifarious treatment of the dead for which there is data for settlement and cemeteries alike. The observed pluralism raised questions regarding the structure of the living community, and whether specific subgroups of that community may have been represented in the different burial contexts or marked by specific funerary objects. As stable isotope compositions of human collagen mirror individual dietary habits, they can contribute to such investigations. Even though insufficient preservation of bones or artifacts alike hampered a full assessment, we explored possible correlations between isotope signals and biological or social criteria such as sex or the presence of funerary objects that may have reflected specific subgroups in the differentiated social structure of the late Iron Age (Alt et al. 2005; Karl 2006).

Age, sex, and funerary objects

Considering the burial community as a whole, the average $\delta^{13}C$ and $\delta^{15}N$ values of males and females were almost identical. There was no indication that any of the sexes had preferred access to certain foodstuffs (at least as far as they are isotopically distinguishable). Basel-Gasfabrik is the only available dataset for burials starting in the middle La Tène period and predominantly dating to its later phase.

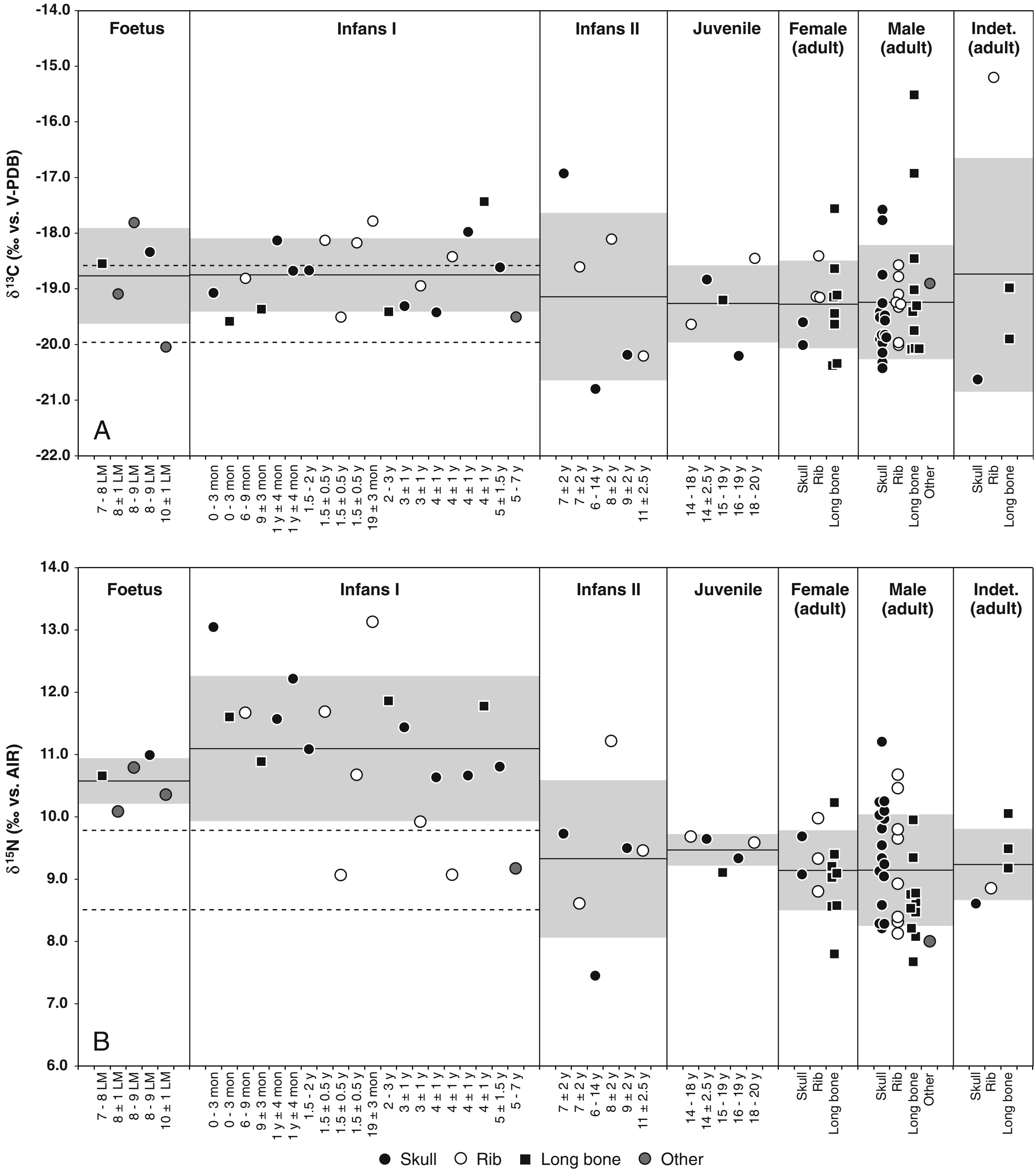


Fig. 6 Carbon (**a**) and nitrogen (**b**) stable isotope composition of human skeletal remains from Basel-Gasfabrik according to sampled skeletal elements and sorted by age groups for subadult and by sexes for adult individuals. The *continuous horizontal lines* show the average and the *gray bars* one standard deviation of the data from each age group. The *dotted lines* in the columns for fetuses and infans I individuals illustrate one standard deviation of the females for comparison

Among the datasets of the early and middle La Tène periods, higher average $\delta^{15}N$ values of males at Münsingen pointed to larger shares of meat and/or dairy products in comparison to the females (Moghaddam et al. 2016). Such patterns were lacking at most investigated sites in the modern Czech Republic (Le Huray 2006) and at Glauberg, Germany (Knipper et al. 2014). However, within the group of the males, burials with weaponry and/or exceptionally rich grave goods often went along with indications for preferred access to animal protein, with examples at the Hallstatt period Magdalenenberg burial mound (Oelze et al. 2012), and in the La Tène cemetery of Münsingen (Moghaddam et al. 2016), Kutná Hora-Karlov (Le Huray and Schutkowski 2005), or the princely grave of Glauberg (Knipper et al. 2014, 2015). In these cases, the stable isotope data contribute to the evidence for social and/or gender differentiation.

Weapon burials, which thus represent a highly informative category regarding dietary and social differentiation, are missing entirely at Basel-Gasfabrik. Instead, fibulae, glass beads, and other items dominate among the grave goods and were more often associated with children than with adults (Rissanen et al. 2013). Among the latter, no sex-specific groupings of individuals with similar stable isotope data or identical funerary objects emerged (Fig. 7a). The elevated $\delta^{15}N$ values of young children were independent of the presence of grave goods and rather due to breastfeeding than to any specific social status being expressed in dietary and funerary distinctions (see above).

The settlement burials at Basel-Gasfabrik were embedded in diverse sediments which contained large amounts of ceramic, animal bones, slag, building rubble and occasional fibulae, coins, or isolated human remains. Under such circumstances, when human skeletons are surrounded by what may be

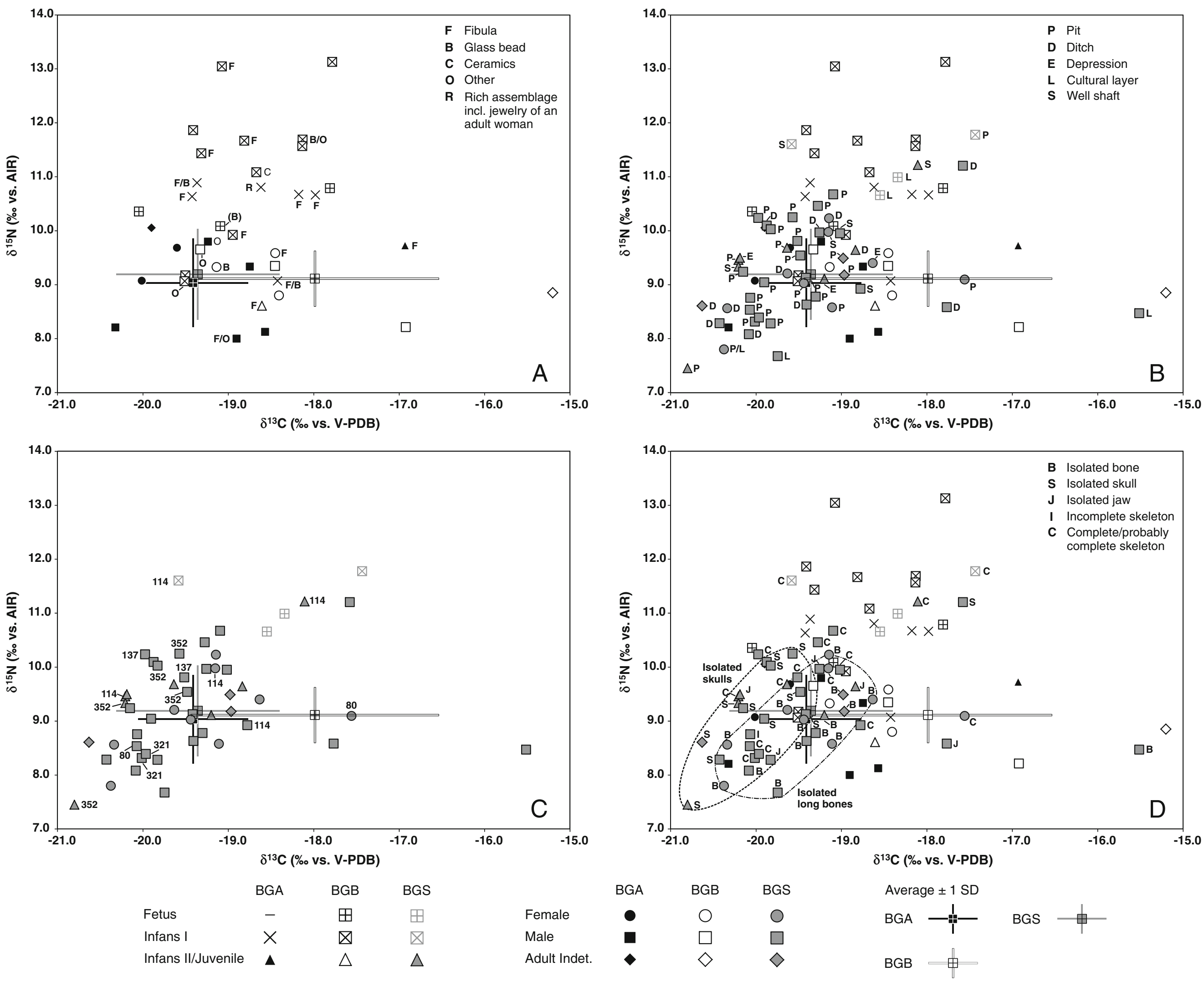


Fig. 7 Stable carbon and nitrogen isotope data of the human remains from cemeteries A (BGA) and B (BGB) and from the Basel-Gasfabrik settlement (BGS) with indications for different kinds of internal differentiation. **a** marks the presence of grave goods for the inhumations in BGA and BGB. BGS is only shown as an average because it was not possible to assign specific grave goods to individuals buried in settlement features. **b** depicts inhumations in both cemeteries in comparison to various burial contexts in the settlement. **c** shows the data for BGS with indication of inhumations in the same features. The cemeteries did not yield any multiple burials. **d** illustrates inhumations in both cemeteries with regard to mortuary treatment in BGS

addressed as "settlement waste," intentionally deposited items or meaningful associations of bio/artifacts are not easily identified, and their function as funerary objects is still under investigation (Brönnimann and Rissanen submitted; Rentzel and Brönnimann forthcoming). All in all, at Basel-Gasfabrik, the isotope data did not suggest any conspicuous correlations between an individual's age, sex, or association with certain funerary objects which may characterize specific social groupings.

Burial locations

Regarding burial in the two cemeteries or in the settlement, some tendencies emerged among the widely overlapping datasets (Fig. 7b). The adults in cemetery B revealed significantly higher collagen $\delta^{13}C$ values than the adults in cemetery A and in the settlement. This was primarily due to a number of individuals with indications of noteworthy millet consumption. Also, there were no representatives of cemetery B in a cluster of individuals with comparatively low $\delta^{13}C$ and $\delta^{15}N$ values. The latter comprised individuals from the settlement and a single male from cemetery A and indicated a diet poor in animal protein and rich in C_3 plants with low $\delta^{13}C$ values (cf. FRUITS mixing model for individual BGS 51 with 67.0 ± 14.8 % of barley and 20.2 ± 11.1 % of herbivore meat [Fig. 4; Suppl. 4]). These tentative hints at different dietary habits reflected in different burial contexts may mirror group distinctions during lifetime. The nature of such distinctions can, however, hardly be revealed based on the stable isotope data alone.

Within the settlement, the stable isotope data of human remains from pits, ditches, depressions, cultural layers/levelled strata, and well shafts overlapped widely (Fig. 7b). Especially those of the most numerous categories, pits and depressions covered the whole data spectrum. There were no indications that factors which influenced lifetime dietary habits were reflected in the kind of settlement features in which remains were encountered.

A number of such features contained the remains of multiple inhumations (Fig. 7c). Two males in pit 321 yielded almost identical stable carbon and nitrogen isotope data indicating largely similar average diets, and matched osteological indicators for lifetime similarities among the two men (Brönnimann and Rissanen submitted). Two possible males in pit 137 also consumed similar foodstuffs in similar proportions. More variation was found among five individuals in well 114, two inhumations in feature 80 and in five skulls in pit 352. Overall, the picture emerging from these evaluations was heterogeneous. In some cases, indications of similar dietary habits may point to connection in life, while in others, heterogeneity of the stable isotope data speaks against straightforward relationships.

Finally, the data ranges of individuals in the settlement represented by complete or partial skeletons and isolated long bones, skulls, or jaws, respectively, again overlapped widely (Fig. 7d). Especially the individuals deposited as complete inhumations had representatives in the whole data range of $\delta^{13}C$ and $\delta^{15}N$ values. Slight indications for diverging data spectra existed between individuals who were represented by isolated skulls and those represented by isolated long bones. Again, the stable isotope data did not point to any obvious parallels of dietary distinction in lifetime and specific mortuary practices.

Conclusion

While archaeozoological and archaeobotanical investigations identified the major domestic animals and staple crops at the La Tène proto-urban settlement of Basel-Gasfabrik (Kühn and Iseli 2008; Stopp 2009; Stopp et al. 1999), stable carbon and nitrogen isotope analyses of bone collagen now add dietary information at an individual level. C_3 plants, such as barley, grew on soils with different manuring levels and were the most widely consumed food stuffs. They were supplemented by millet, herbivore, and pig meat and/or dairy products, while chicken and/or eggs or salmon—anadromous fish that were seasonally available at the site—were of minor importance. There was an appreciable interpersonal variation with single individuals appearing as outliers regarding millet consumption or larger shares of animal-derived food items. Children were breastfed for at least the first 2 years of their lives. Variability in breastfeeding signals may be attributed to either actual differences in the duration of nursing periods but also to variations in metabolic rates between specific bones, affecting the signal's visibility. Higher average $\delta^{13}C$ values of the burials in cemetery B were among the few indications that the individuals from different contexts may represent social groups whose dietary habits were distinguishable by means of stable isotope analysis. There were, however, no straightforward relationships between the stable isotope data and mortuary practices including the presence of funerary objects, the kind of settlement features in which the human remains were found, representation of an individual as either a complete or partial skeleton, an isolated skull or long bone, and between individuals in multiple inhumations. This attests to the social complexity of both mortuary practices and dietary habits observed at the proto-urban central site of Basel-Gasfabrik.

The study, which is part of a larger interdisciplinary project, revealed a wide range of insights not only into the dietary habits of the inhabitants but also into the social conditions prevailing in La Tène Basel-Gasfabrik. Whether the diversity in diets also marks inclusion in specific social groups can, at this time, not be ascertained, yet the data appeared to contradict any straightforward correlations. Future investigations of possible spatial or organizational subdivisions within the settlement might throw further light on this topic. The central function of the site in a diverse settlement landscape with interdepend locations and forming a common area of economic and cultural exchange can, to some degree, be expected to be mirrored by diversity within the site itself. Integration of the dietary patterns with information on community health (Pichler et al. 2014), physiological stress, and diseases, possible kinship and mobility and contextualizing these with the observed differentiation in ritual will contribute to a multi-faceted picture of the late Iron Age population of the proto-urban central site at Basel-Gasfabrik.

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