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Stable Isotope Analysis of Human and Faunal Remains from Rosheim, Middle Neolithic, France

Analyses isotopiques des humains et de la faune du site de Rosheim, Néolithique moyen, France

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Bulletins et Mémoires de la Société d'Anthropologie de Paris

Abstract – The Middle Neolithic cemetery at Rosheim “Rosenmeer” (RR) (Bas-Rhin, France) contains the largest Grossgartach skeletal assemblage (first half of the 5th millennium BC) in Alsace. Rosheim is a key site to help understand the westward movement of neolithisation from the Danubian region towards Western Europe. This study presents original stable isotope analyses of carbon, nitrogen and sulfur from 61 humans from RR and 37 fauna from neighbouring contemporaneous sites. Previously published stable isotope data (19 humans and 7 fauna) from Rosheim are incorporated in the discussion. In addition to stable isotope data, biological information (i.e., age and sex) and archaeological information (i.e., temporal phases and quantity of grave goods) are also included. Consequently, this study presents a comprehensive analysis of diets and social organisation at RR, involving data from over half of the total exhumed individuals from RR. No statistically significant intra-population dietary pattern can be observed at the site, suggesting that the RR inhabitants had a rather homogenous diet for both sexes and across age groups, social stratigraphy and temporal phases. A closer inspection of juvenile isotopic compositions suggests that weaning was completed at around two years old. Faunal isotope data suggest different husbandry practices for herbivores and omnivores, respectively. Through a comparison of stable isotope compositions of human and faunal remains from the Rhine Basin with those from the contemporary Paris Basin (Cerny culture), this study demonstrates that while there are many similarities in terms of burial rites between RR and Cerny, the RR inhabitants had a more agrarian lifestyle.

Keywords – Middle Neolithic, Grossgartach, Alsace, upper Rhine Valley, palaeodiet reconstruction

Résumé – La nécropole de Rosheim “Rosenmeer” (RR) (Bas-Rhin, France) rassemble le plus grand assemblage anthropologique d'Alsace du Néolithique moyen, daté de la culture Grossgartach (première moitié du V^e millénaire). Il constitue un site clé du Néolithique d'ascendance danubienne, diffusé d'abord vers le Bassin parisien, puis le reste de l'Europe occidentale. Cette étude présente une analyse des isotopes stables du carbone, de l'azote et du soufre de 61 individus humains RR ainsi que de 37 individus fauniques provenant de sites contemporains environnants. Complétés par des données publiées (19 humains et 7 animaux), le taux d'individus analysés atteint plus de 65 %. Les données isotopiques sont croisées avec les données biologiques des individus (âge et sexe), les phases d'occupation et le niveau relatif de “richesse” des sépultures (approche quantitative du mobilier). Aucune variation chronologique de l'alimentation n'est observée à RR. L'alimentation ne diffère pas entre les adolescents et les adultes, ni entre les hommes et les femmes. Parmi les plus jeunes enfants, on remarque les effets de l'allaitement. Le sevrage devait se terminer vers l'âge de deux ans. Aucun schéma alimentaire n'est corrélé à la quantité relative d'objets déposés dans les tombes. Les données isotopiques animales suggèrent des pratiques d'élevage spécifiques et différentes entre les herbivores et les omnivores. En comparant les ratios isotopiques des données humaines et animales du Bassin rhénan avec les données contemporaines du Bassin parisien (culture de Cerny), nous montrons, qu'en dépit d'un même contexte

économique, la population inhumée à RR avait une alimentation davantage tournée vers des ressources agricoles.

Mots clés – *Mittelneolithikum*, Grossgartach, Alsace, carbone, azote, soufre, alimentation

Introduction

The “Rosenmeer” burial site in Rosheim (RR) contains the largest number of burials dated to the Middle Neolithic period (*Mittelneolithikum*; 5th millennium BC) in Alsace (Bas-Rhin, Grand Est Region, France). Most burials can be dated to the Grossgartach phase, with a few dating to the Rössen phase. In the region, around 20 sites have yielded burials from the Grossgartach phase, but most of these are isolated burials or smaller cemeteries with less than ten graves (Denaire, 2009; Denaire and Lefranc, 2014). There are some larger funerary sites with several dozen burials, such as Guémar “Rotenberger Weg” (Denaire and Mauvilly, 2012). However, the state of preservation is poor and the size of the site is still small compared to RR. While the cemeteries of Lingolsheim “Sablières Fischer et Schott” and Erstein “Krebsrott” are larger, their discovery and excavations date back to more than a century ago, strongly limiting the quantity (and quality) of the related archival documentary material (Forrer, 1912; Forrer, 1938; Schaeffer, 1932).

The RR site was discovered in 1996 and excavated up until the early 2000s. Excavation at the site followed methodological standards that were beginning to be widespread in France within the framework of archaeology of death and “*anthropologie de terrain*” (Duday et al., 1990). More than 120 Neolithic burials have been unearthed in RR, including 109 attributed to the Grossgartach phase. The burials are generally well preserved, with abundant and diverse grave goods (i.e., ceramics, stone tools, grinding objects, ornaments made of stone, marine shells, animal teeth, etc.). By the quantity and the quality of its funerary and skeletal assemblage, as well as its detailed field documentation, the RR cemetery provides valuable information on human lifeways in the Upper Rhine region during the Middle Neolithic.

Despite its archaeological significance, to date, RR has only given rise to a handful of publications on the data generated during the first years of excavation (Jeunesse and Mauvilly, 1996; Bakaj et al., 1998). Studies of grave furnishings, the “macro-tools” (*macro-outils*) and the human remains exist mostly in grey literature (Robert, 2001; Gelliot, 2002; Horviller 2002; Robert 2002; Chenal, 2007). An exception is Denaire’s published PhD thesis (2009), devoted to the ceramic productions from the region during the Middle Neolithic. More recently, a study aimed at establishing the regional chronological sequence of the Early and Middle Neolithic cultures in Lower Alsace presented radiocarbon dates for some of the RR individuals and touched upon the topic of human palaeodiets (Denaire et al., 2017). All these studies have presented valuable data on the site and the region, but there is limited discussion on the lifeways of the population.

This study aims to fill in the knowledge gap on the site and provide a close examination of social dynamics at RR through the lens of subsistence practices. In terms of subsistence economy, the consensus is that Grossgartach and the succeeding Rössen culture were strongly agrarian by nature. During the Middle Neolithic period, Grossgartach farmers expanded on the range of crops cultivated by their LBK predecessors (*Linearbandkeramik*, Early Neolithic), and grew both hulled and naked varieties of wheat, as well as barley, pea and poppy (Bakels, 2009). From the LBK period onwards, meat consumption in the Upper Rhine valley largely relied on domesticated species, complemented by a small amount of game (<10%) (Arbogast, 1994; Sidéra, 2000; Arbogast and Jeunesse, 2013; Perrin et al., 2018). A recent synthesis on the Grossgartach period, based on all the zooarchaeological data available in the region, shows a rather uniform pattern, with cattle (55-65%) as the most abundant species, followed by pig (24-34%) and sheep/goat (8-18%) (Fabre et al., 2023).

The zooarchaeological data from domestic sites is consistent with the cultural and ideological atmosphere that emerges from RR grave goods. In fact, most of the grave goods relate to agriculture activities (e.g., axes, grinding wheels, sickles). Ceramic dishes, present in most burials with only a few exceptions, are very similar to those discovered in the residential area. Therefore, it seems logical to consider grave goods as a fair representation of daily activities at the site and that RR was likely a “farming population”.

This positive correlation between daily activities and grave goods, however, is not universally true. Among other Middle Neolithic cultures of Danubian origin, Cerny, from the Paris Basin and contemporary with Rosheim, exhibits completely opposite trends in the types of grave goods found. Both Grossgartach and Cerny share the same cultural origin, similar agricultural and pastoral economic contexts (Tresset, 1997; Hachem, 2011) and some significant funerary practices (i.e., supine position of the dead: Jeunesse, 1997; Chambon et al., 2007), but the Cerny grave goods more often relate to hunting activities, with little to no domestic ceramics or agricultural tools (Tresset, 1997; Sidéra, 2000). This stark contrast suggests a duality in the Cerny funerary organisation, expressed through a play of associations/oppositions, and argues for a deliberate social opposition between the two cultural contexts (Chambon and Thomas, 2014). Hence, under this framework, reconstructing past dietary practices using biochemical methods is the most direct way to examine diet at the individual level and to clarify the link between actual dietary behaviours, indirect zooarchaeological evidence and funerary displays.

This study will focus on reconstructing the palaeodietary patterns of the RR population using stable carbon, nitrogen and sulfur isotope analyses. In addition to human remains, faunal samples from nearby contemporary contexts are included to help establish the local isotopic baselines. By comparing this stable isotope data with other archaeological and biological evidence, such as the age and sex of individuals, and the number of grave goods per burial, this

study attempts to provide a comprehensive assessment of the dietary practices as well as of the social organisation of the RR population. The main objective is to present a case study of local and inter-regional interest and to establish baseline isotopic data for the area to allow for larger intra- and inter-regional comparisons. In addition, the Rosheim results will be compared to those of Cerny (Cheung et al., 2021) in order to highlight the social contexts of the two affiliated yet ideologically opposed cultures, between agricultural and hunting lifestyles.

Site background

The Middle Neolithic site at Rosheim is located in Alsace, eastern France, about 20 km southeast of Strasbourg (figure 1). Local archaeological records show continuous occupation at the site from early through to the late Neolithic period (c. 5100-4500 cal. BC), where residential and funerary areas from different cultural phases are organised in separate locations within the site (table 1). The earliest occupation at Rosheim can be dated to the early Neolithic *Linearbandkeramik* culture (LBK). By the beginning of the 5th millennium BC, *Mittelneolithikum* (MTK) cultures succeeded the LBK: Hinkelstein, Grossgartach (Großgartach), and Rössen (Rössen), with the transitional Planig-Friedberg phase between Grossgartach and Rössen (Denaire, 2009; Denaire et al., 2017). One particularly important finding at the site was the MTK cemetery at RR.

Direct radiocarbon dating of the human remains from RR reveals that the site was in use between 4750-4500 cal. BC (2 σ), with most burials falling within the Grossgartach phase (4765-4705 cal. BC, 2 σ) (Denaire et al., 2017). Burial practices at RR were largely homogenous. The cemetery consists of single pit inhumations, with most individuals oriented NW/SE in a supine position. Grave goods are abundant and consist mostly of ceramics, ornaments and agricultural tools. However, there is some occasional weaponry, such as arrowheads, which is consistent with what is known for the region for this time (Bakaj et al., 1998; Lefranc et al., 2018).

Materials and methods

Human and faunal sampling

A total of 61 human and 37 faunal osteological samples were analysed in this study. All of the human samples come from RR. Ribs were preferentially sampled, except for two individuals (RR4 and RR19), where samples were taken from the femora instead. The faunal samples come from two Grossgartach contexts in Rosheim: “Laser” (n=2) and “Mittelweg” (n=8), and a nearby contemporaneous site, Oberschaeffolsheim (n=28) (figure 1). Previously published stable carbon and nitrogen isotope data from 19 humans (RR) and seven fauna (Rosheim “Rittergass” and Rosheim “Lotissement Sainte Odile”) are also included in the analysis (Denaire et al., 2017). In total, stable isotope measurements were taken on over 66% of the individuals discovered at RR (80/120). Individuals not analysed were too poorly preserved to be sampled.

Human age and sex identification

For humans, sex and age-at-death were determined using established methods. Age-at-death was determined using teeth and osseous maturation (Moorrees et al., 1963; Scheuer and Black, 2000) or degenerative processes (Schmitt, 2005). Sex identification was conducted using the morphology and morphometry of the mature *ossa coxae* (Brůžek, 2002; Brůžek et al., 2017). All detailed sexing and aging results are provided in Supplementary information.

“Richness” grave classification

Grave goods are common at RR, with 93% of the burials (99/109) containing at least one object. Some grave goods were made of several elements. This is particularly the case for ornaments (e.g., necklace, headdress, breastplate, bracelet), made up of beads and pendants in stone, shell or animal bone/tooth. The number of elements for one ornament varies from two or three to more than 100.

| Main period | Cultural phases | Locality | Nature of Structure | References |
|--|-----------------------|---------------------------------|---|--------------------------------------|
| Early Neolithic | LBK | <i>Rittergass</i> | Residential | Lefranc et al., 2015 |
| | Late LBK | <i>Lotissement Sainte Odile</i> | | Arbogast, 2000; Lefranc et al., 2015 |
| Middle Neolithic <i>Mittelneolithikum</i> (MTK) | Grossgartach | <i>Laser</i> | | Lefranc et al., 1999 |
| | | <i>Mittelweg</i> | | Jeunesse and Arbogast, 1996 |
| | Grossgartach - Rössen | <i>Sandgrube</i> | Jeunesse and Arbogast, 1996 | |
| | | <i>Rosenmeer</i> | Jeunesse and Mauvilly, 1996; Bakaj et al., 1998; Boës et al., 2000; 2004a; 2004b; Denaire et Boës, 2009 | |
| Late Neolithic | Michelsberg | <i>Leimen</i> | Residential | Lefranc et al., 2007 |

Table 1. Neolithic sites within Rosheim and cultural phases. Site locations are shown in figure 1. For further information on each site please refer to their respective site reports / *Sites néolithiques de Rosheim et phases culturelles. La localisation de chaque site est présentée dans la figure 1. Pour toutes informations complémentaires, voir les rapports et monographies sur chaque site*

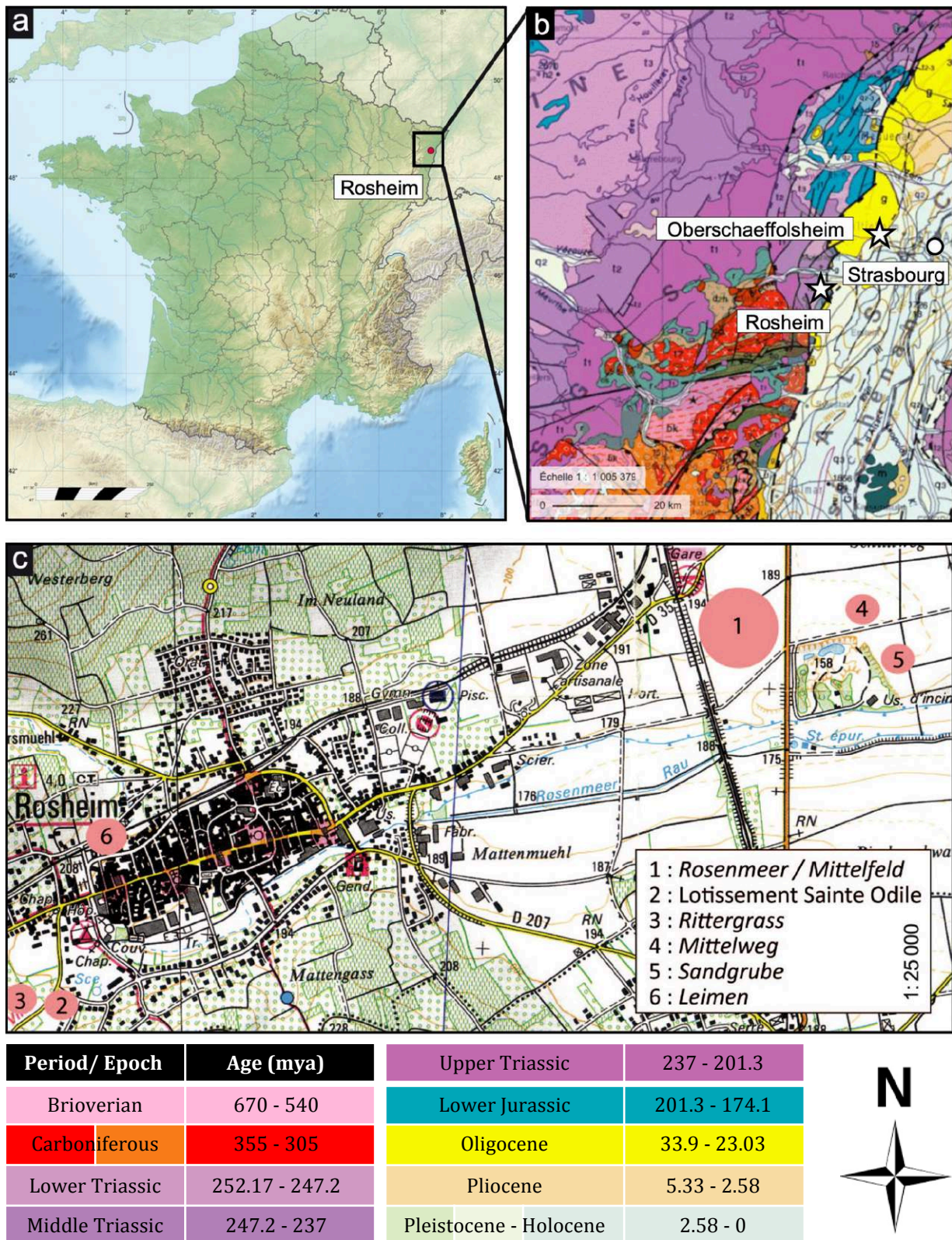


Figure 1. Rosheim within its local context: a) The location of the Rosheim sites within the broader Alsace region; b) *Géoportail* geological map of the region (<https://www.geoportail.gouv.fr/>) and the location of Rosheim and of Oberschaeffolsheim with reference to the modern city of Strasbourg; c) the different Neolithic sites (see table 1 for more information) within Rosheim. The legend shows the major geological bedrocks in the region / *Localisation de Rosheim dans son contexte local.* a) *Localisation des sites de Rosheim en Alsace.* b) *Carte géologique de la région, obtenue sur Géoportail (https://www.geoportail.gouv.fr/) et localisation de Rosheim et Oberschaeffolsheim.* c) *Localisation des sites néolithiques de Rosheim (voir table 1 pour plus d'information). La légende montre les principaux substrats rocheux de la région*

Based on the quantity of grave goods, graves were categorised under five groups of “richness”: *none* – no grave goods; *poor* – between one and four objects (average number of elements per object less than 10); *intermediate* – between five and eight objects (or less but average number of elements per object more than 10); *rich* – between 9 and 12 objects; *very rich* – more than 13 objects.

Using only the quantity of grave goods for wealth class categorisation is not ideal, as it does not consider other less quantifiable parameters, such as duration of acquisition or methods of manufacturing the object, rarity or exotic nature of the raw material, symbolism of the object or its use (Salanova, 1998; Augereau and Chambon, 2003). Notwithstanding, it is a consensual approach based on current available evidence. The classification of the graves is provided in Supplementary information.

Analytical methods and instrumentation for stable isotope analysis

Stable isotope analysis of bone collagen is one of the most widely applied analytical methods used to reconstruct palaeodietary practices in archaeology. In such cases, the most commonly used isotope systems are those of carbon ($^{13}\text{C}/^{12}\text{C}$; $\delta^{13}\text{C}$) and nitrogen ($^{15}\text{N}/^{14}\text{N}$; $\delta^{15}\text{N}$) and more recently, sulfur ($^{34}\text{S}/^{32}\text{S}$; $\delta^{34}\text{S}$) (Makarewicz and Sealy, 2015; Szpak et al., 2017b). Values for $\delta^{13}\text{C}$ are typically used to identify the consumption of food groups with distinctive carbon sources, such as C_3 - vs. C_4 - based systems or terrestrial/marine systems. Nitrogen isotope values are typically used to evaluate the individual’s trophic level, whereas $\delta^{34}\text{S}$ values relate to both the local geology and diet, and therefore are used to answer both questions on diet and on mobility.

All bone samples were prepared at the preparation laboratory at UMR 7269 LAMPEA, Aix-en-Provence (France), and the extracted collagen sent to Iso-Analytical Limited (UK) for analysis. Bone collagen was extracted following a modified ABA procedure (Brock et al., 2010; Szpak et al., 2017a). A detailed description of the procedure can be found in Cheung et al. (2021).

At Iso-Analytical, samples were analysed with a Europa Scientific™ elemental analyser, coupled to a mass spectrometer. Duplicate measures were taken for one in every five samples. Measurement precision was further monitored using an in-house lab standard extracted alongside the archaeological bone samples (CC_REF – cattle bone collagen, $\delta^{13}\text{C} = -20.95 \pm 0.07\text{‰}$, $\delta^{15}\text{N} = +4.19 \pm 0.07\text{‰}$, and $\delta^{34}\text{S} = +1.87 \pm 0.32\text{‰}$). Reported carbon and nitrogen isotope values are reported in “per mil (‰)” and were calibrated to VPDB and AIR, respectively, using IA–R068, IA–R038, IA–R069, and a mixture of IA–R046 and IAEA–C7 as control check standards. IA–R068, IA–R038 and IA–R069 were calibrated and traceable to the international standards IAEA–CH–6 and IAEA–N–1. IA–R046

was calibrated against and traceable to the international standards IAEA–N–1 and IAEA–C7.

For sulfur isotope analysis, all measurements are reported in “per mil (‰)”. Results were calibrated to VCDT using IA–R061. IAEA–SO–5, IA–R068 and IA–R069 were used as control check standards. IA–R061 was calibrated against and traceable to the international standards NBS–127 and IAEA–S–1. IA–R068 and IA–R069 was calibrated against and traceable to the international standards NBS–127 and IAEA–SO–5.

Based on the formulae sheet provided in Szpak et al. (2017b), measurement precision ($u(R_w)$) was determined to be $\pm 0.06\text{‰}$, $\pm 0.06\text{‰}$ and $\pm 0.24\text{‰}$, for $\delta^{13}\text{C}$, $\delta^{15}\text{N}$ and $\delta^{34}\text{S}$, respectively, using the repeated measurements of calibration standards, check standards, in-house lab standard and sample replicates. Accuracy or systematic error ($u(\text{bias})$) was determined to be ± 0.14 for $\delta^{13}\text{C}$, ± 0.13 for $\delta^{15}\text{N}$ and ± 0.33 for $\delta^{34}\text{S}$ on the basis of the difference between the observed and known δ values of the check standards and the long-term standard deviations of these check standards. The total analytical uncertainty (U_c) was estimated at ± 0.15 for $\delta^{13}\text{C}$, ± 0.14 for $\delta^{15}\text{N}$ and ± 0.41 for $\delta^{34}\text{S}$. The formulae sheet with details of all the measured standards is provided in Supplementary information.

Collagen quality was assessed according to the following conventional criteria: %collagen between 0.5% and 22% by weight, %C between 15.3% and 47%, %N between 5.5% and 17.3%, %S between 13% and 35%, atomic C/N ratio between 2.9 and 3.6, atomic C/S ratio between 300 and 900, and atomic N/S ratio between 100 and 300 (DeNiro, 1985; Ambrose, 1990; van Klinken, 1999; Harbeck and Grupe, 2009; Nehlich and Richards, 2009; Bocherens et al., 2011). Only samples with elemental compositions within these ranges were analysed.

Statistical methods

All statistical tests were performed using R version 3.6.0 (R Core Team, 2019) with RStudio (RStudio Team, 2018). Data were visualised using the package “ggplot2” (Wickham, 2016) and “ggpubr” (Kassambara, 2020). Normality of distribution was tested with a Shapiro-Wilk’s test. Variance equality was tested through either the Bartlett’s test (for normally distributed data) or the *F*-test (for data not normally distributed). For groups with normally distributed data and sufficient sample size ($n > 15$), the parametric test, unpaired independent Student’s *t* test was used to determine differences between group means for $\delta^{13}\text{C}$, $\delta^{15}\text{N}$ and $\delta^{34}\text{S}$ values. For groups with not normally distributed data and/or a small sample size ($n < 15$), the non-parametric Wilcoxon test was used. Relationships between variables were evaluated using a Spearman correlation test. A 0.05 probability ($p < 0.05$) is considered significant. R scripts used were modified from a previously published report (Cheung et al., 2021).

Results

Bone preservation was generally good. Fifty-one out of the 61 human samples and all 37 faunal samples yielded well-preserved collagen for stable isotope analysis. The results of all accepted C, N and S measurements, together with the previously published $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values (Denaire et al., 2017), are provided in Supplementary information and summarised in table 3. Details of elemental concentrations and ratios, excluded samples and replicates are also provided in Supplementary information. No interlaboratory pattern was observed (figure S1), attested by Wilcoxon tests

on humans for both $\delta^{13}\text{C}$ ($p=0.083$) and $\delta^{15}\text{N}$ ($p=0.5$) values, therefore all measurements are discussed together. Figure 2a plots the $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values of all humans against those of the fauna, figure 2b plots the $\delta^{34}\text{S}$ values of all humans against those of the fauna. The ranges of $\delta^{13}\text{C}$, $\delta^{15}\text{N}$ and $\delta^{34}\text{S}$ values of all RR humans are -21.1 to -18.0‰ , $+8.4$ to $+12.7\text{‰}$ and $+4.1$ to $+6.8\text{‰}$, respectively. The means of $\delta^{13}\text{C}$, $\delta^{15}\text{N}$ and $\delta^{34}\text{S}$ values of all RR humans are $-20.3 \pm 0.5\text{‰}$ ($n=70$), $+9.7 \pm 0.8\text{‰}$ ($n=70$) and $+5.4 \pm 0.7\text{‰}$ ($n=46$), respectively. The $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values of all humans are consistent with a predominantly C_3 -based terrestrial diet.

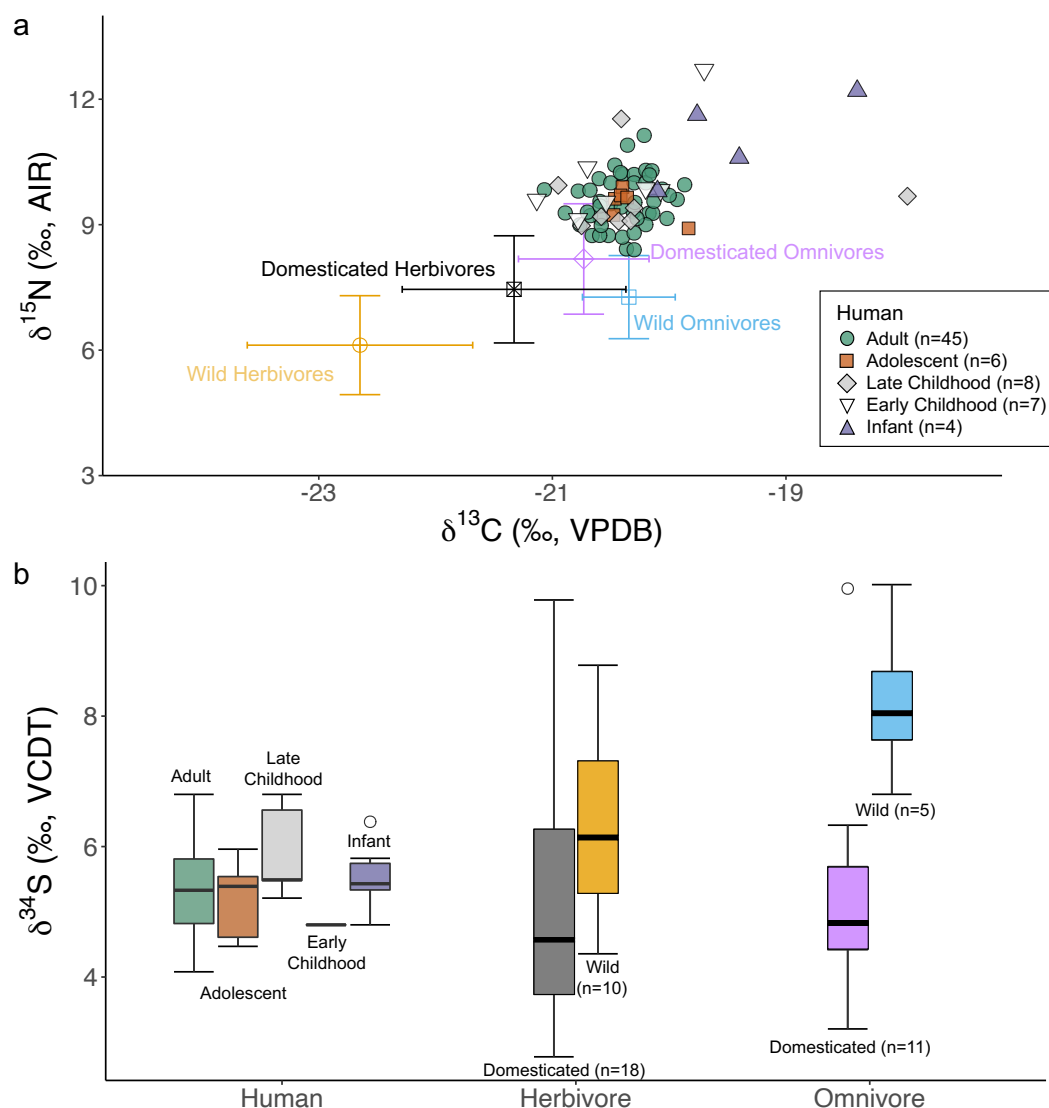


Figure 2. Overall $\delta^{13}\text{C}$, $\delta^{15}\text{N}$ and $\delta^{34}\text{S}$ bone collagen values from the RR humans compared with fauna from Rosheim and Oberschaeffolsheim. Original and published data (Denaire et al., 2017). For the age categories, adult corresponds to individuals aged >20 years; adolescent corresponds to individuals aged 13-19 years; late childhood corresponds to individuals aged 6-12 years; early childhood corresponds to individuals aged 1-6 years; infant corresponds to individuals aged <1 year / *Box-plot pour les valeurs de $\delta^{13}\text{C}$, $\delta^{15}\text{N}$ et $\delta^{34}\text{S}$ du collagène osseux des humains de RR comparées à la faune de Rosheim et de Oberschaeffolsheim. Données originales et publiées (Denaire et al., 2017). Pour les catégories d'âge, adult correspond aux individus de plus de 20 ans, adolescent correspond aux individus âgés entre 13 et 19 ans, late childhood correspond aux individus âgés entre 6 et 12 ans, early childhood correspond aux individus âgés entre 1 et 6 ans ; infant correspond aux individus de moins de 1 an*

Fauna

The ranges of $\delta^{13}\text{C}$, $\delta^{15}\text{N}$ and $\delta^{34}\text{S}$ values of all fauna are -24.0 to -19.7‰ , $+4.4$ to $+10.5\text{‰}$ and $+2.8$ to $+10.0\text{‰}$, respectively. The mean $\delta^{13}\text{C}$, $\delta^{15}\text{N}$ and $\delta^{34}\text{S}$ values of all fauna are $-21.4 \pm 1.1\text{‰}$ ($n=44$), $+7.3 \pm 1.4\text{‰}$ ($n=44$) and $+5.8 \pm 2.0\text{‰}$ ($n=36$), respectively. There are no observed differences in the isotopic faunal measurements from the different contexts (figure S1), thus all faunal data have been pooled together to establish the isotopic baselines for the site. As the isotopic compositions of many species overlap significantly, fauna are grouped according to their general feeding strategies (e.g., herbivore/omnivore; domesticated/wild). Amongst our samples, wild herbivores include beaver, auroch and deer; wild omnivores include badger, bear and boar; domesticated herbivores include cattle and sheep/goat; domesticated omnivores refer to pigs. Table 2 provides summary statistics for all faunal data.

Wilcoxon tests reveal that $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values of herbivores are more elevated among domesticates than wild ones ($\delta^{13}\text{C}$: diff= 1.3‰ ; $p=0.0036$; $\delta^{15}\text{N}$: diff= 1.5‰ , $p=0.021$). Wild animals have more elevated mean $\delta^{34}\text{S}$ values than domesticates (t -test, diff= 1.6‰ , $p=0.0045$).

Humans – cultural phases

Individuals belonging to the age categories of “infant” and “early childhood” (age < 5 years) are excluded from the analysis, as their isotopic compositions could be influenced by the breastfeeding effect (Fuller et al., 2006b; Reynard and Tuross, 2015). Most of the humans belonged to the Grossgartach phase ($n=62$). Only two individuals pertain to the Planig-Friedberg phase and four to the Rössen phase (figure 3). No statistical tests were performed as sample sizes for these two latter stages are too small. Notwithstanding, as no particular trends can be observed, individuals from all phases are treated as one homogenous group in this study.

| | | $\delta^{13}\text{C}$ (‰) | $\delta^{15}\text{N}$ (‰) | $\delta^{34}\text{S}$ (‰) |
|------------|-------------------------|---------------------------|---------------------------|---------------------------|
| Herbivores | Domesticated ($n=18$) | -21.3 ± 1.0 | $+7.5 \pm 1.3$ | $+5.1 \pm 1.9$ ($n=15$) |
| | Wild ($n=10$) | -22.7 ± 1.0 | $+6.1 \pm 1.2$ | $+6.3 \pm 1.4$ ($n=10$) |
| Omnivores | Domesticated ($n=11$) | -20.7 ± 0.6 | $+8.2 \pm 1.3$ | $+5.5 \pm 2.2$ ($n=7$) |
| | Wild ($n=5$) | -20.3 ± 0.4 | $+7.2 \pm 1.0$ | $+8.2 \pm 1.3$ ($n=4$) |

Table 2. Mean and standard deviation values for stable carbon, nitrogen and sulfur isotopes of all fauna, presented according to general feeding strategies. Original and published data (Denaire et al., 2017) / *Moyennes et écarts types des valeurs isotopiques du carbone, de l'azote et du soufre de toute la faune en fonction des stratégies d'alimentation générales. Données originales et publiées (Denaire et al., 2017)*

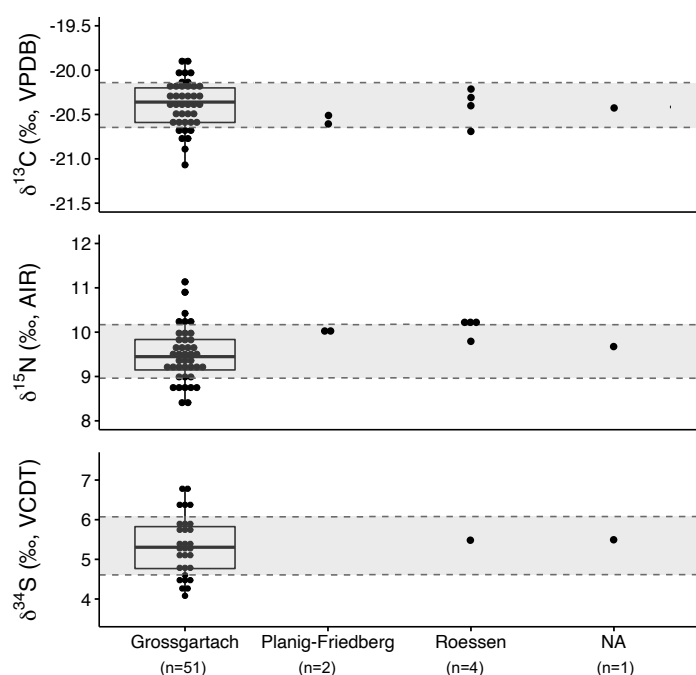


Figure 3. Bone collagen values for $\delta^{13}\text{C}$, $\delta^{15}\text{N}$ and $\delta^{34}\text{S}$ of all humans aged >5 years, presented according to chronological phase. Gray shaded areas cover a one-standard-deviation interval for the whole population in each respective isotope system. Original and published data (Denaire et al., 2017) / *Valeurs de $\delta^{13}\text{C}$, $\delta^{15}\text{N}$ et $\delta^{34}\text{S}$ du collagène osseux des humains âgés de plus 5 ans, en fonction des phases chrono-culturelles. Les zones grisées illustrent l'intervalle d'un écart type de l'ensemble de la population pour chaque système isotopique. Données originales et publiées (Denaire et al., 2017)*

Humans – Sex and age-at-death

Table 3 shows the summarised stable isotope measurements of all 70 RR humans organised by sex and age. Forty-five are adults, of which 28 could be sexed morphologically. *F*-tests indicate that variances in all three isotope systems are not significantly different between the sexes ($\delta^{13}\text{C}$: $p=0.59$; $\delta^{15}\text{N}$: $p=0.13$; $\delta^{34}\text{S}$: $p=0.54$). There are no significant differences between males ($n=8$) and females ($n=20$) (Wilcoxon-tests: $\delta^{13}\text{C}$, $p=0.13$; $\delta^{15}\text{N}$, $p=0.06$; $\delta^{34}\text{S}$, $p=0.52$; figure 4).

A total of 45 adults (>20 years) and 25 juveniles (<20 years) were analysed in this study. The juveniles include six individuals between 13 and 19 years of age (adolescent - ADOL), eight individuals between 6 and 12 years (late childhood - LC), seven individuals between 1 and 6 years (early childhood - EC), and four individuals under the age of one (infant - INF) (figure 2). All age groups have similar mean $\delta^{13}\text{C}$, $\delta^{15}\text{N}$ and $\delta^{34}\text{S}$ values, except for

the two youngest age groups (INF and EC). As shown in figure 5, the $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values of juveniles below the age of six years decrease with increasing age, likely reflecting the weaning effect, as breastfeeding infants are expected to have more enriched $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values compared to their mothers. The isotopic enrichment from breastfeeding, which has been estimated at about 0.5-1‰ in $\delta^{13}\text{C}$ and 2-5‰ in $\delta^{15}\text{N}$, is expected to wane as individuals begin to incorporate food other than human breastmilk (Fuller et al., 2006a; Herrscher et al., 2017). Sample size of S measurements among the INF and EC ($n=6$) is too small for meaningful interpretation. However, based on figure 5c, weaning is unlikely to have influenced juvenile $\delta^{34}\text{S}$ values.

Our sample size at RR is too small to use WARN (Tsutaya, 2019), an approximate Bayesian computation for weaning age estimation. Therefore, to help visualise the weaning process at RR, the $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values of juveniles aged under six were fitted with local regression lines (LOESS – locally estimated scatterplot smoothing, α set at

| | $\delta^{13}\text{C}$ (‰) | $\delta^{15}\text{N}$ (‰) | $\delta^{34}\text{S}$ (‰) |
|---------------------------|---------------------------|---------------------------|---------------------------|
| Overall ($n=70$) | -20.8 ± 0.5 | $+9.7 \pm 0.8$ | $+5.4 \pm 0.7$ ($n=46$) |
| By sex | | | |
| Female ($n=20$) | -20.4 ± 0.2 | $+9.4 \pm 0.8$ | $+5.5 \pm 0.7$ ($n=13$) |
| Male ($n=8$) | -20.3 ± 0.3 | $+9.9 \pm 0.4$ | $+5.4 \pm 0.9$ ($n=5$) |
| By age categories | | | |
| Adult ($n=45$) | -20.4 ± 0.3 | $+9.6 \pm 0.6$ | $+5.3 \pm 0.7$ ($n=29$) |
| Adolescent ($n=6$) | -20.3 ± 0.2 | $+9.5 \pm 0.4$ | $+5.2 \pm 0.6$ ($n=5$) |
| Late childhood ($n=8$) | -20.2 ± 0.9 | $+9.6 \pm 0.8$ | $+5.5 \pm 0.5$ ($n=6$) |
| Early childhood ($n=7$) | -20.4 ± 0.5 | $+10.1 \pm 1.2$ | $+5.9 \pm 0.7$ ($n=5$) |
| Infant ($n=4$) | -19.4 ± 0.7 | $+11.1 \pm 1.1$ | $+4.8$ ($n=1$) |

Table 3. Mean and standard deviation values for stable carbon, nitrogen and sulfur isotopes of all humans, presented by sex and age category. Original and published data (Denaire et al., 2017) / *Moyennes et écarts-types des compositions isotopiques du carbone, de l'azote et du soufre de tous les humains, organisés par catégories de sexe et d'âge. Données originales et publiées (Denaire et al., 2017)*

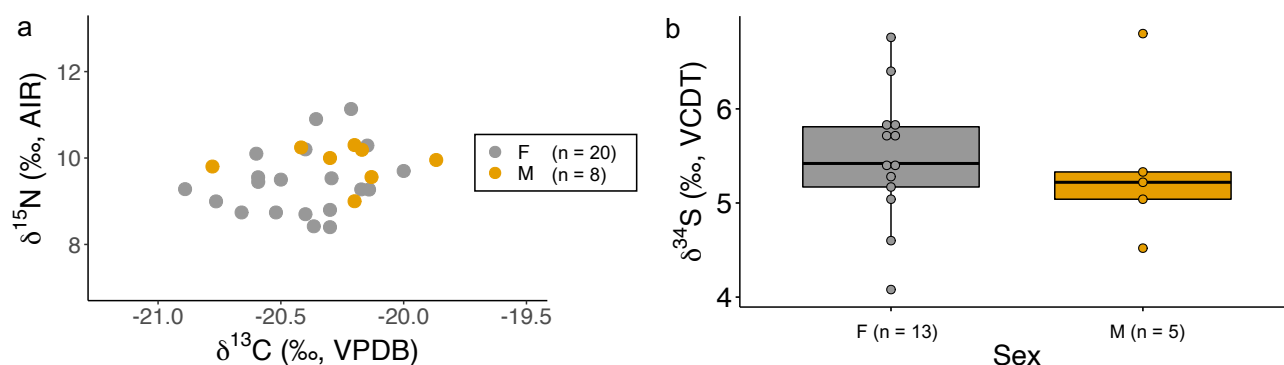


Figure 4. Bone collagen values for $\delta^{13}\text{C}$, $\delta^{15}\text{N}$ and $\delta^{34}\text{S}$ of all humans for whom sex could be morphologically determined. Original and published data (Denaire et al., 2017) / *Valeurs de $\delta^{13}\text{C}$, $\delta^{15}\text{N}$ et $\delta^{34}\text{S}$ du collagène osseux de tous les humains dont la diagnose sexuelle (morphologique) a été possible. Données originales et publiées (Denaire et al., 2017)*

0.80). The beginning and end of the weaning process are estimated using the first inflection point of the regression lines and the point where the lines approach the upper limits of the adult values, respectively (figure 5a-b). Note that RR85 is excluded from the calculations for the regression lines, as this individual has an unusually high $\delta^{15}\text{N}$ value leading to extra inflections on the regression lines. As shown in table 4, the first inflection points of the regression lines denote the beginning of the weaning process, at 0.56 year according to the $\delta^{13}\text{C}$ values and 1.11 years according to

the $\delta^{15}\text{N}$ values. The points at which the regression lines meet the upper limit of the adult values indicate the end of the weaning process: 1.78 years for the $\delta^{13}\text{C}$ values and 2.06 years for the $\delta^{15}\text{N}$ values. This suggests that the isotopic signals for weaning were registered in the bones of these individuals between 6 to 13 months and 1.8 to 2.1 years. Note that this is the estimated age for when the weaning signals were registered in the bone collagen, not the actual estimated age of weaning, which would be slightly earlier.

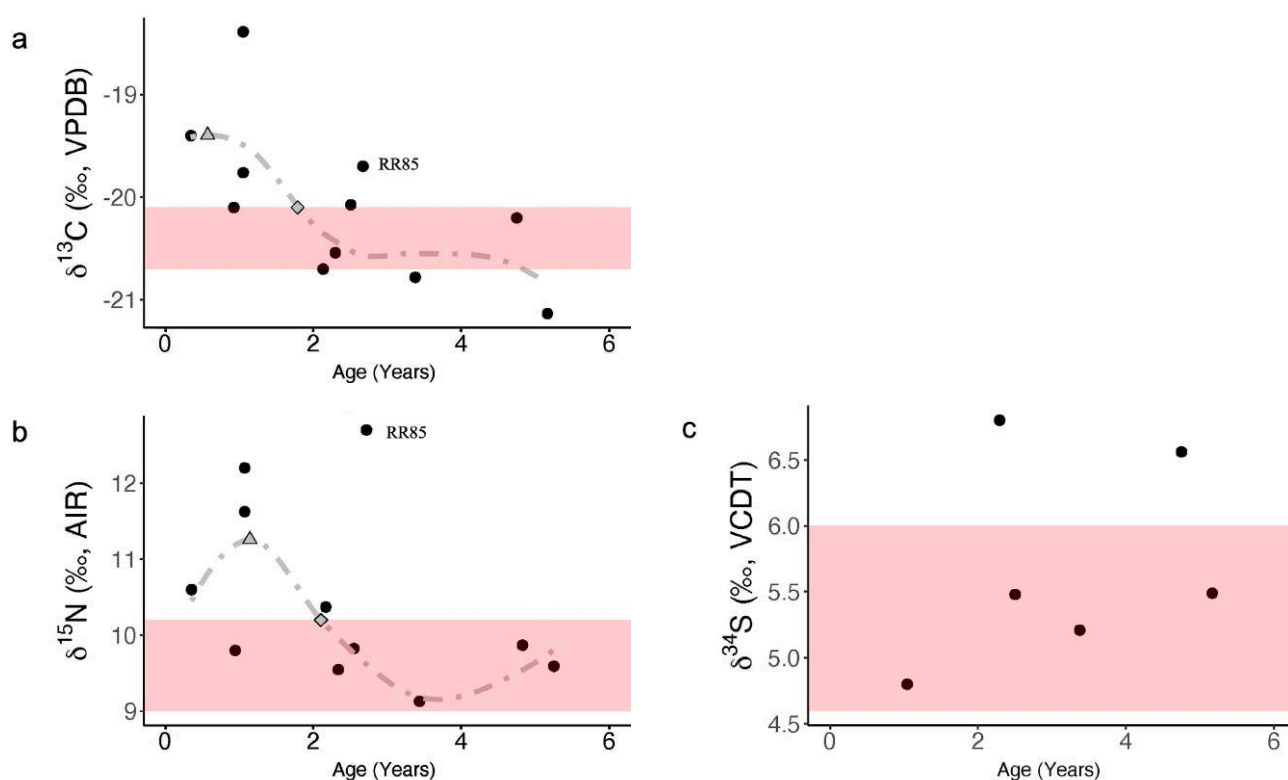


Figure 5. Bone collagen data for carbon, nitrogen and sulfur isotopes for the RR juveniles under the age of 6 (INF and EC). Shaded red areas correspond to the average adult values at the site: a) juvenile $\delta^{13}\text{C}$ values relative to average adult $\delta^{13}\text{C}$ values ($-20.4 \pm 0.3\text{‰}$; $n = 11$); b) juvenile $\delta^{15}\text{N}$ values relative to average adult $\delta^{15}\text{N}$ values ($+9.6 \pm 0.6\text{‰}$; $n = 11$); c) juvenile $\delta^{34}\text{S}$ values relative to average adult $\delta^{34}\text{S}$ values ($+5.3 \pm 0.7\text{‰}$; $n = 6$). In a) and b), the smooth lines are created using LOESS, with α set at 0.80; grey triangles correspond to the estimated beginning of weaning, whereas grey diamonds correspond to the estimated end. Original and published data (Denaire et al., 2017) / *Valeurs isotopiques du carbone, de l'azote et du soufre du collagène osseux des sujets immatures RR de moins de 6 ans (INF et EC), les zones ombrées en rouge correspondent aux valeurs moyennes des adultes sur le site : a) valeurs de $\delta^{13}\text{C}$ des sujets immatures par rapport à la valeur moyenne des adultes ($-20,4 \pm 0,3 \text{‰}$; $n = 11$); b) valeurs de $\delta^{15}\text{N}$ des sujets immatures par rapport à la valeur moyenne des adultes ($+9,6 \pm 0,6 \text{‰}$; $n = 11$); c) Valeurs de $\delta^{34}\text{S}$ des sujets immatures par rapport à la valeur moyenne des adultes ($+5,3 \pm 0,7 \text{‰}$; $n = 6$). En a) et b), les lignes grises sont créées à l'aide de LOESS, avec α fixé à 0,80; les triangles gris correspondent au début estimé du sevrage, les losanges gris correspondent à la fin estimée du sevrage. Données originales et publiées (Denaire et al., 2017)*

| | $\delta^{13}\text{C}$ | | $\delta^{15}\text{N}$ | |
|----------------------|-----------------------|----------|-----------------------|---------|
| | Years (median) | ‰ (VPDB) | Years (median) | ‰ (AIR) |
| Beginning of weaning | 0.56 | -19.4 | 1.11 | +11.3 |
| End of weaning | 1.78 | -20.1 | 2.06 | +10.2 |

Table 4. Estimated ages for the beginning and the end of weaning at RR based on LOESS curves / *Âges estimés du début et de la fin du processus de sevrage à RR d'après les courbes LOESS*

Humans – grave goods

The total number of objects found in each burial ranges from one to 17, but most burials were found with between 4 to 8 objects (figure 6). No pattern in isotopic measurements is observed between individuals buried with different quantities of grave goods. A MANOVA test confirms this ($F(3,42)=1.20$, Pillai's Trace=0.08, $p=0.32$; figure S2).

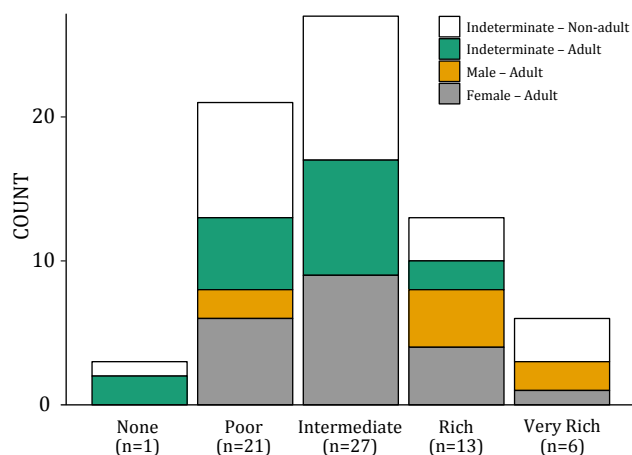


Figure 6. Scoring of RR individuals according to “wealth” of grave goods. “None” refers to graves with no grave goods; “poor” refers to graves with 1 to 4 objects (average number of elements per object less than 10); “intermediate” refers to graves with 4 to 8 objects (or less but average number of elements per object more than 10); “rich” refers to graves with 9 to 12 objects; “very rich” refers to graves with more than 13 objects / *Classement des individus de RR en fonction de la “richesse” du mobilier funéraire.* “None”: tombes sans mobilier funéraire; “poor”: sépultures livrant 1 à 4 objets (nombre moyen d’éléments par objet inférieur à 10); “intermediate”: tombes livrant 4 à 8 objets (ou moins mais avec nombre moyen d’éléments par objet supérieur à 10); “rich”: tombes livrant 9 à 12 objets; “very rich”: tombes livrant plus de 13 objets

The most common type of grave goods are ceramic objects. Almost all graves yielded at least one ceramic item (e.g., vase, bottle, goblet). Grave goods related to agricultural activities, in particular grindstones and sickles, were also found in more than half of the graves. Conversely, weapons, specifically arrowheads, were only found with 13 individuals (only 12 were analysed in this study, among them there were 6 adults and 6 juveniles). Among the individuals who were buried with arrowheads, all those that could be sexed were determined to be male (four among the six adults).

Considering only the adults and adolescents (age>13), figure 7 compares the $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values of individuals buried with arrowheads to that of those buried without arrowheads. A MANOVA test detected no significant differences among the two groups in the $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values ($F(1,64)=0.022$, Pillai's Trace<0.01, $p=0.978$). Similarly,

no differences can be observed between the mean $\delta^{34}\text{S}$ values for those buried with or without arrowheads (Wilcoxon test: $p=0.39$).

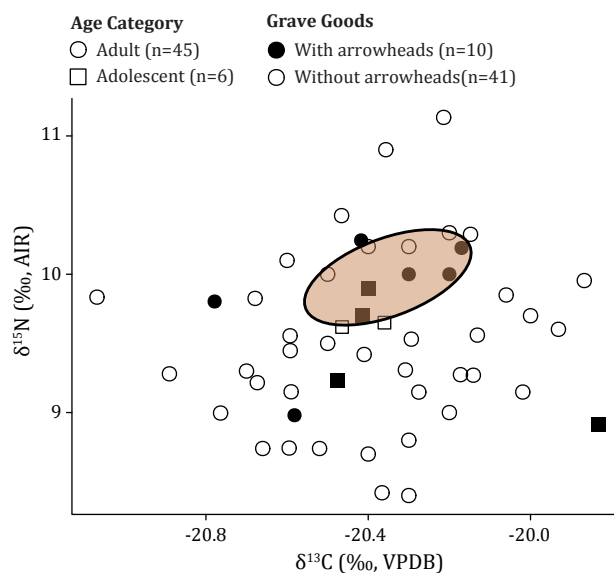


Figure 7. Comparing bone collagen values for $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ of all RR adults and adolescents (age>13 years) buried with or without arrowheads. Unfilled symbols correspond to individuals buried without arrowheads; filled symbols correspond to individuals buried with arrowheads. The shaded ellipse represents the bivariate distribution of all adults buried with arrowheads. The standard ellipse is set to contain about 40% of the data, assuming a multivariable normal distribution. Original and published data (Denaire et al., 2017) / *Comparaison des valeurs de $\delta^{13}\text{C}$ et $\delta^{15}\text{N}$ du collagène osseux de tous les adultes et adolescents RR (>13 ans) enterrés avec et sans armatures de flèche.* Les symboles vides correspondent aux individus sans armature de flèche; les symboles pleins correspondent aux individus avec armatures de flèche. L'ellipse représente la distribution bivariée de tous les adultes inhumés avec des armatures de flèche. L'ellipse standard contient environ 40 % des données, en supposant une distribution normale multivariée. Données originales et publiées (Denaire et al., 2017)

Discussion

Fauna

Though the isotopic variations in the faunal data cannot be examined at the species level, the data presented here reveal that domesticated animals have different isotopic values to those of wild animals. The more negative $\delta^{13}\text{C}$ values observed in the wild animals suggest that these animals likely come from a canopied environment (van der Merwe and Medina, 1991; Bonafini et al., 2013). The relatively elevated $\delta^{15}\text{N}$ values in domesticates could be evidence of certain agricultural practices, such as feeding manured crops to domesticates (Bogaard et al., 2007; Makarewicz, 2014).

In terms of $\delta^{34}\text{S}$ values, Rosheim is located at the junction of several geological formations (figure 1b). The complex geology of the region thus offers an interesting opportunity to examine animal management practices at the site using stable sulfur isotope analysis. As expected, the $\delta^{34}\text{S}$ values of the humans are more similar to those of the domesticates (figure 2b), while the more elevated $\delta^{34}\text{S}$ values in wild animals may indicate that hunting grounds were situated on a different geological formation to that of the residential area. In addition, domesticated herbivores have a much larger range of $\delta^{34}\text{S}$ values (interquartile range: +3.8 – +6.3‰) than domesticated omnivores (interquartile range: +4.4 – +5.7‰), suggesting the latter (only pig here) were probably kept close to the residential area, whereas domesticated herbivores were allowed to roam a larger area (figure 2b).

Humans

All human $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values are consistent with a diet based primarily on terrestrial C_3 sources, as expected for the region. The mean $\delta^{15}\text{N}$ human value is 2.2‰ and 1.5‰ higher than those of domesticated herbivores and domesticated omnivores, respectively. This offset is significantly less than that of the trophic discrimination effect, which is generally considered to be between +3.0 to +6.0‰ per trophic level (DeNiro and Epstein, 1981; Hedges and Reynard, 2007; O’Connell et al., 2012). Therefore, our results suggest a moderate intake of animal protein among the RR humans, further confirming a largely agrarian lifestyle centred around crop cultivation and consumption.

Adolescents appear to have had a similar diet to adults. However, younger children (<6 years old) had slightly more enriched $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values. This is expected as the enriched $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values likely reflect some breastfeeding effect. Table 4 provides estimated weaning ages based on the turning points of the LOESS curves in both $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values in figure 5. Considering that juveniles, especially trabecular bone in infants under the age of one, have much faster turnover rates than adults (Bryant and Loutit, 1964; Valentin, 2002), the actual weaning age would have started several months earlier. Due to the small sample size and other complicated factors involved (Reynard and Tuross, 2015), it is not possible to provide a meaningfully accurate estimation for the age of weaning with the current available data. However, it seems likely that weaning completed at around the age of two at RR.

No isotopic differences can be observed between males and females at RR. Similar findings have been reported for another MTK (Grossgartach, Planig-Friedberg, and Rössen) site – Jechtingen, Germany (Mörseburg et al., 2015) –, while a statistically significant but weak sex-related dietary pattern (<0.5‰ in $\delta^{13}\text{C}$ values) was identified at a Grossgartach and Hinkelstein site – Trebur in Germany (Dürrwächter et al., 2006). It should be noted that at RR, among those that can be sexed morphologically (30/80),

males are significantly underrepresented (8/30). It is therefore possible that certain males were buried elsewhere, and that a holistic comparison between males and females at RR cannot be conducted until burial patterns at the site are better understood.

Looking beyond the MTK cultures, contradictory patterns were also observed in the Middle Neolithic Paris Basin: Monéteau “Macherin” and Gurgy “Les Noisats” revealed sex-related dietary patterns (Rey et al., 2019), whereas Balloy “Les Réaudins”, Orville “Les Fiefs”, and Vignely “La Porte aux Bergers” showed the opposite, no statistically significant differences between both sexes (Cheung et al., 2021). Thus, it is possible that sex-related dietary practices during this period were neither cultural nor regionally specific, but rather, site-specific.

Limited patterns can be observed among individuals buried with various amounts of grave goods. In RR, dietary practices, at least in terms of protein consumption, appear to be unrelated to “wealth” and were relatively homogenous across the group. This lack of intra-site dietary differences is also present in other contemporary sites in the region (Dürrwächter et al., 2006).

Rosheim within the larger Middle Neolithic context of Danubian origin: Rhine versus Paris Basin

During the Middle Neolithic, Grossgartach in the Rhine Basin and Cerny in the Paris Basin, who had maintained clear cultural contacts and links, displayed opposing symbolic trends in their funerary practices (Chambon and Thomas, 2014). The explicit references to hunting activities and the wild in Cerny graves stand in stark contrast to the overwhelmingly domestic and agricultural grave goods in Grossgartach graves. The preferences of each group towards agricultural or hunting symbols in their tombs are also reflected in their isotopic compositions. Figure 8 compares the $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values of humans from the two river basins (Rhine and Paris), with faunal data as regional baselines (all human and faunal data from the Paris Basin is published; please refer to Cheung et al., 2021 for detailed information). Here, in order to ensure comparability between the two regional baselines, only isotopic data from domesticated herbivores (e.g. cattle, sheep/goat) are included. As shown in figure 8, RR and Cerny individuals have almost no overlapping $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values. In both groups, the offsets in $\delta^{13}\text{C}$ values between human and fauna are similar (Paris Basin: 1.4‰; Rhine Basin: 1.0‰). This difference can be explained by the different $\delta^{13}\text{C}$ baselines at the two river basins. The differences in $\delta^{15}\text{N}$ values between human and fauna, however, are more pronounced (Paris Basin: 4.8‰; Rhine Basin: 2.2‰). Recent studies have suggested that the Cerny diet was high in animal protein (Cheung et al., 2021) and likely involved higher trophic resources, such as freshwater fish (Cheung et al., 2022). In contrast, the lower offset in the $\delta^{15}\text{N}$ values between RR human and fauna suggests that, compared to Cerny, the RR individuals likely consumed more plant foods and lower trophic

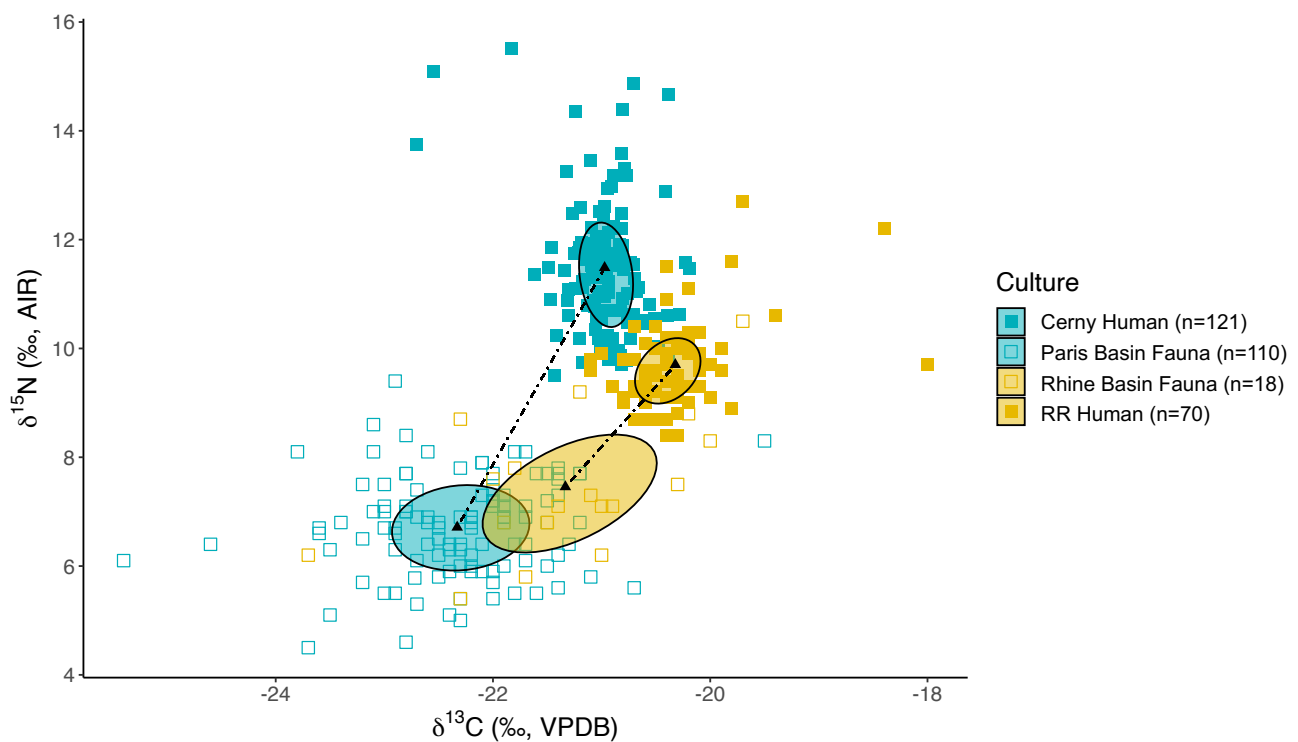


Figure 8. Comparison of stable carbon and nitrogen isotope values for humans and fauna (only domesticated herbivores) in the Rhine and Paris Basins, respectively. All data from Cerny humans and fauna from the Paris Basin are published (see details in Cheung et al., 2021). The RR humans are dated to around 4750-4500 cal. BC, the Cerny humans are dated to around 4700 and 4300 BC / *Comparaison des valeurs isotopiques du carbone et de l'azote des humains et de la faune dans les bassins rhénan et parisien. Toutes les données sur les humains Cerny et la faune du bassin parisien ont été publiées précédemment (détails dans Cheung et al., 2021)*

animal protein, such as domesticated animals. Moreover, zooarchaeological evidence suggests that both groups relied heavily on cattle breeding. There is growing evidence of dairy consumption during the LBK periods in the region (Balasse et al., 2021). One study analysing lipid residues from pottery sherds from several Neolithic sites in Alsace, including Rosheim, revealed an increased prevalence of sherds containing dairy fats from the LBK through to the Rössen phase (Casanova et al., 2020). Thus, a largely agropastoral diet that combines crops with dairy product could also explain the lower offset in the $\delta^{15}\text{N}$ values between human and fauna at the site. Zooarchaeological evidence from Oberschaeffolsheim suggests that dairy products were likely exploited based on the slaughter age profiles of cattle (Perrin et al., 2018). In addition, a “faisselle”, a type of cheese strainer in the region, was also found (Perrin et al., 2018). This archaeological evidence further confirms the consumption of dairy products at the site.

Another interesting observation concerns those buried with arrowheads. In both Cerny and Grossgartach, arrowheads appear to be a sex-specific grave good. Among those that can be sexed, all individuals buried with arrowheads were identified as male. In Cerny burials, individuals with arrowheads tend to also show skeletal markers indicative of the practice of archery (Thomas, 2014). In Rosheim, as

shown in figure 7, there is no statistically significant difference between the two groups of males (with or without arrowheads). In contrast, among Cerny groups, males buried with arrowheads have statistically significant higher $\delta^{15}\text{N}$ values (t -test, $\text{diff}=0.4\text{‰}$, $p=0.025$) than those without (Syrikova et al., 2021). Dental wear patterns further suggest that in the Cerny culture, the presence of arrowheads among grave goods could be indicative of a “hunter” lifestyle (Syrikova et al., 2021). Currently, there is insufficient evidence to suggest that RR individuals buried with arrowheads had a particularly different diet than those buried without arrowheads. This perhaps suggests that, unlike Cerny, RR individuals buried with arrowheads were better integrated with the rest of the group. Osteologically, individuals buried with arrowheads did not exhibit specific pathological pattern compared to the group buried without arrowheads, in contrast to Cerny (Thomas, 2014). However, two RR individuals (RR047 and RR057) buried with arrowheads were affected by severe enthesopathic lesions (stage C in: Villotte, 2006) at the insertion of the biceps brachii muscle (radial tuberosity). Lesions of such severity on young individuals (20-29 and 15-19 years, respectively) are often caused by the overuse of the upper limbs. Thus, there may be a connection between the lesions observed on these two individuals and their grave goods (arrowheads).

Conclusion

This study provides some interesting insights into the lifeways of RR inhabitants that contrast with those of populations living in the Seine Valley (Paris Basin) during the same time period. The stable isotope values for the fauna suggest a highly regulated animal husbandry system, where domesticated herbivores (i.e., cattle, sheep/goat) were allowed to graze further away from the residential area but domesticated omnivores (i.e., pigs) were kept close to home. RR humans appear as having had a largely agrarian lifestyle. Further intra-population comparisons suggest that the RR group had a largely homogenous diet, with little differences observed between individuals of different sexes or belonging to different wealth classes. Notwithstanding, a homogenous isotopic pattern does not necessarily mean a lack of diversity in dietary patterns. Local isotopic variability may be too small to enable discussions on links between dietary practices and social differentiation. Based on the $\delta^{15}\text{N}$ values of juveniles, it is estimated that weaning at RR was completed around the age of two. Finally, a comparison of the isotopic compositions of the RR individuals with those of Cerny suggests that while the two cultures shared some similar burial practices, such as arrowheads as sex-specific grave goods, lifeways between the two groups remained quite different.

The findings of this study pose some interesting questions regarding the westward spread of Danubian cultures into Western Europe. While certain funerary practices, such as burial positions and grave goods (i.e., arrowheads) were shared, lifeways still varied greatly between groups. Rosheim's location at the junction of two major spheres of Neolithic influence makes it the perfect site to help understand the dynamics of neolithisation. Thus, data from this study provides a strong basis from which future research can build and expand upon.

Supplementary information

Calibration :

<https://journals.openedition.org/bmsap/14244?file=1>

Overall_data_Jul2024 :

<https://journals.openedition.org/bmsap/14247?file=1>

S1-2Jul2024 :

<https://journals.openedition.org/bmsap/14252?file=1>

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References

- Ambrose S (1990) Preparation and Characterization of Bone and Tooth Collagen for Isotopic Analysis. *Journal of Archaeological Science* 17(4):431-451 [[https://doi.org/10.1016/0305-4403\(90\)90007-R](https://doi.org/10.1016/0305-4403(90)90007-R)]
- Arbogast R (1994) Premiers élevages néolithiques du nord-est de la France, Université de Liège, Liège, Belgique, 165 p
- Arbogast R (2000) L'habitat* rubané de Rosheim 'Lotissement Sainte-Odile' (Bas-Rhin) : étude de la faune. *Cahiers de l'Association pour la Promotion de la Recherche Archéologique en Alsace* 16:51-65
- Arbogast R, Jeunesse C (2013) Early Neolithic Pastoral Traditions and Cultural Groups in Northern France. In: Colledge S, Conolly J, Dobney K et al (eds) *The Origins and Spread of Domestic Animals in Southwest Asia and Europe*. Left Coast Press, Walnut Creek, pp 271-282
- Augereau A, Chambon P (2003) Nature et statut des mobiliers funéraires de la nécropole chasséenne de Monéteau (Yonne). In: Chambon P, Leclerc J (eds) *Les pratiques funéraires néolithiques avant 3500 avant J.-C. en France et dans les régions limitrophes*, Table ronde SPF, 15-17 juin 2001 Saint-Germain-en-Laye, Société préhistorique française, Mémoire XXXIII, pp 131-145
- Bakaj B, Boës E, Jeunesse C et al (1998) La nécropole Néolithique moyen de Rosheim "Rosenmeer", fouilles 1998. *Cahiers de l'Association pour la Promotion de la Recherche Archéologique en Alsace* 14:45-106
- Bakels C (2009) Heirs to the First Farmers: 4900 BC - 4300 BC. In: *The Western European Loess Belt: Agrarian History, 5300 BC - AD 1000*. Springer, Dordrecht, pp 55-64
- Balasse M, Gillis R, Živaljević I et al (2021). Seasonal calving in European Prehistoric cattle and its impacts on milk availability and cheese-making. *Scientific Reports* 11(1):8185 [<https://doi.org/10.1038/s41598-021-87674-1>]
- Bocherens H, Drucker D, Taubald H (2011) Preservation of Bone Collagen Sulphur Isotopic Compositions in an Early Holocene River-bank Archaeological Site. *Palaeogeography, Palaeoclimatology, Palaeoecology* 310(1-2):32-38 [<https://doi.org/10.1016/j.palaeo.2011.05.016>]
- Boës E, Alix G, Broqua C et al (2004a) Rosheim "Rosenmeer" (Bas-Rhin), Une nécropole Néolithique moyen en Alsace, Fouille programmée, Campagnes 1999 et 2000 1 sur 2, Service Régional de l'Archéologie d'Alsace
- Boës E, Alix G, Broqua C et al (2004b) Rosheim "Rosenmeer" (Bas-Rhin), Une nécropole Néolithique moyen en Alsace, Fouille programmée, Campagnes 1999 et 2000 2 sur 2, Service Régional de l'Archéologie d'Alsace
- Boës E, Jeunesse C, Alix G et al (2000) La nécropole néolithique moyen de Rosheim "Mittelfeld" (Bas-Rhin) : premiers résultats concernant le recrutement des individus. In: Internéo 3, Association pour les études interrégionales sur le Néolithique, Paris, pp 37-50
- Bogaard A, Heaton T, Poulton P et al (2007) The Impact of Manuring on Nitrogen Isotope Ratios in Cereals: Archaeological Implications for Reconstruction of Diet and Crop Management Practices. *Journal of Archaeological Science* 34(3):335-343 [<https://doi.org/10.1016/j.jas.2006.04.009>]

- Bonafini M, Pellegrini M, Ditchfield P et al (2013) Investigation of the ‘canopy effect’ in the isotope ecology of temperate woodlands. *Journal of Archaeological Science* 40(11):3926-3935 [https://doi.org/10.1016/j.jas.2013.03.028]
- Brock F, Higham T, Ditchfield P et al (2010) Current Pretreatment Methods for AMS Radiocarbon Dating at the Oxford Radiocarbon Accelerator Unit (ORAU). *Radiocarbon* 52(1):103-112 [https://doi.org/10.1017/S0033822200045069]
- Brůžek J (2002) A Method for Visual Determination of Sex Using the Human Hip Bone. *American Journal of Physical Anthropology* 117:157-168 [https://doi.org/10.1002/ajpa.10012]
- Brůžek J, Santos F, Dutailly B et al (2017) Validation and reliability of the sex estimation of the human os coxae using freely available DSP2 software for bioarchaeology and forensic anthropology. *American Journal of Physical Anthropology* 164(2):440-449 [https://doi.org/10.1002/ajpa.23282]
- Bryant F, Loutit J (1964) The entry of strontium-90 into human bone. *Proceedings of the Royal Society of London Series B Biological Sciences* 159(976):449-465 [https://doi.org/10.1098/rspb.1964.0013]
- Casanova E, Knowles T, Ford C et al (2020). Compound-Specific Radiocarbon, Stable Carbon Isotope and Biomarker Analysis of Mixed Marine/Terrestrial Lipids Preserved in Archaeological Pottery Vessels. *Radiocarbon* 62(6):1679-1697 [https://doi.org/10.1017/RDC.2020.11]
- Chambon P, Mordant D, Pariat J-G (2007) Sépultures du Néolithique moyen en Bassin parisien : le cas des architectures sépulcrales. In: Le Brun-Ricalens F, Valotteau F, Hauzeur A (eds) *Actes du 26e Colloque interrégional sur le Néolithique*, *Archaeologia Mosellana* (7), Luxembourg, pp 445-466
- Chambon P, Thomas A (2014) Approche structurale des nécropoles monumentales du Ve millénaire dans le bassin Seine-Yonne. *Bulletin de la Société préhistorique française* 111(2):275-290
- Chenal F (2007) Étude paléobiologique des restes humains des individus de la nécropole néolithique moyen de Rosheim ‘Rosenmeer’ (Bas-Rhin), Culture de Grossgartach. *Mémoire de Master 2*, Université Bordeaux 1, 77 p
- Cheung C, Herrscher E, Andre G et al (2021) The Grandeur of Death – Monuments, Societies, and Diets in Middle Neolithic Paris Basin. *Journal of Anthropological Archaeology* 63 (101332):1-17 [https://doi.org/10.1016/j.jaa.2021.101332]
- Cheung C, Herrscher E, Thomas A (2022) Compound specific isotope evidence points to use of freshwater resources as weaning food in Middle Neolithic Paris Basin. *American Journal of Biological Anthropology* 179(1):118-133 [https://doi.org/10.1002/ajpa.24591]
- Denaire A (2009) Le Néolithique moyen du sud de la plaine du Rhin supérieur et du nord de la Franche-Comté. Les cultures de Hinkelstein, Grossgartach et Roessen au travers de leur production céramique. *Coll. Rhin Meuse Moselle*, Monographies d’Archéologie du Grand Est, Strasbourg, 664 p
- Denaire A, Boës E (2009) Rosheim Rosenmeer : une vaste nécropole du Néolithique moyen. In: 10000 ans d’histoire ! Dix ans de fouilles archéologiques en Alsace. Éditions des Musées de la ville de Strasbourg, Strasbourg, pp 23-24
- Denaire A, Lefranc P (2014) Les pratiques funéraires de la culture de Roessen et des groupes épirosséniens dans le sud de la plaine du Rhin supérieur (4750 -4000). In: Lefranc P, Denaire A, Jeunesse C (eds) *Données récentes sur les pratiques funéraires néolithiques de la plaine du Rhin supérieur*. BAR International Series 2633, pp 73-124
- Denaire A, Mauvilly M (2012) Guémar “Rotenberger Weg”, première grande nécropole Grossgartach et Roessen (Néolithique moyen) de Haute-Alsace. *Internéo* 9, pp 73-77
- Denaire A, Lefranc P, Wahl J et al (2017) The Cultural Project: Formal Chronological Modelling of the Early and Middle Neolithic Sequence in Lower Alsace. *Journal of Archaeological Method and Theory* 24(4):1072-1149 [https://doi.org/10.1007/s10816-016-9307-x]
- DeNiro M (1985) Postmortem Preservation and Alteration of in vivo Bone Collagen Isotope Ratios in Relation to Palaeodietary Reconstruction. *Nature* 317:806-809 [https://doi.org/10.1038/317806a0]
- DeNiro M, Epstein S (1981) Influence of Diet on the Distribution of Nitrogen Isotopes in Animals. *Geochimica et Cosmochimica Acta* 45(3):341-351 [https://doi.org/10.1016/0016-7037(81)90244-1]
- Duday H, Courtaud P, Crubézy E et al (1990) L’anthropologie “de terrain” : reconnaissance et interprétation des gestes funéraires. *Bulletins et Mémoires de la Société d’Anthropologie de Paris* 2(3-4):29-50
- Dürrewächter C, Craig O, Collins M et al (2006) Beyond the grave: variability in Neolithic diets in Southern Germany? *Journal of Archaeological Science* 33(1):39-48 [https://doi.org/10.1016/j.jas.2005.06.009]
- Fabre M, Rollinger E, Blondel P et al (2023) Entre fosses et fossés, dépôts et rejets : les vestiges de faune des sites à enceintes du 5ème millénaire de Basse Alsace. In: Lefranc P, Croutsch C, Denaire A (eds) *Les enceintes néolithiques du nord-ouest de l’Europe*. Actes du 33e Colloque interrégional sur le Néolithique de Saint-Dié-des-Vosges 8-9 novembre 2019. Édition Universitaire de Dijon, pp 43-58
- Forrer R (1912) Das neolithische Gräberfeld bei Lingolsheim. *Anzeiger für Elsässische Altertumskunde* 12:215-231
- Forrer R (1938) Le cimetière de Lingolsheim à poteries poinçonnées, au crâne trépané et les tombes de la zone rubanée. *Cahiers Alsaciens d’Archéologie, d’Art et d’Histoire* 111-116: 191-206
- Fuller B, Fuller J, Harris D et al (2006a) Detection of Breastfeeding and Weaning in Modern Human Infants with Carbon and Nitrogen Stable Isotope Ratios. *American Journal of Physical Anthropology* 129:279-293 [https://doi.org/10.1002/ajpa.20249]
- Fuller B, Molleson T, Harris D et al (2006b) Isotopic Evidence for Breastfeeding and Possible Adult Dietary Differences from Late/Sub-Roman Britain. *American Journal of Physical Anthropology* 129:45-54 [https://doi.org/10.1002/ajpa.20244]
- Gelliot E (2002) L’outillage en grès dans le mobilier funéraire de la nécropole néolithique moyen de Rosheim. *Mémoire de maîtrise*, Université Marc Bloch, Strasbourg, 205 p
- Hachem L (2011) Les faunes du Néolithique moyen dans le Nord de la France : bilan et pistes de recherches. *Revue archéologique de Picardie* 28:313-329

- Harbeck M, Grupe G (2009) Experimental Chemical Degradation Compared to Natural Diagenetic Alteration of Collage: Implications for Collagen Quality Indicators for Stable Isotope Analysis. *Archaeological and Anthropological Sciences* 1(1): 43-57 [<https://doi.org/10.1007/s12520-009-0004-5>]
- Hedges R, Reynard L (2007) Nitrogen Isotopes and the Trophic Level of Humans in Archaeology. *Journal of Archaeological Science* 34(8):1240-1251 [<https://doi.org/10.1016/j.jas.2006.10.015>]
- Herrscher E, Goude G, Metz L (2017) Longitudinal Study of Stable Isotope Compositions of Maternal Milk and Implications for the Palaeo-Diet of Infants. *Bulletins et Mémoires de la Société d'Anthropologie de Paris* 29(3-4):131-139 [<https://link.springer.com/article/10.1007/s13219-017-0190-4>]
- Horviller M (2020) Les inhumés de Rosheim “Rosenmeer” (Bas-Rhin) : Identité, Morphologie et état sanitaire d'une population du Mittelneolithikum. Mémoire de Master 2, Université de Bordeaux, 76 p
- Jeunesse C (1997) Les pratiques funéraires de la culture de Cerny et le «Mittelneolithikum» du domaine rhénan. In: Constantin C, Mordant D, Simonin D (eds) *La culture de Cerny Nouvelle économie, nouvelle société au Néolithique, Actes du Colloque International de Nemours 9-11 mai 1994. Mémoires du Musée de Préhistoire d'Île-de-France*, pp 543-555
- Jeunesse C, Arbogast R (1996) L'habitat Néolithique moyen (cultures de Grossgartach et de Roessen) de Rosheim Mittelweg & Sandgrube (Bas-Rhin) Fouilles 1992 et 1993 dans le cadre du Néolithique moyen du sud de la Plaine du Rhin supérieur. Première partie : structures et vestiges façonnés. *Cahiers de l'Association pour la Promotion de la Recherche Archéologique en Alsace* 12:21-118
- Jeunesse C, Mauvilly M (1996) Une nouvelle nécropole du Néolithique moyen (culture de Grossgartach) à Rosheim (Bas-Rhin). *Cahiers de l'Association pour la Promotion de la Recherche Archéologique en Alsace* 12:119-140
- Kassambara A (2020) ggpubr: 'ggplot2' Based Publication Ready Plots [<https://cran.r-project.org/web/packages/ggpubr/index.html>]
- Lefranc P, Arbogast R, Boës E (2007) L'habitat néolithique récent de Rosheim “Leimen”. *Cahiers alsaciens d'archéologie, d'art et d'histoire* 50:11-26
- Lefranc P, Bachelier F, Chenal F et al (2018) La nécropole néolithique moyen d'Obernai “Neuen Brunnen” (Bas-Rhin) : rites funéraires de la première moitié du 5e millénaire dans le sud de la plaine du Rhin supérieur (Grossgartach, Planig-Friedberg, Roessen). *Revue archéologique de l'Est* 67(190):5-57
- Lefranc P, Mauvilly M, Arbogast RM (1999) L'habitat Néolithique moyen (cultures de Grossgartach et de Roessen) de Rosheim “Laser” (Bas-Rhin). *Cahiers de l'Association pour la Promotion de la Recherche Archéologique en Alsace* 15: 113-151
- Lefranc P, Michler M, Serrurier A et al (2015) Une nouvelle maison du Rubané récent sur le “Site central” de Rosheim “Rittergass” / “Sainte-Odile” (Bas-Rhin). *Revue archéologique de l'Est* 64:27-48
- Makarewicz C (2014) Winter pasturing practices and variable fodder provisioning detected in nitrogen ($\delta^{15}\text{N}$) and carbon ($\delta^{13}\text{C}$) isotopes in sheep dentinal collagen. *Journal of Archaeological Science* 41:502-510 [<https://doi.org/10.1016/j.jas.2013.09.016>]
- Makarewicz CA, Sealy J (2015) Dietary reconstruction, mobility, and the analysis of ancient skeletal tissues: Expanding the prospects of stable isotope research in archaeology. *Journal of Archaeological Science* 56:146-158 [<https://doi.org/10.1016/j.jas.2015.02.035>]
- Moorrees C, Fanning E, Hunt E (1963) Age Variation of Formation Stages for Ten Permanent Teeth. *Journal of Dental Research* 42: 1490-1502 [<https://doi.org/10.1177/00220345630420062701>]
- Mörseburg A, Alt K, Knipper C (2015) Same old in Middle Neolithic diets? A stable isotope study of bone collagen from the burial community of Jechtingen, southwest Germany. *Journal of Anthropological Archaeology* 39:210-221 [<https://doi.org/10.1016/j.jaa.2015.04.001>]
- Nehlich O, Richards M (2009) Establishing Collagen Quality Criteria for Sulphur Isotope Analysis of Archaeological Bone Collagen. *Archaeological and Anthropological Sciences* 1(1): 59-75 [<https://doi.org/10.1007/s12520-009-0003-6>]
- O'Connell T, Kneale C, Tasevska N et al (2012) The Diet-Body Offset in Human Nitrogen Isotopic Values: A Controlled Dietary Study. *American Journal of Physical Anthropology* 149(3): 426-434 [<https://doi.org/10.1002/ajpa.22140>]
- Perrin B, Fabre M, Mauduit A et al (2018) Le site Grossgartach d'Oberschaeffolsheim (Bas-Rhin). *Internéo* 12:42-56
- R Core Team (2019) R: A Language and Environment for Statistical Computing. Vienna, Austria: R Foundation for Statistical Computing [<https://www.r-project.org/>]
- Rey L, Salazar-García D, Chambon P et al (2019) A Multi-Isotope Analysis of Neolithic Human Groups in the Yonne Valley, Northern France: Insights into Dietary Patterns and Social Structure. *Archaeological and Anthropological Sciences* 11: 5591-5616 [<https://doi.org/10.1007/s12520-019-00885-6>]
- Reynard L, Tuross N (2015) The Known, the Unknown and the Unknowable: Weaning Times from Archaeological Bones using Nitrogen Isotope Ratios. *Journal of Archaeological Science* 53(Supplement C):618-625 [<https://doi.org/10.1016/j.jas.2014.11.018>]
- Robert F (2001) La nécropole Néolithique moyen de Rosheim : caractérisation de l'outillage lithique taillé. Mémoire de maîtrise, Université Marc Bloch, Strasbourg, 189 p
- Robert F (2002) La parure de la nécropole Néolithique moyen de Rosheim (Bas-Rhin). Mémoire de DEA, Université Marc Bloch, Strasbourg, 94 p
- RStudio Team (2018) RStudio: Integrated Development Environment for R. Boston, USA: RStudio, PBC [<http://www.rstudio.com/>]
- Salanova L (1998) Le statut des assemblages campaniformes en contexte funéraire : la notion de bien de prestige. *Bulletin de la Société préhistorique française* 95(3):315-326 [<https://doi.org/10.3406/bspf.1998.10806>]
- Scheuer JL, Black S (2000) *Developmental Juvenile Osteology*. Academic Press, San Diego, California, 587 p

- Schmitt A (2005) Une nouvelle méthode pour estimer l'âge au décès des adultes à partir de la surface sacro-pelvienne iliaque. *Bulletins et Mémoires de la Société d'Anthropologie de Paris* 17(1-2):89-101 [<https://doi.org/10.4000/bmsap.943>]
- Sidéra I (2000) Animaux domestiques, bêtes sauvages et objets en matières animales du Rubané au Michelsberg : de l'économie aux symboles, des techniques à la culture. *Gallia Préhistoire* 42:107-194 [<https://doi.org/10.3406/galip.2000.2172>]
- Schaeffer FA (1932) Nouvelles sépultures néolithiques trouvées à Lingolsheim et à Entzheim. *Cahiers Alsaciens d'Histoire et d'Archéologie* 85-92(3-7)
- Syrikova P, Le Luyer M, Cheung C et al (2021) Au-delà de l'apport nutritionnel : l'analyse combinée de la macro-/micro-usure dentaire et des isotopes stables révèle des comportements alimentaires néo-lithiques genrés. *Bulletins et mémoires de la Société d'Anthropologie de Paris* 33(S) [<https://doi.org/10.4000/bmsap.7204>]
- Szpak P, Krippner K, Richards M (2017a) Effects of Sodium Hydroxide Treatment and Ultrafiltration on the Removal of Humic Contaminants from Archaeological Bone. *International Journal of Osteoarchaeology* 27(6):1070-1077 [<https://doi.org/10.1002/oa.2630>]
- Szpak P, Metcalfe J, Macdonald R (2017b) Best Practices for Calibrating and Reporting Stable Isotope Measurements in Archaeology. *Journal of Archaeological Science: Reports* 13: 609-616 [<https://doi.org/10.1016/j.jasrep.2017.05.007>]
- Thomas A (2014) Bioarchaeology of the Middle Neolithic: Evidence for Archery among Early European Farmers. *American Journal of Physical Anthropology* 154(2):279-290 [<https://doi.org/10.1002/ajpa.22504>]
- Tresset A (1997) L'approvisionnement carné Cerny dans le contexte néolithique du Bassin parisien, in *La culture de Cerny. Nouvelle économie, nouvelle société au Néolithique. Actes du colloque international de Nemours, 1994, Nemours. Mémoires du musée de préhistoire d'Île-de-France*, pp 299-314
- Tsutaya T (2019) WARN: Weaning Age Reconstruction with Nitrogen Isotope Analysis [<https://cran.r-project.org/web/packages/WARN/index.html>]
- Valentin J (2002) Basic anatomical and physiological data for use in radiological protection: reference values: ICRP Publication 89. *Annals of the ICRP* 32(3-4):1-277 [[https://doi.org/10.1016/S0146-6453\(03\)00002-2](https://doi.org/10.1016/S0146-6453(03)00002-2)]
- van der Merwe N, Medina E (1991) The Canopy Effect, Carbon Isotope Ratios and Foodwebs in Amazonia. *Journal of Archaeological Science* 18(3):249-259 [[https://doi.org/10.1016/0305-4403\(91\)90064-V](https://doi.org/10.1016/0305-4403(91)90064-V)]
- van Klinken G (1999) Bone Collagen Quality Indicators for Palaeodietary and Radiocarbon Measurements. *Journal of Archaeological Science* 26(6):687-695 [<https://doi.org/10.1006/jasc.1998.0385>]
- Villotte S (2006) Connaissances médicales actuelles, cotations des enthesopathies : nouvelle méthode. *Bulletins et Mémoires de la Société d'Anthropologie de Paris* 18(1-2):65-85
- Wickham H (2016) *ggplot2: Elegant Graphics for Data Analysis*. Springer-Verlag, New York, 213 p