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Title: Mobility and diet in Neolithic, Bronze Age and Iron Age Germany : evidence from multiple isotope analysis
Issue Date: 2012-06-06

5. Early Neolithic Diet and Animal Husbandry: Stable Isotope Evidence from three Linearbandkeramik (LBK) Sites in Central Germany

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Journal of Archaeological Science 38 (2): 270-279, accepted 29 August 2010, available online 3 September 2010, published February 2011.

Abstract

The first appearance of the Neolithic Linearbandkeramik (LBK) in Central Germany occurred during the 6th millennium BC. However, though LBK sites are abundant in the German loess areas, there are only a few studies that reconstruct the diet of these first farmers using biochemical methods. Here we present the largest study undertaken to date on LBK material using stable isotope analysis of carbon and nitrogen to reconstruct human diet and animal husbandry strategies. We analysed the bone collagen of 97 human individuals and 45 associated animals from the sites of Derenburg, Halberstadt and Karsdorf in the Middle Elbe-Saale region of Central Germany. Mean adult human values are -19.9 ±0.4 ‰ for δ^{13}C and 8.7 ±0.8‰ for δ^{15}N. The δ^{13}C values are typical for terrestrial, temperate European regions, whereas the δ^{15}N values fall within an expected range for farming societies with a mixed diet consisting of products from domestic animals and plants. The consumption of unfermented dairy products is unlikely as there is direct palaeogenetic evidence of lactose intolerance available for one of the sites. There are no clear indications for dietary differences in sex. Young children under three years of age are enriched in δ^{15}N due to breastfeeding indicating that weaning likely occurred around the age of three years. The fauna exhibit mean δ^{13}C values of -20.9 ±0.8‰ and mean δ^{15}N values of 7.0 ±0.9‰ respectively. Variation in the δ^{13}C and δ^{15}N in the domestic animals is probably caused by different livestock managements.

5.1. Introduction

The Neolithic transition can be viewed as one of the most dramatic and significant changes in modern human economic, social and cultural life. Originating in the Near East approximately 10,000 years ago food production by farming spread quickly throughout the rest of Eurasia. This transition from hunter-gatherer subsistence to sedentary agriculture involved not only the domestication of animals and plants but also the invention of processing and storing objects in the form of grinding stones and pottery and the change to more sedentary lifeways (Price, 2000). These economic and cultural innovations arriving simultaneously during the Neolithic expansion in Europe is referred to as the 'Neolithic package' (Çilingiroĝlu, 2005; Jochim, 2000). Although there are some examples for earlier appearances of Neolithic innovations (Jochim, 2000), the complete 'package' arrives in Central Europe with the Linear Pottery Culture (*Linearbandkeramik* or LBK) that originated in western Hungary between 5,550 and 5,400 BC and spread into middle and western Europe (Bánffy, 2004; Price, 2000; Price et al., 2001; Zvelebil, 2004). The LBK expansion appears to have been a rapid process that lasted only several centuries which required a high level of mobility for the people living in LBK communities. In this context human remains from LBK sites have been analyzed in several biochemical studies using strontium isotopes (Bentley, 2007; Bentley and Knipper, 2005; Bentley et al., 2004; Price et al., 2001). The isotopic data show that at some LBK sites up to 60% of the group consisted of non-local individuals, and predominantly females tend to have migrated from other geological areas (Bentley et al., 2002; Price et al., 2001). Bioarchaeological methods have therefore become a powerful tool to reveal information on LBK mobility, marriage systems and individual life histories.

As the most striking feature of the Neolithic is the invention and spread of agriculture, analysing the human dietary habits of this time period is of significant interest. The analysis of carbon and nitrogen stable isotope composition in human and animal bone or dentine collagen allows the reconstruction of human palaeodiets (Ambrose, 1993; Schwarcz and Schoeninger, 1991) as well as early animal husbandry strategies (Balasse et al., 2002; Balasse and Tresset, 2002; Noe-Nygaard et al., 2005). The method is based on the fact that the stable isotopes of carbon and nitrogen are fractionated during many biochemical reactions due to differences in atomic mass. This results in specific isotope ratios depending on the type of ecosystem (e.g. marine versus terrestrial), position in the food chain and climate conditions (Ambrose, 1993; Lee-Thorp and Sponheimer, 2007; Sealy, 2001).

The largest variations in the stable isotope ratios of carbon ($\delta^{13}C$) in terrestrial ecosystems are a result of different photosynthetic carbon reduction pathways (C_3, C_4 or CAM plants). C_4 plants produce significantly higher $\delta^{13}C$ values than C_3 plants, providing a useful method to trace the domestication and production of important C_4 plants like maize in the New World (Katzenberg et al., 1995; Vogel and Van der Merwe, 1977). As the cultivation of C_4 plants plays only a minor role in European prehistory, consumers of the temperate vegetation zone mostly feature $\delta^{13}C$ values between -18‰ and -23‰ (Richards and van Klinken, 1997). Subtle variation in $\delta^{13}C$ within terrestrial C_3-dominated ecosystems can correspond to the density and position within a forest canopy (Drucker et al., 2008; Tieszen, 1991; van der Merwe and Medina, 1991) or can be affected by latitude and altitude (Körner et al., 1988; Körner et al., 1991).

The stable isotopes of nitrogen ($\delta^{15}N$) enter the biosphere from the atmosphere mainly via N-fixing soil bacteria and are then utilized by plants. Throughout different terrestrial environments variation in $\delta^{15}N$ can be largely affected by climate, temperature, precipitation, and coastal effects (Britton et al., 2008; Heaton et al., 1986; van Klinken et al., 2000), making the analysis of faunal samples so crucial to understand the local isotopic baseline. However, in temperate terrestrial ecosystems the fractionation of $\delta^{15}N$ is dominated by a trophic level effect. This effect leads to an enrichment in $\delta^{15}N$ from diet to body tissue by 2-5‰, on an average 3‰, whereas $\delta^{13}C$ only shows modest enrichment of ~1‰ for each step in the food chain (Ambrose, 1991; DeNiro and Epstein, 1981; Hedges and Reynard, 2007; Minagawa and Wada, 1984). In terrestrial carnivores we measure higher $\delta^{15}N$ values (typically around 10-12‰), lower values of around 4-6‰ in herbivores and intermediate values for omnivorous species (Fizet et al., 1995). As nitrogen is most abundant in the protein fraction of body tissues in the form of amino acids, measures of bone collagen mainly reflect the isotopic composition of dietary protein intake (Ambrose, 1993). Carbon isotope ratios in collagen also reflect the protein component of diet, whereas measures of carbon isotope ratios in apatite potentially provide information on dietary energy (carbohydrates and lipids) intake (Ambrose and Norr, 1993; Kellner and Schoeninger, 2007). However, analysing bone apatite remains controversial in terms of contamination and alteration (Koch et al., 1997).

For Central Europe, dietary studies on Neolithic human populations using stable isotopes are only available for Germany (Asam et al., 2006; Dürrwächter et al., 2006; Meyer et al., 2007; Nehlich et al., 2009a; Nehlich et al., 2009b) and Slovenia (Ogrinc and Budja, 2005), and there are few case studies for the earliest periods of the Neolithic. For the LBK, the only data published are from the sites of Herxheim (n=21) and Nieder-Mörlen (n=12) (Dürrwächter et al., 2006; Nehlich et al., 2009b). Dürrwächter et al. (2006) found the same terrestrial-based omnivorous diet for individuals from Herxheim as for the two middle Neolithic populations in their study. Yet three individuals were enriched in $\delta^{15}N$ probably due to freshwater fish consumption. The heterogeneous values from Herxheim support the assumption that the sampled human remains derive from different spatially dispersed LBK communities. Nehlich et al. (2009b) also describe a terrestrial omnivore diet for Nieder-Mörlen. They could find slight differences in $\delta^{15}N$ between the LBK and the earlier phase Flomborn, yet sample size is small. A third dataset from different LBK sites in Bavaria (total n=24) unfortunately lacked isotopic information from associated fauna (Asam et al., 2006), which are imperative for interpreting human isotope data.

For a better understanding of early Neolithic subsistence more data on these first European farmers are required. Here we present the most extensive palaeodietary reconstruction applying stable isotopes to the remains of human LBK individuals and associated fauna from three recently excavated sites in Central Germany. The human remains were found in association with settlements and represent several generations of three living LBK communities.

5.2. Archaeological sites and material

The material of this study derives from three LBK sites, Derenburg Meerenstieg II, Halberstadt Sonntagsfeld and Karsdorf, which are located in the loess regions of present day Saxony-Anhalt. The sites date from the earlier to the later phases of the LBK (Meier-Arendt, 1966), though a more detailed chronology of the LBK is still not available for this region. AMS radiocarbon dates are available for Derenburg and Halberstadt and range from 5200 cal BC to 4800 cal BC (Fritsch et al., in press), whereas dating of material from Karsdorf is in progress. Yet calibrations of radiocarbon dates in this time period are known to be problematic (Strien and Gronenborn, 2005).

Though Derenburg and Halberstadt (Landkreis Harz, Saxony-Anhalt) are located in close proximity to each other (‹10km) in the foothills of the Harz Mountains, the spatial organization of the settlements and burials is very different. At Derenburg the settlement consists of eleven longhouses of at least three occupancy phases, flanked by the typical pits for clay extraction. The houses are located separately from an almost circularly constructed cemetery with a diameter of 25-30m, containing 44 burials (Müller, 2002). In contrast, in Halberstadt longhouses and burials are directly connected with each other. The grave groups of six to eight individuals mostly cluster around one of the four houses of the settlement (Autze, 2005). This gives the impression that each grave group could actually represent a nuclear family or members of a single household. At both sites, with few exceptions, all individuals are buried in east-west orientation in a left side crouched posture. Most, yet not all graves contained the typical linear decorated pottery as well as flint and animal remains. Some graves contained ornaments made of *Spondylus* or oyster shells; two burials were spread with red ochre (Autze, 2005; Müller, 2002).

The LBK settlement of Karsdorf (Burgenlandkreis, Saxony-Anhalt) is located approximately 100km south of Derenburg and Halberstadt, on the river Unstrut, and was occupied between 5240 and 5000 BC (Behnke, 2007). The Neolithic buildings (n=24) of three settlement stages are dated to the early and middle LBK (after Meier-Arendt 1966). Except for four graves, all of the 30 burials are associated in groups next to houses in the centre of the settlement, similar to the site of Halberstadt. The individuals are buried in house-flanking pit graves at the western side of the houses and mostly arranged in north-east or north-west orientation. Grave goods are sparse; few graves contained more than one pot or a shell or horn pendant. Associated with every house group we can identify a person with outstanding grave inventory, who may represent a founding generation.

Residential groups of the LBK of Central Germany typically settled in small farmsteads, consisting of several long houses standing in some distance to each other (Bogucki, 2000; Lüning, 2000). Domestic animals and staple crops were mainly brought from the Near East; there is minimal evidence for autochthonous domestication of animals in Europe (Edwards et al., 2007; Larson et al., 2007). The domestic animal species bred by LBK farmers are mainly cattle, followed by pig, sheep and goat. It should be mentioned here that sheep and goat will be subsumed hereafter because they can hardly be distinguished in the archaeological record (Benecke, 1994). Hunting of wild animals is only of small relevance in the LBK of the study region. Bones of wild species appear with frequencies of less than 5% at LBK sites in the Middle Elbe-Saale region (Döhle, 1997). Crop cultivation in the loess region around the Harz is dominated by barley, emmer and einkorn wheat with additional legumes like peas and lentils, and to a lesser degree flax seed and millet (Kreuz, 1990). Because cultivable acreage was scarce, the agricultural production is assumed to have been small scale but intensive (Bogaard, 2004). At LKB sites in the western Harz foothills, hazel (50-75%) and oak (20-30%), both light-demanding plants, are represented in high frequencies. Furthermore the proportion of non-arboreal pollen rises during the Neolithic, indicating that the woodlands were replaced by more open habitats (Beug, 1992; Kreuz, 1990). These semi-open woodlands could have been used to feed the domestic animals throughout the year, by using meadow or forest pastures in summer and leaf foddering in winter.

The total sample of the present study contains 39 humans and seven animals from Derenburg, 36 humans and six animals from Halberstadt and 22 humans and 32 animals from Karsdorf. The bone preservation of the human remains was excellent and allowed detailed anthropological examination in most cases.

5.3. Methods

Prior to isotope analysis, age and sex determinations were conducted at the osteological laboratory of the Institute for Anthropology, Mainz, Germany and are listed in Table 5.1. Both sexes and all age classes could be identified in the sample using different morphological and metric methods (Brooks and Suchey, 1990; Ferembach et al., 1980; Knußmann, 1988; Lovejoy, 1985; Lovejoy et al., 1985; Meindl and Lovejoy, 1985; Murail et al., 2005; Phenice, 1969; Ubelaker, 1989).

Rib bones were preferentially sampled for isotope analysis because they should represent a more recent time frame compared to long bones due to generally higher rates of turnover, whereas the collagen of long bones can comprise isotopic signatures leading back to a differing diet in an individual’s adolescence or even childhood (Hedges et al., 2007). We extracted collagen out of 97 human and 45 animal bone samples. The collagen extraction followed the Longin method (Longin, 1971) modified by Brown et al. (1988) and Collins and Galley (1998). Bone samples were cleaned by air abrasion and then demineralized in 0.5M HCl for several weeks, with acid changes every few days. Demineralized samples were then rinsed three times with de-ionized water and gelatinized at 70°C in a pH3 solution for 48 hours. After filtering the insoluble fraction with a 5µm EZEE© filter, samples were again filtered using Amicon© ultrafilters (cut off of <30kDa). The purified solution was then frozen and freeze dried for another 48 hours. Finally, 0.5mg of dried collagen sample was weighed into tin capsules. The measurement was performed in duplicates in a Flash EA 2112 coupled to a DeltaXP mass spectrometer (Thermo-Finnigan®, Bremen, Germany) at the Max Planck-Institute for Evolutionary Anthropology in Leipzig, Germany. $\delta^{13}C$ and $\delta^{15}N$ are reported in 'per mil' (‰) relative to the standards VPDB and AIR. The analytical error, calculated from repeated analysis of internal and international standards, was less than 0.2‰ (1σ) for $\delta^{13}C$ and $\delta^{15}N$.

5.4. Results and Discussion

The mean results for each duplicate measurement are shown for each sample in Tables 5.1 and 5.2. All collagen samples are well preserved and meet the published quality criteria of %C, %N and C/N ratios (Ambrose, 1990; DeNiro, 1985; van Klinken, 1999). Three samples have collagen yield less than 1% due to the generally higher losses of degraded collagen during the ultra filtration step (Jørkov, 2007). These samples were considered acceptable as the other collagen quality criteria were met.

The sampled fauna exhibit mean $\delta^{13}C$ values of -20.9 ±0.8‰ (1σ) and mean $\delta^{15}N$ values 7.0 ±0.9‰ (1σ) respectively (Table. 5.2). These values are similar to those from other Neolithic sites in Germany and reflect terrestrial herbivore diet in temperate climatic regions (Dürrwächter et al., 2006; Meyer et al., 2007; Nehlich et al., 2009a). Animals from Derenburg and Halberstadt show only little variation in both isotopes and sample size is small (Figure 5.1). However, the Karsdorf faunal sample contains cattle (n=12), sheep/goat (n=8), pig (n=8) and wild animals like aurochs (n=3) and deer (n=1), and therefore allows a closer view on animal husbandry practices in the LBK (Figure 5.1). With values of -21.4‰ $\delta^{13}C$ and 5.1‰ $\delta^{15}N$ the deer represents isotope values of wild herbivores that browsed and grazed in semi-open woodlands, as the $\delta^{13}C$ values are less negative than those reported for modern wild deer species feeding in dense deciduous or boreal forests (Drucker et al., 2008) even if fossil fuel effects are taken into account (Friedli et al., 1986). A similar picture derives from the aurochs samples that exhibit slightly less negative mean $\delta^{13}C$ values of -20.5‰. Even though the sample size is very small, isotope signatures of the wild taxa might support the picture of relatively open landscapes in LBK environments (Kreuz, 2008).

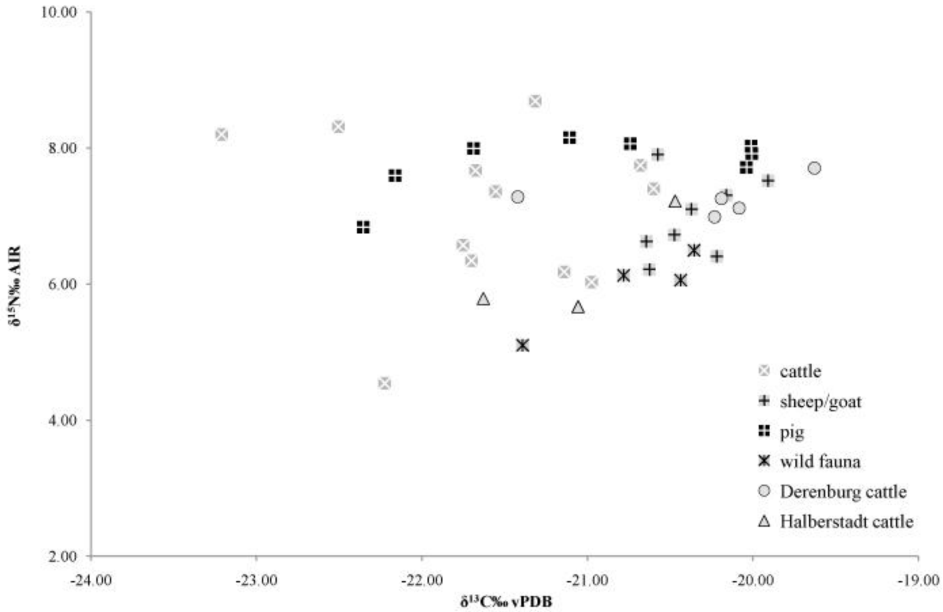

Figure 5.1: Karsdorf faunal sample; scatter blot of $\delta^{13}C$ and $\delta^{15}N$ data for all domestic and wild animals from the site Karsdorf. By means of comparison the cattle samples from Derenburg and Halberstadt are included.

The domestic animal sample from Karsdorf (Figure 5.1) features mean $\delta^{13}C$ values of -21.0 ±0.9‰ (1σ) and mean $\delta^{15}N$ values of 7.3 ±0.9‰ (1σ). Variation in the domestic animals might be introduced by varying baseline isotopic signatures due to browsing or grazing in different habitats with distinct isotopic baselines, or by differences in herding and feeding practices. Different patterns can be observed among the domestic animal species. Sheep and goats for instance cluster between 6.4 and 7.9‰ in $\delta^{15}N$ and around the mean of -20.4 ±0.3‰ (1σ) in $\delta^{13}C$, suggesting that these animals fed on a very similar diet, as on a similar kind of pasture, although sheep are grazers, whereas goats are habitual mixed feeders (Balasse and Ambrose, 2005; Vera, 2000). Similar to the aurochs, the less negative $\delta^{13}C$ values could indicate that pastures were located in open landscapes rather than in dense forests (Drucker et al., 2008). In pigs, mean $\delta^{15}N$ values are slightly higher (7.8 ±0.4‰ 1σ) due to more omnivorous diet (Benecke, 1994). Yet, most variation of the pig sample can be observed in $\delta^{13}C$ (mean: -21.0 ±1.0‰ 1σ) that ranges

Table 5.1: Human bone collagen samples with archaeological identification and individual data on sex (F= female; M= male; F?= probably female; M?= probably male; ?= sex not known), age (infans I= 0-6 years, infans II= 7-14 years, juvenil= 15-20 years, adult= >20 years) and results of isotopic measurements (mean of duplicate measurement for each samples). $\delta^{13}C$ values are reported relative to standard VPDB; $\delta^{15}N$ values are reported relative to the standard AIR.

site	grave	feature	sex	age class	bone	collagen %	$\delta^{13}C$ ‰	$\delta^{15}N$ ‰	%C	%N	C/N
Derenburg	18	565	?	infans I	skull	1.4	-20.5	8.6	32.2	10.8	3.5
Derenburg	20	568?	?	infans I	skull	2.0	-20.0	8.7	35.6	12.5	3.4
Derenburg	23	593	?	infans I	rib	7.0	-19.8	8.9	40.2	14.6	3.2
Derenburg	24	594	?	infans I	rib	3.4	-19.1	11.2	42.5	15.4	3.2
Derenburg	26	595	?	infans I	skull	3.0	-19.2	9.7	37.2	13.4	3.2
Derenburg	27	597	?	infans I	long bone	1.8	-19.5	9.5	42.4	15.5	3.2
Derenburg	47	662 A	?	infans I?	skull	3.9	-19.0	11.5	42.6	15.7	3.2
Derenburg	19	567	?	infans II	rib	4.7	-19.6	8.7	38.9	14.2	3.2
Derenburg	29	604/2	?	infans II	rib	2.9	-19.6	8.6	40.6	14.8	3.2
Derenburg	33	598	?	subadult	rib	5.2	-19.4	8.8	41.0	14.8	3.2
Derenburg	37	606	M?	juvenil	rib	1.9	-20.0	9.0	29.6	10.6	3.3
Derenburg	17	566	M	adult	rib	3.0	-19.4	9.2	38.5	13.9	3.2
Derenburg	31	599	M	adult	rib	4.1	-19.7	8.3	43.0	15.6	3.2
Derenburg	34	596	M	adult	rib	6.6	-19.7	9.2	39.9	14.6	3.2
Derenburg	28	604/1	M	adult	rib	6.1	-19.2	9.2	41.2	15.1	3.2
Derenburg	42	484	M	adult	rib	3.6	-19.8	8.5	42.2	15.3	3.2
Derenburg	46	665	M	adult	rib	6.1	-19.4	8.6	41.6	15.1	3.2
Derenburg	12	486	M	adult	rib	1.9	-20.2	8.3	30.2	10.7	3.3
Derenburg	43	183	M?	juvenil	rib	4.1	-19.7	8.3	41.0	14.8	3.2
Derenburg	9	420	F	adult	rib	7.5	-20.2	8.4	41.9	15.4	3.2
Derenburg	21	591A	F	adult	rib	6.9	-19.8	8.5	41.2	15.2	3.2
Derenburg	30	604/3	F	adult	rib	5.6	-19.4	9.2	40.2	14.7	3.2
Derenburg	38	640	F	adult	femur	1.0	-20.2	10.1	21.7	7.4	3.4
Derenburg	48	643	F	adult	rib	6.9	-19.3	9.1	36.4	13.2	3.2
Derenburg	49	708	F	adult	rib	4.1	-19.6	9.2	43.8	16.3	3.1
Derenburg	32	600	F	adult	rib	4.3	-19.4	8.6	40.4	14.8	3.2
Derenburg	44	644	F	adult	rib	4.0	-19.8	8.4	40.4	14.7	3.2
Derenburg	45	645	F	adult	rib	5.0	-19.8	8.2	40.3	14.9	3.2
Derenburg	16	569	F?	adult	long bone	1.6	-20.6	8.6	18.9	6.3	3.5
Derenburg	35	564	F?	adult	rib	2.5	-20.0	8.4	31.8	11.3	3.3
Derenburg	40	592	F?	adult	rib	5.8	-20.1	8.8	41.3	14.9	3.2
Derenburg	41	649	F?	adult	long bone	1.2	-19.9	8.9	37.1	13.0	3.3
Derenburg	22	590A	F?	adult	long bone	1.0	-20.2	7.9	25.4	8.8	3.4
Derenburg	47	592	F?	adult	long bone	2.0	-20.0	8.7	34.6	12.4	3.2
Derenburg	39	485	F?	adult	rib	3.4	-20.2	8.6	36.5	13.1	3.2
Derenburg	10	421	?	adult	long bone	2.7	-19.5	8.2	36.4	13.0	3.3
Derenburg	11	503	?	adult?	long bone	4.4	-20.5	7.2	32.7	11.9	3.2
Derenburg	21	591B	?	adult?	rib	0.5	-20.2	8.0	33.9	12.1	3.3

Derenburg	52	652	?	?	rib	5.3	-19.8	8.1	40.9	14.9	3.2
Halberstadt	8	322	?	infans I	rib	7.0	-19.0	10.3	39.6	15.5	3.0
Halberstadt	11.2	413	?	infans I	rib	2.8	-19.5	8.7	32.5	11.7	3.2
Halberstadt	17.1	578	?	infans I	rib	6.1	-19.6	10.2	43.6	15.5	3.3
Halberstadt	24	739	?	infans I	rib	1.7	-19.8	8.6	41.2	14.8	3.3
Halberstadt	29	815	?	infans I	rib	4.0	-19.4	10.5	35.8	12.8	3.3
Halberstadt	32	869	?	infans I	long bone	1.6	-19.5	10.0	31.2	11.0	3.3
Halberstadt	33	870	?	infans I	rib	3.7	-19.7	8.9	40.9	14.7	3.2
Halberstadt	37	1076	?	infans I	long bone	2.4	-20.0	9.0	33.8	12.1	3.3
Halberstadt	38	992	?	infans I	rib	3.2	-19.8	7.7	40.3	14.7	3.2
Halberstadt	7	306	?	infans II	rib	1.6	-19.5	9.1	42.3	15.0	3.3
Halberstadt	10.1	343	?	infans II	rib	3.6	-19.2	9.9	41.4	14.7	3.3
Halberstadt	23	741	?	infans II	rib	6.8	-19.7	7.5	39.3	14.5	3.2
Halberstadt	30	859	?	infans II	rib	7.0	-19.8	7.4	40.7	15.0	3.2
Halberstadt	31	860	?	infans II	skull	3.5	-19.9	7.7	35.4	12.9	3.2
Halberstadt	40	1114	?	infans II	rib	8.2	-18.5	9.9	40.9	15.0	3.2
Halberstadt	9	340	?	juvenil	rib	9.4	-20.0	10.5	42.0	15.3	3.2
Halberstadt	28	861	M	adult	rib	4.6	-19.4	9.2	40.6	14.9	3.2
Halberstadt	35	999	M	adult	rib	5.0	-19.7	8.7	39.7	14.5	3.2
Halberstadt	15	430	M	adult	rib	1.9	-19.8	8.4	41.7	15.0	3.3
Halberstadt	2	241	M	adult	rib	1.9	-20.1	8.0	36.5	13.1	3.2
Halberstadt	19.1	613	M	adult	rib	4.3	-19.6	11.7	40.8	14.9	3.2
Halberstadt	27	867	M	adult	rib	5.5	-19.6	9.0	43.0	15.7	3.2
Halberstadt	16	577	M?	juvenil	rib	1.8	-19.8	8.3	37.5	13.4	3.3
Halberstadt	41	1215	M?	juvenil	rib	4.4	-19.6	8.1	33.0	12.1	3.2
Halberstadt	18	536	M?	adult	rib	3.9	-20.1	8.0	37.1	13.3	3.2
Halberstadt	1	139	F	adult	rib	7.7	-19.1	9.1	38.5	14.3	3.2
Halberstadt	17	578	F	adult	rib	3.2	-19.5	8.6	38.0	13.5	3.3
Halberstadt	34	995	F	adult	rib	8.8	-20.2	8.7	40.4	14.8	3.2
Halberstadt	36	1059	F	adult	rib	2.5	-19.9	8.0	39.0	13.9	3.3
Halberstadt	25	804	F	adult	rib	2.2	-19.6	8.2	39.3	14.2	3.2
Halberstadt	42	1324	F	adult	rib	8.2	-19.7	8.2	42.4	15.6	3.2
Halberstadt	22	666	F	adult	rib	4.8	-19.9	8.3	41.9	15.0	3.3
Halberstadt	26	847	F	adult	rib	3.3	-20.2	8.6	33.4	12.0	3.2
Halberstadt	39	1065	F	adult	rib	4.2	-19.7	8.4	41.3	15.2	3.2
Halberstadt	20	662	F?	adult?	long bone	1.8	-20.1	7.4	33.8	11.9	3.3
Halberstadt	10.2	343	?	?	rib	5.5	-20.1	7.6	42.1	15.1	3.3
Karsdorf		115	?	infans I	rib	6.0	-19.9	8.4	38.7	14.0	3.2
Karsdorf		301	?	infans I	rib	4.2	-19.2	12.6	42.4	17.1	2.9
Karsdorf		529	?	infans II	rib	2.8	-20.2	8.1	41.4	13.6	3.6
Karsdorf		305	?	infans I	rib	4.8	-19.7	8.5	39.0	14.2	3.2
Karsdorf		95	?	juvenil	rib	1.0	-20.1	10.8	39.8	13.8	3.4
Karsdorf		509	M	adult	rib	2.1	-20.0	9.1	39.6	14.4	3.2
Karsdorf		537	M	adult	rib	1.4	-19.7	8.9	39.2	14.1	3.2
Karsdorf		611	M	adult	rib	2.0	-20.2	9.1	37.8	14.0	3.2

Karsdorf	304	M	adult	rib	1.9	-20.3	8.8	40.5	14.7	3.2
Karsdorf	300	M	adult	rib	1.1	-20.0	8.7	40.1	14.2	3.3
Karsdorf	605	M	adult	rib	2.2	-19.8	9.0	39.4	14.3	3.2
Karsdorf	170	M	adult	rib	1.1	-20.0	9.0	39.0	14.0	3.3
Karsdorf	303	M	adult	rib	2.5	-20.5	8.8	40.0	14.4	3.3
Karsdorf	122	M	adult	rib	1.4	-19.9	9.3	41.4	14.3	3.4
Karsdorf	131	M?	adult	rib	3.3	-19.5	9.3	36.1	13.0	3.3
Karsdorf	430	F	adult	rib	1.3	-20.1	8.4	39.2	14.0	3.3
Karsdorf	302	F	adult	rib	1.5	-19.6	10.2	39.5	13.9	3.3
Karsdorf	169	F	adult	rib	2.7	-20.0	9.1	38.4	13.9	3.2
Karsdorf	155	F	adult	rib	3.2	-20.1	9.4	40.5	14.7	3.2
Karsdorf	158	F?	adult	rib	2.5	-20.2	6.3	38.3	13.8	3.2
Karsdorf	299	F?	adult	rib	2.7	-19.6	8.9	40.9	15.0	3.2
Karsdorf	192	?	adult	rib	2.2	-20.4	8.5	28.3	10.2	3.2

Table 5.2: Animal bone collagen samples with archaeological and taxonomic identification and the results of isotopic measurements (mean of duplicate measurement for each samples). δ^{13}C values are reported relative to standard VPDB; δ^{15}N values are reported relative to the standard AIR. The tree aurochs samples are tagged with '?' because taxonomic classification is based on metric and not morphological estimations.

site	sample no	species	feature	bone	collagen %	δ^{13}C ‰	δ^{15}N ‰	%C	%N	C/N
Derenburg	D animal 1	cattle	662	vertebra	4.0	-20.2	7.0	43.3	15.6	3.2
Derenburg	D animal 2	cattle	371	skull	2.8	-20.1	7.1	37.5	13.5	3.2
Derenburg	D animal 4	cattle	371	long bone	2.5	-19.6	7.7	40.5	14.2	3.3
Derenburg	D animal 9	cattle	371	vertebra	1.2	-20.2	7.3	44.2	15.9	3.2
Derenburg	D animal 3	cattle	503	long bone	2.1	-21.4	7.3	41.8	15.1	3.2
Derenburg	D animal 8	goat/sheep	371	long bone	4.9	-20.5	7.0	41.8	15.2	3.2
Derenburg	D animal 7	pig	371	skull	7.7	-20.5	7.2	43.5	15.8	3.2
Halberstadt	H animal 1	cattle	3904 k	long bone	5.8	-20.5	7.2	35.4	12.8	3.2
Halberstadt	H animal 2	cattle	3904 k	rib	6.3	-21.6	5.8	41.5	15.2	3.2
Halberstadt	H animal 4	pig	3904 k	mandible	1.0	-21.4	7.7	35.2	12.0	3.4
Halberstadt	H animal 5	?	4217	long bone	1.5	-20.8	5.9	38.6	13.8	3.3
Halberstadt	H animal 6	?	3904	?	2.6	-20.8	5.8	40.8	14.9	3.2
Halberstadt	H animal 10	cattle	4011g	?	1.2	-21.1	5.7	37.4	13.2	3.3
Karsdorf	K animal 1	cattle	26138v	?	5.4	-20.7	7.7	30.8	11.0	3.3
Karsdorf	K animal 2	cattle	26043c	?	2.8	-21.1	6.2	40.6	14.9	3.2
Karsdorf	K animal 3	cattle	26038b	?	1.2	-21.7	6.3	26.5	9.4	3.3
Karsdorf	K animal 4	cattle	26081h	?	1.7	-21.7	7.7	33.2	11.8	3.3
Karsdorf	K animal 5	cattle	26084n	?	4.6	-22.2	4.5	37.9	13.7	3.2
Karsdorf	K animal 6	cattle	26057h	?	1.9	-23.2	8.2	24.0	8.6	3.3
Karsdorf	K animal 7	cattle	26144k	?	2.9	-21.3	8.7	36.5	13.1	3.2
Karsdorf	K animal 8	cattle	26029n	?	2.0	-21.8	6.6	25.4	9.1	3.2
Karsdorf	K animal 9	cattle	26047c	?	3.0	-21.0	6.0	34.0	12.0	3.3
Karsdorf	K animal 10	goat/sheep	26092f	?	0.6	-20.6	7.9	38.4	13.7	3.3

Karsdorf	K animal 11	sheep	26101h	?	2.9	-20.2	7.3	33.4	11.9	3.3
Karsdorf	K animal 12	goat/sheep	26144k	?	9.6	-20.6	6.2	38.2	14.0	3.2
Karsdorf	K animal 13	goat/sheep	26138u	?	5.3	-20.2	6.4	38.5	14.0	3.2
Karsdorf	K animal 14	pig	26138v	?	2.5	-20.0	7.7	41.2	15.0	3.2
Karsdorf	K animal 15	pig	26084n	?	2.9	-22.2	7.6	40.1	14.6	3.2
Karsdorf	K animal 16	pig	26017b	?	2.2	-22.4	6.8	36.9	13.5	3.2
Karsdorf	K animal 17	pig	26092f	?	3.7	-20.7	8.1	33.4	12.0	3.3
Karsdorf	K animal 18	pig	26113i	?	2.9	-21.7	8.0	27.5	9.9	3.2
Karsdorf	K animal 19	deer	26043c	?	2.3	-21.4	5.1	29.0	10.3	3.3
Karsdorf	K animal 20	aurochs?	26144k	?	1.8	-20.8	6.1	39.8	14.6	3.2
Karsdorf	K animal 21	goat/sheep	04:26029 n	long bone	9.4	-20.6	6.6	44.1	16.1	3.2
Karsdorf	K animal 22	cattle	04:26029 n	pelvis	0.6	-21.6	7.4	38.3	12.4	3.6
Karsdorf	K animal 23	aurochs?	04:26043 c	phalange	2.6	-20.4	6.1	42.1	15.2	3.2
Karsdorf	K animal 24	cattle	04:26057 h	phalange	3.1	-22.5	8.3	41.3	14.7	3.3
Karsdorf	K animal 25	pig	04:26092 f	mandibula	3.4	-20.0	7.9	41.5	14.8	3.3
Karsdorf	K animal 26	goat/sheep	04:26092 f	vertebra	1.4	-20.4	7.1	41.1	14.4	3.3
Karsdorf	K animal 27	aurochs?	04:26092 f	phalange	2.9	-20.4	6.5	41.0	14.5	3.3
Karsdorf	K animal 28	sheep	04:26101 h	skull	2.5	-19.9	7.5	42.2	15.3	3.2
Karsdorf	K animal 29	pig	04:26113 i	scapula	1.6	-21.1	8.2	41.7	14.5	3.4
Karsdorf	K animal 30	goat/sheep	04:26138 v	vertebra	1.6	-20.5	6.7	40.7	14.5	3.3
Karsdorf	K animal 31	cattle	04:26138 v	vertebra	4.1	-20.6	7.4	40.7	14.6	3.3
Karsdorf	K animal 32	pig	04:26138 v	metacarpus	3.0	-20.0	8.0	41.2	14.9	3.2

from -22.4‰ to -20.0‰, suggesting that the pigs may have fed in habitats that are differently affected by canopy effects. Negative δ^{13}C values e.g. could be introduced by feeding in forest areas with denser vegetation.

If only the bovid species in the Karsdorf sample are considered, the differences between domestic and wild cattle are pronounced (see Figure 5.1). Contrary to domestic cattle, the aurochs isotope values are more homogenous. The δ^{13}C values of aurochs are significantly higher (one way ANOVA; *p=0.033*) and mean δ^{15}N values are 0.9‰ lower than in domestic cattle. Hence, aurochs might have grazed on different pastures than those of domestic cattle, but similar to the feeding grounds of the domestic sheep and goats from Karsdorf (see above). Although sample size is very small this finding might support the assumption of palaeogenetic studies that domestic cattle herds were spatially kept separate from wild aurochs and genetic introgression was therefore widely prevented (Edwards et al., 2007).

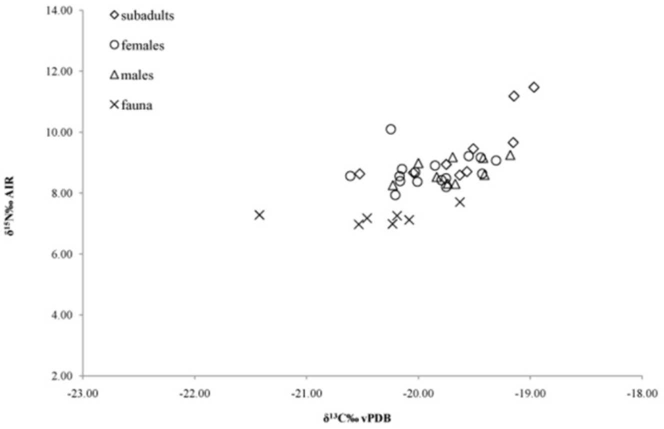

Figure 5.2: Derenburg (Meerenstieg II); scatter blot of $\delta^{13}C$ and $\delta^{15}N$ data for all human and faunal samples.

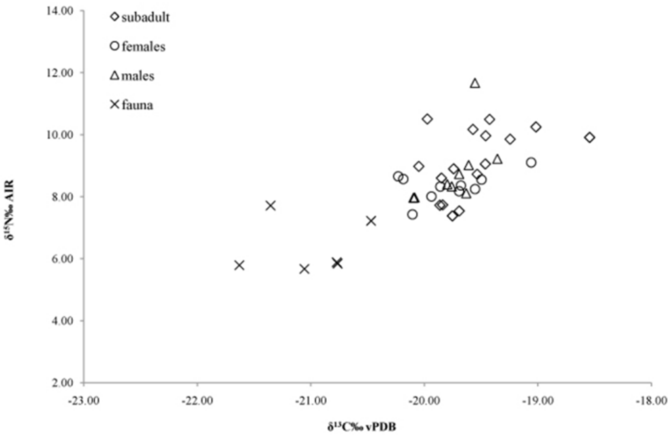

Figure 5.3: Halberstadt (Sonntagsfeld); scatter blot of $\delta^{13}C$ and $\delta^{15}N$ data for all human and faunal samples.

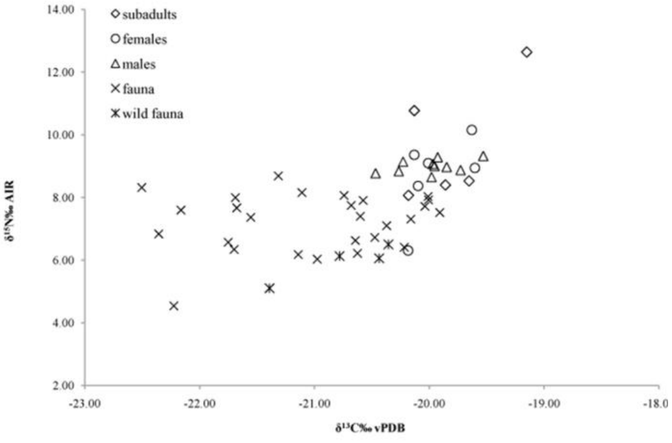

Figure 5.4: Karsdorf; scatter blot of $\delta^{13}C$ and $\delta^{15}N$ data for all human and faunal samples. One cattle specimen (K animal 6) with -23.21‰ $\delta^{13}C$ falls out of the plot area and can be seen in Fig. 1.

The Karsdorf domestic cattle values for $\delta^{13}C$ range from -23.2‰ to -20.6‰ with a mean of -21.6 ±0.8‰ (1σ), and values for $\delta^{15}N$ range from 4.5 to 8.7‰ with a mean of 7.1 ±1.2‰ (1σ). Only one individual, the one with the highest $\delta^{15}N$ value of 8.7‰, is classified as juvenile (K animal 7) by zooarchaeological examination**,** whereas the other animal samples were classified as adults. If the juvenile is removed from the sample the mean $\delta^{13}C$ cattle value remains the same and the mean $\delta^{15}N$ value only decreases to 6.9 ±1.1‰ (1σ). The slightly enriched $\delta^{15}N$ values in some of the cattle can be explained by effects that lead to nitrogen enrichment in the fodder plants, like stocking rate and resulting manuring (Bogaard et al., 2007; Schwertl et al., 2005; van Klinken et al., 2000) or high humidity (Britton et al., 2008). Bogaard et al. (2007) observed an isotopic 'manuring-effect' in crops when fields were intensively cultivated and fertilized with animal manure. This effects ~3‰ higher baseline values, which might be represented by the offset of 2-3‰ in $\delta^{15}N$ between wild and domestic ruminants at the site Karsdorf. In this scenario the $\delta^{13}C$ signatures should rather reflect feeding on open grassland pastures than in dense forests (Benecke, 1994; Drucker et al., 2008). This might be the case for four cattle outliers from Karsdorf (K animals 1, 4, 22, 31).

For salt-marsh fed cattle from the UK, Britton et al. (2008) showed that feeding in boggy and wet pastures leads to significant enrichment in δ^{15}N. Being aware that Britton et al. (2008) deal with pastures under marine influence, we presume that similar effects might cause enrichment in δ^{15}N in freshwater marshes as well. Although freshwater ecosystems are highly variable, δ^{13}C values can be depleted and the complexity of trophic levels leads to enriched δ^{15}N values in freshwater organisms (Dufour et al., 1999; Fry, 1991). It seems plausible that flood plains and meadows that are repeatedly affected by freshwater systems should be enriched in δ^{15}N and could exhibit more negative δ^{13}C values than terrestrial ecosystems. As the site of Karsdorf is located next to the bed of the Unstrut River, it is likely that such wet or damp meadows were easily accessible for the LBK farmers. Based on pollen diagrams, Kreuz (2008) showed that the grassland vegetation in the floodplains of rivers was of special relevance in the LBK as pastures for domestic animals. Additionally there is evidence from wildlife studies that on damp meadows more than twice as many cattle can be fed compared to dry woodland pastures (Nitsche and Nitsche, 1994). Feeding at least some of the livestock on the floodplains seems to be a reasonable scenario for this time period and potentially explains the values of two other cattle outliers that show the highest δ^{15}N values that simultaneously exhibit the lowest δ^{13}C values of the present study (K animal 6 and 24).

Table 5.3: Total sample size of each site, mean isotopic values of adult human individuals and animal samples, and isotopic fractionation of δ^{13}C and δ^{15}N between domestic herbivores (pigs and wild fauna excluded) and humans ($\Delta_{\text{herbivore-human}}$).

site	total human samples	adult human means				total animal samples	animal means				$\Delta_{\text{herbivore-human}}$	
		δ^{13}C‰	1σ	δ^{15}N‰	1σ		δ^{13}C‰	1σ	δ^{15}N‰	1σ	Δ^{13}C‰	Δ^{15}N‰
Derenburg	39	-19.8	±0.4	8.8	±0.5	7	-20.4	±0.5	7.2	±0.2	0.5	1.6
Halberstadt	36	-19.8	±0.3	8.4	±0.5	6	-21.0	±0.4	6.4	±0.9	1.1	2.3
Karsdorf	22	-20.0	±0.3	9.0	±0.4	32	-21.0	±0.8	7.1	±1.0	1.1	2.0

In comparison to the animals, the human sample isotope values cluster more tightly, especially in δ^{13}C (see Figure 5.2 - 5.4 and Table. 5.3). The mean human bone collagen isotope ratios for all three sites are for δ^{13}C -19.9 ±0.4‰ (1σ) and 8.7 ±0.8‰ (1σ) for δ^{15}N, when subadults are excluded from the sample. The spectrum of the $\delta^{13}C$ values from -21.3‰ to -19.1‰ clearly reflects a C_3 based diet. The intensive cultivation of C_4 plants like millet can therefore be excluded, although there is archaeobotanical evidence for the introduction of millet in the earliest LBK in the study area (Beug, 1992). The variation in $\delta^{15}N$ of adult human individuals ranges from 6.3‰ to 11.7‰ and represents more than one trophic level. All adult human values are within the expected range for farming societies with a mixed omnivore diet relying on the products of domestic animals and on field crops. The values for the isotope fractionation between the domestic herbivores (only cattle and sheep/goat) and the adult humans ($\Delta_{\text{herbivore-human}}$) are shown in Table 5.3. For Halberstadt and Karsdorf the fractionation factor $\Delta_{\text{herbivore-human}}$ represent one trophic level in $\delta^{13}C$ and between ½ and one trophic level in $\delta^{15}N$ (Ambrose, 1993; Robbins et al., 2005). From this we can conclude that the Halberstadt and Karsdorf populations had significant amounts of domestic herbivore protein in their daily diet. Yet, a different pattern can be observed for the site of Derenburg. Here the $\Delta_{\text{herbivore-human}}$ values are much lower, indicating that the Derenburg population consumed a lower proportion of animal protein in their regular diet.

In the context of animal protein consumption, it is unique that direct evidence on lactose intolerance from ancient DNA is available for individuals in this study. Burger et al. (2007) analysed three LBK individuals from Derenburg (graves 33, grave 21, grave 34) and could prove the absence of the allele (-13,910*T) responsible for the persistence of the lactase enzyme after childhood. According to the calculations of Burger et al. (2007) the frequency of the lactase persistence allele should be less than 0.25 (confidence 99%) in the Neolithic population sampled in their study. As the sites Halberstadt and Karsdorf are spatially and chronologically significantly closer related to Derenburg than the Eastern European sites in their study, we suggest that even less than 25% of the people in our three populations carried the lactase persistence allele. Therefore it appears likely that $\delta^{15}N$ enrichment in humans is a product of meat eating rather than drinking unprocessed 'raw' milk. This is of particular interest discussing elevated $\delta^{15}N$ values in the Neolithic, where it usually remains ambiguous if higher proportions of dairy products or actually meat has been consumed (Dürrwächter et al., 2006; Nehlich et al., 2009b). However, we cannot completely exclude the possibility that processed milk products with lower lactose levels were consumed.

The subadults of the three sites have slightly more positive mean δ^{13}C values of 19.6 ±0.4‰ (1σ) and δ^{15}N values of 9.2 ±1.2‰ (1σ) compared to adults. This is most likely due to breastfeeding effects. Breastfeeding results in higher nitrogen isotope values in the infant's tissue compared to the mother's (Fuller et al., 2005; Richards et al., 2002). The maximum nitrogen value of 12.6‰ is a strong nursing signal in a one or two year old child from Karsdorf (feature 301), whereas the lowest values <8‰ are found in several post-weaned children that died in the age of approximately eight years. Values of individuals older than three years are similar to the mean value for adults. At this age, children appear to be fully weaned and mother's milk has been replaced with solid foods similar to the adult diet of the populations. Although sample size is small we assume that children were weaned around the age of three in the LBK of Central Germany.

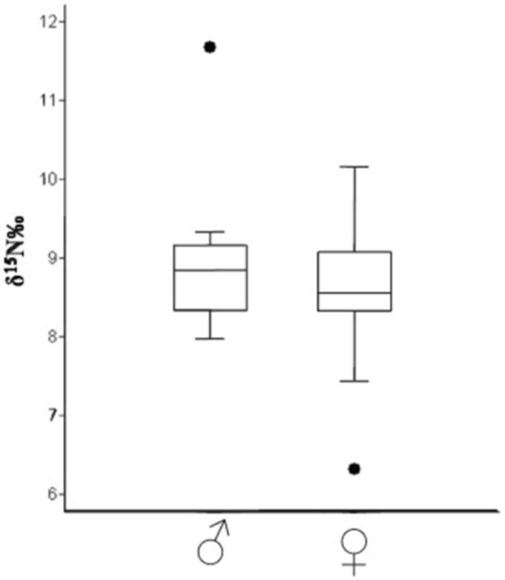

Figure 5.5: Box plot of the mean values, standard deviations and range of δ^{15}N values for adult males (♂) and females (♀) of all three sites. Each dataset has one outlier (males = Halberstadt, grave 19.1; females= Karsdorf, feature 158) that was removed from the analysis (black dots). Both sexes have similar δ^{15}N means, yet females show more variability in their distribution.

In order to investigate potential dietary differences between the sexes**,** the values of all adult females (n=32) and males (n=28) were compared. Two outliers, a male (Halberstadt, grave 19.1) and a female (Karsdorf, feature 158) were excluded from the sample (see Figure 5.5). Differences in δ^{13}C between females with a mean of -19.9 ±0.3‰ (1σ) and males with a mean value of -19.8 ±0.3‰ (1σ) are not significant (*p=0.428*) using a Mann-Whitney U test. The same accounts for δ^{15}N; females with a mean of 8.7 ±0.6‰ (1σ) are not significantly different (*p=0.178*) from the males with mean δ^{15}N values of 8.7 ±0.4‰. Similar results are found if the sexes of each site are compared. However, in Figure 5.5 indicates that females show more variation in δ^{15}N compared to males. This could potentially mean that female's access to animal protein or at least the uptake of enriched δ^{15}N in the bone collagen could vary, possibly in relation to individual social status and maybe even reproductive life history. In direct comparison of the three sites, only slight differences in human diet become visible (see Figure 5.2 - 5.4 and

Table 5.3). As mentioned above we find the lowest $\Delta_{\text{herbivore-human}}$ values at the site of Derenburg, indicating that this community consumed less meat from domestic herbivores than the people from Karsdorf and nearby Halberstadt. In this respect it is interesting that the LBK settlement and burials of Derenburg are also organized in a different way than in the other two sites. This might indicate that although the three sites are contemporary, they reflect two different lifeways. Despite the relative quantities of consumed animal protein the general pattern observed within the three communities is quite similar. At Derenburg adult humans exhibit homogenous δ^{15}N values and only little variation in δ^{13}C (Figure 5.2). One female (grave 38) is slightly enriched in δ^{15}N compared to the rest of the adult population. This 35-45 year old individual was buried with remains of an infant, probably a neonate. In Halberstadt one outlier was excluded from the mean calculation on adult individuals. The resulting mean adult δ^{13}C values for Halberstadt are the same as in the nearby site Derenburg; only the δ^{15}N values are slightly lower. The mentioned outlier is grave 19.1, an elderly male individual (50-65 years), who shows the highest adult δ^{15}N values of 11.7‰ in this study, representing much higher quantities of animal protein in his average diet (Figure 5.3). This male was buried in an extremely crouched posture in some distance to the longhouses or other graves (Autze, 2005).

Finally, the Karsdorf population cluster homogeneously in δ^{13}C around -20‰ and is therefore very similar to the other sites, whereas δ^{15}N is slightly enriched compared to the two other sites, yet there is no archaeological evidence for the exploitation of freshwater protein resources at this site, although the Unstrut River must have been located nearby in prehistoric times. The highest δ^{15}N values for Karsdorf can be observed in one infant with a clear breastfeeding signal (feature 301) and in a 15 to 18 year old individual of unknown sex (feature 95) that is slightly enriched in δ^{15}N, probably due to more meat or milk in its daily diet. In contrast, there is one female individual (feature 158) with the lowest δ^{15}N values in the present study of 6.3‰ that could be classified as a vegan (O'Connell and Hedges, 1999). Her δ^{13}C and δ^{15}N values fall in the range of those of the domestic and wild fauna from Karsdorf (animal mean 7.3 ±0.9‰ 1σ), indicating she might have lived on the similar 'herbivore' diet (see Figure 5.4).

In summary, the general impression of human diet within the three LBK sites is very consistent with little variation, despite a small number of outliers (see Figure 5.6). Dürrwächter et al. (2006) found a different pattern at Herxheim where human δ^{15}N values varied significantly (9.8 ±1.0‰ 1σ), suggesting the burials did not reflect a living community but secondary interments.

Compared to the mean of 10.2 ±0.5‰ (1σ) δ^{15}N values from the adult individuals of LBK site Nieder-Mörlen (n=6), the mean values from Derenburg, Halberstadt and Karsdorf are lower.

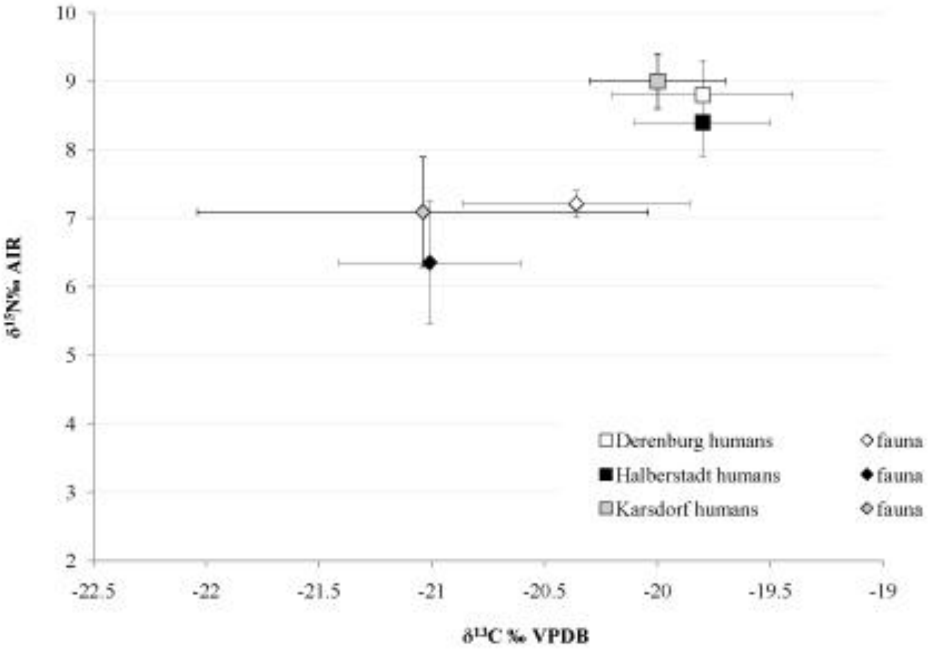

Figure 5.6: Mean values (1σ) for humans and animals of each site.

Nehlich et al. (2009b) suggested that some of the high δ^{15}N values in the domestic animals reflect pre-weaning signals. If this is the case and young animals were culled for meat production at Nieder-Mörlen, this would cause higher δ^{15}N values in the humans. This can be reconstructed by calculating the fractionation factor $\Delta_{\text{herbivore-human}}$ for Nieder-Mörlen (domestic herbivores: n=7; human: n=6, subadults excluded). The values +1.2‰ for $\Delta^{13}C_{\text{herbivore-human}}$ and +2.2‰ for $\Delta^{15}N_{\text{herbivore-human}}$ are remarkably similar to those from Halberstadt and Karsdorf, suggesting that the relative amount of consumed animal protein were almost equal. Yet, the $\Delta_{\text{herbivore-human}}$ factors calculated here for Early Neolithic Germany are not consistent with the Neolithic $\Delta_{\text{fauna-human}}$ values published by Hedges and Reynard (2007) that lie between 3.7‰ and 4.5‰ for $\Delta^{15}N_{\text{fauna-human}}$. Although in that calculation a variety of wild fauna was also taken into account, this may indicate that Neolithic farmers from present day Germany depended less on animal protein compared to the Neolithic people of Britain.

5.5. Conclusion

The human and animal samples from the LBK sites Derenburg, Halberstadt and Karsdorf represent the first farming communities in Central Germany. This sample is the most substantial and detailed dataset on carbon and nitrogen isotopes available for prehistoric Germany and gives insight on different aspects of human subsistence and animal husbandry in the early Neolithic. Although we suggest that the Derenburg population ate less quantities of animal protein than the people in Halberstadt and Karsdorf, the dietary variation within the sites are quite similar. The humans lived on an omnivore diet consisting of C_3 plant crops and animal meat from livestock. The consumption of unfermented dairy products is unlikely as there is direct palaeogenetic evidence of lactose intolerance available for the site Derenburg. There are no significant differences in the access to meat between the sexes. Children in these LBK cultures may have been weaned around the age of three and apparently ate the similar diet as adults after weaning, yet sample size is small. The isotopic signatures of animal bone collagen from Karsdorf reveal that there could have been different strategies of livestock management according to animal species. Comparison of aurochs and domestic cattle indicates that the two species fed in distinct habitats. Both the aspects of human diet and animal husbandry bear direct evidence on early farming subsistence strategy in Central Europe.

5.6. Acknowledgements

This project was funded by the Deutsche Forschungsgemeinschaft (DFG) and by Geocycles, Johannes Gutenberg University, Mainz. The isotope analysis was generously funded by the Max Planck Society. We thank Barbara Fritsch and Robert Ganslmeier from the State Office for Heritage Management and Archaeology, Saxony-Anhalt, for archaeological background information, as well as Hans-Jürgen Döhle for assessing the faunal remains. Furthermore we thank Michael Richards for permission to do isotopic measurements in Leipzig and Stefanie Bösel for technical assistance with the mass spectrometer. Special thanks go to Kate Britton, Olaf Nehlich and to the two anonymous reviewers for the very helpful comments on the manuscript.

5.7. References

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