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ORIGINAL PAPER

A bioarchaeological approach to the Iron Age in Switzerland: stable isotope analyses (δ^{13}C, δ^{15}N, δ^{34}S) of human remains

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Abstract In Switzerland, a large number of Iron Age burial sites were found in the last century. Changes in living conditions and socio-cultural behavior may have occurred over time and space and could be reflected in the dietary habits, social stratigraphy within populations and migration patterns. This study attempts to shed light on these aspects with the application of stable isotope analyses. Human remains from 11 different burial sites ($n = 164$) in the area of today's Swiss Plateau and Swiss Alpine regions were investigated. Temporal and geographical variations as well as sex and age-related dietary differences were analyzed through isotopic studies (δ^{13}C, δ^{15}N, and δ^{34}S). In total, the data of 129 individuals could be evaluated. Highly significant differences between the burial sites were found, with higher δ^{13}C and δ^{15}N values in the Alpine regions. Cultural and/or climatic changes as well as the different geological conditions might have led to distinct patterns of crop cultivation and animal husbandry and consequently to significantly different dietary habits in the Plateau and the Alpine regions. The data indicate a higher intake of millet and animal protein including early dairy production in the southern regions, probably influenced by the Mediterranean world. Cultural exchange between geographical regions might have been facilitated by migration during the Iron Age as suggested by the δ^{34}S.

Keywords Stable isotopes · Paleodiet · Iron Age

Introduction

Bioarchaeological approaches to Late Iron Age human remains have become more and more important for anthropological and archaeological research (Knipper et al. 2014; Koon and Nicholls 2016; Le Huray and Schutkowski 2005; Lightfoot et al. 2015; Moghaddam et al. 2016; Naumann et al. 2014; Oelze et al. 2012; Redfern et al. 2010). Due to the poor preservation of many Iron Age skeletons and the lack of written sources from that time, stable isotope analyses provide important new insights into the Iron Age dietary and migration patterns (Le Huray et al. 2006).

The Iron Age in central Europe is characterized by the Hallstatt (Early Iron Age from 800 to 450 BC) and the La Tène period (Late Iron Age from 450 to 15 BC). The La Tène period is subdivided into the stages LT A (Early La Tène) to LT D (Late La Tène). The foundation of the City of Massalia around 600 BC, nowadays known as Marseille, played a major role in the history of the "Celts" (Müller et al. 1999; Müller and Lüscher 2004). It influenced the Iron Age culture including the greater tribes near the Rhône such as the Sedunii in the area of today's Valais in the south of Switzerland (Curdy et al. 2009). Between the fourth and third centuries BC, La Tène culture expanded in most areas of central Europe including migration waves to Italy, the Balkans and to today's Turkey (Kaenel 1999). Iron Age populations were a diverse group of small-scale societies with similar religion, language, and culture. The term "Celts" should

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therefore be used carefully. It remains unclear whether this term defines populations with the same language or also political groups (Collis 1984). One of the greater tribes was the Helvetii in the Swiss Plateau. Other tribes in the area of modern Switzerland were the Allobroges around Geneva, Raurici and Latobrigi in modern Basel and Schaffhausen, the Leponti in Ticino, and the Raeti in Grisons (Müller et al. 1999). “Celtic” culture, however, rapidly declined after the Roman Empire conquered Spain, Gaul, and areas of the upper Danube.

In the area of Switzerland, a large amount of Iron Age burial sites were excavated in the last century and have raised questions: how was the social structure within populations organized? Were there any differences in the socioeconomic and cultural structure between societies and within a population?

This study presents stable isotope data ($\delta^{13}C$, $\delta^{15}N$, $\delta^{34}S$) of human remains from different regions in Switzerland in order to obtain more information about “Celtic” populations. It is suggested that changes and differences in living conditions and socio-cultural behavior might have taken place through time and space. This might be reflected in the dietary habits, social stratigraphy within populations and possible migration of individuals. Therefore, this study aimed to analyze geographical and temporal dietary differences of individuals from Late Iron Age burial sites in Switzerland. Burials found in the Swiss Plateau and the Swiss Alpine regions were compared to discover whether different geological conditions and climate might have influenced living conditions and economical structures during the period. Cultural changes during the Swiss Late Iron Age are evident through the archaeological findings. Archaeological research shows differences in grave goods and burial rites between the Swiss Plateau and the southern area of Switzerland. Although no items of weaponry were found from the LT C period onwards in a larger necropolis in the area of Bern, weapons as grave goods were found in the burial sites of Sion dating to the LT D period (Jud and Ulrich-Bochsler 2014). In addition, dietary differences should now be brought to light through bioarchaeological studies.

Stable isotope analyses: the reconstruction of diet and migration

The technique of stable isotope ratio analysis is a frequently used tool to assess dietary habits, to obtain information about social stratification and mobility of past populations (Dupras and Schwarcz 2001; Fuller et al. 2012; Jay et al. 2013; Jay and Richards 2006; Katzenberg 2008; Knipper et al. 2016; Lösch et al. 2006).

Stable carbon and nitrogen isotope analyses are the most common methods to examine diet (Katzenberg et al. 2012; Schoeninger and DeNiro 1984; Stevens and Hedges 2004). Analysis of $\delta^{13}C$ provides information about the different plant sources in the diet: C_3 and C_4 plants differ in their photosynthetic pathway and therefore show different $\delta^{13}C$ values (Ambrose 1993; Ambrose and Norr 1993; Hoefs 2009). Due to a strong discrimination against ^{13}C the $\delta^{13}C$ values in C_3 plants such as wheat and barley are more negative (−19 to −35‰) than in C_4 plants (−9 to −35‰) (Ambrose 1993; Lee-Thorp 2008). The $\delta^{13}C$ value becomes enriched by +1‰ for each trophic level, from prey to predator collagen (Redfern et al. 2012).

Additionally, analysis of $\delta^{15}N$ can be used to predict a relative animal protein intake. Towards the top of the food chain, the $\delta^{15}N$ increases (“trophic level effect”) and therefore the variation of stable nitrogen isotope ratios provide information about trophic level (Richards et al. 1998). In bone collagen, the approximate shift from one trophic level to the next one is about +3 to +5‰ (Bocherens and Drucker 2003; Hedges and Reynard 2007). Individuals with mostly animal protein in their diet have higher $\delta^{15}N$ values than those consuming mainly plants (Richards et al. 1998; Stevens et al. 2010). Furthermore, $\delta^{15}N$ values show the relative contribution of terrestrial and marine resources (Schoeninger and DeNiro 1984).

The analysis of $\delta^{34}S$ has become important for stable isotope research for analyses of dietary habits and migration (Bollongino et al. 2013; Craig et al. 2006; Fornander et al. 2008; Kinaston et al. 2013; Moghaddam et al. 2016; Nehlich et al. 2011, 2012; Oelze et al. 2012; Privat et al. 2007; Richards et al. 2001, 2003; Vika 2009). In bone collagen, the $\delta^{34}S$ is passed along the food chain with just a small fractionation of approximately −1‰. Organisms in marine ecosystems have stable sulfur isotope ratios around +20‰ while terrestrial mammals have values even lower than +10‰ (Nehlich et al. 2012; Richards et al. 2003). However, the values of freshwater and terrestrial ecosystems range from −22‰ to +22‰ (Oelze et al. 2012; Privat et al. 2007). Additionally, the $\delta^{34}S$ values vary between geographical regions due to different geological conditions (Vika 2009). Therefore, sulfur isotopic signatures are influenced by dietary habits and location (Howcroft et al. 2012; Nehlich et al. 2011).

Material

In total, samples of 164 human and 5 animal bones were collected from 11 sites: 7 sites located on the Swiss Plateau and 4 sites in the Swiss Alps (Fig. 1; Table 1).

The animal bones from Reichenbachstrasse were identified as one pig, one cattle and two samples from ovicaprids (Rehazek and Nussbaumer 2014). One ovicaprid sample from Bonaduz in the area of Grisons was included (Table 2).

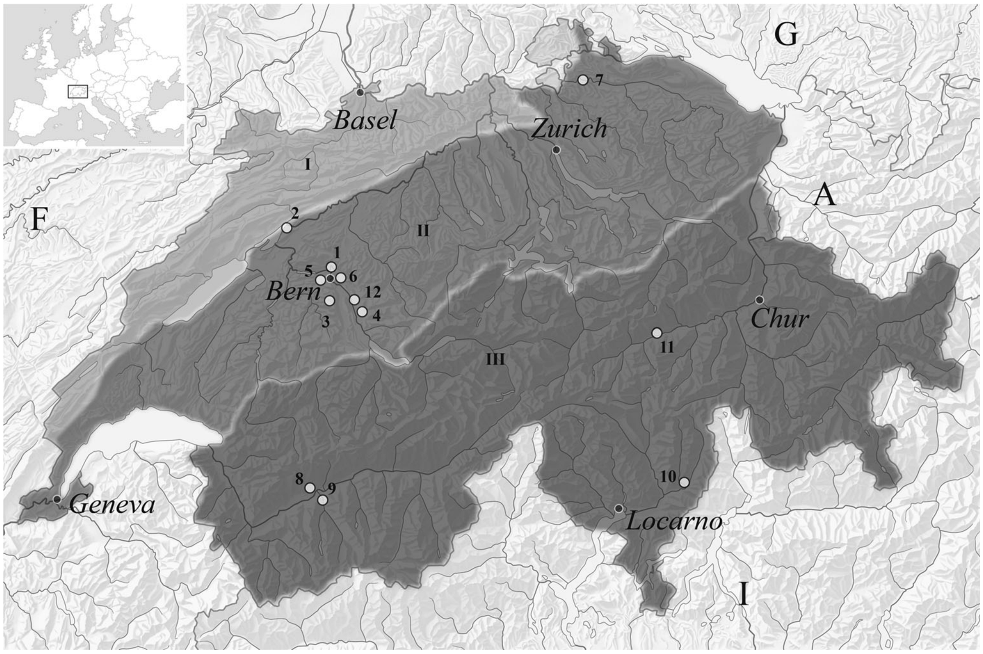


Fig. 1 Switzerland (provided by the Archaeological Service Bern; Source: Swisstopo): Major landscapes shown as *I* Jura Mountains, *II* Swiss Plateau, *III* Swiss Alps. Burial sites are indicated with numbers (*1* Engehalbinsel, *2* Ipsach, *3* Belp, *4* Niederwichtrach, *5* Bümpliz, *6* Stettlen-Deisswil, *7* Andelfingen, *8* Sion, *9* Bramois, *10* Castaneda, *11* Trun Darvella). Additionally, burial site of Münsingen is marked by *12*

Iron Age burial sites at the Swiss plateau

Today, the Swiss Plateau between the Jura Mountains and the Alps covers about 30% of Switzerland and elongates from Geneva in the south west to the German border in the north east (Fig. 1). Even though the area is flat in some parts, it shows mainly hilly areas, several large lakes (such as Lakes Geneva, Neuchâtel and Zurich) and rivers. The city of Bern and the surrounding area provide the largest amount of skeletal material of Late Iron Age Switzerland. During the Iron Age, the Aare valley between the city of Bern and Lake Thun seems to have been part of a fairly well-developed settlement area that reached out to the West (Müller 1996). The Enge peninsula (Engehalbinsel) held the Celtic oppidum "Brenodor", a city-like settlement, between the third and first centuries BC (Jud and Ulrich-Bochsler 2014). For some burial

Table 1 Summary of all burial sites: burial sites are indicated by numbers (*1* Engehalbinsel, *2* Ipsach, *3* Belp, *4* Niederwichtrach, *5* Bümpliz, *6* Stettlen-Deisswil, *7* Andelfingen, *8* Sion, *9* Bramois, *10* Castaneda, *11* Trun Darvella)

	Region	Burial site	Number of samples	Archaeological dating	Primary sources and additional literature
Swiss Plateau	Bern	1: Engehalbinsel	38	LT C–D	Hug (1956); Jud and Ulrich-Bochsler (2014)
		2: Ipsach	5	LT B–C	Ramstein (2010); Zweifel (2015)
		3: Belp	7	LT C–D	Schoch and Ulrich-Bochsler (1987); Suter and Ulrich-Bochsler (1984)
		4: Niederwichtrach	5	LT B–C	Schoch and Ulrich-Bochsler (1987); Stöckli (1995)
		5: Bümpliz	11	LT B–C	Hug (1956); Schoch and Ulrich-Bochsler (1987); Stähli (1977)
		6: Stettlen - Deisswil	8	LT B–C	Rey (1999)
	Zurich	7: Andelfingen	16	LT B–C	Viollier (1912)
		Total	90	LT B–D	
Swiss Alps	Valais	8: Sion	53	LT B–D	Curdy et al. (2009); Debard (2014)
		9: Bramois	17	LT B–D	Curdy et al. (2009); Debard (2014)
	Grisons	10: Castaneda	1	LT (A)B–C?	Keller-Tarnuzzer (1933); Nagy (2008)
		11: Trun Darvella	3	LT B–D	Tanner (1980)
		Total	74	LT B–D	

Table 2 Anthropological and stable isotope data of human ($n = 164$) and faunal ($n = 5$) remains; excluded samples are shown in italics and classification of dating group through ^{14}C analyses in bold.

Burial sites	Number	Age	Age class	Sex	Sample	Archaeological dating	^{14}C dating (2)	Grave goods	δ^{13}C [‰]$_{V\text{-}PDB}$	δ^{15}N [‰]$_{AIR}$	δ^{34}S [‰]$_{V\text{-}CDT}$	%$_{coll}$	%C	%N	%S	C/N mol	C/S	N/S
Bern: Engehalbinsel (Reichenbachstrasse)	A5182	46–51	Mature	f	Skull	D1			−18.9	7.8	5.1	2.6	40.7	15.5	0.1	3.1	313.1	119.2
	A5184	*8–10*	*Infant II*	*nd*	*Long bone*	/			*−19.5*	*9.1*	*6.7*	*4.8*	*37.0*	*17.4*	*0.1*	*2.5*	*370.0*	*174.0*
	A5185/13	*8–9*	*Infant II*	*nd*	*Skull*	/			*−19.6*	*6.3*	*6.7*	*7.3*	*39.0*	*16.8*	*0.1*	*2.7*	*354.5*	*152.7*
	A5185/16	23–40	Adult	f	Skull	C2			−19.8	6.9	6.8	5.6	41.8	16.5	0.1	3.0	380.0	150.0
	A5187	7–9	Infant II	nd	Skull	/			−20.2	7.8	5.6	1.0	36.6	12.8	0.1	3.3	406.7	142.2
	A5188	*10–11*	*Infant II*	*nd*	*Skull*	*C2*		*Gold or bronce ring and/or pearl*	*−20.0*	*6.2*	*6.9*	*4.4*	*38.8*	*16.3*	*0.1*	*2.8*	*352.7*	*148.2*
	A5189	30–50	Mature	f	Skull	C2			−19.6	8.1	6.6	3.9	41.9	16.8	0.1	2.9	299.3	120.0
	A5190	*2–3*	*Infant Ia*	*nd*	*Skull*	C2		*Gold or bronce ring and/or pearl*	*−19.8*	*8.3*	*6.6*	*7.1*	*38.6*	*16.7*	*0.1*	*2.7*	*350.9*	*151.8*
	A5191	*18–30*	*Adult*	*f*	*Skull*	C2		*Gold or bronce ring and/or pearl*	*−20.1*	*6.6*	*7.2*	*4.1*	*36.9*	*16.0*	*0.1*	*2.7*	*335.5*	*145.5*
	A5192	30–40	Adult	f	Skull	D1		Gold or bronce ring and/or pearl	−19.1	8.0	4.7	4.0	45.0	16.8	0.1	3.1	321.4	120.0
	A5193	*3–4*	*Infant Ib*	*nd*	*Long bone*	/			*−19.7*	*6.6*	*6.8*	*3.8*	*39.8*	*16.8*	*0.1*	*2.8*	*306.2*	*129.2*
	A5194	*4–5*	*Infant Ib*	*nd*	*Skull*	*D1*			*−19.9*	*7.5*	*6.0*	*4.7*	*40.5*	*16.9*	*0.1*	*2.8*	*337.5*	*140.8*
	A5195	4–5	Infant Ib	nd	Skull	/			−20.2	8.2	5.4	2.7	41.6	15.6	0.1	3.1	297.1	111.4
	A5196	8–11	Infant II	nd	Long bone	C/D			−20.1	7.0	5.8	2.3	42.3	17.1	0.1	2.9	352.5	142.5
	A5197	37–33	Adult	f	Skull	C2			−19.7	7.1	6.7	4.7	44.0	16.9	0.1	3.0	366.7	140.8
	A5198	4–5	Infant Ib	nd	Skull	C2			−19.8	7.6	6.3	6.0	42.6	16.2	0.1	3.1	327.7	124.6
	A5199	37–46	Adult	f	Skull	C2		Gold or bronce ring and/or pearl	−19.6	8.1	6.0	4.5	39.9	15.4	0.1	3.0	306.9	118.5
	A5200	*30–40*	*Adult*	*nd*	*Skull*	*C2*		*Coins*	/	/	/	/	/	/	/	/	/	/
	A5201	*54–60*	*Mature*	*f*	*Skull*	/			*−18.8*	*4.8*	*7.1*	*1.5*	*32.7*	*16.1*	*0.1*	*2.4*	*327.0*	*161.0*
	A5202	23–30	Adult	f	Skull	D1		Gold or bronce ring and/or pearl	−19.2	7.6	5.9	1.7	41.9	15.1	0.1	3.2	419.0	151.0
	A5203	4–5	Infant Ib	nd	Skull	D1			−19.5	8.0	6.4	5.2	41.3	16.0	0.1	3.0	375.5	145.5
	A5204	3–5	Infant Ib	nd	Skull	D1			−19.5	8.4	6.3	5.7	42.0	16.4	0.1	3.0	323.1	126.2
	A5205	3–4	Infant Ib	nd	Skull	C/D			−19.7	8.6	6.3	5.8	43.1	17.1	0.1	2.9	359.2	142.5
	A5206	23–40	Adult	f	Skull	/			−19.8	8.0	6.6	6.0	41.4	16.2	0.1	3.0	345.0	135.0
	A5207	23–40	Adult	f	Skull	C2		Gold or bronce ring/pearl	−19.5	6.9	7.1	4.1	43.2	17.3	0.1	2.9	360.0	144.2
	A5208	*30+*	*Adult*	*f*	*Skull*	*C2*		*Coins and gold or bronce ring and/or pearl*	/	/	/	/	/	/	/	/	/	/
	A5209	40+	Mature	f	Skull	C2		Coins	−19.3	8.8	5.4	4.2	42.1	15.8	0.1	3.1	323.8	121.5
	A5210	0.5–1	Infant Ia	nd	Skull	D1			−18.7	11.3	6.7	3.3	39.7	14.6	0.1	3.2	397.0	146.0
	A5211	*3–4*	*Infant Ib*	*nd*	*Skull*	*D1*			*−19.3*	*7.1*	*7.0*	*5.7*	*33.0*	*16.1*	*0.1*	*2.4*	*330.0*	*161.0*
	A5212	*30–50*	*Adult*	*nd*	*Skull*	*D1*		*Coins*	*−19.3*	*7.0*	*7.0*	*4.2*	*39.4*	*16.6*	*0.1*	*2.8*	*328.3*	*138.3*
	A5213	4–5	Infant Ib	nd	Skull	/			−19.5	10.4	5.3	2.4	41.1	15.4	0.1	3.1	342.5	128.3
	A5214	0.5–1	Infant Ia	nd	Skull	C2			−19.1	10.3	6.6	4.5	41.8	15.3	0.1	3.2	418.0	153.0
	A16	30–50	Adult	f	Femur	/			−18.2	8.1	5.4	5.1	44.3	16.4	0.1	3.2	316.4	117.1

Table 2 (continued)

Burial sites	Number	Age	Age class	Sex	Sample	Archaeological dating	^{14}C dating (2)	Grave goods	δ^{13}C [‰]$_{V-PDB}$	δ^{15}N [‰]$_{AIR}$	δ^{34}S [‰]$_{V-CDT}$	%$_{coll}$	%C	%N	%S	C/N mol	C/S	N/S
Bern: Engehalbinsel (Rossfeldstrasse)	A17	20–30	Adult	m	Skull	/			−19.8	7.4	3.3	2.0	42.8	16.3	0.1	3.1	305.7	116.4
	A18	20–30	Adult	m	Ulna	/			−19.0	7.5	5.6	3.9	42.4	16.1	0.1	3.1	302.9	115.0
	A19	20–40	Adult	f	Skull	/			−19.7	8.2	1.6	1.4	41.7	16.1	0.1	3.0	320.8	123.8
	A20	*30–40*	*Adult*	*m*	*Skull*	/			*−18.7*	*7.2*	*6.0*	*1.5*	*33.7*	*15.2*	*0.1*	*2.6*	*306.4*	*138.2*
	A21	21–25	Adult	f	Ulna	/			−18.7	7.8	5.9	4.3	44.1	16.5	0.1	3.1	315.0	117.9
Bern: Ipsach	IP14	35–45	Adult	f	Skull	C1			−18.0	8.9	6.7	3.5	34.8	12.1	0.1	3.4	316.4	110.0
	IP50	*14–20*	*Juvenile*	*f*	*Skull*	B			/	/	/	/	/	/	/	/	/	/
	IP73	4–6	Iinfant Ib	nd	Skull	B2			−19.2	10.7	6.2	3.2	26.5	9.0	0.1	3.4	240.9	81.8
	IP133	2.5–3.5	Infant Ia	nd	Skull	B1/B2		Gold or bronce ring and/or pearl	−16.3	10.2	3.6	2.3	38.3	13.5	0.1	3.3	319.2	112.5
	IP136	5–7	Infant Ib	nd	Skull	B2			−18.1	9.7	6.2	2.7	32.2	11.1	0.1	3.4	292.7	100.9
Bern: Belp	BEB-A4	20–30	Adult	m	Skull	C			−20.0	8.3	4.0	3.9	45.1	16.1	0.2	3.3	205.0	73.2
	BEB-A2268	45–60	Mature	f	Skull	**C–D**	196–55 BC		−18.8	9.3	1.8	2.1	43.3	15.0	0.2	3.4	206.2	71.4
	BEB-A2269	40+	Mature	m	Long bone	**C–D**	201–55 BC		−19.1	7.8	0.2	1.6	44.9	16.3	0.2	3.2	224.5	81.5
	BEB-A2270	45–60	Mature	m	Skull	C			−18.5	8.1	3.3	3.6	44.4	15.9	0.2	3.3	233.7	83.7
	BEB-A2271	40–55	Mature	m	Skull	**C–D**	348–94 BC		−19.6	8.6	5.1	1.5	44.0	15.9	0.2	3.2	209.5	75.7
	BEB-A2272	25–35	Adult	f	Skull	C			−16.1	8.3	3.7	1.9	42.6	15.4	0.2	3.2	224.2	81.1
	BEB-A2276	30–50	Adult	f	Maxilla	/			−18.9	8.7	1.9	3.8	41.1	14.6	0.2	3.3	216.3	76.8
Bern: Niederwichtrach	*NW-A1191*	*45–60*	*Mature*	*m*	*Skull*	/			*−20.6*	*9.0*	*3.9*	*1.9*	*29.3*	*10.2*	*0.2*	*3.3*	*172.4*	*60.0*
	NW-A1189	25–40	Adult	f	Skull	**B–C** (D)	363–203 BC		−19.7	8.8	2.0	1.9	42.9	15.0	0.2	3.3	204.3	71.4
	NW-A1190	20–40	Adult	nd	Mandibula	/			−21.5	8.8	2.3	3.3	43.5	14.3	0.2	3.5	241.7	79.4
	NW-A1188	55–70	Senile	nd	Skull	**B–C**	374–204 BC		−20.1	8.8	2.5	4.1	44.0	15.0	0.2	3.4	220.0	75.0
	NW-A2415	*1–3*	*Infant Ia*	*nd*	*Skull*	/			*−19.8*	*8.8*	*1.3*	*2.3*	*35.9*	*12.1*	*0.2*	*3.5*	*188.9*	*63.7*
Bern: Bümpliz	BBÜ-A6	25–40	Adult	f	Skull	A			−19.0	7.9	6.4	2.5	40.8	14.9	0.2	3.2	226.7	82.8
	BBÜ-A7	20–30	Adult	f	Skull	**B–C**	385–206 BC		−18.4	7.3	6.5	4.8	44.2	16.0	0.2	3.2	294.7	106.7
	BBÜ-A8	30–50	Adult	f	Skull	/			−18.2	7.7	6.4	4.3	44.4	16.0	0.1	3.2	317.1	114.3
	BBÜ-A9	30–45	Adult	f	Skull	**B–C**	389–209 BC		−18.0	7.3	6.7	4.3	43.9	15.8	0.1	3.2	337.7	121.5
	BBÜ-A10	55–70	Mature	f	Skull	/			−19.7	8.4	2.1	2.6	44.8	16.3	0.1	3.2	373.3	135.8
	BBÜ-A11	20–40	Adult	f	Skull	C2		Gold or bronce ring and/or pearl	−17.7	7.0	6.7	2.4	43.6	15.7	0.1	3.2	311.4	112.1
	BBÜ-A12	20–40	Adult	m	Skull	**B–C**	388–208 BC		−17.8	7.4	7.1	2.0	44.0	16.1	0.1	3.2	314.3	115.0
	BBÜ-A13	20–35	Adult	f	Skull	B1		Torc and gold or bronce ring	−19.1	8.4	5.4	3.0	42.2	15.3	0.1	3.2	301.4	109.3
	BBÜ-A375	30–40	Adult	f	Skull	**B–C**	360–176 BC		−17.9	7.6	6.8	5.2	44.5	16.2	0.2	3.2	296.7	108.0
	BBÜ-A376	14–18	Juvenile	nd	Skull	**B–C**	382–204 BC		−17.6	7.2	6.9	3.2	45.2	16.3	0.1	3.2	347.7	125.4
	BBÜ-A833	3–4	Infant Ib	nd	Skull	A/B		Gold or bronce ring and/or pearl	−20.3	8.2	6.2	2.5	43.9	15.5	0.2	3.3	199.5	70.5
Bern: Stettlen-Deisswil	SD-A126	25–40	Adult	f	Skull	C			−19.6	8.9	1.9	7.1	45.2	16.5	0.2	3.2	265.9	97.1

Table 2 (continued)

Burial sites	Number	Age	Age class	Sex	Sample	Archaeological dating	^{14}C dating (2)	Grave goods	δ^{13}C [‰]$_{V\text{-}PDB}$	δ^{15}N [‰]$_{AIR}$	δ^{34}S [‰]$_{V\text{-}CDT}$	%$_{coll}$	%C	%N	%S	C/N mol	C/S	N/S
	SD-A127	40–60	Mature	f	Skull	C			−18.6	8.5	1.4	5.6	44.1	15.9	0.2	3.2	294.0	106.0
	SD-A128	40–50	Mature	f	Skull	**B–C**	365–198 BC		−19.0	8.6	2.6	1.4	40.3	14.3	0.2	3.3	212.1	75.3
	SD-A129	40–55	Mature	f	Skull	B		Gold or bronce ring and/or pearl	−19.9	10.4	1.3	5.0	43.8	15.9	0.1	3.2	312.9	113.6
	SD-A775	6–7	Infant Ib	id	Skull	C			−18.7	8.6	2.1	7.0	43.2	15.7	0.1	3.2	308.6	112.1
	SD-A776	14–18	Juvenile	nd	Skull	**B–C**	365–203 BC		−18.6	8.2	3.1	6.3	46.2	16.9	0.2	3.2	243.2	88.9
	SD-A130	40–55	Mature	m	Tibia	B		Weapon	−19.9	9.1	2.2	5.7	45.2	16.3	0.2	3.2	226.0	81.5
	SD-A131	40–60	Mature	m	Skull	C			−19.9	9.0	3.8	5.7	44.9	15.8	0.2	3.3	299.3	105.3
Zürich: Andelfingen	ZAF-4	25+	Adult	m	Femur	C			−18.1	8.8	8.5	1.9	43	15.3	0.1	3.3	390.9	139.1
	ZAF-5	25–40	Adult	f	Femur	C			−17.1	8.4	8.4	1.6	45	16.2	0.1	3.2	346.2	124.6
	ZAF-6	14–20?	Juvenile	f	Tibia	B		Gold or bronce ring and/or pearl	−19.5	8.2	4.7	6.2	47.4	17.2	0.1	3.2	364.6	132.3
	ZAF-7	18–30	Adult	m	Femur	/			−16.7	8.6	2.4	1.6	42.3	15	0.1	3.3	325.4	115.4
	ZAF-8	25–35	Adult	f	Fibula	C		Gold or bronce ring and/or pearl	−18.4	8.9	4.6	1.6	42.6	15.3	0.1	3.2	304.3	109.3
	ZAF-9	20–40	Adult	f	Ulna	C		Gold or bronce ring and/or pearl	−17.5	9.0	3.8	3.0	48	17.4	0.1	3.2	342.9	124.3
	ZAF-11	*25–35*	*Adult*	*m*	*Tibia*	*C*			*−16.9*	*7.9*	*6.8*	*5.6*	*39*	*16.7*	*0.1*	*2.7*	*354.5*	*151.8*
	ZAF-12	>50	Senile?	m	Femur	C		Weapon	−18.0	8.6	6.1	5.0	43.6	16.4	0.1	3.1	396.4	149.1
	ZAF-13	nd	nd	nd	Femur	**B–C**	396–211 BC		−19.3	8.2	5.3	1.6	45.4	16.5	0.1	3.2	324.3	117.9
	ZAF-15	nd	nd	f	Humerus	**B–C** (C)	392–210 BC	Gold or bronce ring and/or pearl	−17.9	9.0	3.8	6.0	46.4	16.9	0.1	3.2	356.9	130.0
	ZAF-19	*25+*	*Adult*	*f*	*Femur*	/		*Gold or bronce ring and/or pearl*	*−17.7*	*8.8*	*3.3*	*0.6*	*37.9*	*13.1*	*0.1*	*3.4*	*315.8*	*109.2*
	ZAF-21	25+	Adult	m	Femur	C			−17.8	9.6	4.6	1.6	48.3	17.4	0.1	3.2	345.0	124.3
	ZAF-22	17–25	Adult	m	Skull	/			−19.4	8.1	3.1	25.4	45.3	15.9	0.2	3.3	283.1	99.4
	ZAF-24	50+	Senile	f	Femur	B/C			−18.6	9.2	8.7	52.8	47.8	17.4	0.1	3.2	341.4	124.3
	ZAF-27	25–35	Adult	m	Femur	D			−18.6	9.5	3.4	1.6	44.9	16	0.2	3.3	299.3	106.7
	ZAF-28	25+	Sdult	m	Fibula	C			−18.0	9.5	8.3	6.2	43	16.8	0.1	3.0	358.3	140.0
Valais: Sion Ancienne Placette	SA4	20–40	Adult	f	Skull	**HA** (C2)	914–811 BC		−16.3	9.0	2.3	5.8	45.0	17.0	0.2	3.1	300.0	113.3
	SA5	*nd*	*nd*	*m*	*Long bone (radius/-ulna)*	/			*−15.7*	*5.3*	*0.9*	*5.4*	*26.1*	*13.0*	*0.1*	*2.3*	*326.3*	*162.5*
	SA6	nd	nd	nd	Skull	**HA**	914–814 BC		−16.8	8.5	0.4	2.7	43.0	15.8	0.1	3.2	358.3	131.7
Valais: Sion Nouvelle Placette	SN1	20–49	Adult	m	Skull	D1		Weapon	−18.8	8.4	−0.5	3.0	44.6	17.5	0.1	3.0	371.7	145.8
	SN2	*40+*	*Mature*	*m*	*Skull*	*D1*			*−17.9*	*10.0*	*4.4*	*1.0*	*23.2*	*7.8*	*0.1*	*3.5*	*193.3*	*65.0*
	SN3	*20–49*	*Adult*	*m*	*Skull*	*C2*			*−17.7*	*10.1*	*6.1*	*2.5*	*32.6*	*14.7*	*0.1*	*2.6*	*407.5*	*183.8*
	SN4	30–59	Mature	m	Long bone	C2			−18.3	8.6	1.7	2.0	40.8	15.3	0.1	3.1	370.9	139.1
	SN5	30–59	Mature	f	Skull	D2			−19.6	9.7	3.7	1.8	43.6	15.7	0.1	3.2	396.4	142.7
Valais: Sion Parking Remparts	SP1	30–59	Mature	m	Femur	**B–C**	391–207 BC		−16.9	8.5	2.5	2.6	46.2	17.0	0.1	3.2	420.0	154.5
	SP11	30–59	Mature	nd	Skull	C1			−18.2	9.4	1.8	2.8	44.9	17.0	0.1	3.1	449.0	170.0
	SP12	20–29	Adult	m	Skull	**B–C**	384–205 BC		−18.9	6.8	5.5	7.9	46.2	17.0	0.1	3.2	420.0	154.5
	SP13	20–39	Adult	f	Skull	**B–C**			−18.2	9.3	1.8	2.7	43.8	16.6	0.1	3.1	336.9	127.7

Table 2 (continued)

Burial sites	Number	Age	Age class	Sex	Sample	Archaeological dating	^{14}C dating (2)	Grave goods	δ^{13}C [‰]$_{V-PDB}$	δ^{15}N [‰]$_{AIR}$	δ^{34}S [‰]$_{V-CDT}$	%$_{coll}$	%C	%N	%S	C/N mol	C/S	N/S
							394–209 BC											
	SP14	5–9	Infant II	nd	Skull	D1			−19.0	9.8	5.4	4.9	41.6	14.9	0.1	3.3	462.2	165.6
	SP15	30–59	Mature	nd	Fibula?	/			−17.7	9.9	5.4	2.6	45.4	16.7	0.1	3.2	567.5	208.8
	SP16	*30–59*	*Mature*	*nd*	*Femur*	/			*−18.9*	*9.7*	*6.6*	*2.5*	*35.8*	*11.6*	*0.1*	*3.6*	*275.4*	*89.2*
	SP17	30–59	Mature	nd	Skull	C1			−18.0	9.6	2.5	3.3	43.2	16.9	0.1	3.0	540.0	211.3
	SP18	40+	Mature	m	Skull	C1			−18.2	8.0	−0.1	1.8	43.1	15.9	0.1	3.2	538.8	198.8
	SP19	60+	Senile	m	Skull	C2			−18.1	9.4	4.8	1.8	40.5	15.0	0.1	3.1	578.6	214.3
	SP27	40–60	Mature	m	Skull	C1			−17.9	9.5	5.9	3.1	44.9	16.6	0.1	3.2	449.0	166.0
Valais: Sion Passage de la Matze	*SM1*	*18–30*	*Adult*	*m*	*Skull*	/			*−18.8*	*8.1*	*4.1*	*8.3*	*38.9*	*17.1*	*0.1*	*2.7*	*324.2*	*142.5*
	SM2	nd	nd	nd	Skull	/			−19.0	9.6	0.5	4.5	39.8	14.8	0.1	3.1	284.3	105.7
Valais: Sion Petit-Chasseur	SPC2	5–9	Infant II	nd	Skull	B1	400–212 BC		−19.5	8.6	2.0	1.2	37.3	14.7	0.1	3.0	373.0	147.0
	SPC4	*30–59*	*Mature*	*f*	*Skull*	*Augustus*		*Coins*	*−20.4*	*8.8*	*4.2*	*2.0*	*31.8*	*9.2*	*0.1*	*4.0*	*353.3*	*102.2*
	SPC5	*20–39*	*Adult*	*f*	*Scapula*	*D1*		*Weapon*	*−19.1*	*9.9*	*2.4*	*2.1*	*38.1*	*15.8*	*0.1*	*2.8*	*317.5*	*131.7*
	SPC6	20–29	Adult	m	Skull	**C–D**	349–54 BC		−18.5	9.1	2.5	2.8	48.2	17.7	0.1	3.2	482.0	177.0
	SPC7	*50–60*	*Mature*	*f*	*Skull*	*D1*			*−19.0*	*10.0*	*3.8*	*2.4*	*34*	*12.4*	*0.1*	*3.2*	*425.0*	*155.0*
Valais: Sion-sous-le-Scex	S297	20–49	Adult	m	Skull	**C–D**	191–45 BC		−18.7	10.1	3.8	2.2	43.3	16	0.1	3.2	433.0	159.0
	S422	20–49	Adult	m	Skull	**B–D**	353–61 BC		−18.1	9.2	2.2	3.6	43.6	16	0.1	3.1	363.3	135.0
	S424	*5–9*	*Infant II*	*nd*	*Skull*	*C2*		*Gold or bronce ring and/or pearl*	*−19.0*	*9.0*	*2.6*	*5.3*	*34.3*	*12.5*	*0.1*	*3.2*	*343.0*	*125.0*
	S426	30–59	Mature	f	Long bone	C2		Gold or bronce ring and/or pearl	−18.5	8.9	2.3	4.7	39.7	15.5	0.1	3.0	397.0	155.0
	S427	5–9	Infant II	nd	Skull	C2			−18.2	9.4	3.8	5.9	41.2	15.2	0.1	3.2	316.9	116.9
	S429	20–29	Adult	f	Skull	C2		Gold or bronce ring and/or pearl	−18.9	9.2	2.3	4.2	44.6	16.6	0.1	3.1	405.5	150.9
	S430	*40+*	*Mature*	*f*	*Skull*	*D1*			*−19.0*	*7.9*	*2.2*	*4.5*	*36.7*	*15.3*	*0.1*	*2.8*	*333.6*	*139.1*
	S431	60+	Senile	f	Skull	/			−19.3	9.8	4.7	1.2	40.0	14.5	0.1	3.2	285.7	103.6
	S432	20–29	Adult	f	Mandibula	C2			−18.9	9.6	4.1	4.8	43.7	16.2	0.1	3.1	397.3	147.3
	S436	30–59	Mature	nd	Humerus?	D1			−18.2	9.5	3.3	3.0	44.1	16.8	0.1	3.1	400.9	152.7
	S437	30–59	Mature	m	Femur	C1			−18.2	8.2	3.8	6.5	45.3	16.6	0.1	3.2	348.5	127.7
	S438	20–39	Adult	f	Fibula	D1			−20.0	7.3	4.9	4.0	44.5	17.9	0.1	2.9	404.5	162.7
	S439	30–59	Mature	m	Fibula	D1		Weapon	−19.0	9.2	3.6	3.0	45.6	16.6	0.1	3.2	380.0	138.3
	S528	20–39	Adult	f	Long bone (radius/-ulna)	D1		Gold or bronce ring and/or pearl	−18.5	10.1	5.5	3.7	42.9	17.2	0.1	2.9	390.0	156.4
	S533	30–59	Mature	nd	Skull	D1			−18.5	8.9	−2.0	5.5	42.2	16.0	0.1	3.1	383.6	145.5
	S535	30–59	Mature	nd	Scapula	/			−18.3	8.1	−1.0	4.1	42.5	16.9	0.2	2.9	265.6	105.6
	S537	20–29	Adult	f	Long bone (radius/-ulna)	/			−16.3	10.7	4.8	7.1	45.2	16.9	0.1	3.1	376.7	140.8
	S538	30–59	Mature	f	Skull	C2			−18.2	8.6	1.8	3.9	43.2	16.5	0.1	3.1	308.6	117.9
	S539	20–39	Adult	f	Femur	C2		Coins	−18.7	9.3	1.7	5.8	46.0	16.8	0.1	3.2	460.0	168.0
	S540	*40+*	*Mature*	*f*	*Skull*	*C1*			*−18.4*	*9.8*	*2.3*	*5.0*	*35.1*	*12.7*	*0.1*	*3.2*	*438.8*	*158.8*
	S542	20–39	Adult	m	Humerus	C2			−18.4	9.0	2.0	7.4	45.3	16.6	0.1	3.2	566.3	207.5
	S546	>30	Adult	m	Skull	D1			−19.2	9.1	2.6	4.6	40.1	15.6	0.1	3.0	572.9	222.9
	S547	*<50*	*Adult*	*f*	*Skull*	*C2*		Coins and gold or bronce ring and/or pearl	*−18.8*	*9.5*	*3.2*	*5.0*	*35.9*	*13.2*	*0.1*	*3.2*	*398.9*	*146.7*

Table 2 (continued)

Burial sites	Number	Age	Age class	Sex	Sample	Archaeological dating	^{14}C dating (2)	Grave goods	δ^{13}C [‰]$_{\text{V-PDB}}$	δ^{15}N [‰]$_{\text{AIR}}$	δ^{34}S [‰]$_{\text{V-CDT}}$	%$_{\text{coll}}$	%C	%N	%S	C/N mol	C/S	N/S
	S548a	>50	Mature	m	Fibula	D1		Weapon	−18.7	9.9	3.7	2.0	43.4	16.2	0.1	3.1	542.5	202.5
	S548b	<50	Adult	m	Fibula	D1			−18.7	8.3	2.6	3.9	46.8	17.0	0.1	3.2	520.0	188.9
	S549	20–39	Adult	f	Scapula	D1		Gold or bronce ring and/or pearl	−18.4	9.5	1.0	2.9	45.0	16.6	0.1	3.2	500.0	184.4
	S551	60+	Senile	m	Fibula	**B–D**	360–125 BC		−18.2	9.3	0.3	1.6	41.8	15.5	0.1	3.1	418.0	155.0
Valais: Bramois Panoë	*BP-1*	*30–59*	*Mature*	*m*	*Skull*	/			*−18.6*	*10.4*	*1.8*	*3.7*	*37.3*	*13.5*	*0.1*	*3.2*	*310.8*	*112.5*
	BP-2	*40–60*	*Mature*	*m*	*Skull*	/			*−17.1*	*9.7*	*5.9*	*3.2*	*37.6*	*14.3*	*0.1*	*3.1*	*289.2*	*110.0*
	BP3	40+	Mature	f	Skull	B2			−18.2	8.5	3.0	2.4	44.0	16.8	0.1	3.1	338.5	128.5
	BP4	30–59	Mature	f	Skull	D1			−16.7	9.6	6.5	4.3	44.9	16.5	0.1	3.2	345.4	126.9
	BP5	20–49	Adult	m	Skull	D1		Weapon	−18.6	10.5	4.9	3.0	41.8	16.0	0.1	3.0	348.3	133.3
	BP6	*20–49*	*Adult*	*f*	*Skull*	*D2*			*−19.1*	*10.2*	*5.5*	*1.4*	*36.6*	*15.3*	*0.1*	*2.8*	*305.0*	*127.5*
	BP7	50–60	Mature	m	Skull	**C–D**	191–47 BC		−17.9	10.6	5.1	1.7	42.4	16.4	0.1	3.0	326.2	126.2
	BP8	50–60	Mature	f	Skull	D1		Coins	−18.4	9.1	5.3	2.2	44.4	16.0	0.1	3.2	341.5	123.1
	BP9	*60+*	*Senile*	*m*	*Skull*	/			*−19.0*	*7.1*	*4.6*	*1.3*	*34.5*	*14.9*	*0.1*	*2.7*	*313.6*	*135.5*
	BP10	60+	Senile	m	Skull	C1			−18.2	9.5	5.1	4.3	42.2	15.1	0.1	3.3	376.7	137.3
	BP12	40+	Mature	m	Femur	**B–C** (C1)	348–55 BC		−18.1	8.1	2.7	2.3	41.6	16.5	0.1	2.9	341.5	137.5
	BP13	60+	Senile	f	Long bone (radius/-ulna)	D2			−18.0	9.9	5.6	4.4	43.4	16.4	0.1	3.1	313.6	149.1
	BP14	20–29	Adult	nd	Skull	**B–C**	389–208 BC		−17.9	10.5	7.6	5.3	41.7	15.9	0.1	3.1	379.1	144.5
Valais: Bramois Villa Lathion-Lopes	BV28	60+	Senile	m	Skull	/			−18.5	9.9	4.2	2.2	49.4	17.9	0.1	3.2	380.0	137.7
Valais: Bramois Villa Schaller	BV25	20–49	Adult	m	Fibula	/			−17.3	9.1	7.4	3.7	43.0	16.4	0.1	3.1	358.3	136.7
	BV26	30–59	Mature	m	Skull	**C–D**	190–41 BC		−18.3	9.9	7.1	2.1	42.7	16.5	0.2	3.0	284.7	110.0
	BV27	*60+*	*Senile*	*m*	*Skull*	/			*−18.2*	*10.1*	*5.4*	*2.4*	*43.7*	*17.9*	*0.1*	*2.8*	*437.0*	*179.0*
Grisons: Trun - Darvella	TDA-20	30–40	Adult	m	Skull	B/C			−19.7	8.8	4.0	2.1	42.6	15.8	0.2	3.1	284.0	105.3
	TDA-21	40–60	Mature	m	Skull	B/C			−19.4	8.4	4.3	5.5	44.2	16.1	0.1	3.2	315.7	115.0
	TDA-22	20–35	Adult	f	Skull	B/C			−18.9	8.1	4.5	5.1	42.0	15.4	0.1	3.2	323.1	118.5
Grisons: Castaneda	CAS-6	<18	Juvenil	nd	Skull	**A–B** (C?)	513–393		−16.3	8.3	6.2	2.9	42.1	15.5	0.1	3.2	323.8	119.2
Bern: Engehalbinsel (Reichenbachstrasse)	15	Animal			Pig	C–D			−21.4	4.8	8.0	9.7	47.4	17.4	0.1	3.9	395.0	145.0
	26				Ovicaprid	C–D			−20.4	6.6	7.7	3.0	43.5	16.3	0.1	3.6	334.6	125.4
	7 (1)				Ovicrapid	**C–D**	193–55		−21.2	4.3	6.3	2.6	44.6	16.3	0.1	3.7	371.7	135.8
	7 (2)				Cattle	**B–D**	348–61		−21.5	6.0	4.8	4.0	47.0	17.4	0.1	3.9	391.7	145.0
Grisons: Bonaduz	4	Animal			Ovicrapid	**A–C**	535–111		−21.3	2.3	−0.3	2.4	42.6	15.7	0.1	3.2	355.0	130.8

Selected grave goods are shown

m male; *f* female; *nd* not determined sites of the Swiss Plateau, the area of Bern in particular, noticeably more female than male burials were found (Fig. 2). This, however, seems to be a “Bernese phenomenon” which was previously described by Jud and Ulrich-Bochsler (2014). Biased excavation techniques and collection practices at the beginning of the twentieth century could have caused the unbalanced sex distribution with a loss of skeletal material and a lack of information on burial findings from that time. Different mortuary practices for males and females might have also led to the specific sex distribution as found in Engehalbinsel. Iron Age human remains were also found in Ipsach (Ramstein 2010; Zweifel 2015), and burials were discovered in Belp and Niederwichtrach (Schoch and Ulrich-Bochsler 1987; Suter and Ulrich-Bochsler 1984). Geographical clusters within the findings’ distribution suggest two centers around the Belp Mountain including Belp, Münsingen, Niederwichtrach and around the Enge peninsula. Different burial sites in the area of Bümpliz, a suburb of Bern, revealed Late Iron Age burials (Schoch and Ulrich-Bochsler 1987; Stähli 1977). Additionally, burials in Deisswil, a district of the Bernese suburb Stettlen, were excavated (Rey 1999). In total, samples of 74 individuals were taken from burial sites within the region of Bern for stable isotope analysis (Table 1). Previous published stable isotope data from the burial site of Münsingen (Moghaddam et al. 2016) are part of the analyses for comparison.

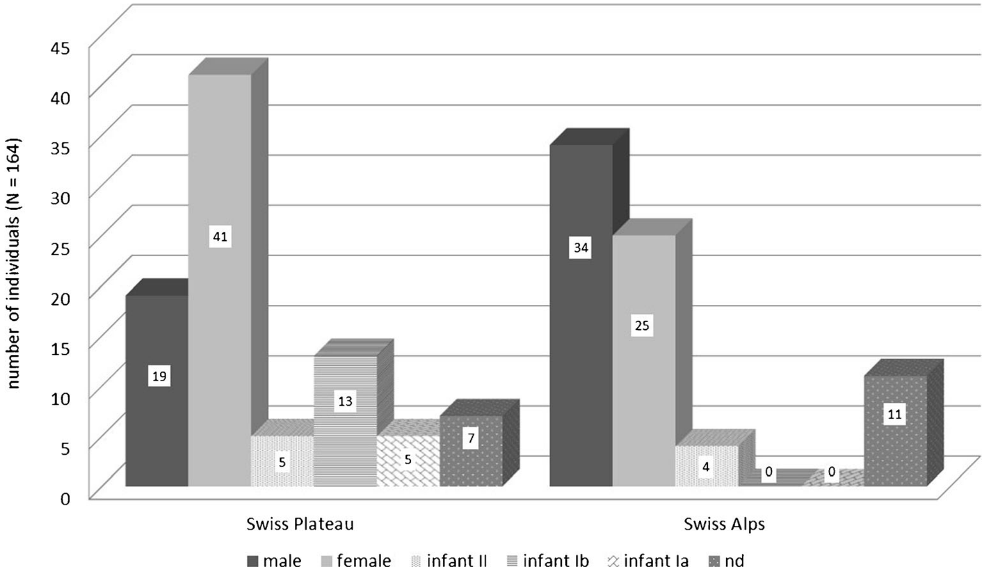
The village of Andelfingen is situated in the north of the Canton of Zurich, between Winterthur and Schaffhausen (Fig. 1). It was believed that the Late Iron Age burial site here might have been connected to a later Celtic oppidum. Nine male and 12 female graves were found (Viollier 1912). A total of 16 samples could be collected (Table 1).

Iron Age burial sites in the Swiss Alps

The Swiss Alps in the south of the country stretches from Geneva in the west to the Austrian border in the east. Almost 60% of the Swiss landscape is covered by the Alps. During the last century, many Iron Age burials were found in the Swiss Alps including the burial sites of Sion, Bramois, Castaneda and Trun Darvella (Kaenel 1999). Sion and Bramois lie between the Pennine and the Bernese Alps (Fig. 1), where a great number of Iron Age burials were found but destroyed in the nineteenth century before documentation. Burials were excavated in Sion, Sous le Scex Passage de la Matze, at the center of Sion at Nouvelle Placette and in the Avenue du Petit Chasseur in Sion (Curdy et al. 2009; Debard 2014). Furthermore, 3 km from Sous le Scex further burials were found at Bramois (Fig. 1) and excavated during recent years (Curdy et al. 2009). Findings of animal bones lead to the assumption that a settlement was located nearby. In total, samples of 70 individuals were taken from within the region of Valais for the stable isotope analysis (Table 1).

The area of Grisons is entirely mountainous. Several burials were excavated in the Darvella village at the Rhine headwaters (Fig. 1). The burial site might have belonged to a larger settlement (Tanner 1980). The village of Castaneda is located at an ancient transalpine route that connected the Raetia with the southern Alpine valleys via the Little St. Bernhard. Four samples from Grisons could be used for this study (Keller-Tarnuzzer 1933; Nagy 2008).

Fig. 2 Distribution of sex and age of all individuals grouped in the Swiss Plateau and Swiss Alps



Methods

Morphologic–anthropological analysis

The age at death of adults was established through analyzing the closure of the cranial sutures (Szilvássy 1988), age-related changes of the pubic symphysis (Acsádi and Nemeskéri 1970) and also the dental surface wear (Brothwell 1981). The stages of the epiphyseal union (Ferembach et al. 1979), long bone measurements (Scheuer and Black 2000; Schmid and Künle 1958) and eruption of deciduous and permanent teeth were studied for non-adults (Ubelaker 1989). The individuals were assigned to the following age classes:

Infants Ia (0–3 years); Infants Ib (4–7 years); Infants II (8–14 years); Juvenile (15–18/20 years); Adult (20–45 years); Mature (46–60 years); Senile (61 years and over).

For sex estimation, features on the Os coxae including the ventral arc, subpubic concavity, medial surface of the ischiopubic ramus and differences in the greater sciatic notch were analyzed (Ferembach et al. 1979; Grupe et al. 2015; Herrmann et al. 1990; Sjøvold 1988). Cranial morphology such as the nuchal crest, mastoid process, supra-orbital margin and the mental eminence were observed (Buikstra and Ubelaker 1994) and femoral head diameters were measured, after Herrmann et al. (1990). Sexual dimorphic features are not fully developed in subadults and therefore no sex estimation was performed.

For some sites morphological analyses were verified and/or additional information was taken from publications (Debard 2014; Hug 1956; Schoch and Ulrich-Bochsler 1987; Ulrich-Bochsler and Rüttimann 2014; Viollier 1912).

The faunal remains have been published by Rehazek and Nussbaumer (2014).

Stable isotope analysis

Most of the samples were collected from crania to have similar bone turnover rates. The collagen extraction of all samples ($n = 164$) was conducted by modified methods of Ambrose (1993) and Longin (1971). For detailed information of the extraction method and stable isotope analysis, see supplement material.

Collagen with less than 1% in proportion to the dry weight and samples with a molar C/N relation beyond a 2.9–3.6 range were excluded. Furthermore, %C, %N and %S values that strongly diverge from recent collagen values (C: 43%, N: 15–16% and S: 0.2%) were not taken into consideration (Ambrose 1990, 1993; DeNiro 1985; Nehlich and Richards 2009).

Dating

Most burial sites were dated through archaeological studies (Debard 2014; Jud and Ulrich-Bochsler 2014; Rey 1999; Stähli 1977; Suter and Ulrich-Bochsler 1984; Viollier 1912). Additionally, selected samples were radiocarbon-dated after Szidat et al. (2016) (Department of Archaeometrie of the Curt-Engelhorn-Center in Mannheim, Germany; Department of Chemistry and Biochemistry at the University of Bern, Switzerland).

Statistics

The individuals were divided into two geographical groups, the Swiss Plateau and Swiss Alpine regions. Furthermore, statistical analyses were carried out for groups of sex and age.

The results were analyzed via SPSS Statistics 23. Tests of normality were performed through Kolmogorov–Smirnov. Non-parametric tests (Mann–Whitney-*U* test and Kruskal–Wallis test) for independent samples were used due to the sample size and not normal distribution of the data (Fagerland 2012). As non-parametric tests are less robust than *t* tests, a rejection of the null hypothesis is more assured, while the same outcome can be observed in parametric tests. Nevertheless, analysis of variance (*t* test and ANOVA) for independent groups was performed to verify the non-parametric tests. Multivariate testing was conducted through the $\delta^{13}C/\delta^{15}N$-ratio in order to analyze differences in the distribution of the values.

Null hypothesis stating that the mean stable isotope values of categorical groups are equal was rejected with $p < 0.05$. The level of significance is indicated as following: $p \leq 0.05$ (*); $p \leq 0.01$ (**); $p \leq 0.001$ (***).

Results

Morphological and individual data

A total of 52 adult individuals were aligned as male, 66 as female and 19 non-subadults as indeterminate. Age estimation for subadults revealed 5 infant Ia, 13 infants Ib, and 9 infants II. In total, 90 individuals were sampled from the Swiss Plateau and 74 individuals from the Swiss Alps (Fig. 2). Results of radiocarbon dating of selected samples were assigned to dating phases (Table 2).

Descriptive statistics of total stable isotope data

Due to collagen quality criteria, 129 out of 164 samples could be further analyzed for stable carbon, nitrogen and sulfur isotopes. Descriptive statistics of all stable isotope data are shown in Table 3.

In total, $\delta^{13}C$ values of all individuals range from −21.5‰ to −16.1‰ with a mean of −18.7‰ and a standard deviation (SD) of 1.0‰. The $\delta^{15}N$ values range from 6.8‰ to 11.3‰ (mean = 8.8‰; SD = 0.9‰). The $\delta^{34}S$ range from −2.0‰ to 8.7‰ (mean = 4.2‰; SD = 2.2‰).

Table 3 Descriptive statistics of $\delta^{13}C$, $\delta^{15}N$, and $\delta^{34}S$ with means, standard deviation (*SD*), median, minimum (*Min*) and maximum (*Max*)

				$\delta^{13}C$ [‰]$_{V\text{-}PDB}$					$\delta^{15}N$ [‰]$_{AIR}$					$\delta^{34}S$ [‰]$_{V\text{-}CDT}$				
Geography	Region	Site	*n*	Mean	SD	Median	Min	Max	Mean	SD	Median	Min	Max	Mean	SD	Median	Min	Max
Münsingen			63	−19.5	0.7	−19.6	−20.8	−17.4	8.8	0.5	8.8	7.6	10.2	1.0	2.2	0.4	−2.3	7.6
Swiss Plateau	Bern	Engehalbinsel	25	−18.0	1.2	−18.0	−20.0	−16.3	8.2	1.1	8.0	6.9	11.3	5.7	1.2	5.8	1.6	7.1
		Ipsach	4	−17.9	1.2	−18.0	−19.2	−16.3	9.8	0.8	9.9	8.9	10.7	5.7	1.4	6.2	3.6	6.7
		Belp	7	−18.7	1.3	−18.9	−20	−16.1	8.4	0.5	8.3	7.8	9.3	2.9	1.7	3.3	0.2	5.1
		Niederwichtrach	3	−20.4	0.9	−20.1	−21.5	−19.7	8.8	0.02	8.8	8.8	8.8	2.3	0.3	2.3	2	2.5
		Bümpliz	11	−18.5	0.9	−18.2	−20.3	−17.6	7.7	0.5	7.6	7.0	8.4	6.1	1.4	6.5	2.1	7.1
		Stettlen-Deisswil	8	−19.3	0.6	−19.3	−19.9	−18.6	8.9	0.7	8.7	8.2	10.4	2.3	0.9	2.1	1.3	3.8
		Total	58	−19.1	0.9	−19.2	−21.5	−16.1	8.4	1.0	8.2	6.9	11.3	4.8	2.0	5.5	0.2	7.1
	Andelfingen		14	−18.2	0.8	−18.1	−19.5	−16.7	8.9	0.5	8.9	8.1	9.6	5.4	2.2	4.6	2.4	8.7
Total	72	−18.9	1.0	−19.1	−21.5	−16.1	8.5	0.9	8.4	6.9	11.3	4.9	2.0	5.4	0.2	**8.7**		
Swiss Alps	Valais	Sion	41	−18.4	0.8	−18.4	−20.0	−16.3	9.0	0.8	9.2	6.8	10.7	2.7	1.9	2.5	−2.0	5.9
		Bramois	12	−18.0	5.3	−18.1	−18.6	−16.7	9.6	0.8	9.7	8.1	10.6	5.4	1.6	5.2	2.7	7.6
		Total	53	−18.3	0.7	−18.3	−20.0	−16.3	9.2	0.8	9.3	6.8	10.7	3.3	2.2	3.3	−2.0	7.6
	Grisons	Castaneda	1	−16.3	/	8.3	/	6.2	/									
		Trun Darvella	3	−19.3	0.4	−19.4	−19.7	−18.9	8.4	0.4	8.4	8.1	8.8	4.3	2.5	4.3	4.0	4.5
		Total	4	−18.6	1.6	−19.2	−19.7	−16.3	8.4	0.3	8.4	8.1	8.8	4.8	1.0	4.4	4.0	6.2
Total	57	−18.3	0.8	−18.3	−20.0	−16.3	9.1	0.8	9.2	6.8	10.7	3.4	2.1	3.7	−2.0	7.6		
Overall total	**129**	**−18.7**	**1.0**	**−18.7**	**−21.5**	**−16.1**	**8.8**	**0.9**	**8.8**	**6.8**	**11.3**	**4.2**	**2.2**	**4.6**	**−2.0**	**8.7**		
sex and age	Male	42	−18.5	0.8	−18.5	−20.0	−16.7	8.8	0.9	8.9	6.8	10.6	3.9	2.1	3.8	−5.0	8.5	
	Female	54	−18.6	0.9	−18.8	−20.0	−16.1	8.6	0.9	8.6	6.9	10.7	4.5	2.1	4.7	1.0	8.7	
	Infants II	5	−19.4	0.8	−19.5	−20.2	−18.2	8.5	1.2	8.6	7.0	9.8	4.5	1.6	5.4	2.0	5.8	
	Infants Ib	10	−19.4	0.7	−19.5	−20.3	−18.1	8.9	1.0	8.6	7.6	10.7	5.6	1.3	6.2	2.1	6.3	
	Infants Ia	3	−18.0	1.5	−18.7	−19.1	−16.3	10.6	0.6	10.3	10.2	11.3	5.6	1.8	6.6	3.6	6.7	
	nd	15	−18.4	1.3	−18.2	−21.5	−16.3	8.9	0.9	8.8	7.2	10.5	3.0	2.8	2.5	−2.0	7.6	

Data for Münsingen are presented in a separate row for comparison. All data are divided into geography, region, and sites. Totals are shown separately for geography and regions. Results of sex and age are shown with the overall total in bold

Stable isotope data for the faunal remains range from −21.5 to −20.2‰ for δ^{13}C (mean = −21.1‰; SD = 0.4‰), 2.3‰ to 6.6‰ (mean = 4.8‰; SD = 1.5‰) for δ^{15}N and −0.3‰ to 8.0‰ (mean = 5.3‰; SD = 3.0‰) for δ^{34}S (Table 2).

Statistical tests of stable isotope data

Results of the statistical tests are shown in Table 4. The geographical sites of the Swiss Plateau and the Swiss Alps showed highly significant differences considering all stable isotope data (δ^{13}C, δ^{15}N, and δ^{34}S $p = 0.000$***). A significant higher δ^{13}C mean for the Swiss Alps was observed (Table 3). In total, 27 individuals showed enriched δ^{13}C values (higher than or equal to −18.0‰) 11 were female, 9 male, 4 non-determinable adults, 1 infant Ia and 1 juvenile (Fig. 3); 15 derive from the Swiss Plateau, and 12 from the Swiss Alps (Table 2). High;y significant differences were also observed for the δ^{15}N values with the highest mean for the Swiss Alpine regions (Fig. 4). Regarding the distribution of the δ^{13}C/δ^{15}N-ratio, a high significance ($p = 0.000$***) was also obtained.

Analyses of the different sexes revealed no significance regarding the two different geographical areas (Table 4). The evaluation of each burial site also separately revealed no differences. Additionally, δ^{13}C/δ^{15}N-ratio for sex was not significant for the Swiss Alps ($p = 0.315$) and the Swiss Plateau ($p = 0.452$), whereas on adding the Münsingen individuals to the Swiss Plateau significant distinct mean values could be observed within the Swiss Plateau (δ^{13}C, $p = 0.011$*; δ^{15}N, $p = 0.006$**). Additionally, differences between the sexes from all burial sites in the δ^{15}N values ($p = 0.006$**) with males having higher δ^{15}N values (mean = 9.0‰) than females (mean = 8.6‰) could be observed.

Non-parametric tests showed differences in the δ^{13}C ($p = 0.042$*), δ^{15}N ($p = 0.003$**) and δ^{34}S ($p = 0.006$**) mean values between the different age classes of the whole dataset (excluding Münsingen), but individuals from the Swiss Alpine regions showed no differences between the age classes. In contrast, the individuals within the Swiss Plateau showed high significances in the mean values (δ^{13}C $p = 0.045$*; δ^{15}N $p = 0.002$**; δ^{34}S $p = 0.018$*).

Discussion

Consumption of millet in Late Iron Age Switzerland

The data of the human remains indicate an overall diet mainly based on animal protein and C_3 plant sources. The data are in agreement with previously published isotopic data from Iron Age sites of present-day Germany (Knipper et al. 2014; Oelze et al. 2012). In total, the δ^{13}C data show a relatively wide range, both in the Swiss Plateau (Δ5.0‰) and in the Swiss Alpine habitat (Δ3.7‰), and some individuals show a clear enrichment in ^{13}C. This variation shows that there must have been a big diversity in plant food resources in these societies, especially in C_3 and C_4 plants. The reason for this could have been, e.g., different food preferences and also different food distribution. Various migration patterns in these societies might also be a reason for the observed variations. Values greater than −18‰ indicate a significant intake of C_4-plants in the diet, such as millet (Le Huray and Schutkowski 2005). In this study, 21% of the individuals show enriched δ^{13}C values, both in the Swiss Plateau (15/72) and in the Swiss Alps (12/57). The frequency of enriched specimens is highly related to the site: e.g., Zürich Andelfingen (7/14) and Bern Bümpliz (5/11) have frequencies of 50 and 45%, respectively (both Swiss Plateau). These frequencies imply a regular consumption of millet in these populations compared to, e.g., Bern Engehalbinsel with none of the individuals revealing values higher than or equal to −18.0‰. Different frequencies of enriched individuals are also shown for the Valais (Swiss Alps), e.g., for Sion 17% (7/41) and 33% (4/12) for Bramois. However, the statistics indicate an overall higher intake of C_4 plant for populations from the Swiss Alpine regions. As no animal samples from these areas could be analyzed, and the faunal–human trophic level cannot be reconstructed, it remains unclear whether this result might reflect a direct consumption of millet and/or a consumption of animal proteins originating from animals fed on C_4 plants. For the Iron Age, isotopic evidence for millet consumption in continental Europe has been shown by, e.g., Knipper et al. (2014), Le Huray and Schutkowski (2005), and Lightfoot et al. (2012). Evidence of, especially, broomcorn millet (*Panicum miliaceum*) in Late Iron Age Switzerland was mentioned by Jacomet and Jacquat (1999). Broomcorn millet as one of the earliest crops was first cultivated in Asia and reached Eastern Europe in the first millennium BC (Miller et al. 2016). Hence, the cultivation of millet in Late Iron Age Switzerland must have been affected through influences from other regions, especially the Mediterranean. Other studies confirm that millet has been cultivated in, e.g., Late Bronze Age Greece (Petroutsa and Manolis 2010) and in northern Greek Early Iron Age sites (Papathanasiou et al. 2013). Furthermore, it is known that there were intense economic exchanges from Massalia to surrounding areas (Bouby et al. 2011). From findings in Mediterranean France, it has been reported that Greek ceramics and wine amphorae also played a major role in imports (Loughton 2009) as well as agricultural resources. Among different rivers, the Rhône has been a main trade route from the Mediterranean to east-central Gaul spreading Greek cultural influences. Hence, different kinds of seeds were probably brought from the Mediterranean world to the Celtic culture.

Climatic variability might also hhave ad an effect on farming as warmer climates favor the growth of C_4 plants

Table 4 Statistical non-parametric Mann–Whitney *U* and Kruskal–Wallis tests for independent groups

	Isotope	Swiss Plateau vs. Swiss Alps	Male vs. female	Male vs. female Swiss Plateau	Male vs. female Swiss Alps	Age classes	Age classes Swiss Plateau	Age classes Swiss Alps	Swiss Plateau vs. Swiss Alps (males)	Swiss Plateau vs. Swiss Alps (females)
Non-parametric *p* value	δ^{13}C	0.000***	0.308	0.984	0.793	0.042*	0.045*	0.109	0.282	0.101
	δ^{15}N	0.000***	0.115	0.234	0.417	0.003**	0.002**	0.272	0.042*	0.000***
	δ^{34}S	0.000***	0.181	0.416	0.914	0.006*	0.018*	0.481	0.306	0.022*

Significance: $*p \leq 0.05$; $**p \leq 0.01$; $***p \leq 0.001$

(Ehleringer et al. 1991). These variabilities could have been due to regional climatic differences (Van Klinken et al. 2000), but also due to climate changes through time. The climate of Switzerland which is also influenced by the Atlantic Ocean shows great variability among different regions. The west–east-oriented Alps lead to relatively strong gradients in the climate (Wanner et al. 1997) and act as a barrier between the moderate European and the Mediterranean climate. Southern Switzerland, influenced by Mediterranean weather, is therefore characterized by a much milder climate than the north (Brönnimann et al. 2014). C_4 plants such as millet are more drought-tolerant than C_3 plants and therefore its cultivation is easier in warmer climates including with short growing seasons (Lightfoot et al. 2015). In fact, this could have favored the cultivation of C_4 plants in southern areas of Switzerland. A connection between millet cultivation and climate variation was also observed by Jacob et al. (2009). Their study indicated climate deterioration with a decline of agricultural work during the Bronze Age–Iron Age transition in the French Prealps.

For Münsingen, the δ^{13}C values were more positive in the later compared to the earlier phases (Moghaddam et al. 2016). Including Münsingen in the dataset, the highest mean (−18.6‰) was observed in individuals dating to LT C (Kruskal–Wallis $p = 0.000$***). The highest δ^{13}C value overall was found in an adult female from Bern Belp (BEB-A2272) dating to the LT C period. A climate change during the Late Iron Age with a warmer climate in the Late La Tène phases should be taken into consideration which could have also facilitated the cultivation of C_4 plants. However, isotopic variability between plants and within plants can be very large even over short distances (Van Klinken et al. 2000). Non-photosynthetic tissues of plants such as roots are generally ^{13}C-enriched (Cernusak et al. 2009), which might have played a minor role in the diet for some populations.

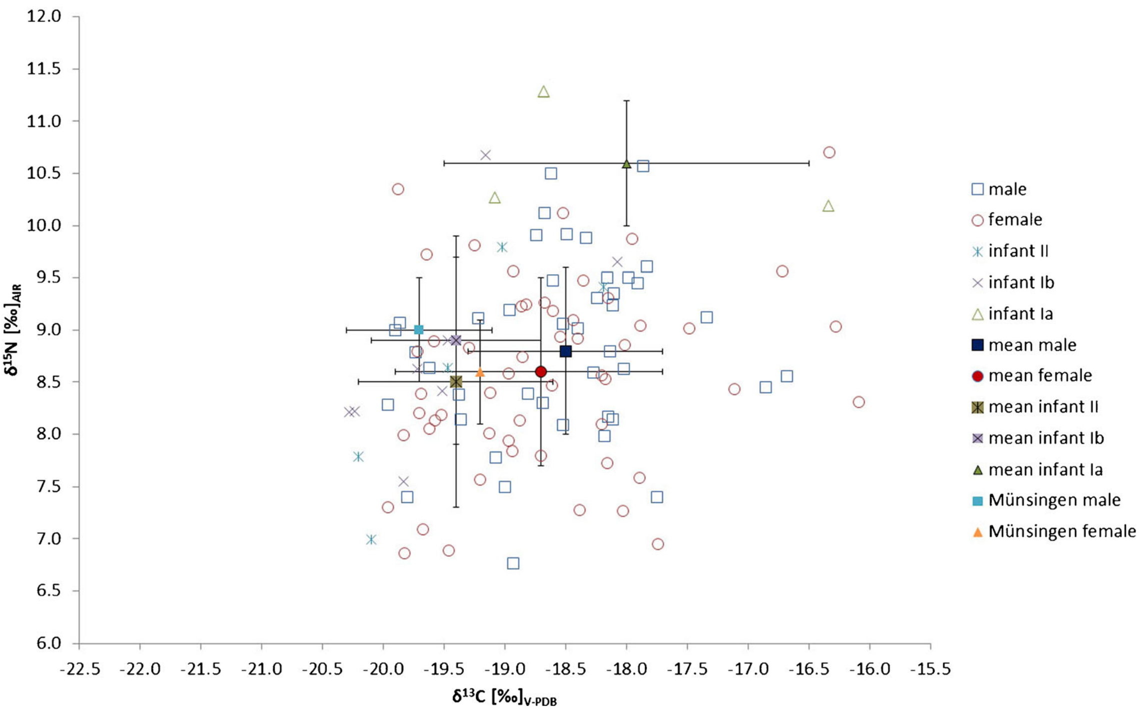


Fig. 3 Stable carbon and nitrogen isotope data, means and standard deviation (SD) of different sexes and subadults. Additionally, means and SD of Münsingen males and females are shown

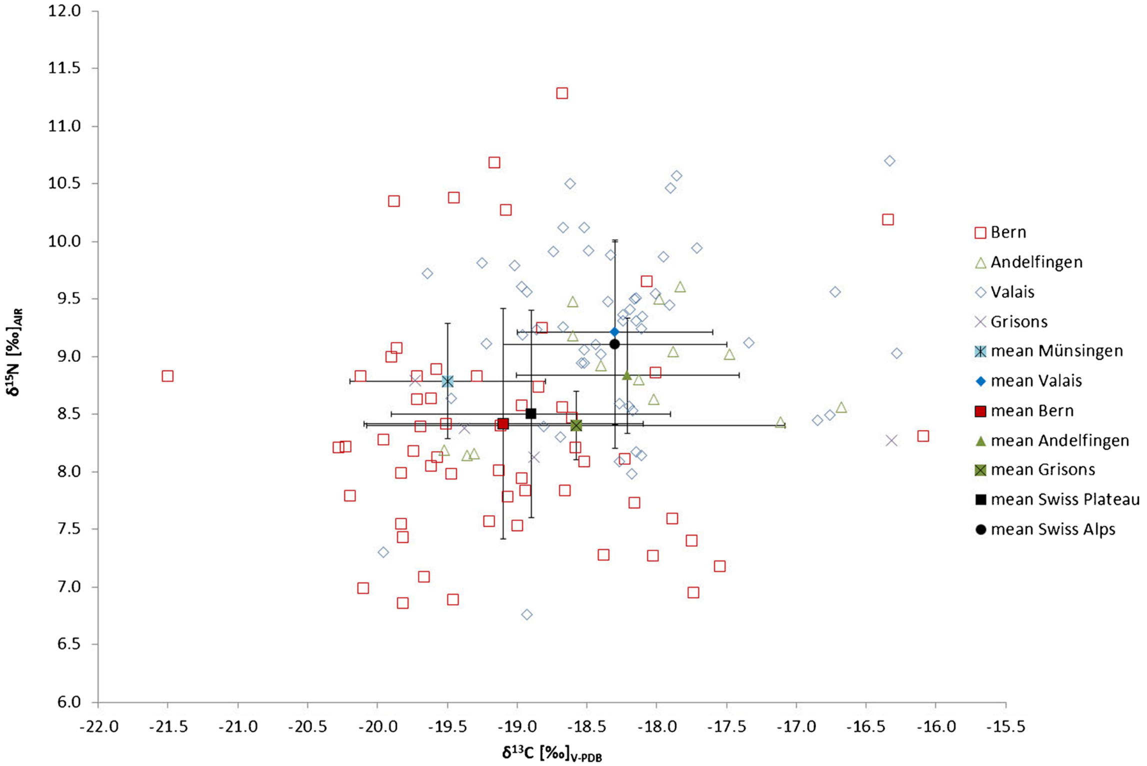


Fig. 4 Stable carbon and nitrogen isotope data, means and standard deviation (SD) of the different sites. Additionally, mean and SD of Münsingen, Swiss Plateau, and Swiss Alps are shown

The question emerges whether millet might have been part of a "low" or "high" status food. The data do not support any correlation between social status expressed by precious grave goods and millet consumption. Some burials contained no grave goods at all, others large amounts of jewelry (IP133, ZAF5 and ZAF 9). No difference between the sexes could be observed, and individuals with a signal of C_4 plant consumption were of both sexes and all ages (Fig. 3).

The evaluation of the age classes revealed significant differences for the Swiss Plateau. A mean of −18.7‰ for the females shows a ^{13}C-enrichment of almost 1‰ in the infants Ia (mean −18.0‰) probably indicating a breastfeeding signal (Fuller et al. 2006).

The intake of animal protein and social status

The overall δ^{15}N data show a relatively wide range, both in the Swiss Plateau (Δ4.4‰) including all individuals from the Bern region and in the Swiss Alpine habitat (Δ3.9‰). This variation indicate a high diversity in food resources in these societies, in particular in the distribution of animal proteins. The nitrogen isotope values of the animals show that the omnivore pig lies within the range of the herbivores (Table 2). It is likely that domestic pigs were fed similarly to herbivores, as found for Roman Age Italy (Prowse et al. 2004). The δ^{15}N mean of the humans is about 4.4‰ higher than that of the herbivores and agrees with a difference of one trophic level (Hedges and Reynard 2007; Schwarcz and Schoeninger 1991). Differences were observed between the Swiss Plateau and Swiss Alps where the individuals showed significantly higher δ^{15}N values (Fig. 4). When assuming a general shift of 3‰ between trophic levels (Schwarcz and Schoeninger 1991), the 5‰ difference in the herbivores for the burial sites in the region of Valais (Sion and Bramois) correspond to a shift of almost two levels. This indicates a diet higher in animal proteins of these populations in comparison to the others. It could be evidence for consumption of dairy products and/or meat in these Alpine regions. This corresponds to the recently published study by Carrer et al. (2016), even if their data are not directly comparable to this study. They identified dairy lipids on Iron Age ceramics from the high Alps, indicating the earliest evidence of dairy production in the Alps.

The intake of freshwater fish for the Valais populations should be mentioned as the sites are close to the River Rhône. Nevertheless, a significant consumption of freshwater fish is less likely as the δ^{13}C and δ^{34}S values reflect a more terrestrial-based diet.

Depending on soil types, climate and land use, the δ^{15}N can vary widely (Goude and Fontugne 2016; Van Klinken et al. 2000). The "manuring effect", however, should be taken into account. Manuring is known to have been practiced since prehistoric times (Bakels 1997; Nielsen and Kristiansen 2014). The populations in the southern Alpine areas compared to the Swiss Plateau probably had distinct patterns of crop cultivation and husbandry influenced by different geological conditions and climatic variabilities.

The Münsingen population revealed sex-specific dietary differences with males having a diet higher in animal protein (Moghaddam et al. 2016). None of the other sites revealed a similar result. The Münsingen population indeed had a distinct social structure based on sex. However, the question remains whether the higher δ^{15}N values of the Swiss Alpine populations might derive from a larger number of male samples (Fig. 2), as males had generally higher δ^{15}N (Fig. 3), but the analyses of the females exclusively still showed significant differences ($p = 0.000^{***}$) in the mean δ^{15}N (9.3‰). Therefore, the higher values of the Alpine regions do not derive from a larger number of males.

There was no correlation between grave goods, such as weapons and jewelry, with δ^{15}N values, in contrast to Münsingen and Iron Age Bohemia (Le Huray and Schutkowski 2005). However, a higher mean for burials with weapons ($n = 6$; δ^{15}N, mean = 9.0‰) was observed compared to other adult and older individuals ($n = 101$, δ^{15}N mean = 8.7‰; Table 2).

The means of the infants Ia and adult females result in a shift of almost one trophic level ($\Delta^{15}N = 2$‰). According to previous published studies ,this result agrees with a breastfeeding signal (Beaumont et al. 2015; Katzenberg 2008; Katzenberg et al. 1996)

Migration in the Late Iron Age

Sulfur data of the ovicaprids showed a relatively wide range. The pig showed the highest value of 8.0‰ (Table 2). Since there is just little fractionation between consumer and food (Jay et al. 2013; Nehlich et al. 2011), the human sulfur values indicate a terrestrial-based diet for Iron Age Switzerland. It should be kept in mind that the faunal data represent more or less the local value. This hampers the interpretation between the faunal and human samples from different regions.

Comparing the sites, there are highl,y significant differences (Fig. 5) as δ^{34}S values reflect local geological data and indicate different local δ^{34}S values (Vika 2009). In total, the δ^{34}S data show the highest variations, both in the Swiss Plateau (Δ8.5‰) and in the Swiss Alpine regions (Δ10.7‰). Comparing sites from the Bern, Zurich and Grisons regions, no significant differences were observable (Kruskal–Wallis; $p = 0.832$). The populations from Valais differ significantly with lower δ^{34}S values compared to other sites. The significantly different local signature becomes more evident by comparing the data within the area of Grisons (Table 1). The samples from Trun Darvella show little variation while the sample from Castaneda is higher. The significantly different value of the ovicaprids from Bonaduz (near Trun Darvella) shows local differences in the area of Grisons. The sulfur standard deviation shows higher variations in all sites compared to their δ^{13}C and δ^{15}N values.

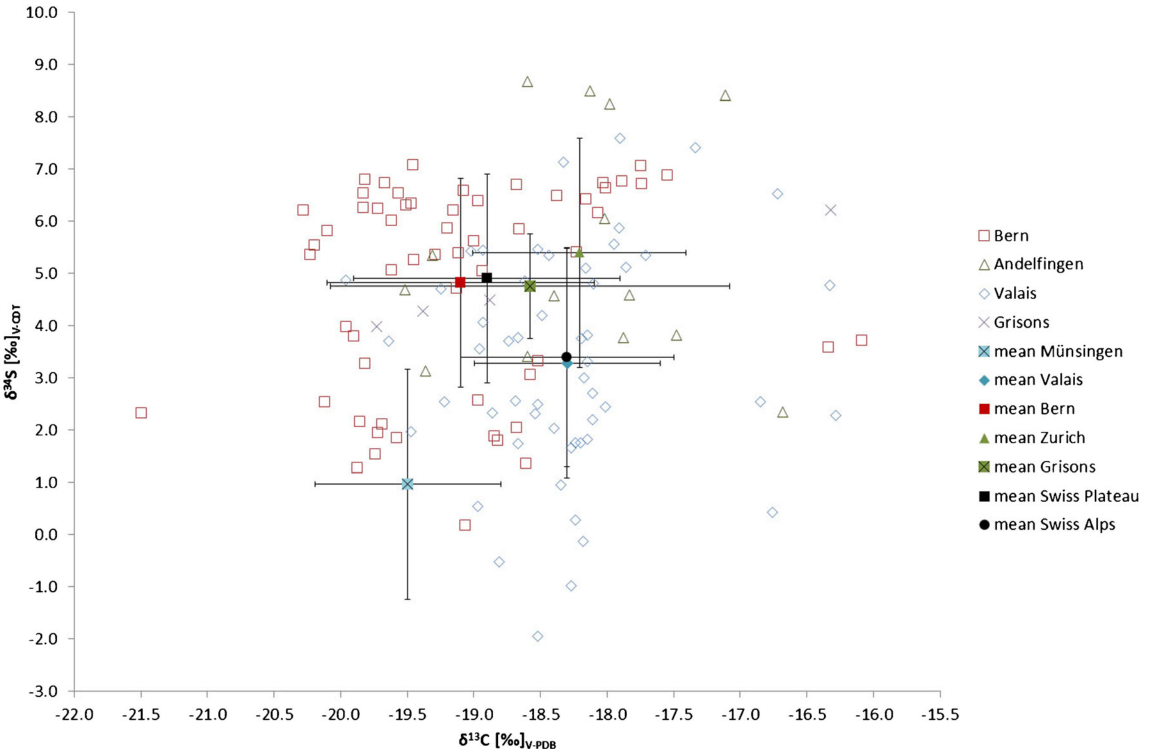


Fig. 5 Stable carbon and sulfur isotope data, means and standard deviation (SD) of the different sites. Additionally, mean and SD of Münsingen, Swiss Plateau, and Swiss Alps are shown

The reasons for this are different small-scale geological formations of these regions but it could also show migration of single individuals within the societies. Significant differences could be observed between the sites within the Valais with Sion having lower $\delta^{34}S$ than Bramois (Table 3). The high SD for the area of Valais most likely derives from local specific sulfur isotope differences. The same could be observed for the individuals in the area of Bern. The $\delta^{34}S$ of the different sites in Bern, with Engehalbinsel, Ipsach and Bümpliz, have more positive means than Stettlen-Deisswil and Niederwichtrach (Table 3), which is very likely due to regional–geographical variabilities (Fig. 1). Nevertheless, mobility in Iron Age Switzerland is obvious, as has already been published for Münsingen (Moghaddam et al. 2013; Scheeres et al. 2016). In the case of Andelfingen, the data differ significantly in their $\delta^{34}S$ values (Fig. 5). Their variances might derive through geological distinction of the soil which is reflected by the plants grown at that place. A certain proportion of freshwater fish in the diet is proposed for individuals with higher values than 8.0‰, the maximum value for terrestrial animals. The high amount of methionine in fish protein also reveals a higher amount of methionine in the consumers' amino acid compound. This causes a reflection of higher values in the consumer even with a small intake of fish (Nehlich et al. 2010).

Limitation of the study

The sex and age determination was analyzed by morphological features of the bones. Even though the maximum number of features were analyzed, in some cases the skeletons were not complete. This could have led to uncertainties, especially for ageing older individuals, and thus might have had a minor effect on the statistical analysis. For more valid data, morphological analyses were carried out in comparison with previous published analyses and archaeological data. In cases of high uncertainties, the individuals were assigned as not determined.

Additionally, more animal bones would be needed to create a convenient food-web. Faunal remains from the Swiss Alpine regions, in particular, would be necessary to obtain information about the intake of animal protein.

Conclusion

This study suggests great differences in the subsistence strategies of Swiss Late Iron Age populations from different regions. Geological conditions with different environments, climate and cultural aspects probably led to differences in agricultural practice and animal husbandry. Isotopic analyses indicate dietary differences between geographical regions that were also caused by migration during the Iron Age. The exchange with the Mediterranean world probably had a great influence on the Iron Age culture of this region. Sex-related dietary differences were found only in Münsingen which led to the assumption that this population may have differed from the populations studied here in their socio-economic structure.

The presented isotopic data provide a vast overview of the Swiss Late Iron Age and are relevant for future studies of prehistoric populations. These isotopic data are indispensable for projects on the spread of millet in prehistoric central Europe.

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Compliance with ethical standards

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