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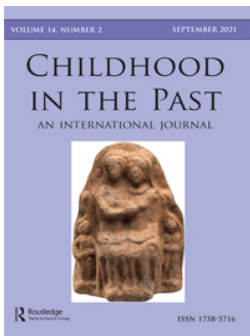
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Feeding Babies at the Beginnings of Urbanization in Central Europe

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ABSTRACT



Small ceramic vessels with spouts, from which liquid can be poured, became popular during the Late Bronze and Early Iron Ages in Central Europe (c. 1200–600 BC). Such feeding vessels represent a functional type and are highly variable in size, shape and decoration. Found both on settlements and within graves, their association with child burials suggest they might have been used to feed babies and small children. Combined lipid and isotope analysis was performed on 24 of these feeding vessels, with seven delivering interpretable results. Feeding vessels associated with child burials tend to deliver a ruminant milk signal, whereas other vessels were used to process ruminant and non-ruminant adipose fats. Here, we highlight the potential significance of feeding vessels as indicators of changing childcare practices during times of population increase, settlement nucleation and mobility, possibly involving out-sourcing the feeding of babies and small children to persons other than the mother.


KEYWORDS

Milk; baby bottles; feeding vessels; Bronze Age; Iron Age; organic residue analysis; isotopes

Introduction

The feeding and weaning of children varies cross-culturally and temporally, and has major implications for child health, mortality and maturation (Howcroft 2013; Mays et al. 2017; Tomori et al. 2018). It is no surprise, then, that the combined topic has received much attention (e.g. Beaumont et al. 2015; Knipper et al. 2018; Rebay-Salisbury et al. 2018; Ventresca Miller et al. 2017). At the same time, evidence for both weaning foodstuffs and feeding equipment is difficult to identify or interpret, and questions persist. Recent developments and extensions of analytical instrumentation and sampling methods has enabled the investigation of small, ceramic vessels from prehistoric Central Europe as a potential childcare toolset.

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The Late Bronze and Early Iron Ages (c. 1200–600 BC) in Central Europe were characterized by population increase and settlement aggregation, with cremation being the predominant burial rite (Fokkens and Harding 2013; Harding 2000; Kristiansen 1998). The Late Bronze Age population increase (Nikulka 2016) is visible as an expansion in areas which were previously less populated, including at higher elevations. Towards the end of the Late Bronze Age, a denser settlement network developed, with settlements centring around nodal points at rivers, lakes and mountaintops (Primas 2008, 46). Many of these nodal points developed into early central places as large settlements fortified with ramparts and palisades enclosing areas of c. 20–30 ha and evidence for spatial planning (Urban 2000, 188–190). Examples of such early centres, which pre-date Iron Age urbanization (Fernández-Götz, Wendling, and Winger 2014; Guichard, Sievers, and Urban 2000), include Stillfried (Griebel and Hellerschmid 2015; Hellerschmid 2015) and Thunau am Kamp (Kern 2001; Wewerka 2001) in Austria.

Pottery of the period includes a wide range of well-differentiated vessel types catering for food storage, cooking, serving, drinking and eating. Most common are large cylinder-necked and conical-necked vessels, medium-sized globular and oval vessels, jugs with handles, plates and bowls, as well as handled cups. Additional forms appear in the Early Iron Age, including ceramic buckets mimicking bronze *situlae*, cists reminiscent of wooden forms, pedestal bowls, as well as double and triple vessels (Nebelsick et al. 1997, 68). Complex assemblages of pottery vessels accompany the dead in funerary contexts, which are most often interpreted in terms of drinking and feasting sets, with containers for wine, vessels for mixing with water and spices, cups for scooping and bowls for drinking (Kaus 1980; Nebelsick 1997).

Among these types, small ceramic vessels with spouts through which liquid can be poured become particularly common during the Late Bronze and Early Iron Ages, although such finds occasionally appear in Neolithic contexts. For example, one of the earliest known finds is a Linear Pottery Culture (LBK, c. 5500–4800 BC) feeding vessel from Steigra, Germany (Meller 2011, 95; Nieszery 1995). In functional terms, feeding vessels are highly variable in size, shape and decoration. Most measure between 80–120 mm in height and are shaped and decorated according to the prevailing fashion of ceramic style, but many are unique, individually crafted, idiosyncratic pieces, for example, shaped like animals (Eibner 1973; Furmánek and Mitáš 2007; Kalicz-Schreiber 2010). Feeding vessels are found on settlements, as stray finds, and in graves. Their inclusion in burials demonstrates care for the sick and dying, on both a practical and symbolic level. For some, associated with the skeletal remains of children, it is hypothesized that they were used for infant feeding. Feeding vessels worked in a very similar way to baby bottles and enabled the feeding of alternative foodstuffs to breast milk to infants, either as a supplement or for weaning purposes (Rebay-Salisbury 2017; Stevens, Patrick, and Pickler 2009, 35).

Until recently, however, it has been unclear whether these vessels were used for feeding and what foodstuffs, if any, they may have contained. The reconstruction of past infant breastfeeding and weaning practices traditionally involved the combined analyses of written sources, dental microwear and stable isotopes ($\delta^{15}\text{N}$) of bone and dentine infant collagen (Beaumont et al. 2013; Beaumont et al. 2015; Bourbou 2014; Burt and Garvie-Lok 2013; Dupras, Schwarcz, and Fairgrieve 2001; Fulminante 2015; Mays et al. 2017; Scott and Halcrow 2017). However, these techniques do not provide direct evidence for what types of food were used for supplementary feeding and/or to wean prehistoric

babies and infants. Thus, in the framework of the ERC-funded project 'The value of mothers to society', we employed a combined molecular and isotopic approach to investigate what particular foodstuffs may have been processed within a series of Late Bronze Age and Early Iron Age infant feeding vessels from settlement sites and graves in Central Europe.

Lipid residue analysis is a widely used technique that can identify specific archaeological biomarkers at a molecular level. This enables identification of a considerable range of commodities such as terrestrial animal fats (Evershed et al. 1997a; Mottram et al. 1999), marine animal fats (Copley et al. 2004; Craig et al. 2007), plant waxes (Cramp, Evershed, and Eckardt 2011; Dunne et al. 2016; Evershed, Heron, and Goad 1991), and beeswax (Evershed et al. 1997b; Roffet-Salque 2015) among others. Of these, preserved animal fats are by far the most commonly observed constituents of lipid residues recovered from archaeological ceramics. An isotopic approach enables the differentiation between ruminant and non-ruminant carcass fats and between ruminant carcass and dairy fats. Here, we were able to provide direct chemical evidence for the processing of both ruminant milk and carcass products in prehistoric ceramic feeding vessels, thus contributing to the reconstruction of infant feeding practices in prehistoric Central Europe.

The sampled vessels in their context

Because of the rarity, uniqueness and small size of feeding vessels, museum curators are understandably hesitant to grant permissions for the destructive sampling normally required for organic residue analysis. Nevertheless, we were able to collect 24 Central European Late Bronze Age and Early Iron Age feeding vessels for analysis (Figure 1), from the Natural History Museum in Vienna, the collection of the Institute of Prehistoric and Historical Archaeology in Vienna, the Museum Regensburg, the Museum of Prehistory in Nußdorf ob der Traisen and the Museum of Carinthia. Six of the feeding vessels sampled came from settlements and 18 from burial contexts.

Five of the settlement finds are stray finds found at various settlement sites across Central Europe (Table 1), including Regensburg-Harting, Bavaria (2, unpublished), Znojmo, Czech Republic (3; Eibner 1973, 153), Oberleiserberg, Lower Austria (4; Kern 1987, 28, Tafel 170/2) and two from Batina, Croatia (5, 6; Eibner 1973, 166). The exception is one vessel excavated from a secure context at Regensburg-Burgweinting, Bavaria (1; Zuber 2013, 88, Taf. 78.2). Their heights range between c. 65 and 156 mm, and they were assigned to the Late Bronze Age on the basis of their zoomorphic, lemon and conical-necked vessel shapes.

Of the 18 vessels from burial contexts, nine originate in the Late Bronze Age (c. 1200–800 BC; Table 2) and the other nine are from the Early Iron Age (c. 800–450 BC; Table 3). The dating of the vessels has been taken from the primary publications and relies on stylistic and typological observations as well as contextualization with well datable bronze finds (Dietz and Jockenhövel 2016; Sperber 1987). Age and gender of the deceased are not known for the two Tyrolian (western Austrian) assemblages now held at the Natural History Museum in Vienna. The sampled Late Bronze Age vessels are characterized by remarkably narrow holes in the spouts, which measure only c. 1 mm in diameter. One feeding vessel with a small hole to the side, which once had a spout attached, was found in Völs, Austria, in 1883 (7). The grave assemblage also contained two bronze pins (one with globular head, one with poppy-head), a bronze bracelet, a bronze knife and two

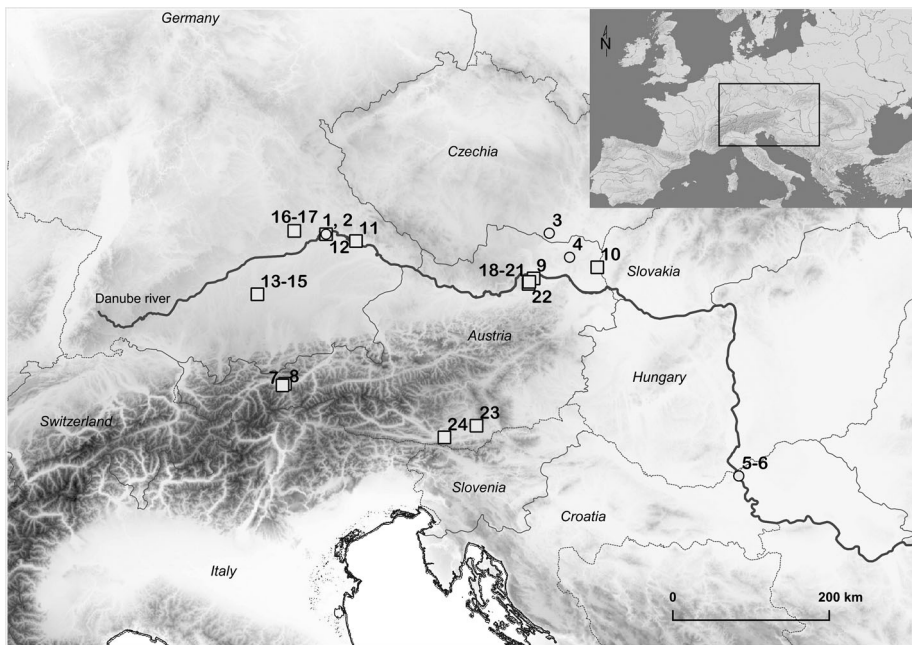


Figure 1. Map of the sites with sampled feeding vessels. □ = grave, O = settlement, 1: Regensburg-Burgweinting, 2: Regensburg-Harting, 3: Znojmo, 4: Oberleiserberg, 5–6: Batina, 7: Völs, 8: Innsbruck-Hötting, 9: Franzhausen-Kokoron, 10: Stillfried, 11: Straubing-Sand, 12: Regensburg-Burgweinting, 13–15: Augsburg-Haunstetten, 16–17: Dietfurt, 18–21: Statzendorf, 22: Fugging, 23: Führholz, 24: Frög

copper ingot fragments (Eibner 1973, 152; Pittioni 1957, 50) and dates to c. 1200–1050 BC. Grave 23 from Innsbruck-Hötting, Austria (8; Eibner 1973, 152; Wagner 1943, 72) contained a feeding vessel together with other pottery and a bronze belt plate.

Feeding vessels from Lower Austria include one from Franzhausen-Kokoron, Grave 344 (9; Lochner and Hellerschmid 2016), shaped like a miniature conical necked vessel with a short, narrow spout which was found together with the cremated remains of a 0.5–3-year-old child in an urn; two accessory vessels were placed next to the urn. Little is known of the context of the small vessel measuring c. 60 mm in height from Stillfried, Lower Austria, Grave A (10; Strohschneider 1976, 43, Pl. 14.11), except that it was found in a grave with three or four other vessels. In Bavaria, the cemetery of Straubing-Sand yielded a feeding vessel in Grave 239 (11; Frisch 2018, 459, Pl. Grab 239.5). Taking the shape of a small pipe, the main body is only 34 mm high, and the elongated spout has a very narrow opening. The feeding vessel was placed with a bowl and a funnel-necked vessel next to the covered urn containing the remains of a, probably female, adolescent aged between 14 and 20 years at death. The fragmented feeding vessel from Regensburg-Burgweinting (12, Feature 5893, FZ 14272) is not yet published although post-excavation work ascertained it was found with the remains of a 4–8-year-old child. Three vessels come from the Late Bronze Age necropolis of Augsburg-Haunstetten in the valley of the Lech in Bavaria, where rescue excavations revealed 139 cremation graves from four grave groups. Augsburg-Haunstetten I, Grave 29, was an urn burial destroyed by the plough. The base of the urn held the fragments of two bronze arm rings and fragments of two vessels interpreted

Table 1. Sampled feeding vessels from Late Bronze Age settlement contexts (Photos: K. Rebay-Salisbury).












	Site	Context	Height	Shape	Date	Museum	Reference	Result	
1	Regensburg-Burgweinting	settlement, Feature 86	80 mm	lemon shaped	LBA 1000–800 BC	Regensburg	Zuber 2013, 88, Pl. 78.2	contaminated	
2	Regensburg-Harting	settlement	111 mm	zoomorph, lemon shaped	LBA 1200–800 BC	Regensburg	not published	contaminated, low level of lipids	
3	Znojmo	settlement, stray find	156 mm	zoomorph	LBA 1200–800 BC	Natural History Museum Vienna, PA68885	Eibner 1973, 166; Michna 1930, 73–74	contaminated	
4	Oberleiserberg	settlement, stray find	–	–	LBA 1200–800 BC	Institute for Prehistoric and Historical Archaeology Vienna, 371	Kern 1987, 28, Pl. 170/2	contaminated	
5	Batina	settlement, stray find	80 mm	conical necked	LBA 1200–800 BC	Natural History Museum Vienna, PA37718	Eibner 1973, 153	contaminated	
6	Batina	settlement, stray find	65 mm	conical necked, five spouts	LBA 1200–800 BC	Natural History Museum Vienna, PA40023	Eibner 1973, 153	contaminated	

Table 2. Sampled feeding vessels from Late Bronze Age burial contexts (Photos 7–10: K. Rebay-Salisbury, 11–15: A. Frisch).

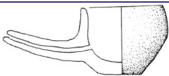
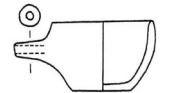
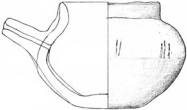


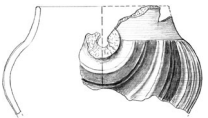
	Site	Context	Sex/age	Height	Shape	Date	Museum	Reference	Result	
7	Völs	grave		72 mm	cylinder necked	LBA 1200–1050 BC	Natural History Museum Vienna, PA68878	Eibner 1973, 152; Pittioni 1957, 50	ruminant adipose, concentrated, some contamination	
8	Innsbruck-Hötting	Grave 23		84 mm	cylinder necked	LBA 1200–1050 BC	Natural History Museum Vienna, PA34548	Eibner 1973, 152; Wagner 1943, 72	contaminated	
9	Franzhausen-Kokoron	Grave 344	child, 0.5–3 years old, (cremated)	80 mm	conical necked	LBA 1050–800 BC	Museum Nußdorf ob der Traisen	Lochner and Hellerschmid 2016	contaminated, probably not used	
10	Stillfried	Grave A, 1879	–	60 mm	conical necked	LBA 1050–800 BC	Institute for Prehistoric and Historical Archaeology Vienna Inv. Nr. 8656	Strohschneider 1976, 43, Pl. 14.11	contaminated, probably not used	
11	Straubing-Sand	Grave 239	female?, 14–20 years old (cremated)	34 mm	pipe	LBA 1200–800 BC	Regensburg	Frisch 2018, 459, Pl. Grab 239.5	contaminated, probably not used	
12	Regensburg-Burgweinting	Feature 5893, FZ 14272	child, 4–8 years old	–	–	LBA 1200–800 BC	Regensburg	unpublished	contaminated, probably not used	

(Continued)

Table 2. Continued.

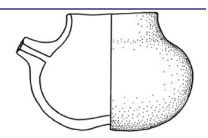
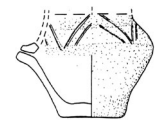

	Site	Context	Sex/age	Height	Shape	Date	Museum	Reference	Result	
										
13	Augsburg-Haunstetten I	Grave 29 (vessel 3)	child, 1–2 years old (cremated)	–	–	LBA 1200–800 BC	Regensburg	Wirth 1998, 159	contaminated	
14	Augsburg-Haunstetten I	Grave 29 (vessel 4)	child, 1–2 years old (cremated)	55 mm	–	LBA 1200–800 BC	Regensburg	Wirth 1998, 159	milk, concentrated	
15	Augsburg-Haunstetten III	Grave 19	female??, 8–12 years old (cremated)	–	–	LBA 1200–800 BC	Regensburg	Wirth 1998, 175	contaminated	

Table 3. Sampled feeding vessels from Early Iron Age burial contexts.

	Site	Context	Sex/age	Height	Shape	Date	Museum	Reference	Result	
16	Dietfurt-Tankstelle	Grave 65	child, c. 1 year old (inhumed)	37 mm	pipe	EIA 800–600 BC	Museum Regensburg, Alexander Frisch	Augstein 2015, 498, Pl. 69,3	ruminant animal milk	
17	Dietfurt-Tennisplatz	Grave 80	child, 0–6 year old (inhumed)	32 mm	pipe	EIA 800–450 BC	Museum Regensburg	Röhrig 1994, 168, Pl. 57	ruminant animal milk	
18	Statzendorf	Grave B127	–	67 mm	collard-necked	EIA 800–450 BC	Natural History Museum Vienna, PA43104	Rebay 2006, 106–107	contaminated	
19	Statzendorf	Grave A036	(male), cremated	98 mm	zoomorph	EIA 800–450 BC	Natural History Museum Vienna, PA38325	Rebay 2006, 106–107	contaminated	
20	Statzendorf	Grave A071	–	106 mm	zoomorph	EIA 800–450 BC	Natural History Museum Vienna, PA42779	Rebay 2006, 106–107	ruminant/non-ruminant adipose	
21	Statzendorf	stray find from cemetery	–	–	collard-necked	EIA 800–450 BC	Natural History Museum Vienna, PA56290	Rebay 2006, 106–107	ruminant/non-ruminant adipose; high level of contamination	
22	Fugging	Grave 34	child, 0–3 year old (cremated)	90 mm	conical-necked	EIA 800–450 BC	Natural History Museum Vienna, PA87745	Windl 1975, 104	ruminant adipose	

(Continued)

Table 3. Continued.

Site	Context	Sex/age	Height	Shape	Date	Museum	Reference	Result
								
23	Führholz Burial mound 81	female, 19–40 year old (cremated)	93 mm	conical necked	EIA 800– 450 BC	Kärntner Landesmuseum, not inventarised	Wedenig 1993, 135	contaminated
								
24	Frög Burial mound 63 (D), Grave 1	(male), cremated	145 mm	zoomorph	EIA 800– 450 BC	Natural History Museum Vienna, PA73704 (Schausammlung)	Tomedi 2002, 467, Pl. 23	contaminated
								

as feeding vessels. A few fragments of the cremated remains of a 1–2 year-old child were also recovered (13, 14; Wirth 1998, 159, 196). Augsburg-Haunstetten III, Grave 19 contained fragments of a feeding vessel with the cremated remains of an 8–12-year-old, possibly female, individual (15; Wirth 1998, 175).

In summary, the Late Bronze Age feeding vessels sampled were recovered from graves that are normally found in urnfields that contain several hundred individuals, and are often associated with children and young women.

Iron Age feeding vessels (Table 3) include the pipe-shaped vessel from Grave 65 from Dietfurt-Tankstelle, Bavaria, Germany (16). The 36 mm high and 48 mm wide feeding vessel with a 45 mm long spout attached to the vessel wall was found within a bowl deposited at the right hip of a c. 1-year-old child, which was placed extended on the back with the head oriented to the south (Augstein 2015, 498, Pl. 69.3). Grave 80 from Dietfurt-Tennisplatz (Röhrig 1994, 57, 168, Pl. 57.2) is an east–west oriented inhumation of a small child approximately 0–6 years at death. Only parts of the cranium and long bones were preserved; the grave was lined and covered with large blocks of limestones and the feeding vessel was placed at the feet (17). A small bronze bracelet was found where the left arm of the child might have been. The Dietfurt cemeteries are embedded in the Lower Altmühl valley landscape, where there are several large and well-documented Early Iron Age cemeteries, including cremations and inhumations deposited in pits, flat graves and burial mounds, dating to c. 800–450 BC (Augstein 2015).

Four vessels were sampled from the Early Iron Age cemetery of Statzendorf, in Lower Austria, comprising 373 cremations and inhumations (Rebay 2006, 106–107). The period of cemetery use at Statzendorf began at the Late Bronze Age/Early Iron Age transition and covered predominantly the beginning of the Early Iron Age (c. 800–600 BC). One vessel, from Grave B127 (18), is only 67 mm high, and has a simple shape with collared neck and spout extending from the shoulder. A stray find from the cemetery area was probably a similar shape (21). The vessels from Graves A036 and A071, however, are slightly larger (19, 20: 98 and 106 mm respectively) and their spout is shaped in animal form. No human remains were recovered upon excavation, but the assemblage of Grave A036, with an iron axe, two knives and a large glass bead, points to at least one male occupant of the grave. Grave A71 was a cremation grave in an urn with rectangular stone cover; the grave goods assemblage includes a bronze pin and iron knife, together with a set of pottery vessels (large, conical necked vessel, globular vessel, miniature cup and two bowls). The miniature cup and the feeding vessel suggest the presence of a child in the grave (Rebay 2006, 62–63, pl. 53–54).

A globular feeding vessel of 90 mm height, with conical neck and spout attached at the shoulder, was discovered in Grave 34 of the nearby Early Iron Age cemetery of Fugging, Lower Austria (22). The cremated remains were deposited in a heap together with fire-affected remains of the bronze costume; a large, globular vessel containing a small cup, a handled vessel, a bowl, an iron knife and the feeding vessel were arranged around the cremated remains of a child aged under three years at death (Windl 1975, 104).

Burial mound 81 at Führholz, Carinthia, Austria (Wedenig 1993, 135) included a 93 mm tall feeding vessel (23) with a very short spout as part of an Early Iron Age pottery assemblage that also included three conical-necked vessels, one collar-necked vessel and five bowls. The assemblage was found with the cremated remains of a 19–40-year-old

woman whose attire likely included some fire-affected bronze fragments. One of the most finely crafted objects sampled was the vessel from Grave 1, Tumulus 63, from the Carinthian cemetery at Frög (Tomedi 2002, 467, Pl. 23) on display in the Natural History Museum in Vienna. However, it is debatable whether this shape/type of vessel can be interpreted as a feeding vessel, or if it is more likely to represent an *askos*, a type of ancient Greek and Etruscan pottery used to pour small quantities of liquids.

Methods and results

Combined lipid and isotope analysis using gas chromatography (GC) and gas chromatography-mass spectrometry (GC-MS) was conducted on the 24 vessels, mainly as described in previous publications (Correa-Ascencio and Evershed 2014; Dudd and Evershed 1998),¹ except that a modified sampling procedure was adopted for all complete vessels ($n = 20$) to minimize damage to these precious artefacts. Part of the internal surface layer of each vessel was carefully removed by abrasion to remove surface contamination, after which the underlying material was abraded as a powder for analysis of absorbed organics. The remaining samples ($n = 4$) comprised potsherds, where the exterior surface was also cleaned by abrasion to remove surface contamination.

Interpretable lipid profiles were recovered from seven of 24 (29%) pottery samples. The mean lipid concentration of these samples (Table 4) was 5.4 mg g^{-1} , with a maximum lipid concentration of 29.7 mg g^{-1} (Dietfurt-Tennisplatz, 17). Lipid concentrations from vessels Statzendorf Grab A071 (20) and Statzendorf strayfind (21) were also high at 1.6 and 2.5 mg g^{-1} , respectively, indicating that these vessels were subjected to sustained use in the processing of high lipid-yielding commodities.

To date, analysis of the total lipid extracts (TLEs, $n = 24$) from the various vessels, demonstrated that seven samples contained sufficient concentrations ($>5 \mu\text{g g}^{-1}$) of lipids that can be reliably interpreted (following Evershed 2008). These extracts comprised lipid profiles dominated by free fatty acids, palmitic (C_{16}) and stearic (C_{18}), typical of a degraded animal fat (Figure 2, vessels 16 and 22) (e.g. Berstan et al. 2008; Evershed et al. 1997a).

GC-C-IRMS (gas chromatography-combustion-isotope ratio mass spectrometry) analyses were carried out on fatty acid methyl esters (FAMES) from the seven samples (Table 4 and Figure 3) to determine the $\delta^{13}\text{C}$ values of the major fatty acids, $\text{C}_{16:0}$ and $\text{C}_{18:0}$, and ascertain the source of the lipids extracted. The $\delta^{13}\text{C}$ values of the $\text{C}_{16:0}$ and $\text{C}_{18:0}$ fatty acids reflect their biosynthetic and dietary origin, allowing non-ruminant and ruminant adipose and ruminant dairy products to be distinguished (Copley et al. 2003; Dunne et al. 2012).

Here, the vessels from Dietfurt-Tankstelle (16) and Augsburg-Haunstetten I (14) plot just outside the reference ellipse for dairy products (Figure 3a), suggesting these vessels were primarily used to process dairy products from cattle, sheep or goat, with some very minor mixing of ruminant carcass products. Vessel 17, from Dietfurt-Tennisplatz (Figure 3a), plots between the dairy and non-ruminant adipose ranges (although closer to the dairy ellipse), indicating minor mixing of non-ruminant (pig or, possibly, human milk) and dairy products. The remaining four vessels from Statzendorf (20 and 21), Fugging (22) and Völs (7) plot between the ruminant dairy, ruminant adipose and non-ruminant adipose ellipses (Figure 3a), albeit closer to the ruminant adipose and

Table 4. Vessel number, site, context, lipid concentrations ($\mu\text{g g}^{-1}$), total lipid concentration in extract (μg), $\delta^{13}\text{C}$ and $\Delta^{13}\text{C}$ values, and attributions of pottery lipid residues from Late Bronze Age and Early Iron Age infant feeding vessels.

Vessel number	Site	Context	Lipid concentration ($\mu\text{g g}^{-1}$)	Total lipid in extract (μg)	$\delta^{13}\text{C}_{16:0}$	$\delta^{13}\text{C}_{18:0}$	$\Delta^{13}\text{C}$	Attribution
1	Regensburg-Burgweinting	settlement, Feature 86	266.2	190.3	–	–	–	Plasticiser & petroleum contamination
2	Regensburg-Harting	settlement	16.6	9.6	–	–	–	Trace lipids & plasticiser
3	Znojmo	settlement	1087.5	1903.1	–	–	–	Petroleum contamination
4	Oberleiserberg	settlement	1208.4	495.5	–	–	–	Petroleum contamination
5	Batina	settlement	185.4	83.4	–	–	–	Plasticiser & petroleum contamination
6	Batina	settlement	924.6	1220.5	–	–	–	Plasticiser & petroleum contamination
7	Völs	grave	845.9	879.7	–26.3	–29.0	–2.7	Ruminant adipose
8	Innsbruck-Hötting	Grave 23	580.9	151.0	–	–	–	Trace lipids & plasticiser
9	Franzhausen-Kokoron	Grave 344	74.5	67.1	–	–	–	Trace lipids & plasticiser
10	Stillfried	Grave A, 1879	348.5	216.1	–	–	–	Trace lipids & plasticiser
11	Straubing-Sand	Grave 239	19.7	7.1	–	–	–	Trace lipids & plasticiser
12	Regensburg-Burgweinting	settlement, Feature 5893	31.7	31.2	–	–	–	Trace lipids & plasticiser
13	Augsburg-Haunstetten I	Grave 29, vessel 3	1830.1	1116.4	–	–	–	Petroleum contamination
14	Augsburg-Haunstetten I	Grave 29, vessel 4	882.5	838.4	–29.1	–32.7	–3.6	Ruminant dairy (Dunne et al. 2019)
15	Augsburg-Haunstetten III	Grave 19	132.0	80.5	–	–	–	Trace lipids
16	Dietfurt-Tankstelle	Grave 65	1491.8	492.3	–29.0	–32.7	–3.7	Ruminant dairy (Dunne et al. 2019)
17	Dietfurt-Tennisplatz	Grave 80	29738.1	24980.0	–27.6	–31.1	–3.4	Ruminant dairy (Dunne et al. 2019)
18	Statzendorf	Grave B127	6178.2	12480.0	–	–	–	Fatty acids & petroleum contamination
19	Statzendorf	Grave A036	2100.9	4327.8	–	–	–	Fatty acids & petroleum contamination
20	Statzendorf	Grave A071	1619.9	1765.7	–28.4	–28.5	–0.2	Ruminant/non ruminant adipose
21	Statzendorf	stray find from cemetery	2529.7	3010.3	–29.1	–29.6	–0.5	Ruminant/non ruminant adipose
22	Fugging	Grave 34	889.3	960.4	–26.9	–28.3	–1.4	Ruminant adipose
23	Führholz	Grave 81	445.2	311.7	–	–	–	Trace lipids & plasticiser
24	Frög	Burial mound 63 (D), Grave 1	1167.7	934.1	–	–	–	Plasticiser & petroleum contamination

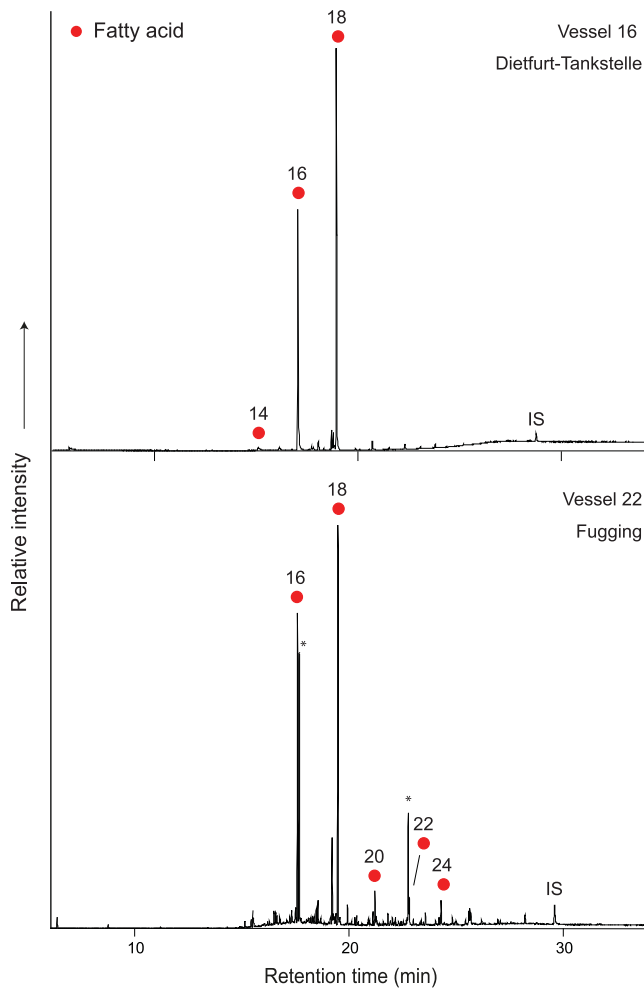


Figure 2. Partial gas chromatograms of trimethylsilylated FAMES from pottery extracts 16 Dietfurt-Tankstelle and 22 Fugging. Circles, n-alkanoic acids (fatty acids, FA); * plasticisers; IS, internal standard, C₃₄ n-tetratriacontane.

dairy ellipses, indicative of some mixing of animal products from ruminants (cattle, sheep and goat) and non-ruminants (pig), in varying degrees.

Ruminant dairy fats are differentiated from ruminant adipose fats when they display $\Delta^{13}\text{C}$ values of less than -3.1‰ (Dunne et al. 2012). Lipid residue results show that three lipid residues, Dietfurth-Tennisplatz (17), Dietfurt-Tankstelle (16) and Augsburg-Haunstetten I (14) plot in the ruminant dairy region with $\Delta^{13}\text{C}$ values of -3.4 , -3.7 and -3.6‰ respectively (Figure 3b), consistent with the processing/serving of predominantly dairy products in these feeding vessels (Dunne et al. 2019). Of the remaining four feeding vessels, Fugging (22) and Völs (7), with $\Delta^{13}\text{C}$ values of -1.4 and -2.7‰ respectively, plot within the ruminant carcass product region and two vessels from Statzendorf (20 and 21), with $\Delta^{13}\text{C}$ values of -0.2 and -0.5‰ respectively, plot at the boundary between the ruminant and non-ruminant products region (Figure 3b). This suggests these vessels were primarily used to process ruminant carcass products with the minor addition of non-ruminant products.

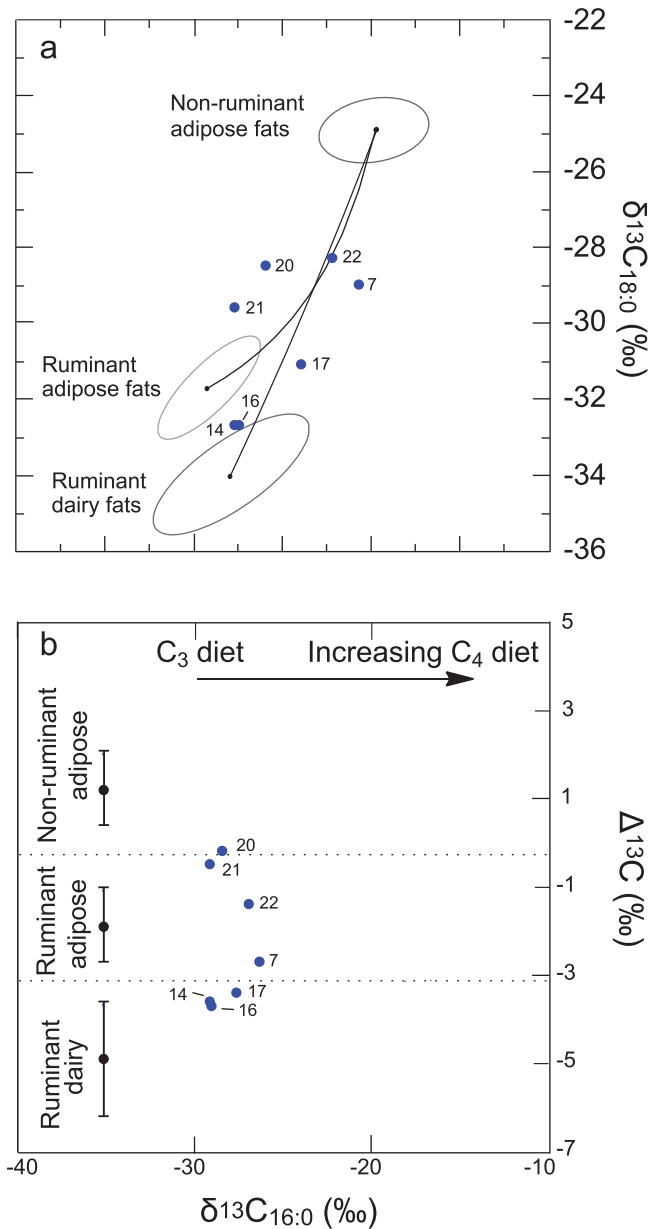


Figure 3. Graphs showing: **a.** $\delta^{13}\text{C}$ values for the $\text{C}_{16:0}$ and $\text{C}_{18:0}$ fatty acids for archaeological fats extracted from Late Bronze Age and Early Iron Age infant feeding vessels. The three fields correspond to the $P=0.684$ confidence ellipses for animals raised on a strict C_3 diet in Britain (Copley et al. 2003). Each data point represents an individual vessel. **b** shows the $\Delta^{13}\text{C}$ ($\delta^{13}\text{C}_{18:0} - \delta^{13}\text{C}_{16:0}$) values for the same vessels. The ranges shown here represent the mean ± 1 s.d. of the $\Delta^{13}\text{C}$ values for a global database comprising modern reference animal fats from Africa (Dunne et al. 2012), UK (animals raised on a pure C_3 diet) (Dudd and Evershed 1998), Kazakhstan (Outram et al. 2009), Switzerland (Spangenberg, Jacomet, and Schibler 2006) and the Near East (Gregg et al. 2009).

The lipid profiles from the remainder of the vessels (Table 4) contain known modern contaminants, sometimes in high abundance (e.g. vessels 3 and 4), comprising plasticisers and lipid distributions indicative of modern petroleum contamination. This contamination most likely derives from storage and curation methods. These contaminants are sometimes the only compounds found in the vessels, although trace lipids are occasionally also present. Lipid profiles from vessels 18 and 19 do include palmitic (C₁₆) and stearic (C₁₈) acids, typical of a degraded animal fat, but are again dominated by petroleum lipids and, consequently, not taken forward for further analysis.

Discussion

Lipid residue results from GC, GC-MS and GC-C-IRMS analyses demonstrate that three of the feeding vessels were predominantly used to process ruminant dairy products, most likely milk from cattle, sheep or goat (Dietfurt-Tankstelle, Dietfurt-Tennisplatz and Augsburg-Haunstetten I, Dunne et al. 2019). Four further vessels were used to process mainly ruminant carcass products (Völs, Fugging, Statzendorf A071, Statzendorf-strayfind) with some minor mixing of non-ruminant products, pig, or possibly, human milk. The narrow size of the spout suggests these vessels may have held a thin broth or stew made mainly from meat from ruminants and non-ruminants.

In addition, vessels from Regensburg-Harting, Franzhausen-Kokoron, Straubing-Sand and Regensburg-Burgweinting contained trace lipids ($\leq 100 \mu\text{g g}^{-1}$, Table 4) at 16, 74, 20 and $32 \mu\text{g g}^{-1}$, respectively, which were dominated by plasticisers, indicating modern contamination. This suggests that these four vessels did not contain high lipid-yielding products, possibly because they were not used intensively, for example, due to the death of the child. Alternative interpretations include poor lipid recovery due to unknown factors.

As noted, the remainder of the sampled feeding vessels also did not yield interpretable results, being either contaminated with a high level of modern contamination (e.g. vessels 1, 4 and 13) or contained fatty acids possibly indicating animal fat processing, but in conjunction with modern contaminants (e.g. 18 and 19). This is not entirely unexpected given that many of the sampled vessels had been held in museum collections, often for decades, and had likely been heavily handled. None of the vessels from settlement contexts yielded interpretable lipid profiles, containing only modern contaminants.

The three vessels with clear ruminant milk signals (14, 16 and 17) are associated with the burials of Late Bronze Age and Early Iron Age young children (Dunne et al. 2019). Their age estimations, c. 1, 1–2 and 0–6 years at death, suggests that they may have still been breastfeeding or were in the process of gradual weaning. The vessel from Fugging, associated with the cremated remains of a 0–3-year-old child, contained traces of ruminant adipose fat. In this case, the child's diet may have been supplemented with non-dairy foods.

The feeding of animal milk and/or grain-based substitutes such as porridge, pap (bread soaked in water, milk or broth) and gruel (cereals cooked in water, milk or broth, Obladen 2014) carries the risk of delivering less than sufficient nutritional value for new-borns and young infants. However, they may provide a valuable source of nutrients during weaning. The process of infant feeding through to weaning begins with exclusive breastfeeding, followed by the inclusion of specific foods (known as supplementary feeding), such as

animal milk or grain-based meals, to the infant and toddler diet. Following this, family foods may be introduced to the infant, ultimately leading to the cessation of breastfeeding (Reynard and Tuross 2015). This sequence may take several years, which makes it hard to pinpoint a specific age of weaning (Bourbou et al. 2013; Fulminante 2015). The presence of feeding vessels in prehistoric child graves suggests that children were cared for and fed, but it remains unclear if animal milk and meat produce substituted or supplemented mother's milk, or both. It should be noted that the use of feeding vessels, the early form of baby bottles, carries a significant risk of bacterial contamination to the infant from the vessel itself (Stevens, Patrick, and Pickler 2009). Since the cause of death for the buried children is unknown, we do not know if the inclusion of the feeding vessel in the graves reflects daily feeding practices or a form of special care for sick and dying children. Furthermore, it is possible that feeding vessels were included in the graves for their symbolic significance. The feeding vessels from Franzhausen-Kokoron, the urn burial of a 0.5-3-year-old child, Regensburg-Burgweinting, the burial of a 4–8-year-old, and Straubing-Sand, of a young woman, do not appear to have been used to process foodstuffs and thus might have been included in the graves as a sentiment of care. The vessel of a deceased child may not have been deemed useful or suitable for other children.

The Late Bronze Age vessel from Völs contained ruminant adipose products, but its shape and the small diameter of its outlet means it can still be considered an infant feeding vessel. It is less clear that this is the case with some of the Early Iron Age vessels sampled. During the Iron Age, we see the development of ever more elaborate zoomorphic ceramic shapes with both a ritual and representational function, culminating in the bull-headed ritual pottery included in elite graves, whose distribution area defines the eastern Hallstatt cultural area (Nebelsick et al. 1997; Preinfalk 2003; Rebay-Salisbury 2016, 85).

This vessel type may develop from Late Bronze Age infant feeding vessels, but its increasingly elaborate design, larger size (Siegfried-Weiss 1979) as well as an increase in the diameter of the outlet suggest a different use: to pour liquid. The ritual pouring of food and drink as an offering to a deity or in commemoration of the dead was common in the Mediterranean world (Malkin 2016), and connections to Greeks and Etruscans result in an adoption of this practice north of the Alps during the Early Iron Age (Rebay-Salisbury 2016, 85). This shift in the function and form of spouted vessels is evident in that they are increasingly found in (elite) male burial contexts rather than with children and women. Lipid results from the two Early Iron Age vessels from Statzen-dorf (20 and 21) suggesting mixing of ruminant products with minor amounts of non-ruminant fats, may suggest a change in content although it should be noted this is a very small dataset.

Conclusion

Whilst this is not a large-scale study, as the rarity and special nature of these infant feeding vessels meant that it was difficult to obtain permissions for destructive sampling, and thus care must be taken in interpretations, nonetheless, some broad conclusions can be drawn.

The increased use of vessels suitable for feeding infants may indicate a change in childcare practices in the Late Bronze Age. Successful breastfeeding requires that mother and

child are constantly and intimately connected. The composition of breast milk is dynamic and changes according to the age of the baby as well as in response to environmental conditions such as heat and humidity. The composition also changes during each feed, as the baby receives diluted milk to address thirst first, followed by a fattier version to address hunger. Pumping breast milk and feeding it to an infant with a bottle is therefore not the same as feeding directly from the breast (Ballard and Morrow 2013; Tomori et al. 2018) and neither is wet-nursing, which has been practiced throughout history, primarily by more wealthy families (e.g. Boon 2010; Thorley 2015).

The use of feeding vessels suggests that, at times, it was possible to remove the breast-feeding connection between mother and child – allowing other members of the community to take over the task of feeding infants. This may have made mothering a more collective, shared responsibility within the community. It may also have played a role in liberating women from a duty, perhaps unwanted at times, much like when large-scale formula feeding was introduced in the middle of the twentieth century. This may have contributed to an increase in women's mobility, at a time when early centralization and urbanization trends are noticeable in the archaeological record.

Earlier weaning is further associated with a quicker return of fertility for women, and therefore with closer sibling spacing and a population increase (Porčić, Blagojević, and Stefanović 2016). Certainly, the rise of feeding vessels in the Late Bronze Age neatly coincides with the Late Bronze Age population increase.

Note

1. Lipid analyses were performed largely as described in earlier publications, except that a modified sampling procedure was adopted for complete vessels (as described above). All solvents used were HPLC grade (Rathburn) and the reagents were analytical grade (typically > 98% of purity). Shed powder was measured and placed in culture tubes. An internal standard, typically 40 µg, was added to enable quantification of the lipid extract (n-tetratriacontane; Sigma Aldrich Company Ltd). Following the addition of 5 mL of H₂SO₄/MeOH 2 - 4% (δ¹³C measured), the culture tubes were placed on a heating block for 1 h at 70 °C, mixing every 10 min. Once cooled, the methanolic acid was transferred to test tubes and centrifuged at 2500 rpm for 10 min. The supernatant was then decanted into another furnace culture tube (II) and 2 mL of dichloromethane extracted double distilled water was added. In order to recover any lipids not fully solubilised by the methanol solution, 2 x 3 mL of n-hexane was added to the extracted potsherds contained in the original culture tubes, mixed well and transferred to culture tube II. The extraction was transferred to a clean, furnace 3.5 mL vial and blown down to dryness. Following this, 2 x 2 mL n-hexane was added directly to the H₂SO₄/ MeOH solution in culture tube II and whirlmixed to extract the remaining residues. This was transferred to the 3.5 mL vials and blown down under a gentle stream of nitrogen until a full vial of n-hexane remained. Aliquots of the extracts (containing fatty acid methyl esters, FAME's) were derivatised using N,O-bis(trimethylsilyl)trifluoroacetamide (BSTFA) containing 1 % v/v trimethylchlorosilane (TMCS; Sigma Aldrich Company Ltd.; 20 µL; 70°C, 1 h). Excess BSTFA was removed under nitrogen and the extract was dissolved in n-hexane for analysis by gas chromatography (GC), GC-mass spectrometry (GC-MS) and GC-combustion-isotope ratio MS (GC-C-IRMS). Further analysis was carried out using the solvent extraction method. An internal standard was added to the sherd powder and they were solvent extracted by ultrasonication (chloroform/methanol 2:1 v/v, 30 min, 2 x 10 ml). The solvent was evaporated under a gentle stream of nitrogen to obtain the total lipid extract (TLE). Aliquots of the TLE were trimethylsilylated (N,O-bis(trimethylsilyl)trifluoroacetamide 20 µL, 70°C, 1 h), diluted with n-hexane and submitted to analysis by high-temperature-GC (HTGC)

and HTGC-MS. All FAMEs initially underwent HTGC using a gas chromatograph (GC) fitted with a HT non-polar column (DB1-HT; 100% dimethylpolysiloxane, 15 m x 0.32 mm i.d., 0.1 µm film thickness). The carrier gas was helium and the temperature programme comprised a 50°C isothermal hold followed by an increase to 350°C at a rate of 10°C min⁻¹ followed by a 10 min isothermal hold. A procedural blank (no sample) was prepared and analysed alongside every batch of samples. Further compound identification was accomplished using GC-MS. FAMEs were then introduced by autosampler onto a GC-MS fitted with a non-polar column (100% dimethyl polysiloxane stationary phase; 60 m x 0.25 mm i.d., 0.1 µm film thickness). The instrument was a ThermoFinnigan single quadrupole TraceMS run in EI mode (electron energy 70 eV, scan time of 0.6 s). Samples were run in full scan mode (m/z 50–650) and the temperature programme comprised an isothermal hold at 50°C for 2 min, ramping to 300°C at 10° min⁻¹, followed by an isothermal hold at 300°C (15 min). Data acquisition and processing were carried out using the HP Chemstation software (Rev. C.01.07 (27), Agilent Technologies) and Xcalibur software (version 3.0). Peaks were identified on the basis of their mass spectra and GC retention times, by comparison with the NIST mass spectral library (version 2.0). Carbon isotope analyses by GC-C-IRMS were also carried out using a GC Agilent Technologies 7890A coupled to an Isoprime 100 (EI, 70eV, three Faraday cup collectors m/z 44, 45 and 46) via an IsoprimeGC5 combustion interface with a CuO and silver wool reactor maintained at 850°C. Instrument accuracy was determined using an external FAME standard mixture (C11, C13, C16, C21 and C23) of known isotopic composition. Samples were run in duplicate and an average taken. The δ¹³C values are the ratios ¹³C/¹²C and expressed relative to the Vienna Pee Dee Belemnite, calibrated against a CO₂ reference gas of known isotopic composition. Instrument error was ±0.3‰. Data processing was carried out using Ion Vantage software (version 1.6.1.0, IsoPrime).

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