

**Figure 1** | **A module for microfluidics. a**, In Gökçe and colleagues' microfluidic architecture<sup>1</sup>, a straight microchannel is divided by a shallow barrier, and dried reagents are spotted along one half. A liquid sample entering from the inlet first passes down one side, and then fills the side containing the reagents. Air pushed ahead of the moving front of the liquid escapes through a vent. **b**, The dried reagents dissolve, and the resulting solution spills over the shallow barrier to fill the whole channel. The capillary forces generated in the system prevent the reagents from being dispersed so that they become concentrated at the moving front, as they would have been in a simple channel. Once the channel is full, the liquid is released through the diversion barrier to the outlet. The system allows multiple reagents to be dissolved in a liquid sample without being mixed together by dispersion.

its volume. By contrast, when dried reagents are dissolved by a liquid in a simple, unstructured microchannel, dispersion processes cause the reagents to become concentrated at the moving front of the liquid.

The authors went on to demonstrate how their system could be used to precisely control the concentration and the timing of addition of reagents in complex biochemical reactions, in two assays: one that detected DNA sequences of the human papilloma virus, and the other that quantified the activity of an enzyme. In both cases, the assays involved the use of several reagents (enzymes and their substrates, cofactors, fluorescent reporter molecules, and so on).

The key to Gökçe and co-workers' invention is the shallow barrier in the channel, which acts as a capillary pinning line — an interface with the liquid that constrains the liquid's motion through capillary forces. The phenomenon of capillary pinning is common in nature; for example, it holds water droplets to minuscule specks of dirt on glass. Capillary-pinning lines underlie such diverse effects as the formation of coffee rings from droplets spilt on a table<sup>8</sup>, or the unidirectional flow of water in the carnivorous pitcher plant *Nepenthes alata*<sup>9</sup>.

Capillary pinning has been used in microfluidics systems before, for example in capillary valves<sup>10</sup>, which control liquid flow without using mechanical parts. They have also been used in phaseguides, which form barriers to flow perpendicular to the direction of motion of the liquid–air meniscus these barriers hold the meniscus until enough pressure has built up for liquid to flow over the barrier<sup>11</sup>. Gökçe *et al.* have used capillary pinning in a new way: to enable liquids to flow over dried spots of reagents without causing the reagents to disperse uncontrollably within the liquid, thus allowing the concentration profile of the reagents in the resulting

#### ARCHAEOLOGY

solution to be controlled by the positioning of the original spots.

The authors' use of small-scale capillary forces allowed them to segregate reactions without using solid walls. This opens up a simple approach for preprogramming and implementing large numbers of biochemical reactions in straight microchannels, removing the need for complex microfluidic chips that have large numbers of compartments and valves. The authors also show that the geometries of their microchannel systems can be made using inexpensive mass-production methods. These systems could therefore help to bring increasingly sophisticated biochemical assays closer to patients in point-of-care devices.

Robert Hołyst and Piotr Garstecki are at the Institute of Physical Chemistry, Polish Academy of Sciences, Warsaw 01-224, Poland. e-mails: rholyst@ichf.edu.pl; garst@ichf.edu.pl

- 1. Gökçe, O. et al. Nature 574, 228–232 (2019).
- Kenis, P. J. A., Ismagilov, R. F. & Whitesides, G. M. Science 285, 83–85 (1999).
- Teh, S.-Y., Lin, R., Hung, L.-H. & Lee, A. P. Lab Chip 8, 198–220 (2008).
- Hindson, C. M. et al. Nature Methods 10, 1003–1005 (2013).
- Prakadan, S. M., Shalek, A. K. & Weitz, D. A. Nature Rev. Genet. 18, 345–361 (2017).
- Hon, C.-C., Shin, J. W., Carninci, P. & Stubbington, M. J. T. Briefings Funct. Genom. 17, 283–294 (2018).
- Chin, C. D., Linder, V. & Sia, S. K. Lab Chip 12, 2118–2134 (2012).
- 8. Deegan, R. D. et al. Nature 389, 827-829 (1997).
- 9. Chen, H. et al. Nature **532**, 85–89 (2016).
- 10.Glière, A. & Delattre, C. Sensors Actuators A 130–131, 601–608 (2006).
- 11.Vulto, P. et al. Lab Chip 11, 1596-1602 (2011).

# Early European babies bottle-fed animal milk

The foods used to supplement or replace breast milk in infants' diets in prehistoric times aren't fully understood. The finding that ancient feeding vessels from Europe had residues of animal milk offers a clue. SEE LETTER P.246

### SIÂN E. HALCROW

**S** mall pottery vessels, sometimes with animal-like forms (Fig. 1), containing a spout through which liquid could be poured, have been found at prehistoric archaeological sites in Europe. One idea put forward is that they were used as feeding vessels for sick adults and the elderly. However, on page 246, Dunne *et al.*<sup>1</sup> describe an analysis of spouted vessels found in ancient graves of infants in Germany that indicates that these artefacts contained animal milk. This evidence suggests that such vessels were used to feed animal milk to children, providing crucial insight into the diet of developing infants in prehistoric human populations.

For years, many archaeologists ignored children when studying ancient populations, but researchers now increasingly recognize the importance of children when trying to understand the factors affecting earlier societies<sup>2.3</sup>. One such example concerns a major societal turning point in human prehistory, known as the Neolithic demographic transition, when there is evidence of a substantial increase

in fertility and a growth in the number of individuals in human populations compared with that of earlier societies<sup>4</sup>.

The Neolithic period in Europe began roughly around 7000 BC. During the Neolithic, some humans began to move away from a hunter-gatherer lifestyle towards one that depended on crops and domesticated animals. How did this transition to agriculture lead to a baby boom? An exploration of the approaches used to feed infants might provide some of the evidence needed to answer this question.

Some of the earliest known pottery vessels of a suitable size and shape for use in feeding infants are from the Neolithic period. These artefacts, discovered in Germany, have been dated<sup>5</sup> to between 5500 and 4800 BC. It has been suggested<sup>6</sup> that during the Neolithic, weaning - when an infant's diet changes from breast milk to other foods - occurred earlier in an infant's life than was previously the case. This earlier weaning might have been accomplished by using animal milk and plant sources of carbohydrates. It has been argued that such early weaning could have helped to counteract the period of infertility that can occur while a mother is breastfeeding<sup>7</sup>, and thus might have led to the increase in fertility and population size during the Neolithic demographic transition. In the archaeological record, this fertility increase is evidenced, somewhat counter-intuitively, by an increase in the number of infants found at burial sites - if more babies are born in a population, then more babies will also die, and be buried<sup>8</sup>.

Dunne and colleagues examined ceramic vessels with spouts found in children's graves from burial sites in Bavaria, Germany. One vessel came from a burial site dated to around 1200-800 BC (during the late Bronze Age), and two vessels came from a burial site from around 800–450 BC (during the early Iron Age).

The authors analysed traces of ancient food in these vessels to determine the origin of these residues, by assessing specific characteristics of fatty-acid molecules. Dunne et al. used isotope analysis to study the chemistry of specific compounds in the vessels, and also obtained molecular 'fingerprints' of the ancient lipids. They then compared this information with the fingerprints of known reference compounds. This evidence indicates that the vessels contained fatty acids from dairy products, probably milk, that came from domestic ruminant animals. The specific type of animal that provided this milk was not identified.

It is thought that humans first started drinking animal milk in Europe. A study<sup>9</sup> published this year of proteins captured in dental plaque provides direct evidence that adults drank animal milk during the Neolithic period in Europe, with the earliest dates for this occurring around 6,000 years ago. Now Dunne et al. present the earliest known evidence of animal milk in small bottles for infants.

The exploration of infant feeding provides



Figure 1 | Ancient pottery vessels. Vessels with a spout for pouring liquid and of a size suitable for feeding babies have been found at archaeological sites. The earliest examples of such vessels<sup>5</sup> have been dated to around 5500-4800 BC, but whether these were used to feed infants is unknown. Two vessels are shown of this size and shape from the late Bronze Age or early Iron Age (vessels dated between 1200 and 800 BC). The vessel on the left, from Vösendorf, Austria, is approximately 90 millimetres high. The vessel on the right, from Statzendorf, Austria, is about 85 mm high. Dunne and colleagues' analysis' of organic residues found in ancient spouted vessels (not those pictured) sheds light on how early populations might have fed young infants.

information about how babies have been cared for and how social attitudes towards infant feeding have changed over time<sup>10</sup>. Dunne and colleagues' investigation of infant feeding during the Neolithic provides insight into cultural beliefs related to the body, infancy and motherhood. Furthermore, the type of food infants are fed, and when during their development they are given food in addition to breast milk, has a strong relationship to infant health and survival<sup>11</sup>.

Human breast milk is a perfect baby food, containing carbohydrates, protein, fat, vitamins, minerals, digestive enzymes and hormones<sup>12</sup>. It provides protection from infection because it contains numerous types of immune cell<sup>13,14</sup>. Some of the sugars it contains, although not digested by babies, support certain communities of gut microorganisms, which prevent disease-causing microbes from establishing a presence in the body<sup>14</sup>. By contrast, animal-milk products do not provide a complete nutritional source for infants. And the use of hard-to-clean bottles for animal milk poses a risk of exposure to life-threatening infections such as gastroenteritis. The introduction of milk in bottles during the Neolithic, therefore, might have led to a deterioration in the health of some infants.

Further research on the remains of people in European prehistoric cemetery sites should be undertaken to explore the effects of the introduction of animal milk as an infant food. This could be assessed by analysing the rate of infant and child mortality, and determining whether any signs of nutritional or infectious disease are present when studying the bones and teeth in infant remains. Furthermore, the age at which a child was weaned can be investigated using techniques that analyse teeth<sup>15</sup>, and gathering such data can uncover the variation in weaning approaches that existed in a population<sup>16</sup>. Such knowledge, together with evidence of disease for the individual being studied, might help to provide a greater understanding of the significance of the introduction of animal milk for the lives of ancient children.∎

## Siân E. Halcrow is in the Department of Anatomy, University of Otago, Dunedin 9016, New Zealand.

e-mail: sian.halcrow@otago.ac.nz

- 1. Dunne, J. et al. Nature 574, 246-248 (2019).
- 2. Lillehammer, G. in The Oxford Handbook of the Archaeology of Childhood (eds Crawford, S. Hadley, D. & Shepherd, G.) 38-51 (Oxford Univ. Press, 2018).
- З Halcrow, S. & Tayles, N. in Social Bioarchaeology (eds Agarwal, S. & Glencross, B.) 333-360 (Oxford Univ. Press, 2011).
- Bocquet-Appel, J. P. Science 333, 560-561 (2011). 5 Meller, H. E. Bronzerausch: Spätneolithikum und Frühbronzezeit. Begleithefte zur Dauerausstellung 4
- (State Museum of Prehistory Halle, 2011) Bocquet-Appel, J.-P. Curr. Anthropol. 43, 637-650 (2002).
- 7. Chao, S. Clin. Perinatol. 14, 39-50 (1987).
- 8. Jackes, M. in Strength in Diversity: A Reader in Physical Anthropology (eds Herring, A. & Chan, L.) 155-185 (Canadian Scholars, 1994).
- Charlton, S. et al. Archaeol. Anthropol. Sci. https:// doi.org/10.1007/s12520-019-00911-7 (2019).
- 10. Tomori, C., Palmquist, A. E. L. & Quinn, E. À. in Breastfeeding: New Anthropological Approaches (eds Tomori, C., Palmquist, A. E. L. & Quinn, E. A.) Ch. 1, 1-25 (Routledge, 2017).
- 11.Halcrow, S. E. et al. in Breastfeeding: New Anthropological Approaches (eds Tomori, C. Palmguist, A. E. L. & Quinn, E. A.) Ch. 11, 155-169 (Routledge, 2017).
- 12.Lessen, R. & Kavanagh, K. J. Acad. Nutr. Diet. 115, 444–449 (2015). 13.Martin, C. R., Ling, P.-R. & Blackburn, G. L. *Nutrients*
- 8,279 (2016).
- 14.Allens-Blevins, C. R., Sela, D. A. & Hinde, K. Evol. Med. Public Health 2015, 106-121 (2015).
- 15.Beaumont, J., Gledhill, A., Lee-Thorp, J. & Montgomery, J. Archaeometry 55, 277–295 (2013).
- 16.King, C. L. et al. Int. J. Osteoarchaeol. 28, 599–612 (2018).

#### This article was published online on 25 September 2019.