Early Weaning of Neolithic Domestic Cattle (Bercy, France) Revealed by Intra-tooth Variation in Nitrogen Isotope Ratios

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Evaluating the role of milk production in prehistoric subsistence economies requires a better estimation of the capacity of a milk-oriented husbandry under prehistoric conditions. Weaning pattern, which is linked to the length of lactation, is an important parameter in this estimation. In this study, weaning pattern is closely examined in Neolithic cattle from the site of Bercy (Paris, France, *c.* 4000 BC), by a study of intra-tooth (M1, M2) variation in the nitrogen isotope ratios ($\delta^{15}N$) of dentine collagen. Collagen $\delta^{15}N$ is commonly used to trace the change of trophic level at weaning time. The pattern of change in collagen $\delta^{15}N$ in the first molar of two archaeological bovines is then compared with that observed in modern cattle weaned at known age. Results suggest that the Neolithic calves were weaned early. This could reflect either a shorter lactation for Neolithic cows, or early weaning imposed by the herder in order to reserve a bigger proportion of milk production for human consumption. © 2002 Published by Elsevier Science Ltd.

Keywords: MILK PRODUCTION, WEANING, NEOLITHIC, NITROGEN ISOTOPE RATIOS, COLLAGEN, DENTINE.

Introduction

Milk production may have been a non negligible component of European pre- and protohistoric economies (Bogucki, 1984; Legge, 1989; Helmer, 1991; McCormick, 1992; Tresset, 1996; Dudd & Evershed, 1998; Craig *et al.*, 2000). Evaluating the role of milk production in a subsistence economy requires estimation of the amount of milk available for human consumption. Greatly divergent figures have been proposed for European primitive domestic cattle (IJzereef, 1981; Gregg, 1988; Peske, 1994; Tresset, 1996). Accurate estimation requires better definition of two parameters: first, the milk capacity of prehistoric cattle, which depends partly on the length of lactation; and second the amount of milk actually devoted to human versus calf's consumption, which is linked to the weaning pattern. Length of lactation and weaning pattern are closely linked. Weaning age is primarily function of, and can help evaluate, the length of lactation. In a milk-oriented economy, however, weaning age can also be subjected to control by herders: early weaning provides more milk for human consumption.

Weaning pattern in prehistoric domestic animals can be determined by biogeochemical analysis of bone remains. The nitrogen isotope composition ($\delta^{15}N$) of bone and tooth collagen is linked to the trophic level: at the base of the food web, $\delta^{15}N$ values are determined by those of plants, and a stepwise ^{15}N-enrichment of 3–3·5‰ has been observed between trophic levels in many ecosystems (DeNiro & Epstein, 1981; Minagawa & Wada, 1984; Schoeninger & DeNiro, 1984; Ambrose, 1991). The suckling mammal is one trophic level higher than its mother. Weaning involves descending to the same trophic level as the mother, resulting in a decrease in the $\delta^{15}N$ value of the weanling's collagen. This principle was first demonstrated in humans (Fogel, Tuross & Owsley, 1989; Katzenberg, Herring & Saunders, 1996) and since has been shown in modern cattle (Balasse *et al.*, 1999, 2001). In this paper, we use this principle to examine more closely the weaning pattern of domestic cattle from the Middle Neolithic site of Bercy, where archaeological evidence for milk exploitation has been clearly established.

Bercy (Paris, France) is a large village site on the bank of the Seine river. The main phase of occupation is attributed to the Chasséen Septentrional culture (very beginning of the IVth millennium BC). Domestic rubbish accumulated in the palaeochannel adjacent to the agro-pastoral settlement. Excavation produced a very rich collection of faunal remains, which were especially well-preserved in this waterlogged environment. Analysis of the faunal assemblage (Tresset, 1996, 1997) revealed that the subsistence economy relied heavily on cattle husbandry. The herd management, as documented on the basis of tooth eruption and tooth-wear analysis, suggests that cattle were raised for meat and milk. The meat component of this mixed production system is reflected in the mortality profile by the

culling of individuals when the growth slows down (age 2–4 years). Milk exploitation is suggested by the presence of old individuals (age >8 years), presumably cast milking cows, and a very high mortality of young individuals from age class 6–12 months. The culling of the young individuals fits with what has been defined as a post-lactation slaughter pattern (Peske, 1994), in which young males kept alive for stimulation of milk production are slaughtered when lactation ends. Slaughter may also have coincided with the onset of the cold season and the necessity to reduce the herd size (Tresset, 1996, 1997). The hypothesis of post-lactation slaughter at Bercy has been supported by an isotope study of the cattle bones, which showed that the young individuals were killed around weaning age (Balasse *et al.*, 1997, 2000). In that isotopic study, we compared $\delta^{15}N$ values of bone collagen of individuals from different age classes in order to differentiate between non-weaned and weaned age classes.

A more detailed study of weaning pattern can be performed at the individual scale, by looking at the intra-tooth change in nitrogen isotope ratios. Unlike bone, dentine is not renewed (Gage *et al.*, 1989). The $\delta^{15}N$ of dentine collagen reflects the trophic level of the individual at time of tooth formation. A study on molar teeth of modern steers has shown that it is possible, by performing sequential sampling of dentine along the tooth, to observe the decrease in $\delta^{15}N$ of collagen at weaning time (Balasse *et al.*, 2001). In five modern steers, weaned when 9–10 months old, the cessation of suckling was recorded in the nitrogen isotope ratios of first and second molars, with a very similar pattern in all individuals analysed. The results obtained on modern cattle provide a standard for a late weaning pattern. We have applied the same sampling procedure to archaeological cattle teeth in order to compare the results with those obtained from the modern steers.

Material and Methods

Two immature mandibles (MB 19000 and MB 28000) with first (M1) and second (M2) molars were chosen for intra-tooth isotope analysis. It was important to make sure that these individuals were domestic rather than wild bovines, because both are present in the faunal assemblage (Tresset, 1996). Diagnosis from morphometric criteria is not applicable to immature bones. Fortunately, at Bercy, domestic cattle differ from aurochs in their collagen carbon isotopic composition (Balasse *et al.*, 2000), probably because the latter were feeding in areas with denser vegetation cover, where the canopy effect produced lower carbon isotope values for the understorey plants (Tieszen, 1991; Van der Merwe & Medina, 1991). By this isotopic criterion, all the immature bovine bones included in the isotopic study of the site have been identified as domestic animals (Balasse *et al.*, 2000).
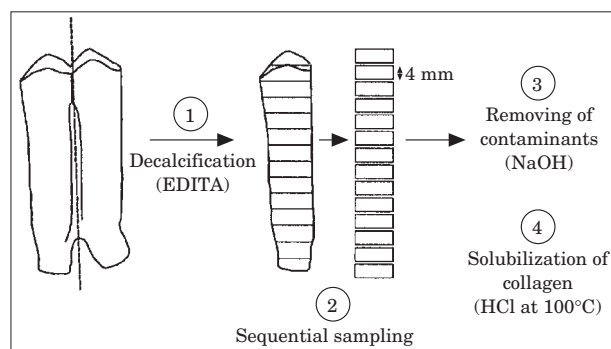

Figure 1. Tooth sampling and collagen extraction procedure.

One loph of each of the four teeth were decalcified in EDTA (0·5 M, pH=7·4) at room temperature (Tuross *et al.*, 1988), with solution renewed every three days. Decalcification took two months. The collagen isomorph was soaked in distilled water for a week and rinsed twice a day in order to remove EDTA. Sequential sampling of 4 mm sections was performed from the apex to the root of the tooth (Figure 1). Each sample was soaked in NaOH (0·125 M) at room temperature for 20 h. This step removed the humic acids, which were present in high concentrations in the Bercy bones (Bocherens *et al.*, 1997a). Comparison of results obtained from analysis of dentine collagen prepared with EDTA plus NaOH or with EDTA alone has shown that EDTA alone is not sufficient for removing humic acids: after treatment with NaOH, the samples showed a significant increase in their carbon and nitrogen isotope compositions and had carbon content, nitrogen content and C/N ratio more comparable to those of modern collagen (Balasse, 1999). Treatment with NaOH is known to induce a quantitative loss of collagen (Chisholm *et al.*, 1983; Boutton *et al.*, 1984; Katzenberg, 1989; Katzenberg *et al.*, 1995). However, the loss of a small amount of collagen was preferable to heavy contamination by humic acids. Because of the solubility of collagen in NaOH, this step was applied after the sequential sampling, as the latter requires preservation of the shape of the tooth. The samples were homogenized by solubilization (HCl 10^{-2} M, 100°C, 17 h), filtered and freeze-dried. The nitrogen isotope composition of collagen was measured by isotope ratio mass spectrometry as described elsewhere (Bocherens *et al.*, 1997b). The analytical precision is 0·2‰.

Results

Results are presented in Table 1 and in Figure 2. The carbon content (%C), nitrogen content (%N) and atomic C/N ratio of collagen extracted from the archaeological dentine (Table 1) are similar to those of modern dentine collagen (%C=37·6–44·3; mean ± 1σ=42·2 ± 1·7; %N=13·2–16·5; mean ± 1σ=15·5 ± 1·3; atomic C/N ratio=3·1–3·3; Balasse *et al.*, 2001).

Table 1. Carbon content (%C), nitrogen content (%N), C/N ratio and nitrogen isotope composition ($\delta^{15}N$) of dentine collagen from archaeological cattle. M1: first molar; M2: second molar. Sample numbers were assigned from the apex to the root of each tooth

Individual	Sample	%C	%N	C:N	$\delta^{15}N$ (‰)
MB 19000	M1–1	40·7	14·9	3·2	+9·0
	M1–2	41·2	15·1	3·2	+9·0
	M1–3	41·2	15·2	3·2	+9·1
	M1–4	41·7	15·2	3·2	+8·6
	M1–5	41·3	15·1	3·2	+8·7
	M1–6	41·3	15·2	3·2	+8·3
	M1–7	41·7	15·2	3·2	+8·1
	M1–8	42·1	15·5	3·2	+7·9
	M1–9	39·2	14·4	3·2	+7·4
	M1–10	41·6	15·3	3·2	+7·4
	M1–11	41·6	15·3	3·2	+7·0
	M1–12	41·0	15·0	3·2	+7·2
	moy	41·2	15·1		
	std	0·7	0·3		
MB 19000	M2–1	39·0	14·1	3·2	+7·1
	M2–2	32·3	11·6	3·3	+7·7
	M2–3	41·7	15·2	3·2	+7·3
	M2–4	42·7	15·5	3·2	+7·2
	M2–5	43·0	15·6	3·2	+7·0
	M2–6	42·9	15·4	3·3	+7·3
	M2–7	42·8	15·4	3·2	+7·5
	M2–8	42·2	15·2	3·2	+7·3
	M2–9	43·6	15·7	3·2	+7·9
	moy	41·1	14·8		
	std	3·4	1·2		
MB 28000	M1–1	40·8	14·9	3·2	+8·5
	M1–2	42·4	15·5	3·2	+8·7
	M1–3	43·1	15·9	3·2	+8·9
	M1–4	42·3	15·5	3·2	+8·8
	M1–5	42·1	15·5	3·2	+8·9
	M1–6	42·7	15·7	3·2	+8·4
	M1–7	42·9	15·8	3·2	+8·6
	M1–8	41·0	15·0	3·2	+8·4
	M1–9	42·5	15·6	3·2	+8·3
	M1–10	43·2	15·8	3·2	+7·9
	M1–11	43·1	15·9	3·2	+7·9
	M1–12	42·6	15·7	3·2	+7·6
	M1–13	41·4	15·4	3·1	+7·4
	moy	42·3	15·6		
	std	0·7	0·3		
MB 28000	M2–1	41·3	14·9	3·2	+7·9
	M2–2	41·5	15·0	3·2	+8·0
	M2–3	41·0	14·9	3·2	+8·2
	M2–4	41·4	15·1	3·2	+7·9
	M2–5	42·1	15·3	3·2	+7·6
	M2–6	42·1	15·3	3·2	+7·7
	M2–7	42·2	15·4	3·2	+7·8
	M2–8	41·8	15·1	3·2	+7·5
	M2–9	41·8	15·1	3·2	+7·3
	M2–10	40·6	14·8	3·2	+7·4
	moy	41·6	15·1		
	std	0·5	0·2		

The decrease of $\delta^{15}N$ values of dentine collagen along the first molar (Figure 2) reflects the step down one trophic level at weaning time. The amount of decrease of $\delta^{15}N$ values (2·1‰ and 1·5‰ in M1 of MB 19000 and MB 28000) is slightly low when compared to the +3·2–3·6‰ ^{15}N-difference actually measured

between cow's milk and diet (Steele & Daniel, 1978; Koyama, Madoke & Tadakatu, 1984). In the second molar, $\delta^{15}N$ values vary unsystematically around a relatively low average (7·4‰ and 7·7‰ in M2 of MB 19000 and MB 28000).

The lowest $\delta^{15}N$ values occur in the lower parts of the teeth, 7‰ for MB 19000 and 7·3‰ for MB 28000. These values seem still a little high when compared to a mean value of 6·6‰ measured for bone collagen of adult bovines at Bercy (n=9, 5·5‰–7·5‰, Balasse et al., 1997). Although these apparently high values could be explained by inter-individual variability, it is possible that these young individuals have not yet attained the $\delta^{15}N$ values corresponding to a pure herbivore diet in that ecosystem. Whether stabilization of the $\delta^{15}N$ values has occurred is not clear, especially in individual MB 28000 (Figure 2). It could also be possible that lower $\delta^{15}N$ values would have been measured in the very lowest part of the teeth, a very thin and fragile part formed soon before death that could have been destroyed by diagenetic processes and/or lost during decalcification.

Discussion

Cows are weaned during the first year of life. Therefore weaning has to occur during formation of the second molar, which extends between the second month and the end of the second year of life (Brown et al., 1960). Figure 2 shows, for comparison with the archaeological individuals, the results obtained from one of the five modern cattle teeth analysed in a previous study with the same analytical procedure (Balasse et al., 2001). Although weaning was recorded in both the first and the second molar teeth of the modern steers, it does not appear in the second molar of the archaeological bovines, where no clear pattern of $\delta^{15}N$ decrease is observed.

Dentine grows by apposition of stacked cones (Hillson, 1986). The dentine layer becomes thicker as the tooth is growing in length: in a dental bud, the dentine layer is very thin, while in a mature tooth, dentine tends to fill up the pulp cavity. The earlier weaning occurs in the development of a tooth, the thinner the dentine layer formed before weaning and the bigger the amount of dentine accumulated in thickness after weaning. The absence of a pre-weaning signal in the archaeological second molars suggest that weaning occurred at a very early stage of development of the tooth. The relative proportion of pre-weaning dentine would have been so low that it does not contribute to the isotope signal measured through the whole thickness of dentine. An early weaning could also explain the low amplitude of variation of $\delta^{15}N$ values in the first molar: the pre-weaning isotope values have been lowered when dentine has accumulated in thickness.
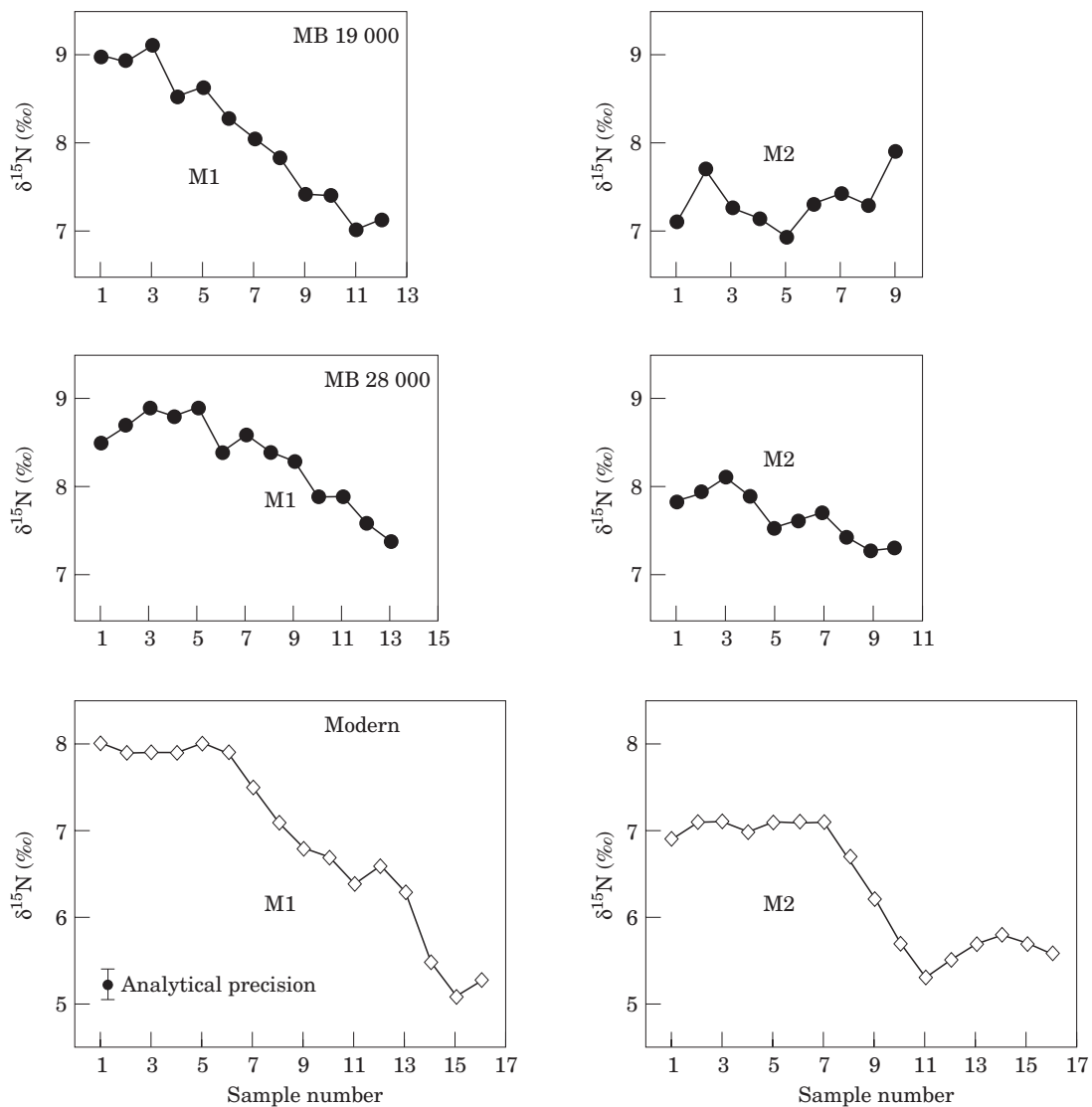
Figure 2. Change in the nitrogen isotope composition (δ^{15}N) of dentine collagen along the first (M1) and second molars (M2) of two domestic bovines from the site of Bercy (MB 19000 and MB 28000). The figure includes for comparison results obtained from the same sampling procedure applied to a modern individual weaned at age nine to ten months (data Balasse *et al.*, 2001). In each tooth, sample numbers were assigned from the apex (formed the earliest) to the root (formed the latest) of the tooth. The modern steer has on average lower collagen δ^{15}N values than the archaeological bovines because both the mother cow and the calf were fed soy beans (Balasse *et al.*, 2001), a leguminous plant characterized by low δ^{15}N values.

The pattern of change of δ^{15}N values in the first molar of archaeological and modern individuals is compared in Figure 3. Because the teeth are not at the same stage of growth and wear, and because the range of variation in isotopic values is not the same in every tooth, comparison requires the curves to be aligned with each other by choosing for origins the tooth crown-root junction (x=0) and the highest δ^{15}N value in each tooth (y=0). Comparison shows that the decrease in δ^{15}N values appears at an earlier stage of development in the archaeological teeth than in the modern ones, suggesting that the Neolithic calves were weaned significantly earlier than the modern ones.

When doing this comparison, three important points must be borne in mind: (1) the comparison assumes that dental growth rhythm is the same in Neolithic and modern cattle. This assumption, currently unverifiable, underlies every zooarchaeological analysis. (2) The comparison assumes that the initial height (unworn) of the first molar crown was the same in Neolithic and modern cattle. Morphometric data (Tresset, unpublished data) suggest that the domestic bovines at Bercy were slightly shorter than the modern individuals used as reference (Charolaise breed). If this difference in stature (withers height) means a difference in the size of the teeth, the modern cattle may have larger teeth, and
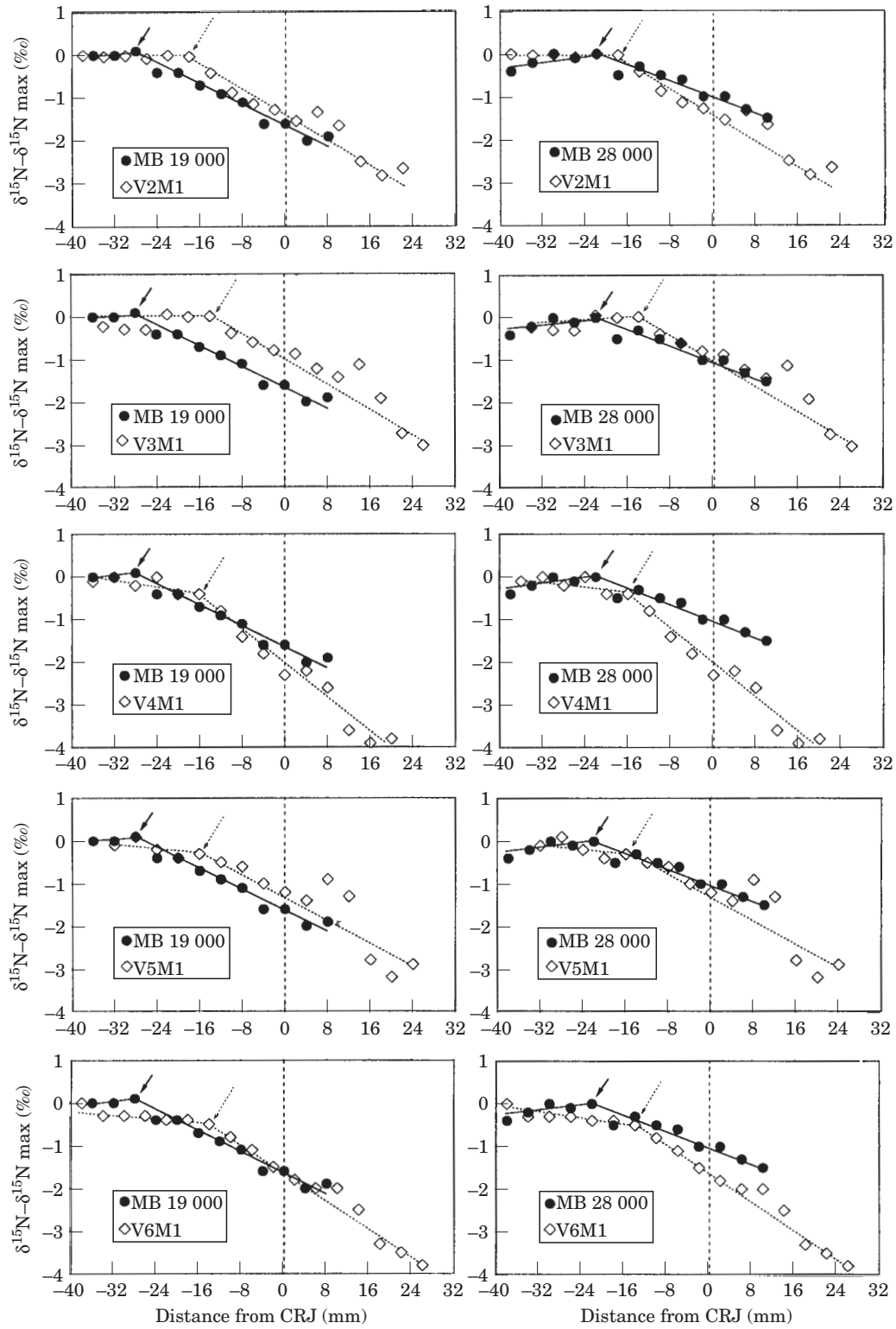
Figure 3. Comparison of the pattern of variation of dentine collagen nitrogen isotope ratios ($\delta^{15}N$) along the first molar (M1) of two Neolithic bovines (MB 19000 and MB 28000, this study) and five modern steers (V2, V3, V4, V5 and V6) weaned at age nine to ten months (data Balasse *et al.*, 2001). Curves have been aligned with each other by choosing for origins the tooth crown-root junction (x=0) and the highest $\delta^{15}N$ value in each tooth (y=0). The arrow shows where the change in $\delta^{15}N$ values occurs. CRJ=crown-root junction.

thus a greater molar crown height. If this assumption is correct, and if the initial crown height is greater in modern individuals, the change in $\delta^{15}N$ values has been recorded proportionally even lower in the crown of the modern individuals than it appears, and the difference in timing of weaning could have been greater. (3) The modern teeth were at a more advanced stage of growth than the archaeological ones when the animals died, and the greater dentine thickness may have modified the pattern of isotopic variation along the tooth. However, dentine accumulated after weaning would have lowered the $\delta^{15}N$ values in the higher part of the crown, and would have attenuated the difference between the modern and archaeological individuals. In other words, the actual difference in timing of weaning could have been even greater.

The pattern of variation of $\delta^{15}N$ values in both first and second molar teeth suggest that the Neolithic cattle were weaned earlier than the modern ones, earlier than age 9–10 months. This result can be interpreted as reflecting either (1) a shorter lactation for Neolithic cattle than for modern cows, or (2) an early weaning imposed on the calves by the herders.

(1) A short lactation span has been assumed for primitive domestic females (6–7 months for Neolithic European cattle: Gregg, 1988; Peske, 1994; Tresset, 1996). Zootechnical data on unimproved cattle breeds, essentially African cattle, show that the average length of lactation is around 7–9 months, and that lactations shorter than 6 months are not rare (Dahl & Hjort, 1976). However, they also show that the length of lactation depends greatly on the grazing conditions, which suggests that data from arid or semi-arid environments may not be applicable to the European Neolithic. Irregardless, it is likely that the 10 months of lactation observed on modern European breeds (Metge, 1990) results from long-term improvements, and that the length of lactation of primitive domestic females was shorter.

(2) The hypothesis of an early weaning imposed by the herders is interesting in a context where herd management suggests a milk production. Artificial weaning may have been imposed to reserve milk production for human consumption.

The hypothesis of artificial weaning is not incompatible with that of a post-lactation slaughter, which is based on the assumption that the presence of the calf was necessary for inducing the milk ejection reflex (Peske, 1994; Tresset, 1996; Balasse *et al.*, 2000). The calf can be weaned early, and still be presented to the cow at milking time: it will initiate the ejection reflex and be immediately removed from the udder. This system is currently employed in traditional milk husbandry in Auvergne (France): the calf of the unimproved Salers breed is weaned when four month-old but not sold until the lactation ends, five months later, because its presence is required each day at milking time (Bonal *et al.*, 1985). At Bercy, in the same way, the young bovines could have been weaned early but

slaughter of the males would have been deferred until end of lactation. It should be observed that if the hypothesis of an early weaning is correct, the slaughter peak has been appropriately called "post-lactation" rather than "post-weaning" slaughter.

Whether the short lactation hypothesis is correct could be determined by performing the same kind of analysis on cattle teeth from other Neolithic sites showing different pattern of herd management. If early weaning is observed in sites where herd management suggests that cattle were not raised for milk, it is likely that it was due to a short length of lactation for Neolithic cattle rather than early weaning imposed by the herders: artificial weaning can weaken the calf, which would not be compatible with a meat production system that depends upon optimization of weight gain.

Conclusion and Perspectives

The pattern of intra-tooth variation of collagen nitrogen isotope composition suggests, when compared to results obtained on modern individuals weaned at age 9–10 months, that the domestic bovines from the Neolithic site of Bercy were weaned earlier. Early weaning can be interpreted as reflecting either a shorter length of lactation in primitive domestic females, or weaning imposed by the herder in order to reserve a bigger part of milk production to human consumption. Both hypotheses are likely and are not mutually exclusive.

More analyses should be performed at Bercy and on other Neolithic sites to confirm the weaning pattern. The modern referential should also be enriched by analysis of individuals weaned at different ages, from traditional pastoral societies.

Acknowledgements

References

Ambrose, S. H. (1991). Effects of diet, climate and physiology on nitrogen isotope abundances in terrestrial foodwebs. *Journal of Archaeological Science* **18,** 293–317.

Balasse, M. (1999). *De l'exploitation du lait au Néolithique moyen, en Europe tempérée. Examen des modalités de sevrage des bovins, par*

l'analyse isotopique des ossements archéologiques. Thèse de doctorat, Université Paris 6, Mémoires des Sciences de la Terre no 99–25.

Balasse, M., Bocherens, H., Tresset, A., Mariotti, A. & Vigne, J.-D. (1997). Emergence de la production laitière au Néolithique? Contribution de l'analyse isotopique d'ossements de bovins archéologiques. *C.R. Acad. Sci. Paris, Sciences de la terre et des planètes* **235,** 1005–1010.

Balasse, M., Bocherens, H. & Mariotti, A. (1999). Intra-bone variability of collagen and apatite isotopic composition used as evidence of a change of diet. *Journal of Archaeological Science* **26,** 593–598.

Balasse, M., Tresset, A., Bocherens, H., Mariotti, A. & Vigne, J.-D. (2000). Un abattage ''post-lactation'' sur des bovins domestiques néolithiques. Etude isotopique des restes osseux du site de Bercy (Paris, France). In B. Bassano, G. Giacobini et V. Peracino (La gestion démographique des animaux à travers le temps—Animal management and demography through the ages (VIe Colloque international de l'association ''L'Homme et l'Animal, Société de Recherche Interdisciplinaire'', Turin, Italie, 16–18 September 1998). *Ibex J. Mt Ecol.* **5**—*Anthropozoologica* **31**, 39–48.

Balasse, M., Bocherens, H., Mariotti, A. & Ambrose, S. H. (2001). Detection of dietary changes by intra-tooth carbon and nitrogen isotopic analysis: an experimental study of dentine collagen of cattle (*Bos taurus*). *Journal of Archaeological Science* **28,** 235–245.

Bocherens, H., Tresset, A., Wiedemann, F., Giligny, F., Lafage, F., Lanchon, Y. & Mariotti, A. (1997*a*). Diagenetic evolution of mammal bones in two French Neolithic sites. *Bull. Soc. geol. France* **168,** 555–564.

Bocherens, H., Billiou, D., Pathou-Mathis, M., Bonjean, D., Otte, M. & Mariotti, A. (1997*b*). Paleobiological implications of the isotopic signatures (13C, 15N) of fossil mammal collagen in Scladina Cave (Sclayn, Belgium). *Quaternary Research* **48,** 370–380.

Bogucki, P. I. (1984). Ceramic sieves of the Linear Pottery Culture and their economic implications. *Oxford Journal of Archaeology* **3,** 15–30.

Bonal, A., Bougler, J., del Porto, P. & Havy, A. (1985). *La race Salers*. Aurillac: Vedreine Imprimeurs.

Boutton, T. W., Klein, P. D., Lynott, M. J., Price, J. E. & Tieszen, L. L. (1984). Stable isotope ratios as indicators of Prehistoric human diet. In (J. R. Turnlund & P. E. Johnson, Eds) *Stable isotopes in Nutrition*. American Chemical Society Symposium series 258, pp. 191–204.

Brown, W. A. B., Christofferson, P. V., Massler, M. & Weiss, M. B. (1960). Postnatal tooth development in cattle. *American Journal of Veterinary Research* **21**(80), 7–34.

Chisholm, B. S., Nelson, D. E., Hobson, K. A., Schwarcz, H. P. & Knyf, M. (1983). Carbon isotope measurement techniques for bone collagen: notes for the archaeologists. *Journal of Archaeological Science* **10,** 355–360.

Craig, O., Mulville, J., Parker-Pearson, M., Sokol, R., Gelsthorpe, K., Stacey, R. & Collins, M. (2000). Detecting milk protein in ancient pots. *Nature* **408,** 312.

Dahl, G. & Hjort, A. (1976). *Having herds. Pastoral herd growth and household economy*. Stockholm Studies in Social Anthropology 2. Stockholm: Stockholm University.

DeNiro, M. J. & Epstein, S. (1981). Influence of diet on the distribution of nitrogen isotopes in animals. *Geochimica et Cosmochimica Acta* **45,** 341–351.

Dudd, S. N. & Evershed, R. P. (1998). Direct demonstration of milk as an element of archaeological economies. *Science* **282,** 1478–1481.

Fogel, M. L., Tuross, N. & Owsley, D. W. (1989). *Nitrogen isotopes tracers of human lactation in modern and archaeological populations*. Washington: Annual Report of the Director, Geophysical Laboratory, Carnegie Institution.

Gage, J. P., Francis, M. J. O. & Triffit, J. T. (1989). *Collagen and dental matrices*. London: Wright.

Gregg, S. (1988). *Foragers and Farmers. Population interaction and agricultural expansion in Prehistoric Europe*. Chicago: The University of Chicago Press.

Helmer, D. (1991). Les faunes chasséennes du Sud-Est de la France, essai de synthese. In *Identité du Chasséen*. Actes du Colloque International de Nemours 1989. Mémoires du Musée de Préhistoire d'Ile-de-France 4, pp. 343–349.

Hillson, S. (1986). *Teeth*. Cambridge: Cambridge University Press.

IJzereef, G. F. (1981). *Bronze Age animal bones from Bovenkarspel. The excavation at Het Valkje*. Nederlanse oudheden 10. Project Noord-Holland 1. Amersfoort: ROB.

Katzenberg, M. A. (1989). Stable isotope analysis of archaeological faunal remains from Southern Ontario. *Journal of Archaeological Science* **16,** 319–329.

Katzenberg, M. A., Herring, D. A. & Saunders, S. R. (1996). Weaning and infant mortality: evaluating the skeletal evidence. *Yearbook of Physical Anthropology* **39,** 177–199.

Katzenberg, M. A., Schwarcz, H. P., Knyf, M. & Melbye, F. J. (1995). Stable isotope evidence for maize horticulture and paleodiet in Southern Ontario, Canada. *American Antiquity* **60,** 335–350.

Koyoma, T., Madoka, S. & Tadakatu, Y. (1984). Fractionation of nitrogen isotopes by domestic animals. *Japanese Journal of Zootechnical Science* **56,** 361–363.

Legge, A. J. (1989). Milking the evidence: a reply to Entwistle and Grant. In (A. Milles, D. Williams & N. Gardners, Eds) *The Beginnings of Agriculture*. Oxford: British Archaeological Reports, International Series 496, pp. 217–242.

McCormick, F. (1992). Early faunal evidence for dairying. *Oxford Journal of Archaeology* **11,** 201–209.

Metge, J. (1990). *La production laitière*. Paris: Nathan.

Minagawa, M. & Wada, E. (1984). Stepwise enrichment of ^{15}N along the food chain: further evidence and the relation between δ^{15}N and age. *Geochimica et Cosmochimica Acta* **48,** 1135–1140.

Peske, L. (1994). Contribution to the beginning of milking in Prehistory. *Archeologishe rozhledy* **46,** 97–104.

Schoeninger, M. J. & DeNiro, M. J. (1984). Nitrogen and carbon isotope composition of bone collagen from marine and terrestrial animals. *Geochimica et Cosmochimica Acta* **48,** 625–639.

Steele, K. W. & Daniel, R. M. (1978). Fractionation of nitrogen isotopes by animals: a further complication to the use of variations in the natural abundance of ^{15}N for tracer studies. *Journal of Agricultural Science* **90,** 7–9.

Tieszen, L. L. (1991). Natural variations in the carbon isotope values of plants: implications for archaeology, ecology, and paleoecology. *Journal of Archaeological Science* **18,** 227–248.

Tresset, A. (1996). *Le rôle des relations hommelanimal dans l'évolution économique et culturelle des sociétés des V-IVe millénaires en Bassin Parisien*. Thèse de doctorat, Université Paris 1.

Tresset, A. (1997). L'approvisionnement carné cerny dans le contexte néolithique du Bassin Parisien. In *La Culture de Cerny: Nouvelle économie, nouvelle société au Néolithique*. Actes du colloque de Nemours 1994. Mémoires du Musée de Préhistoire d'Ile de France 6, pp. 299–314.

van der Merwe, N. J. & Medina, E. (1991). The canopy effect, carbon isotope ratios and foodwebs in Amazonia. *Journal of Archaeological Science* **18,** 249–259.