International Journal of Osteoarchaeology, Vol. 7: 221–229 (1997)

Infant Taphonomy

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ABSTRACT In almost all living creatures, in Primates as well as in seventeenth–eighteenth century human populations, a high infant mortality is the rule; therefore, the scarcity of children's bones in cemeteries is suspicious from a demographic point of view. Though possible in some cases, sociological causes appear less important than the peculiar behaviour of infants' bones in the tomb. This paper examines the physico-chemical properties of infants' bones and their consequences for the preservation of archaeological samples; it proposes a new way of approaching distributions at death in the past. © 1997 by John Wiley & Sons, Ltd

Int. J. Osteoarchaeol. Vol. **7**: 221–229 (1997)
No. of Figures: 1 No. of Tables: 6 No. of References: 58

Key words: infant mortality; palaeodemography; bone minerals; taphonomy.

The problem

We know that cemetery excavation rarely yields numerous remains of very young children. This fact, although ordinary, is none the less surprising in many respects, if only because of the great variety of situations observed. Limiting our study to the remains of children under the age of 1 year, at least in sites where all other age classes are represented, we note that they may oscillate from zero to 25 per cent, and even 33 per cent, of the total buried: Fonyód, in Hungary, is an example of the first case,[1] Pines Point, in Arizona, or Lerna, in Argolid, illustrating the second case, respectively 23.8[2] per cent and 35.9 per cent.[3] If we leave aside these extreme cases, Table 1, which shows the data from 10 Hungarian cemeteries dating between the tenth and twelfth centuries, gives an idea of the situations encountered most often. It both expresses the amplitude of current variations and shows that the proportion of children under 1 year of age fluctuates frequently around 5 or 6 per cent.

Table 1. Proportion of newborns in some Hungarian cemeteries from the Middle Ages (tenth to twelfth centuries), by decreasing infant mortality. After Acsádi and Nemeskéri[4]

	Total buried (all ages: 0 –ω)	Number between 0 and 1 year	Proportion under 1 year (per cent)
Fiad-Kérpuszta	395	72	18.2
Zalavar village	141	19	13.5
Oroszvár	115	9	7.8
Halimba-Cseres	932	62	6.7
Zalavar castle	426	23	5.4
Skékesfehérvár Bikasziget	75	4	5.3
Somogy-Vasas	162	8	4.9
Skékesfehérvár Szárazrét	117	5	4.3
Zsitvabenesenyö	73	3	4.1
Zalavar chapel	177	5	2.8

CCC 1047–482X/97/030221–09$17.50
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Received 29 November 1996
Accepted 28 February 1996

Table 2. Infant mortality in a few 'pre-Jennerian' populations, after different authors (Saint-Laurent-des-Eaux, Auneuil;[5] France 1740;[6] India;[7] Geneva;[8] Sweden[9]).

	Out of 1000 live births, the proportion deceased beefore the age of 1 (per cent)
Saint-Laurent des Eaux (Sologne, France; seventeenth century)	32.6
France 1740–1749	29.6
Auneuil-en-Beauvaisis (France, seventeenth century)	28.8
India 1901–1911	28.7
Geneva 1625–1684	26.4
Sweden 1757–1759	22.7

With reference to the populations known from historical demography, at least to those who lived prior to the invention of vaccination by Jenner ('pre-Jennerian' populations), such proportions are surprisingly low. Formerly, the recording of infant deaths was not satisfactory, precisely because they were so common place. When we can determine relatively reliable figures, however, these are always high and only exceptionally fall below 25 per cent of live births, as shown by Table 2. After the age of 1, death rates decrease rather sharply, but not enough for half of children to reach adulthood (Table 3).

We are no longer used to such high death rates in infancy, which were normal in the past, just as among other living species. We can mention the hundreds of thousands of alevins from certain fishes, but it is more interesting to observe our relatives, the primates, at least those for whom a figure was published. To ensure a valid comparison, we shall partly discard infant mortality *sensu stricto* and consider mainly death prior to puberty.

Considering these figures, which largely integrate old Regime populations, we find it hard to imagine that the scarcity of infant remains in our cemeteries can be a true reflection of a demographic fact. If such were the case, we should have to admit the following: that, in our species, infant and child mortality, as far back as prehistory, had clearly broken away from what can be observed among wild animals; that this peculiarity had lasted almost unceasingly until the end of the Middle Ages; that then it had been replaced, between the sixteenth and eighteenth centuries, by a brief episode of the 'wild animals' type, precisely at the moment when parish registers came into use. This latter point is all the more strange because no author in this otherwise well-documented period seems to have noticed such a demographic seism. Indeed, the change would have been very swift, because the above-mentioned cemetery of Fonyód dates from between the fourteenth and sixteenth centuries.[1] In it, children under 5 years old number 2.5 per cent of the total, whereas, a century later, in Geneva, they will represent 44.9 per cent, almost 20 times as many, according to the parish registers.[8]

Table 3. Proportions of immature deaths in some species of primates, after different authors (for *Macaca*;[10] *Pan*;[11] *Propithecus* (Sifaka);[12] pre-Jennerian *Homo sapiens*: here, France 1740–1749[6]).

	Deaths per 1000 births	
	During the first year	Between birth and puberty
Macaca fuscata		600
Pan troglodytes (East Africa)		580
Propithecus verreauxi (Madagascar)	390	?
Macaca mulatta (Caribbee)		300
Pre-Jennerian *Homo sapiens*	300	550

A sociological interpretation?

Palaeodemographers, confronted by so marked and extended an anomaly, have been divided in opinion. A number, despite the above improbabilities, accepted without argument the scarcity of infants in cemeteries, to the point of calculating on this basis the life expectancy at birth in their cemetery population. Knowing how heavily infant mortality presses on life expectancy at

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birth, we have to be cautious as regards the quality of the results thus obtained. Others, such as Acsádi and Nemeskéri,[4] did not underestimate the difficulty. They refused to admit that children's bones may be worse-preserved in the earth than adults', and they looked for other explanations. Notably, they proposed the shallower depth of children's graves, which would have been more exposed to ploughing. Their demonstration is convincing (4, p. 239), and would have been even more so if applied to a site other than Fiad-Kérpuszta, the least problematic of all their cemeteries (Table 1 above). Besides, when reading their text carefully, we note that a shallow grave entails destruction of remains only in sites damaged by erosion; consequently, the plough is not involved alone. Their explanation is therefore not applicable for non-eroded sites, or for those sites (the overwhelming majority) where the proportion of infants is far from reaching that of Fiad-Kérpuszta.

Infanticide was suggested, and especially the exposure of new-borns. As a high infant mortality was common place, it was also thought that, in the past, a real funeral ceremony would not be organized for infants, at least by non-moneyed people: they no doubt would often get rid of the small remains in secret, as proved by a few findings, for instance from Gailhan[13] or from Sallèles-d'Aude.[14] What is awkward in such theories is their too universal character, suitable for all populations in the world; it is difficult to believe that all funeral customs would have been so closely related. Moreover, these theories cannot be admitted for medieval populations who punished infanticide and practised the baptism of neonates, because, even though the small bodies could not be interred anywhere else than in hallowed ground, their cemeteries yield as few infant remains as older necropoles. This is the case for the above Hungarian sites. Still more convincing is the Saint-Maclou parish, at Pontoise (France, Val-d'Oise), in the eighteenth century, a site where both a partial excavation of the cemetery and the relevant registers are available.[15] In its ground, where bones are well preserved, the rate of infants represents a fifth of what should have been found (see Table 5). Let us not imagine an *ad hoc* ritual, which would have excluded infants from the communal cemetery or relegated them into some recess of the cemetery. The funeral customs of the Pontoise population living 200 years ago are well known, and we know in particular how they would proceed with the small corpses whose baptism and decease had been duly entered into their parish register.

Table 4. Bone mineral and water content (after Vinz[19]).

Age groups	Age	Bone mineral content	Bone water content
I	0–2 weeks	64.3	19.8
II	3–5 months	62.9	20.5
III	7–11 months	62.9	19.4
IV	1.5–2.2 years	63.7	16.9
V	4–13 years	66.0	14.2
VI	18–40 years	66.8	12.1

A taphonomic process?

All these reflections recall us back unrelentingly to the hypothesis of differential destruction. This conjecture could account for the generality of the phenomenon and for the amplitude of the variation between sites, and even between individuals. More than 40 years ago, Angel believed that infant remains disappeared more readily than adults, he even rectified his palaeodemographic curves according to this conjecture, which he credited, but was unable to demonstrate.[3,16] Others, such as Nemeskéri, as seen above, shrank from the subjective aspect of such a rectification, preferring the supposedly more secure field of raw data from excavation. This is also the case of Moore *et al*,[17] who thought that, in this field, the deficiency of ethnographic data would have made it necessary to take the findings from cemeteries for gospel truth. Lastly, others — who express the current opinion — surprised by the relatively good preservation of infant bones when they are found, cannot imagine that most have been lost without trace: at this juncture, they would expect a majority of small remains to be left, even if in a bad state.

This expectation is rather unfounded, but it played an essential role in many anthropologists' reluctance to admit a taphonomic difference to the prejudice of infants. If such a difference does exist, then it almost involves a law of all or

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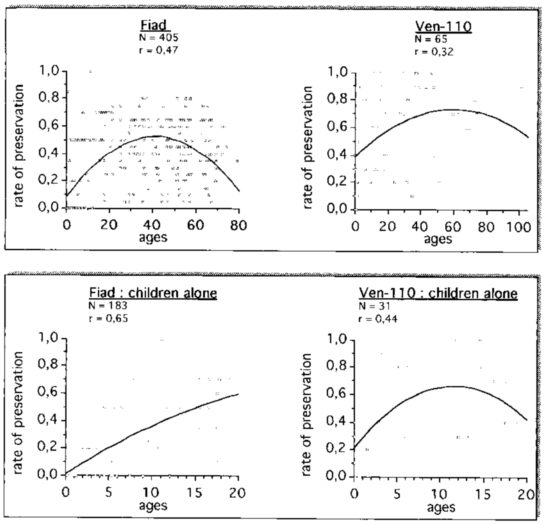

Figure 1. Quality of preservation of children's bones in two cemeteries where, by way of exception, their state had been carefully noted: Fiad-Kérpuszta, in Hungary, eleventh century;[48] Ven-110, in California, beginning of the present era.[51, pers. comm.]

nothing: either the bone remains or is lost. We say 'almost' because the preservation of extant bones is not always so good as believed (Figure 1). Besides, adult bones sometimes present anomalies of the same order, when some are found missing in association with others relatively well preserved. Consequently, we should examine more closely the bone characteristics during the first years of life, which are well-marked in the mineral component, the only one considered in this paper.

Bone mineral in infants

Quantitative data

The mineral content of bone evolves characteristically as a function of age.[18,19] Density, measured by pycnometer, and the mineral content, evaluated as percentage of ash, decreases after birth. It is maintained at a minimum value during the first year, and increases to reach the level of birth at the end of the second year. It continues to increase until adult age, but reaches values which are close to the later ones from the end of infancy.

The values of the mineral content and water content of bone observed by Vinz[19] are given in Table 4, for age groups in logarithmic increments.

In the same way, measurements of whole bones have shown that bones of children under 2 years old were less dense than fetal skeletons.[20] This is not peculiar to the human species: in all the mammals studied, the mineral content of the bone regresses at the beginning of the post-natal period, then develops with growth.[21,22]

Qualitative data

The distribution of the mineral substance at the microscopic scale is revealed by microradiography. In new-borns and infants, a regular distribution of the mineral content is never observed. On the contrary, we can observe adjoining areas of low and high mineralization over distances of a few microns.[23]

The size of crystals in the mineral matter, measured by infrared spectrophotometry[24] or by X-ray diffraction[25], is very small at birth and enlarges progressively until full adult age.

The orientation of crystals in the bone, measured by X-ray diffraction[26] or by neutron diffraction,[27] is ill-marked at birth and in the first 6 months, then grows progressively, to reach its maximum at about 3 years old.

The crystalline structure, drawn from the size of the unit cell in the lattice measured by X-ray diffraction,[25] is that of a hydroxy-carbonato-apatite at birth. The length of lattice parameter *a* and the volume of the unit cell lessen with age, as a function of ionic substitutions in the lattice. Hydroxyl ions are replaced mainly by fluoride, the concentration of which in the bone mineral is low in young children.[28]

Mineral matter and mechanical properties of bone

The compressive strength increases with the density of the bone.[29] Hardness, which means resistance to indentation and scratching, depends on density and on the size and orientation

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of crystals.[30–32] The resistance to abrasion grows with density and the orientation of crystals in the bone.[33] The tensile strength also increases with the density of the osseous matter.[34,35]

The relationship between the characteristics of mineral and the mechanical properties of bone explains why bone is brittle in young children. Its tensile strength is low,[36,37] and its compressive strength and hardness are extremely low (Vinz,[38] who observed that, below 1.9 years, hardness was so low that he was not able to measure it).

Mineral matter and physico-chemical properties of bone

The resistance of the bone to demineralization, or mineral dissolving in an acid medium, depends on many factors,[39] some of which are thermodynamic, especially the hetero-ionic substitutions in the crystal lattice which affect solubility. Other factors are kinetic, in particular porosity, which is inversely proportional to the degree of mineralization,[40] controlling directly ionic diffusion and the access of demineralizing agents to the mineral matter. Moreover, for a given volume of mineral matter, the smaller the crystals the larger the surface area in contact with demineralizing agents. Therefore, bone from young children is quite easily reached by these agents, because it is poorly mineralized, hence more porous, and because its small crystals present a large surface of attack *per* unit volume. Lastly, crystals do not contain much substituted fluoride in the lattice and are more soluble for this reason.[39]

Archaeological considerations

The low mineralization of bone and the qualities of the bone mineral in young children can explain the poor preservation of their skeletons in burials. Under some pressure, notably that of overlying sediments,[41] these skeletons poorly resist crushing into the ground. The bones are easily attacked by the acid products of organic matter decomposition[42] or by acid soils.[43]

Table 5. Mortality by ages in some ancient cemeteries, as compared with Ledermann's model life table net 100, Q=30, a plausible image of pre-Jennerian populations as a whole.[45] The values stated here are for 1000 at birth. They represent the manner in which an age group decreases through the course of time. (They are not death probabilities.)

Sites[b]		N	e_0[a]	0–12 months	1–4 years	0–4 years	5–9	10–14	15–19	20– ω: adults
Model life tables		(1000)	27	270	197	467	33	18	24	460
France 1740–1749		(40 000)	25	296	178	474	57	23	23	424
St Maclou registers		661	30	251	239	490	36	15	32	427
Fiad-Kérpuszta	(Late medieval)	404	26	189	131	320	57	35	74	514
Tournedos	(Early medieval)	1665	29	90	152	242	113	38	54	553
Serris	(Early medieval)	953	22	65	139	204	96	41	29	630
Ven-110	(Californian Indians)	95	24	63	42	105	95	31	53	716
St Maclou graveyard	(Modern; eighteenth century)	86	30	53	51	104	56	39	65	736
Feigneux	(Neolithic)	116	31	26	121	147	78	17	69	690
Loisy-en-Brie	(Neolithic)	164	25	24	91	115	91	43	55	695
Sézegnin	(Early medieval)	332	22	18	51	69	96	63	84	667
Fonyód	(Late medieval)	167	17	0	96	96	144	54	54	407

The sites are classified on the basis of their apparent infant mortality (between 0 and 1 year). The choice of cemeteries depends on their capacity and on how the ages of immature individuals were published: those for which the analysis cannot single out the groups stated in this table (0–1,1–4, 5–9, 10–14 and 15–19) were not used.

[a] Life expectancy at birth (except for 'Pontoise registers', where it is replaced by the mean life). In cemeteries, it is estimated by Bocquet and Masset's formulae,[46] on the assumption of stationarity.

[b] France 1740–1749 (sampling at 1/500);[6] Saint-Maclou at Pontoise (France, eighteenth century, Val-d'Oise), registers,[15] Saint-Maclou cemetery;[47] Fiad-Kérpuszta (Hungary eleventh century);[48] Tournedos (France, Eure, eighth to fourteenth centuries);[49] Serris (France, Seine-et-Marne, seventh to tenth centuries);[50] Ven-110 (USA, California, late middle period, i.e. beginning of Christian era);[51] Feigneux (France, Oise, late neolithic);[52] Loisy-en-Brie (France, Marne, late neolithic: between 2400 and 1800 BC);[53,54] Sézegnin (Switzerland, Geneva, fifth to sixth centuries);[55] Fonyód (Hungary, fourteenth to sixteenth centuries).[1]

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Are these remarks on bone structure and composition reflected at the taphonomic level?

Herein, we have had to put forward the first assumption that (young children's or even adults') bones can either remain or disappear, with few other possibilities. In addition, however, the above considerations strongly suggest the existence of a threshold, some time before the age of 3, separating two types of human remains: on one hand, an 'infant' type, with soft ill-structured bones, rich in interstitial water, poorly protected against chemical or mechanical aggressions; on the other, an 'adult' type, which seems to form within a few months, *grosso modo*, of when babies can walk. From this viewpoint, the outburst of apparent mortality, observed at several sites, towards the ages of 2 or 3, would first express a better visibility of children's death. The deadly effects of weaning, usually put forward in such cases, would have been less acute than was thought.

These assumptions appear to be confirmed by the site of Elko Switch, in Alabama, a cemetery of American blacks used between 1850 and 1920.[44] Each grave still contained a part of the coffin, the size of which, combined with that of the pit, supplies information about the deceased. Indeed, for reasons of time and money, it was out of the question to make oversized graves or pits. Where immature people are concerned, their height is, of course, linked to age. At Elko Switch, 15 of 52 tombs contained no bones, and none of the 15 tombs corresponded to an individual over 5 years of age. On the whole, 21 tombs belonged to the 0–5 age group, only six being occupied by bodies of which something was left.

Another confirmation is supplied by the manner in which the distribution of deaths by ages in cemetery populations deviates from model life tables. However different, these populations present the same anomaly at the same place. A sample is provided by Table 5.

We can see from Table 5 that this anomaly is often outstanding before the age of 1; its difference from model life tables diminishes in the 1–4 age group and disappears completely from the age of 5. Let us note in passing that this characteristic *a posteriori* justifies palaeodemographic estimators, whether Jackes' *Mean childhood mortality*[56] or Bocquet and Masset's *index of juvenility*,[46] because these estimators exclude children below the age of 5.

How many children have disappeared?

It would be difficult, albeit necessary, to appreciate the amplitude of such a shortage of infant remains *per* site. It is impossible to measure it directly, from the state of the remaining bones, because a sort of 'law of all or nothing' seems to be involved in the preservation. Only comparison with a norm appears to be possible, as illustrated by Table 6. Here also, the norm is Ledermann's model life table net 100, $Q=30$,[45] which we can see must be close to the mean death conditions pertaining to a few centuries ago (Table 5). In this table, the 'estimated total' corresponds to the sum of the age groups from 5 onwards, completed by the quantity that can be anticipated below this age, if relying upon the life table.

Between 0 and 1, we observe in Table 6 that both the shortage and its variation between sites

Table 6. Shortage of very young children in some cemetery populations, by comparison with Ledermann's model life table, net 100, Q=30 (1969). Classed by shortages in mortality beween 0 and 1 (MNI=minimum number of individuals, which means actual numbers in the cemetery; estimated total, see text).

	Total		0.0–0.99			1.0–4.99			5.0–9.99		
	MNI	Estimate	*N*	Anticipated	Deficit (%)	*N*	Anticipated	Deficit (%)	*N*	Anticipated	Excess (%)
Fiad-Kérpuszta[48]	404	450	76	122	38	52	89	42	23	15	+60
Ven-110[51]	95	150	7	40	83	9	30	70	9	5	+80
Loisy-en-Brie[53,54]	164	250	4	68	94	15	49	69	15	8	+88
Sézegnin[55]	332	580	6	157	96	17	114	85	32	19	+68
Fonyód[1]	167	280	0	76	100	16	55	71	24	9	+167

are considerable; both decrease between 1 and 5, to be regularly replaced by an excess. This excess is considerable as a percentage, but relates to reduced populations, hence far from compensates for previous shortages. It could be interpreted in different ways: it may mean a still higher death rate among children in general, or, on the contrary, a sort of retrieval for a lower rate in preceding age groups. The fact that it is well-marked in the Saint-Maclou cemetery, as compared with the registers of the same parish (Table 5), raises the question as to whether or not it is a bias in the appreciation of the mortality age towards the fifth year. This age estimation is based on tables of tooth eruption which are drawn up, of course, from modern populations: can such tables be perfectly applied to former populations? Might they not lead to abstracting, unduly, a small number of individuals from the 1–4 age group to transfer them to the following group?

Conclusion

We do not know whether the underrepresentation of very young children in almost all cemeteries can be explained mainly by taphonomy. In this sort of field, where experiments are not possible, it is difficult to provide 'proof' *sensu stricto*. We think, however, that we have contributed more than a mere set of presumptions to this point of view.

Even if we have not obtained the reader's agreement, we consider these presumptions so strong that it is now illicit to register uncritically, as if nothing had happened, infant mortality as it is shown in cemeteries. Effectively, if infant' bones behave in a characteristic manner from a taphonomic perspective, it is impossible to put forward, as was often the case, conclusions on the fatal effects of weaning. As for the calculations of life expectancy at birth, based on the death rates observed, they are considered illegitimate *ipso facto*. Thus are partly undermined the 'palaeodemographic life tables' arduously drawn up by many authors, from Hooton[57] and Vallois[58] to the present time. 'Palaeodemography' can expect a bright future if only it becomes aware of its restrictions.

Acknowledgements

It is a pleasant duty for us to express our warm gratitude to Mrs Patricia Lambert, from the University of California in Santa Barbara, who kindly conveyed to us the individual data from the Indian cemetery of Ven-110, in California, and of Elko Switch, in Alabama. The English translation of the text was by Jacqueline Gaudey, CRA, CNRS.

References

1. Deszö, Gy, Ery, K., Harsányi, L., Huszár, Gy, Nemeskéri, J., Nozdroviczky, S., Thoma, A., Tóth, T. and Wenger, S. Die spätmittelalterliche Bevölkerung von Fonyód. *Acta Hungarica*, 1963; 6.
2. Bennett, K. A. On the estimation of some demographic characteristics on a prehistoric population from the American Southwest. *American Journal of Physical Anthropology*, 1973; 39: 223–231.
3. Angel, J. L. Lerna. A Pre-classical Site in the Argolid, vol. II: the People. Washington DC: American School of Classical Studies at Athens, Smithsonian Institution Press, 1971.
4. Acsádi Gy, and Nemeskéri, J. History of Human Life Span and Mortality. Budapest: Akadémiai Kiadó, 1970.
5. Goubert, P. Beauvais et le Beauvaisis de 1600 à 1730. Contribution à l'histoire sociale de la France du XVII^{e} siècle. Paris: Ecole pratique des hautes études, SEVPEN, 1960.
6. Blayo, Y. La mortalité en France de 1740 à 1829. *Population* (numéro spécial 'Démographie historique'), 1975; 30: 123–142.
7. United Nations. Age and Sex Patterns of Mortality. Model Life Tables for Underdeveloped Countries. New York: UN, Department of Social Affairs, Population Branch, Population Studies 22, 1955.
8. Perrenoud, A. L'inégalité sociale devant la mort à Genève au XVII^{e} siècle. *Population* (numéro spécial 'Demographie historique'), 1975; 30: 221–243.
9. Wargentin, P. W. Tables of Mortality Based upon the Swedish Population Presented and Proposed in 1766. Stockholm: Thule Life Insurance Co., 1940.
10. Dunbar, R. I. M. Demography and Reproduction, In: *Primate Societies* (edited by B. B. Smuts, D. L. Cheney, R. M. Seyfarth, R. W. Wrangham and

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Th. T. Struhsaker). Chicago University Press, 1987: 240–249.

11. Nishida, N., Takasaki, H. and Takahata, Y. The Chimpanzees of the Mahale Mountains. Sexual and Life History Strategies. University of Tokyo Press, 1990: 63–97.
12. Richard, A. F., Rakotomanga, P. and Schwartz, M. Demography of *Propithecus verreauxi* at Beza Mahafaly, Madagascar: sex ratio, survival and fertility, 1984–1988. *American Journal of Physical Anthropology*, 1991; 84: 307–322.
13. Bedet, B., Duday, H. and Tillier, A. M. Inhumations de foetus, nouveau-nés et nourrissons dans les habitats protohistoriques du Languedoc: l'exemple de Gailhan (Gard). *Gallia*, 1991; 48: 59–108.
14. Duday, H., Laubenheimer, F. and Tillier, A. M. Sallèles d'Aude. Nouveau-nés et nourissons gallo-romains. Besançon: Centre de recherches d'histoire ancienne 144, série Amphores 3 (diffusé par "Les Belles Lettres", 95 bd. Raspail, F-75006 Paris).
15. Guy, H. and Wabont, M. Contrôle des estimateurs en paléodémographie à l'aide des registres de la paroisse Saint-Maclou à Pontoise. *Bulletins et Mémoires de la Société d'Anthropologie de Paris* (to be published).
16. Angel, J. L. The basis of paleodemography. *American Journal of Physical Anthropology*, 1969; 30: 427–438.
17. Moore, J. A., Swedlund, A. C. and Armelagos, G. J. The use of life-tables in paleodemography. In: *Populations Studies in Archaeology and Biological Anthropology. A Symposium* (edited by A. C. Swedlund). *Society for American Anthropology, Memoir*, 1975; 30: 57–70.
18. Dickerson, J. W. T. Changes in the composition of the human femur during growth. *Biochemical Journal*, 1962; 82: 56–61.
19. Vinz, H. Untersuchungen über die Dichte, den Wasser- und den Mineralgehalt des kompakten menschlichten Knochengewebes in Abhängigkeit vom Alter. *Morphologisches Jahrbuch*, 1970b; 115: 273–283.
20. Trotter, M. and Hixon, B. B. Sequential changes in weight, density, and percentage ash weight of human skeletons from an early fetal period through old age. *Anatomical Record*, 1974; 179: 1–18.
21. Burns, C. M. and Henderson, N. The mineral constituents of bone. II. The influence of age on the mineral constituents of bone from kittens and pups. *Biochemical Journal*, 1936; 30: 1207–1214.
22. Weidmann, S. M. and Rogers, H. J. Studies on the skeletal tissues. 5. The influence of age upon the degree of calcification and the incorporation of 32P in bone. *Biochemical Journal*, 1958; 64: 338–343.
23. Müller, K. H. G. Mikroradiographische Untersuchungen zur Mineralisation der Knochen Frühgeborener und junge Saüglinge. *Acta Anatomica Supplementum*, 1980; 64: 1–43.
24. Gebhardt, M. and Münzenberg, K. J. Kristallinitätsgrad und Mineralarten des Knochens in Abhängigkeit von Alter und Lokalisation. *Zeitschrift für Orthopaedie und ihre Grenzgebiete*, 1970; 108: 104–112.
25. Handschin, R. G. and Stern, W. B. Crystallographic lattice refinement of human bone. *Calcified Tissue International*, 1992; 51: 111–120.
26. Chatterji, S., Wall, J. C. and Jeffery, J. W. Changes in the degree of orientation of bone materials with age in the human femur. *Experientia*, 1972; 28: 156–157.
27. Bacon, G. E. and Griffiths, R. Texture, stress and age in the human femur. *Journal of Anatomy*, 1985; 143: 97–101.
28. Hellström, I. Studies on fluoride distribution in infants and small children. *Scandinavian Journal of Dental Research*, 1976; 84: 124–136.
29. Carter, D. R. and Hayes, W. C. Bone compressive strength: the influence of density and strain rate. *Science*, 1976; 194: 1174–1176.
30. Amprino, R. Investigations on some physical properties of bone tissue. *Acta Anatomica*, 1958; 34: 161–186.
31. Amprino, R. Microhardness testing as a means of analysis of bone tissue biophysical properties. In: *Biomechanical Studies of the Musculo-Skeletal System* (edited by F. G. Evans, *et al.*). Springfield: C. C. Thomas, 1961: 20–48.
32. Weaver, J. K. The microscopic hardness of bone. *Journal of Bone and Joint Surgery*, 1966; 48-A: 273–288.
33. Boyde, A. Dependence of rate of physical erosion on orientation and density in mineralised tissues. *Anatomy and Embryology*, 1984; 170: 57–62.
34. Wall, J. C., Chatterji, S. K. and Jeffery, J. M. The influence that bone density and the orientation and particle size of the mineral phase have on the mechanical properties of bone. *Journal of Bioengineering*, 1978; 2: 517–526.
35. Martin, R. B. and Ishida, J. The relative effects of collagen fiber orientation, porosity, density, and mineralisation on bone strength. *Journal of Biomechanics*, 1989; 22: 419–426.

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36. Hirsch, C. and Evans, F. G. Studies on some physical properties of infant compact bone. *Acta Orthopaedica Scandinavica*, 1965; 35: 300–313.
37. Currey, J. D. and Butler, G. The mechanical properties of bone tissue in children. *Journal of Bone and Joint Surgery*, 1975; 57-A: 810–814.
38. Vinz, H. Die Änderung der Festigkeitseigenschaften des kompakten Knochengewebes in Laufe der Altersentwicklung. *Morphologisches Jahrbuch*, 1970a; 115: 257–272.
39. Baud, C. A., Bang, S. and Very, J. M. Minor elements in bone mineral and their effects on its solubility. *Journal de Biologie Buccale*, 1977; 5: 195–202.
40. Strandh, J. and Norlen, H. Distribution per volume bone tissue of calcium, phosphorus and nitrogen from individuals of varying ages as compared with distribution per unit weight. *Acta Orthopaedica Scandinavica*, 1965; 35: 257–263.
41. Shipman, P. Life History of a Fossil. An Introduction to Taphonomy and Paleoecology. Cambridge: Harvard University Press, 1981.
42. White, E. M. and Hannus, L. A. Chemical weathering of bone in archeological soils. *American Antiquity*, 1983; 48: 316–322.
43. Gordon, C. C. and Buikstra, J. E. Soil pH, bone preservation and sampling bias at mortuary sites. *American Antiquity*, 1981; 46: 566–571.
44. Shogren, M. G., Turner, K. R. and Perroni, J. C. Elko Switch Cemetery: an Archaeological Perspective. The University of Alabama, Alabama State Museum of Natural History, Division of Archaeology, Report of Investigations 58, 1989.
45. Ledermann, S. Nouvelles tables-types de mortalité. Paris: Presses universitaires de France (Institut national d'études démographiques, Travaux et documents cahier 53), 1969.
46. Bocquet, J. P. and Masset, C. Estimateurs en paléodémographie. *L'Homme*, 1977; XVII (4): 65–90.
47. Cocquerelle, S. Etude paléodémographique des sépultures de Saint-Maclou, Val d'Oise. Mémoire de maîtrise, université Paris-I, 1993.
48. Acsádi, Gy, Nemeskéri, J. and Harsányi, L. Analyse des trouvailles anthropologiques du cimetière de Kérpuszta (XI^{e} siècle) sous l'aspect de l'âge (Etude paléodémographique). *Acta Archaeologica Academiae Scientiarum Hungaricae*, 1959; 11: 419–455.
49. Guillon, M. Val-de-Reuil: Chapelle Sainte Cécile de Portejoie. *Bilan scientifique, SRA haute Normandie*. Rouen, ministère de la Culture, 1993: 45–47.
50. Guy, H. Principes méthodologiques appliqués à la paléodémographie d'un cimetière du haut Moyen Age (Serris, Les Ruelles, Seine-et-Marne). *Les nouvelles de l'archéologie*, 1995; 59: 39–45.
51. Walker, P. L., Johnson, J. R. and Lambert, M. Age and sex biases in the preservation of human skeletal remains. *American Journal of Physical Anthropology*, 1988; 76: 183–188.
52. Bendezu Sarmiento, J. La grotte sépulcrale Seine-Oise-Marne du "Larris Goguet" à Feigneux (Oise): étude des sujets immatures. Mémoire de l'Université Paris I, 1996.
53. Bocquet-Appel, J. P. L'hypogée néolithique de Loisy-en-Brie (Marne), lieu-dit Les Gouttes d'Or. L'interprétation paléodémographie. *Préhistoire et protohistoire en Champagne-Ardenne*, 1994; 18: 55–60.
54. Bocquet-Appel, J. P. and Bacro, J. N. The estimates of some demographic parameters in a neolithic rock-cut chamber (ca. 2000 B.C.) using interactive techniques for aging and demographic estimators. *American Journal of Physical Anthropology*, 1997; 102: 1–7 .
55. Simon, C. Nécropole de Sézegnin (Avusy, Genève), nécropole de Thoiry (Ain, France): étude anthropologique et paléodémographique. Thèse de l'université de Genève et *Archives suisses d'anthropologie générale* 46, I, 1982: 77–174.
56. Jackes, M. The mortality of Ontario archaeological populations. *Canadian Review of Physical Anthropology*, 1986; 5: 33–48.
57. Hooton, E. A. Indians of Pecos Pueblo. A Study of their Skeletal Remains. New Haven: Yale University Press, 1930.
58. Vallois, H. V. La durée de la vie chez l'Homme fossile. *L'Anthropologie*, 1937; 47: 499–532.

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