

# The Mesolithic–Neolithic Transition in Portugal: Isotopic and Dental Evidence of Diet

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Paired radiocarbon (AMS) and stable isotope ( $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$ ) analyses of human bone collagen from Mesolithic and Neolithic Portuguese skeletons suggest a marked change of diet just prior to 7000 BP at the Mesolithic–Neolithic transition. The Mesolithic diet was based on foods of both marine and terrestrial origins, while the Neolithic diet was more dependent on terrestrial food sources. A linear correlation trend between  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  for the Mesolithic samples implies that the marine component of their diet was isotopically homogeneous, and consisted either of a well-defined mixture of several species, or a single species that was consistently exploited. Changes in the rate and type of dental attrition and differences in dental pathology confirm that a change of diet was established by 7000 BP, but suggest that the trend had been initiated soon after 8000 BP.

**Keywords:** PORTUGAL, MESOLITHIC-NEOLITHIC TRANSITION, PALAEODIET, STABLE ISOTOPES,  $\delta^{15}\text{N}$ ,  $\delta^{13}\text{C}$ , MARINE FOODS, DENTAL ATTRITION, DENTAL PATHOLOGY.

## Introduction

The transition from the Mesolithic to the Neolithic in western Europe is generally characterized by a shift in subsistence from foraging and fishing to agriculture. The transition is usually recognized in archaeological sites through changes in artefact assemblages, faunal and floral remains and settlement patterns (e.g. Chapman, 1985; Price, 1987). Very little attention has been paid to the biological characteristics of the human populations involved, although a variety of hypotheses based on modern genetic data have been proposed to account for the spread of Neolithic economies (e.g. Ammerman & Cavalli-Sforza, 1984; Sokal, Oden & Wilson, 1991).

In Portugal, the distinction between the Mesolithic and the Neolithic is defined almost exclusively on the basis of artefact assemblages from a limited number of coastal and near-coastal sites (Veiga Ferreira & Leitão, 1981). Several of these, excavated in the 19th century, contained large samples of human skeletal remains which were never studied in detail. Attribution of these

remains to either the Mesolithic or the Neolithic has been based almost exclusively on the associated artefacts rather than on economic criteria or direct dating. Most Neolithic remains come from ossuary caves and no associated settlements have been found and excavated with modern techniques. There is thus an almost total absence of palaeoeconomic data for the Neolithic (see Zilhão, 1988, 1990, 1993; LeGall *et al.*, 1992; Straus *et al.*, 1992). This contrasts markedly with the Mesolithic situation in which the dead were buried, as individuals, within occupation middens, analyses of which have given a reasonably clear picture of the animal component in the diet of these Mesolithic groups. Therefore, while  $^{14}\text{C}$  dating of the Neolithic human remains allows us to fix them in the temporal sequence, we cannot yet reconstruct the palaeoeconomy of Neolithic populations.

In this paper we present evidence from two data sets. Firstly, we examine chronologically-controlled stable isotopic palaeodiet studies which allow us to discuss the relative contribution of marine and terrestrial resources to the diets of these peoples. We have found clear evidence of a shift away from a heavily

marine-based economy through the period from 8500 to 4500 BP.

Stable isotopic analyses of human bone collagen can be used to reconstruct the isotopic composition of the diet (DeNiro & Epstein, 1978, 1981; Schwarcz & Schoeninger, 1991; Schoeninger & Moore, 1992). The  $^{13}\text{C}/^{12}\text{C}$  and  $^{15}\text{N}/^{14}\text{N}$  ratios of foods vary sufficiently that it is possible to determine the proportions of these foods in a human diet from the corresponding isotope ratios of fossil tissues. Bone collagen is the longest surviving organic tissue, and can be extracted from bones up to several thousands of years in age. The isotopic compositions of C and N in collagen are offset by constant amounts from the corresponding ratios in foods. When correction is made for this offset, the isotope ratio of the diet can be reconstructed. The first application of this method was based on the  $^{13}\text{C}$  enrichment of maize with respect to other native foods in temperate North America; changes in the proportion of corn in the diet of North American native populations could thus be inferred from  $^{13}\text{C}/^{12}\text{C}$  ratios (van der Merwe & Vogel, 1977; Schwarcz, Melbye & Katzenberg, 1985; White & Schwarcz, 1989). Similarly it is known that  $^{13}\text{C}$  and  $^{15}\text{N}$  are enriched in marine organisms with respect to terrestrial plants and animals. Carbon and nitrogen isotope ratios have thus been used to indicate consumption of marine resources (Chisholm, Nelson & Schwarcz, 1982; DeNiro, 1987; Lovell *et al.*, 1986; Minagawa & Akazawa, 1992). In this paper we shall also exploit isotopic differences between marine and terrestrial food sources.

Secondly, we show that independent evidence supporting the Mesolithic–Neolithic difference in diet is provided by data from the human dentitions, which also reflect diet and can be adduced as evidence of broad changes over time and space (if the geological and/or genetic backgrounds are held constant).

The analyses reported here were undertaken as part of an interdisciplinary project investigating the archaeology and human biology of the transition from foraging to agricultural economies in southern and central Portugal. Preliminary reports have been published (Lubell, 1984; Lubell & Jackes, 1985, 1988; Silva, Soares & Penalva, 1985; Lubell *et al.*, 1986; Meiklejohn, Jackes & Lubell, 1986; Jackes, 1988, 1992a; Jackes & Lubell, 1988, 1992; Meiklejohn, Baldwin & Schentag, 1988; Meiklejohn & Schentag, 1988; Lubell, Jackes & Meiklejohn, 1989).

## Isotopic Evidence of Diet

### *Materials and methods*

**Sample sites.** The sites from which our samples came are shown in Figure 1 and the data are given in Table 1. Moita do Sebastião, Cabeço da Arruda (hereafter Moita and Arruda), Fontainhas and Casa da Moura were first investigated in the 19th century and again in the 20th (for a history of investigations and

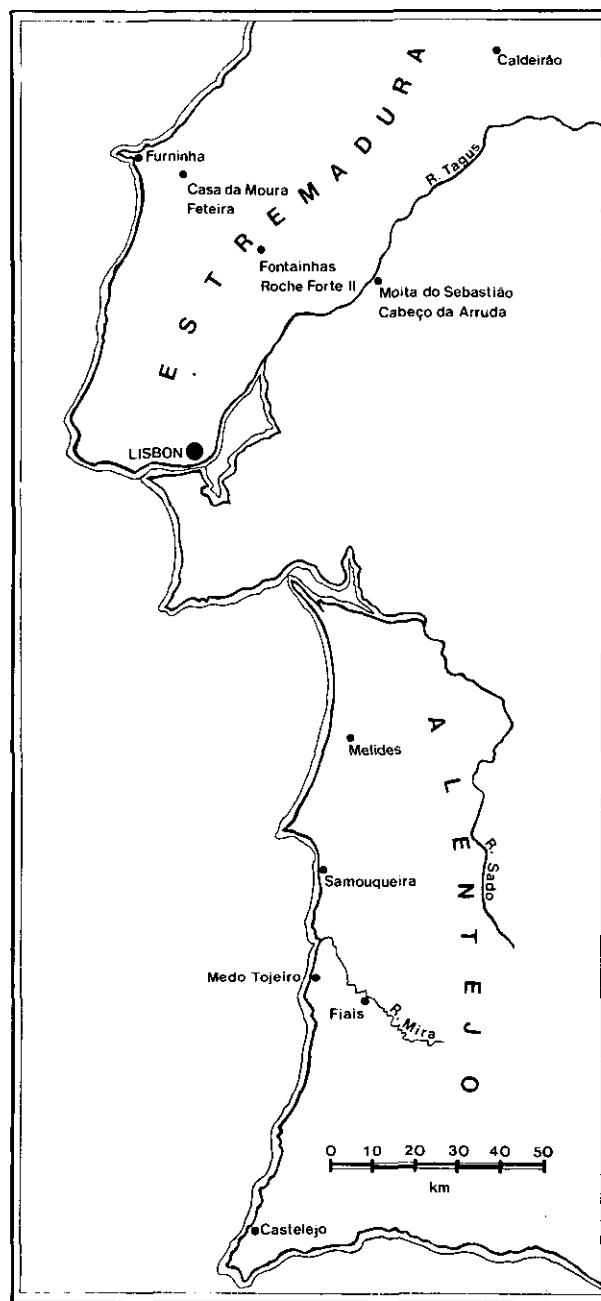


Figure 1. Map of central-western Portugal, showing locations of sites which were sampled in this study.

further references see Delgado, 1867; Roche, 1972a,b; Newell, Constandse-Westermann & Meiklejohn, 1979: 146–154; Straus *et al.*, 1988). Our samples for Moita, Arruda and Fontainhas come from the 19th-century collections housed at the Serviços Geológicos de Portugal in Lisbon. Previously, only limited studies of these materials had been undertaken (Lefèvre, 1973; Ferembach, 1974). The sample used for Casa da Moura 1 comes from a 1987 test (Straus *et al.*, 1988); the samples for Casa da Moura 2, 3 and 4 were

Table 1. Radiocarbon dates and stable isotope values for Mesolithic and Neolithic Portuguese samples of human collagen

Sample	Period	Lab. No.	Date bp	$\delta^{13}\text{C}$	$\delta^{15}\text{N}$	Cal. BP*		
						–1 $\sigma$	$\bar{X}$	+1 $\sigma$
Cabeço da Arruda (Ossada A)	M	TO-354	6970 $\pm$ 60	–19.0	12.2	7906	7769	7689
Cabeço da Arruda (Ossada D)	M	TO-355	6780 $\pm$ 80	–18.9	10.3	7681	7590	7522
Cabeço da Arruda (Ossada N)	M	TO-356	6360 $\pm$ 80	–15.3	12.5	7329	<b>7224</b>	7184
Cabeço da Arruda (Ossada III)	M	TO-360	6990 $\pm$ 110	–17.7	11.2	7929	7783	7679
Cabeço da Arruda (Ossada 42)	M	TO-359	6960 $\pm$ 70	–17.2	11.8	7909	7761	7683
Moita do Sebastião (Ossada CT)	M	TO-135	6810 $\pm$ 70	–15.3	13.4	7688	7597	7578
Moita do Sebastião (Ossada 22)	M	TO-131	7240 $\pm$ 70	–16.1	12.2	8078	8037	7942
Moita do Sebastião (Ossada 24)	M	TO-132	7180 $\pm$ 70	–16.8	11.9	8042	<b>7988</b>	7923
Moita do Sebastião (Ossada 29)	M	TO-133	7200 $\pm$ 70	–16.9	10.4	8057	<b>7989</b>	7929
Moita do Sebastião (Ossada 41)	M	TO-134	7160 $\pm$ 80	–16.7	11.2	8040	<b>7988</b>	7915
Samouqueira (H2)	M	TO-130	6370 $\pm$ 70	–15.3	16.5	7331	<b>7224</b>	7187
Casa da Moura 1 (1987 test)	N	TO-953	5990 $\pm$ 60	–19.6	8.5	6893	<b>6869</b>	6749
Casa da Moura 2 (1867 excavation)	N	TO-2092	4850 $\pm$ 100	–19.3	8.5	5726	5594	5470
Casa da Moura 3 (1867 excavation)	N	TO-2093	5070 $\pm$ 70	–19.2	9.5	5928	<b>5820</b>	5733
Casa da Moura 4 (1867 excavation)	N	TO-2094	5020 $\pm$ 70	–19.6	9.0	5901	<b>5794</b>	5657
Gruta do Caldeirão (Ea top)	N	TO-349	4940 $\pm$ 70	–19.6	8.8	5736	<b>5693</b>	5638
Gruta do Caldeirão (Ea base)	N	TO-350	5810 $\pm$ 70	–20.2	8.7	6731	6668	6537
Gruta da Feteira 1 (FET-227)	N	TO-352	4110 $\pm$ 60	–20.4	8.3	4822	<b>4660</b>	4532
Gruta da Feteira 2 (FET-1938)	N	TO-353	4570 $\pm$ 70	–19.1	8.9	5322	5297	5058
Gruta da Fontainhas	N	TO-358	4170 $\pm$ 60	–19.7	9.7	4838	<b>4724</b>	4571
Roche Forte II	N	TO-357	4480 $\pm$ 60	–19.7	8.9	5288	<b>5163</b>	4988
Cêrca do Zambujal 1 (Melides)	N	TO-2090	4420 $\pm$ 70	–19.7	7.6	5251	4989	4873
Gruta do Lagar 1 (Melides)	N	TO-2091	5340 $\pm$ 70	–14.9	13.1	6280	<b>6144</b>	5991

Period: M=Mesolithic; N=Neolithic.

\*Calibrations follow conventions established by the 12th International Radiocarbon Conference (Stuiver & Kra, 1986), and were calculated using CALIB, Version 2.0 (Stuiver & Reimer, 1986). In those instances where the slope of the calibration curve provides several possibilities for the calibrated mean, the average of all possibilities is given, in **bold italic**.

excavated in the 1860s (Delgado, 1867) and selected by Jackes in 1989. Samples from Feteira and Caldeirão were excavated by Zilhão (1984, 1992). The material from Samouqueira was recovered during our test excavations in 1984 (Lubell & Jackes, 1985). The sample from Roche Forte II was obtained during a test conducted in 1984 by E. Serrão on behalf of the Associação dos Arqueólogos Portugueses. The samples from the neighbouring caves of Zambujal and Lagares were excavated in the 1920s (Mello Nogueira, 1930) and selected by Jackes in 1989.

Moita and Arruda are Mesolithic shell middens located near Muge, northeast of Lisbon. At the time of occupation they were situated on the banks of tributaries to the Tagus estuary. Samouqueira, on the Alentejo coast south of Sines, is badly disturbed; the deposits appear to contain mixed materials of both Neolithic and Mesolithic date. Casa da Moura, Feteira, Fontainhas, Roche Forte II and Caldeirão are all Neolithic caves located in the Estremadura north of Lisbon. The first four appear to have been used exclusively as ossuaries; there is some evidence for occupation at Caldeirão although the Neolithic levels are disturbed (Zilhão, 1992). All are located in limestone regions: Fontainhas on the coast at Peniche, Casa da Moura and Feteira on the Cesareda Plateau a few kilometres to the east of Peniche, Roche Forte II on the Montejunto to the east of Torres Vedras, and Caldeirão further inland near Tomar (Figure 1).

Zambujal and Lagares are located in a calcareous sandstone outcrop at Melides, south of the Tagus near Santiago do Caçem.

The 20th-century researches at Moita and Arruda provided data on context and associations as well as several radiocarbon dates, but the Mesolithic status of the 19th-century collections was not certain (Newell, Constandse-Westermann & Meiklejohn, 1979), partly because of reports that Neolithic artefacts occurred at the sites (Veiga Ferreira, 1974). One priority of our research was, therefore, to date samples of human bone from the 19th-century collections housed at the Serviços Geológicos in Lisbon.

*Sample selection and preparation.* Skeletal remains from Moita and Arruda are almost always encrusted with a densely cemented matrix. While cleaning the Moita collections we observed variations in the colour, texture and hardness of this matrix. We suspected that these variations might represent different burial locations (and perhaps times) within the site, and therefore chose five samples, representing bones from each major variety of matrix, for dating. The dates clustered and energy dispersive X-ray analysis by SEM of the five varieties of matrix failed to show significant differences (Lubell & Jackes, 1985: 123–124). The samples for Arruda were therefore chosen at random, while samples from the other sites were either selected in consultation with the excavators or chosen

by Lubell and Jackes during analysis. All samples were cleaned mechanically: no preservatives or chemicals were used.

**Isotopic analysis.** Collagen was extracted from the bone samples using the modified Longin method, as described by Chisholm *et al.* (1983). Preliminary inspection of the bone suggested that, in general, it was relatively free of humic contaminants; we therefore did not pretreat the bone to remove humic material. Low levels of humic matter may have slightly decreased  $\delta^{13}\text{C}$  values but will have little effect on  $\delta^{15}\text{N}$ ; for samples with low collagen yields, humic contaminants may also cause slight lowering of  $^{14}\text{C}$  ages. Yields for these samples were generally high, however. Most of the isolated collagen samples were freeze-dried and given to the Isotrace Laboratory of the University of Toronto for AMS radiocarbon dating. The unused portions were then returned to McMaster for stable isotope analysis.

Two portions of each of the collagen samples were oxidized *in vacuo* in sealed glass tubes, using cupric oxide.  $\text{CO}_2$  was isolated from one portion for analysis of the  $^{13}\text{C}/^{12}\text{C}$  ratio while nitrogen was isolated from the other portion for  $^{15}\text{N}/^{14}\text{N}$  determination. The isotope ratios were reported in the usual  $\delta$ -notation:

$$\delta^{13}\text{C} = \left\{ \left[ \frac{(R_c)_x}{(R_c)_s} \right] - 1 \right\} \times 1000 \text{ (‰)}$$

$$\delta^{15}\text{N} = \left\{ \left[ \frac{(R_n)_x}{(R_n)_s} \right] - 1 \right\} \times 1000 \text{ (‰)}$$

where  $R_c = ^{13}\text{C}/^{12}\text{C}$ ,  $R_n = ^{15}\text{N}/^{14}\text{N}$ , and  $x$  = the sample,  $s$  = a standard. For  $\delta^{13}\text{C}$ , the standard is PDB, while for  $\delta^{15}\text{N}$ , it is atmospheric  $\text{N}_2$ . The precision of analysis of  $\delta^{13}\text{C}$  is  $\pm 0.1\text{‰}$ ; for  $\delta^{15}\text{N}$ ,  $\pm 0.2\text{‰}$ .

The reliability of stable isotopic analyses of collagen depends somewhat on the degree of preservation of collagen, which can be estimated from its C/N ratio (DeNiro, 1985). We have analysed representative portions of those collagens for which sufficient material remained after  $^{14}\text{C}$  and stable isotopic analysis. These data (Table 1) suggest that the samples were reliable. Well-preserved collagen should display a C/N ratio between 2.9–3.6 (DeNiro, 1985). All samples tested fell within the prescribed range, suggesting that the collagen samples are generally well-preserved.

#### Analytical data

The stable isotopic and radiocarbon data are given in Table 1 and presented graphically in Figures 2, 3 & 4. Several trends are apparent:

1. The  $^{14}\text{C}$  data confirm the age assignments based on cultural data. All samples from Moita and Arruda are of Mesolithic age, and fit the chronology for southwestern Europe (Chapman, 1985; Gilman, 1992; Lubell *et al.*, 1986; Meiklejohn, Jackes & Lubell, 1986; Price, 1987; Zilhão, 1993). The Samouqueira human remains are Mesolithic although later materials are present at this site. The

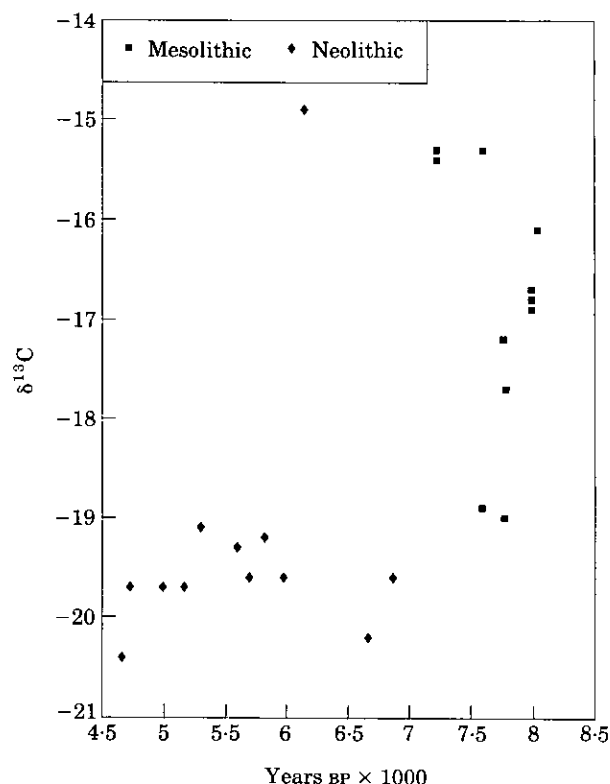


Figure 2. Variation of carbon isotopic ratio of bone collagen with time.

Neolithic age of the ossuary collections and all other sites suggested as Neolithic is confirmed.

2. Both  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  are lower and more uniform after about 7000 BP. The  $\delta^{13}\text{C}$  values actually appear to decrease toward the present whereas the  $\delta^{15}\text{N}$  data show no correlation with age in the Mesolithic sites. The separation in isotopic compositions between the earlier and the later sites confirms that there was a major shift in subsistence pattern at about 7000 BP. We also note that, after this date, both  $\delta^{15}\text{N}$  and  $\delta^{13}\text{C}$  of bone collagen became extremely uniform. Thus, it seems as if the pre-7000 economy was more diversified, leading to a wide range of isotopic compositions that do not overlap the more limited range of the Neolithic.
3. Nitrogen and carbon isotope ratios are linearly correlated (Figure 4); the only notable outlier is Samouqueira, which gives much higher  $\delta^{15}\text{N}$  values than expected for its  $\delta^{13}\text{C}$  value. One sample shown here (from Lagares) is anomalous: the  $\delta^{15}\text{N}$  and  $\delta^{13}\text{C}$  values for this Neolithic sample group with those from Mesolithic individuals.

**Isotopic evidence of multiple food sources.** Figure 4 shows a good linear correlation between  $\delta^{15}\text{N}$  and  $\delta^{13}\text{C}$ . A simple explanation of this trend is that the individuals whose collagen is plotted along it were eating varying proportions of two isotopically distinct,

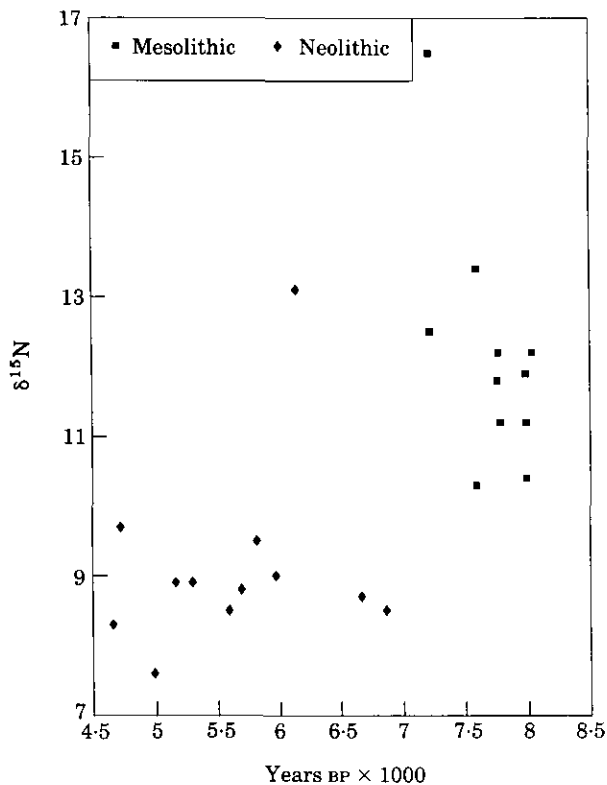


Figure 3. Variation in nitrogen isotopic composition of bone collagen with time.

homogeneous food sources. The  $\delta$ -values of the endpoints of this trend line are as follows:

	$\delta^{13}\text{C}$	$\delta^{15}\text{N}$
Low end (T)	$-20.0\text{‰}$	$8.5\text{‰}$
High end (M)	$-15.0\text{‰}$	$13.0\text{‰}$

The low end-point, T, is approximately the isotopic composition expected for the collagen of a human consuming a mixture of two possible foods: flesh of herbivores feeding on  $\text{C}_3$  plants; and  $\text{C}_3$  plants themselves (Schwarcz & Schoeninger, 1991). We have labelled this point T to signify that it marks the position of consumers of a terrestrial diet. The upper endpoint marks an isotopic composition typical of consumers of a wholly marine diet (Chisholm, Nelson & Schwarcz, 1982), and is labelled M.

Collagen from individuals whose diet had consisted solely of either purely terrestrial or purely marine foods would plot along this trend line either at the respective ends of the line-segment defining this trend, or possibly at points which lay on linear extensions of the segment, beyond the limits of the actual data set (Schwarcz, 1991), since individuals at the T end-point may have been consuming small quantities of marine foods and vice versa.

The isotopic compositions of the foods that could have been consumed by these individuals can be esti-

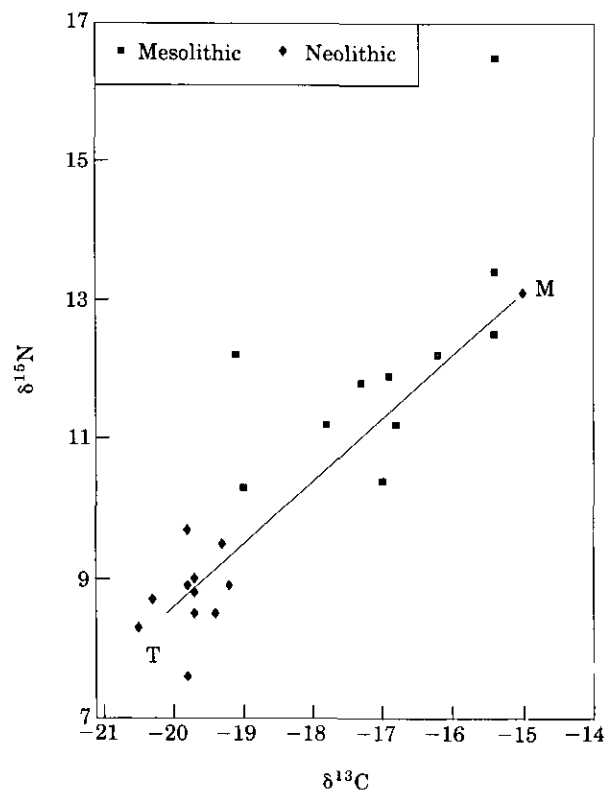


Figure 4. Correlation between  $\delta^{15}\text{N}$  and  $\delta^{13}\text{C}$  for Portuguese collagen samples. The points M and T represent proposed endpoints representing collagen of individuals consuming a pure marine or terrestrial diet, respectively (see text).

mated if we correct the  $\delta$ -values of the collagen for isotopic fractionation. Collagen is enriched by about  $5\text{‰}$  with respect to the food consumed (van der Merwe & Vogel, 1977). This offset in  $\delta^{13}\text{C}$  is due to isotopic fractionation between collagen and the carbon of the whole body. The nitrogen isotope ratio of consumers is similarly enriched by about  $3\text{--}4\text{‰}$  with respect to the food which they consumed; this is called the trophic level effect (Schoeninger, 1985).

Figure 5 shows the  $\delta^{15}\text{N}$  and  $\delta^{13}\text{C}$  fields of various food resources available to human beings. We have replotted on this figure the trend-line from Figure 4 after correcting for the respective offsets between food and collagen. We see that T lies, as expected, in the field of the flesh of  $\text{C}_3$ -consuming herbivores, although the actual diet could have included  $\text{C}_3$  plants as well. The other end of the trend, M, lies within the range of marine animal foods, well below the top of the marine trophic level (marine carnivores). Various types of marine food might have this value, including certain types of marine invertebrates such as mussels and clams. Further isotopic analyses of mollusc and fish remains from these sites are needed to specify the actual marine foods that were consumed, although the broad range is known (see below).

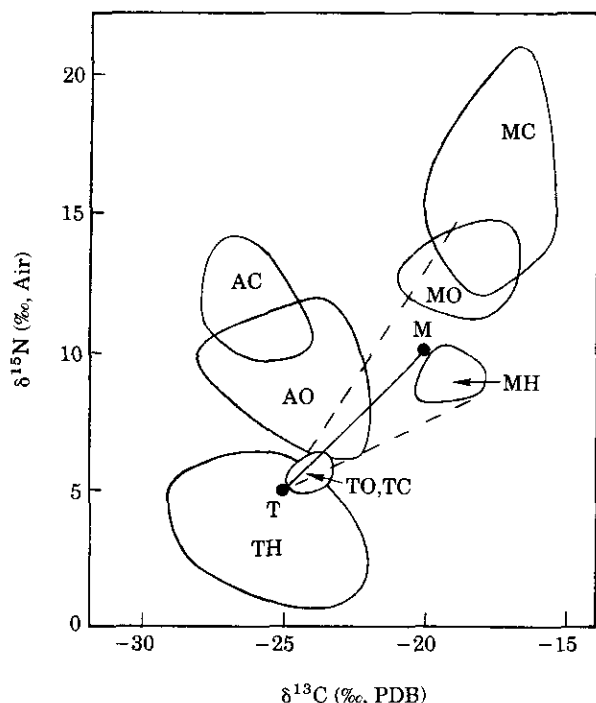


Figure 5. Plot of  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  of principal nutrients of human populations, modified from Schwarcz (1991). The isotopic trend for the Portuguese Mesolithic and Neolithic populations is superimposed, offset by the appropriate fractionations between diet and bone collagen (+5‰ for  $\delta^{13}\text{C}$ ; +3‰ for  $\delta^{15}\text{N}$ ). The dotted lines show how the data would have appeared if Mesolithic individuals had consumed marine foods of varying trophic level (see text). M, T, A=marine, terrestrial, aquatic; H=herbivore, O=omnivore, C=carnivore.

*Secular trends in food consumption.* The plots of  $\delta$ -values versus  $^{14}\text{C}$  age for the archaeological samples (Figures 2 & 3) clearly show a decrease in utilization of marine resources through time. This is also shown qualitatively in Figure 4 by the placement of Neolithic and Mesolithic samples along the trend between the marine and terrestrial food components, with the Neolithic samples clustered near the terrestrial end. The temporal trends for carbon and nitrogen are quite similar in that both show an abrupt decrease at the Mesolithic–Neolithic boundary. The wide range in both  $\delta$ -values in the Mesolithic might be interpreted as indicating that individual Mesolithic consumers ate a wide range of marine foods which were somewhat dispersed in their  $\delta^{15}\text{N}$  values depending on their trophic level (Figure 5). However, the well-defined linear trend in Figure 4 suggests rather that this variation is due to consumption of differing proportions of only two types of food:  $\text{C}_3$ -based terrestrial foods (herbivore flesh and plants); and a single, well-defined marine nutrient source with an isotopic composition near point M. Consumption of variable amounts of marine foods of varying trophic level would have caused the Mesolithic data points to fan out at higher  $\delta^{15}\text{N}$  values (broken lines on Figure 5).

Another possible explanation for the well-defined position of point M is that it represents a mixture of various marine foods which were always consumed in a certain well-defined proportion. The present data cannot distinguish between these hypotheses. The second model is supported by evidence from food refuse of more than one kind of marine food (e.g. Lentacker, 1986, 1991). In either case, some of the variation in  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  of the Mesolithic population may have been due to variation in the proportions of marine and terrestrial resources available at living sites for individual Mesolithic consumers.

There appears to be a decrease in diversity of food choices in the Neolithic, as indicated by the uniform  $\delta^{15}\text{N}$  and  $\delta^{13}\text{C}$  values of collagen over the last 3000 years of the record. This is somewhat illusory, however. A population committed to consuming only terrestrial resources (possibly including domesticated animals) would show very little range in  $\delta^{13}\text{C}$  as long as  $\text{C}_3$  grasses predominated in the browsing areas of the herbivores. On the other hand, the very uniform  $\delta^{15}\text{N}$  values around 9‰ through this interval are indicative of a population getting most of its protein from herbivore flesh and relatively little from plant foods. Similar values are observed for Iron Age burials near Rome (Schwarcz & Sestieri, in prep.), and for Neolithic human remains from southern Portugal (Schwarcz in Straus *et al.*, 1992). Not much fish of either marine or aquatic (riverine) origin could have been consumed, although this may not have been the case at all Neolithic sites as LeGall *et al.* (1992) have shown.

*Archaeozoological and palaeobotanical evidence of food sources.* The three Mesolithic middens at Muge (Moita, Arruda and Cabeço de Amorera) contain evidence for the consumption of both marine and terrestrial animal foods. Roche (1972a: 135–137) and Lentacker (1986, 1991) describe faunal assemblages with a wide range of species including amphibians, reptiles and birds. Based on fragment counts (Lentacker, 1991: tables 1–4), the most abundant remains in the Muge sites are *Cerastoderma* (cockles), *Oryctolagus* (rabbits), *Sus* (wild boar) and *Cervus* (red deer). At the sites with perhaps more careful (20th-century) excavation (Amoriera and Arruda), *Myliobatus* (the eagle ray), Brachyura crustaceans and mugilid saltwater fish are also well represented.

Mesolithic sites along rocky portions of the Atlantic coast such as Castelejo (BM-2276R,  $8220 \pm 120$  bp; Beta-2908,  $7450 \pm 90$  bp: both on marine shell) and Samouqueira attest to the occasional (seasonal?) importance of *Mytilus* (mussels) and *Patella* (limpets) (Lentacker, 1991).

Most Mesolithic sites are, however, known from estuarine situations equivalent to those found at Muge, and these appear to have functioned as more-or-less permanently-occupied base camps. At Pandeiro, near Toledo north of Lisbon, a single  $^{14}\text{C}$  analysis of

mammal bone of  $7800 \pm 110$  bp (TO-707), dates a midden containing abundant remains of cockles (*Cerastoderma*). A small sample of these were analysed by Lello (1990), who concluded that they had been collected between mid-August and early October, but that other indications suggested this site had served as a base camp. At Fiais, near Odemira in the Alentejo, excavations by Lubell and Arnaud in 1986 revealed an extensive midden deposit that included abundant remains of oyster (*Ostrea*) within a concentrated butchering activity area which contained large numbers of bones of red deer, wild boar, roe deer, aurochs and lagomorphs. Rowley-Conwy (per. comm. 1987) believes this site may represent a base camp occupied for perhaps six months from late spring through autumn. Three samples place the age of this site between 8000–7000 BP (TO-705,  $6840 \pm 70$  bp [charcoal]; TO-706,  $6260 \pm 80$  bp [mammal bone]; TO-806,  $7010 \pm 10$  bp [charcoal]). Fiais can eventually be compared to the series of Mesolithic middens found along the Sado River, somewhat to the north in the Alentejo (Arnaud, 1989; Gonzales Morales & Arnaud, 1990) as well as to the nearby site of Vidigal (Straus, 1991).

There is no direct evidence for the contribution of plants to the Mesolithic diet at these sites. Palmer (1987) identified fluorescing rings in the human bone from Moita which she interprets tentatively as the result of the inclusion of tetracycline during bone growth. The source of this must have been dietary, and Palmer considers the possibility that plant foods such as pine nuts, pistachios and acorns could have been stored and that fruits and grains might have been fermented (see also Gasco, 1979: 373; Clark, 1987: 300). Meiklejohn, Baldwin & Schentag (1988) and Jackes, Lubell & Meiklejohn (1991) have shown caries rates to be very high in the Muge dentitions (particularly at Moita, see below) and suggest that the consumption of dried fruit such as figs produced the observed dental pathologies.

Evidence for diet at Neolithic sites is much less well documented; only a few Portuguese Neolithic habitation sites have been excavated, and only four (Caldierão: Zilhão, 1992; Vidigal in Alentejo: LeGall *et al.*, 1992 and Straus, 1991; and two sites in the Algarve, Goldar and Igrejinha dos Soidos: Straus *et al.*, 1992) using fully modern methods of recovery. At Caldeirão, Rowley-Conwy (1992) identified both wild (*Sus scrofa*) and domestic (*Ovis*, *Bos*) mammalian species in the Early Neolithic levels.

Evidence from the Early Neolithic coastal site of Medo Tojeiro (BM-2275R,  $6820 \pm 140$  bp on marine shell Beta-11723,  $5420 \pm 160$  bp on charcoal) indicates a continued but seasonal dependence into the Neolithic on marine resources, with major emphasis on *Mytilus* and *Patella* along this rocky coast.

At Vidigal (Straus, 1991; LeGall *et al.*, 1992), the Neolithic levels in the cave have produced remains from both cartilaginous and bony fish. The marine specimens are tentatively identified to the genus

*Mustelus*, and there is also a member of the freshwater genus *Abramis* present.

Lentacker (1991) discusses Barrosinha, a Neolithic estuarine site about 30 km north of Melides, dated  $4730 \pm 50$  bp (lab identification unknown). This site contains evidence of ovicaprids, yet the faunal remains attest to the importance of *Venerupis* (peppery furrow shell) and *Solen* (razor clam) amongst the marine bivalves, sparids among the fish, and birds and rabbits.

Goldra, near Faro in the Algarve (Straus *et al.*, 1992), also contains abundant marine molluscs, especially *Scobicularia* and *Solen* (both clams), as well as ovicaprids, *Sus* (possibly domestic) and domestic cow. The Middle Neolithic at Goldra is dated to  $4990 \pm 320$  bp (SMU-2197) and provides the only palaeobotanical or palynological studies of Neolithic occupation deposits yet available. Deforestation suggests clearing for husbandry and agriculture and a cereal pollen grain is present, but it appears that wild olives, pistachios and acorns were also available and thus may have been consumed.

Fluorescent labelling reappears in the Neolithic at Melides, with very strong linear markings in rib cortical bone, suggesting reliance on stored foods following a period of reduced bone deposition. Seasons of reduced food supply leading to growth arrest seems the most likely explanation. The labelling is very clearly not the result of post-mortem changes which have been intensively studied in the Portuguese samples (Jackes, 1990; Jackes, Barker & Wayman, 1992).

### Discussion

The Mesolithic Portuguese seem to have lived on estuaries and streams within 10–20 km of the present sea coast. Sea level changes may mean that the coast was closer in Mesolithic times (see discussion in Lello, 1990). In such areas we have large open-air middens into which the full range of dead were buried: neonates (some not even full term), children, young and old adults. At the very least, these cemeteries indicate base camps. The evidence of the human skeletons is consistent with that afforded by the food debris. Overall, the three Muge middens indicate year-round habitation (Lentacker, 1991: 235). These were long-term living sites (over periods of at least four or five hundred years), garbage dumps and burial grounds all in one, maintained on estuaries and tributary streams, protected in the winter. Such estuary base camps are consistent with what is known ethnographically and archaeologically of populations relying on the continual presence of rich molluscan populations (Waselkov, 1987). The existence of satellite camps would introduce heterogeneity; diets varying according to whether spring and summer coastal camps were on rocky or sandy shores and on movement to areas particularly good for hunting boar and red deer in the summer and autumn.

The single individual from Samouqueira, found buried in a scatter of food remains on a high cliff far above a very rocky shore, indicates that some heterogeneity may be idiosyncratic. This adult male was crippled—an arm and a foot show extensive post-traumatic infection and deformity. All other Mesolithic samples derive from two similar and neighbouring sites, Moita and Arruda.

Our data set is inadequate for discussions of gender and age differences in access to foodstuffs: our Mesolithic sample consists of six adult males, one juvenile male, three adult females and one adult of indeterminate gender. There is no discernable differentiation among these in terms of the stable isotopes.

Lentacker (1986) estimates the percentages of mammalian versus non-mammalian foods as being approximately equal in their contributions to the later Muge diets (Arruda and Amoreira), and it is possible that the earlier Moita diet was less dependent on terrestrial sources. This change may be demonstrated by emphasizing the central tendencies of the stable isotope values for the Mesolithic sites. Four of the Moita samples cluster around a mean date of 7997 BP, and these have mean  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  values of  $-16.6$  and  $11.4$  respectively. The equivalent Arruda cluster is looser, dated at 7699 BP, and has precisely the same mean  $\delta^{15}\text{N}$  value as Moita ( $11.4$ ), but a  $\delta^{13}\text{C}$  mean of  $-18.2$ . Each site has one individual, considerably more recent than the others, with much lower  $\delta^{13}\text{C}$  values, equivalent to that of the outlier, Samouqueira. These three males may well represent deviations from the general Mesolithic pattern of an increasing terrestrial dietary element.

The Mesolithic variability is thus underlain by a variety of factors; elements of seasonality and transhumance for some of the population may enter the picture, but a change through time is of major importance.

Reliable data on palaeoenvironments for the critical period between 8000–7000 BP are still not abundant. Deep sea cores off the Portuguese coast suggest marked changes in temperature during this time (Duplessy *et al.*, 1992), as elsewhere in the North Atlantic (Veum *et al.*, 1992), and recent palynological analyses of slightly later coastal deposits (Mateus, 1989) indicate change in forest cover continuing into the early Neolithic time period. The available data are reviewed in Vierra (1992).

The tetracycline labelling of Moita bone provides quite good evidence for periodic growth arrest at Moita, and from this we might suggest seasonal (winter?) shortages with reliance on tainted stored food. The apparent lack of labelled arrest lines at Arruda may indicate that the shift in diet led to a reduced chance of late winter famine, coupled with improved storage techniques.

Besides the evidence of an increase in terrestrial food sources and a decrease in winter famines, other evidence of change through the Mesolithic supports this

interpretation of the broad spread of Mesolithic stable isotope values.

Known Neolithic sites cover a wider area than that identified for the Mesolithic, mostly in caves: coastal caves, limestone solution cavities, deep caves in the inland mountains. But most of these caves are ossuaries, and thus we have only a vague idea of what the Neolithic living sites were like, although short-term seaside encampments again appear a possibility. Deep caves in inland mountains may have been occupied for short periods. But the majority of Neolithic living sites must have been in areas where subsequent continuous occupation has destroyed most traces of these settlements (but see Zilhão, 1993).

An intensification of the trend towards terrestrial dietary sources occurred in the Neolithic, as evidenced by the stable isotope results. There is also the suggestion of increased homogeneity in the Neolithic dietary regime. Faunal studies of Neolithic and Chalcolithic sites demonstrate that even when domestic pig and sheep/goat made up a good portion of the diet, marine bivalves (e.g. *Mytilus*, *Venerupis*) and gastropods (e.g. *Patella*) were still eaten, just as they are in Portugal today—even inland Chalcolithic sites provide evidence of the consumption of marine molluscs. Nevertheless, coastal Neolithic and Chalcolithic sites actually derive smaller proportions of their faunal remains from the sea than Mesolithic sites (Gautier & Lentacker, 1985; Lentacker, 1991). We would thus expect an increasing homogeneity in Neolithic diets, irrespective of whether the sites were coastal or inland, and an increasing emphasis on terrestrial sources of food.

While variations in types and rates of dental pathology among Neolithic sites (see below) and palynological data from non-archaeological deposits (reviewed in Lubell & Jackes, 1988; Mateus, 1989; Lello, 1990; Vierra, 1992) suggest that regional variability was as characteristic of the early and middle Holocene as of recent times, the stable isotopic data give no indication of this.

## Dental Evidence of Dietary Change

While the stable isotope data give us a specific picture of the trophic levels being exploited by the various samples under study, the dental remains are also primary sources for interpretation of diet. Although some elements of the dentition may reflect use of the teeth for other purposes (e.g. hide chewing), or simply the degree to which a population was concerned with oral hygiene, it is still clear that elements such as dental wear, caries levels and other pathologies are reflections of the type and nature of food sources, and thus add to the picture discussed above.

## Materials

Dentitions from the Mesolithic Muge sites of Moita do Sebastião and Cabeço da Arruda were studied,



together with Neolithic materials from the large ossuary cave of Casa da Moura and smaller samples from Zambujal Cave at Melides and from Furninha, Fontainhas and Feteira. Furninha is a coastal cave near Peniche not described above because bone samples from that site retained insufficient collagen for analysis (perhaps because of periodic seawater inundation).

### Methods

The lower molars of the Mesolithic samples were analysed separately by Jackes and Meiklejohn, and our discussion is based on independent data which has been extensively cross-checked. Neolithic samples were analysed by Jackes. The Mesolithic angle of wear was measured by Meiklejohn using an exact replication of Smith's (1984) technique. This technique was found to be prone to intra- and interobserver error, and the Neolithic angle was calculated by trigonometry from buccal and lingual crown heights (Jackes, 1992a).

Rates of attrition can be estimated only if the criteria for coding wear are not sensitive to observer error. Our criteria were set up by having three experienced independent observers make repeated observations of the same set of Moita mandibles until complete agreement was reached on wear categories. The system used is a version of that developed by Smith (1984; see Lubell, Jackes & Meiklejohn, 1989). The attrition codes were then applied to the two Mesolithic sites independently by Jackes and Meiklejohn and to the Neolithic sites by Jackes. Seriation of the mandibles preceded all coding by Jackes except in the case of one sample from Casa da Moura. After analysis, the latter sample was computer sorted using multiple metrical variables and cheek tooth wear and then sorted in with the first sample based on the position of a number of control mandibles.

### Rates of wear

The results of our studies of attrition show dramatic differences in rates of wear. In Figure 6, we see that in the earliest site, Moita, 87.5% of first lower molars ( $M_1$ ) are already heavily worn (wear stage 4, i.e. dentine broadly exposed) when the third lower molar ( $M_3$ ) erupts or comes into initial occlusion. In later samples, the 12 or so years between the eruption of the  $M_1$  and the eruption of the  $M_3$  are represented by less and less wear on the  $M_1$ . In contrast with the 87.5% at Moita, the equivalent figures are 44.4% for Arruda and 33% for Casa da Moura, confirmed by two separate analyses on two different samples, while only 25% of Melides mandibles have wear 4 on  $M_1$  when  $M_3$  comes into occlusion.

While it could be argued that there is some genetic shift at the Mesolithic-Neolithic boundary, with the change in relative first and third molar wear caused by

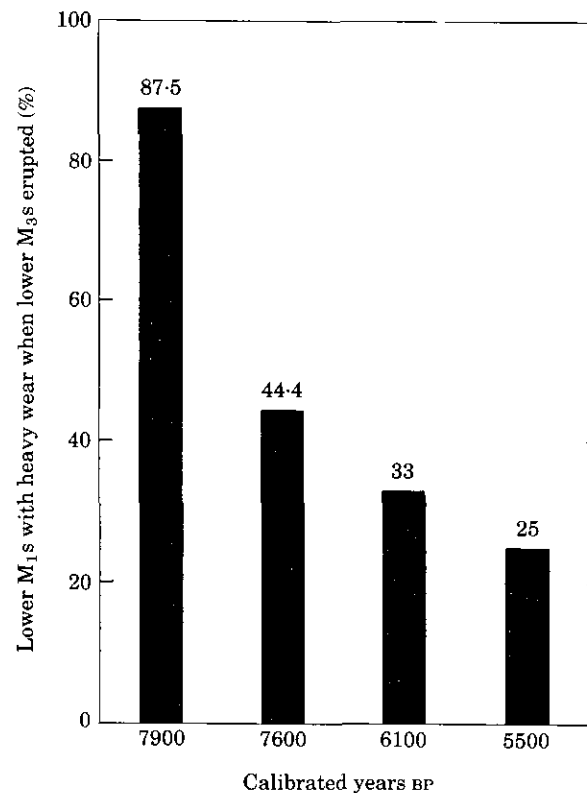


Figure 6. Incidence of heavy wear on mandibular first molars at the time of eruption of mandibular third molars, plotted against calibrated mean radiocarbon age.

an eruption of the Neolithic  $M_3$  at an earlier age, the alternative explanation is that Neolithic attrition is reduced.

In fact, we can show that Neolithic attrition is reduced by comparing the relative first and second molar wear in 70 Mesolithic individuals and 30 Neolithic individuals (the Neolithic samples are small because Neolithic teeth are rarely found *in situ* in the mandibles). Figure 7 shows that the relationship between the attrition stages of the first two molars is markedly different across the Mesolithic-Neolithic boundary. We examine here only those jaws with wear stages 1-6, i.e. in which the second molar is in occlusion but is not worn below the level at which some occlusal enamel remains. We exclude the most highly worn dentitions because the greater percentage of Mesolithic worn teeth might alter the regression line in such a way as to reflect demographic rather than dietary differences.

In the Mesolithic, early adolescents already display quite marked wear on the  $M_1$ . Indeed, the  $M_1$  stage of wear (stage 3) when the  $M_2$  just comes into occlusion, at around age 12, is the equivalent of the wear of Neolithic people in their twenties. In the Neolithic attrition pattern, stage 3 attrition occurs on first molars after the eruption of third molars, i.e. after age 18

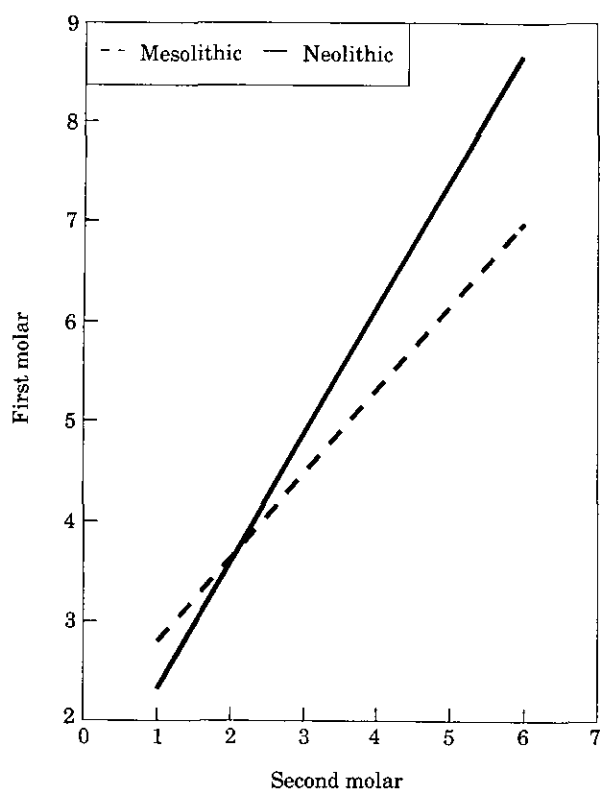


Figure 7. Relative wear of lower molars: regression of second molar wear on first molar wear for Mesolithic and Neolithic mandibles.

(Jackes, 1988, 1992a). Stage 3 attrition is defined in terms of the beginning obliteration of the occlusal fissures so that the fissure pattern is no longer clear, together with the occurrence of 2–4 discrete exposures of dentine.

Not only is the Mesolithic  $M_1$  wear fairly marked at stage 3 soon after age 12, but the  $M_2$  comes into wear relative to the  $M_1$  at a faster rate in the Mesolithic than in the Neolithic.

#### *Type of wear*

We can confirm that attrition rates changed between the Mesolithic and the Neolithic. Furthermore, the wear changed from predominantly flat wear to a much higher incidence of cupped wear in broad dentine exposures. Smith (1984) has suggested that cupped wear appears with the introduction of techniques for fine-grinding grain. In contrast, the Mesolithic flat wear could reflect the presence of large amounts of coarse sand in a diet heavily dependent on marine and estuarine shell fish.

Mesolithic wear is not literally flat: it is quite sharply angled, as demonstrated by a study comparing the angle of wear of right lower molars in the samples from Moita and Arruda ( $N=31$ ) and Casa da Moura ( $N=220$ ).

Figure 8 shows that, wear stage for wear stage, the Mesolithic teeth are much more sharply angled down to the buccal side than the Neolithic, because the Mesolithic lower molar buccal crown height is much reduced relative to the lingual. Figure 8 also provides data from Smith (1984) for her British agriculturalist sample. Smith (1984: 47) has stated that “agriculturalists develop higher angles than hunter-gatherers, ultimately reaching a  $10^\circ$  difference in high wear.” Our results contradict this.

It seems unlikely that differences in technique explain the contradiction, since the wear codes are basically similar and the technique for measuring Mesolithic angles exactly replicated Smith’s. Furthermore, the Casa da Moura right  $M_1$  angle at wear level 1 is the same as for the British agriculturalists [Duarte (1992), using the same techniques as Jackes, has equivalent results at level 1 wear from another Portuguese sample]. Portuguese Neolithic buccal wear may be reduced because cupped wear allows the maintenance of buccal crown height despite the loss of occlusal enamel. One possible explanation for the differing results at high wear level is that Smith measured angles on teeth in which the high-standing buccal enamel rim had fractured, a common feature in agricultural dentitions. But the reasons for the contradictory results must lie deeper.

The Portuguese data are logically plausible in that the slower Neolithic attrition rate means that a Neolithic lower first molar does not become flat until level 4 wear is reached. This level of wear is defined by complete obliteration of the occlusal fissures together with large exposures of dentine, discrete buccally but with possible distal coalescence. The fast removal of Mesolithic enamel is reflected in the fact that the lower first molars are already flat at wear level 1 (which is defined by polishing of the cusps). Smith’s results require that agriculturalists have a faster rate of buccal cusp removal than either Australian or Eskimo hunter-gatherers. In fact, it is likely that each wear stage is passed through much more slowly in agricultural populations than in hunter-gatherers, perhaps allowing variation in occlusal angle, so that full analysis of this problem would take the age structure of the samples into account, together with rates of wear and the definition of the wear categories (see Jackes, 1992a,b). Smith’s data (1984: Figure 5) also suggest the possibility that there are differences among her samples in lower molar cusp morphology, so unworn crown morphology must be examined and taken into account.

#### *Dental pathology*

Caries rates are important indications of diet, and many anthropologists maintain that alterations in caries rates mark dietary shifts world wide. Turner (1979, Jomon Japan) and Patterson (1986, Ontario), for example, discern increases in caries rates as dependence on domestic crops of rice, tubers and maize

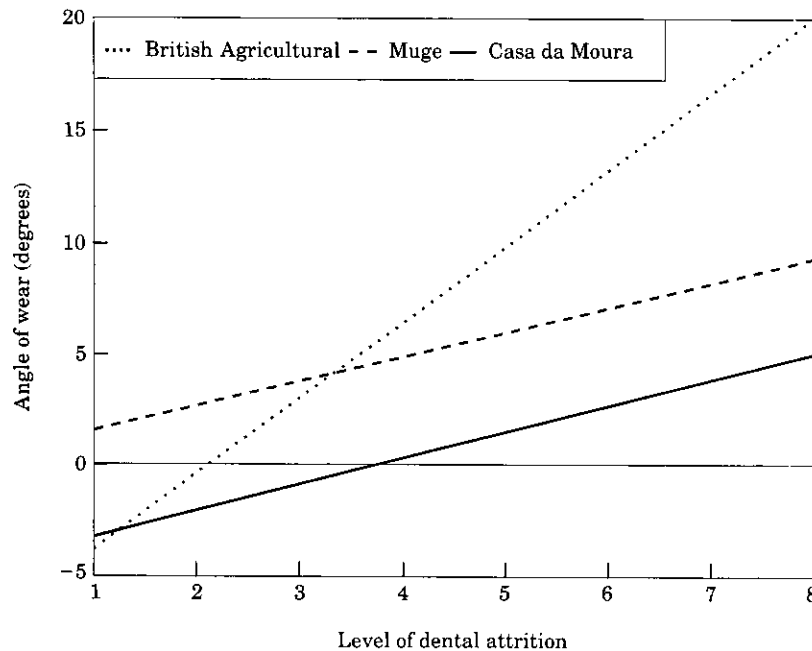


Figure 8. Portuguese Mesolithic (Muge, broken line) and Neolithic (Casa da Moura, solid line) right  $M_1$  angle of wear plotted against attrition, compared to data for British agriculturalists (dotted line, data from Smith, 1984: table 4).

increases. Low caries rates are postulated for hunter-gatherer populations because the diet is expected to be non-cariogenic and because high rates of attrition reduce the potential for occlusal caries (although see Meiklejohn, Wyman & Schentag, 1992). On the other hand, agricultural populations are expected to have uniformly high rates of pathology because of the cariogenic nature of carbohydrates, coupled with reduced attrition.

Dental caries rates are very low in the Mesolithic of Scandinavia (Alexandersen, 1988), while the large Mesolithic sites in northern France have low caries rates of 2–5% (Meiklejohn *et al.*, 1984: 84). On the other hand, higher rates have been reported for Mesolithic sites in Sicily (especially Uzzo where 13% of teeth are carious, most commonly with interproximal caries: Borgognini Tarli & Repetto, 1985).

The Portuguese Mesolithic sites were considered to have low caries rates until our recent re-analyses suggested a much more complex diachronic pattern of dental pathology. Frayer (1987), after examination of a limited sample of dentitions, has questioned the validity of our analyses of dental pathology in the Portuguese Mesolithic. However, four independent examinations of Moita dentitions (once by Meiklejohn and Schentag in 1984, once by Lubell in 1989 and twice by Jackes in 1984 and 1989) confirm the high incidence of dental pathology in Moita skulls. Our analyses all suggest that the Moita dentition is more pathological than that of Arruda, and it is significant that Moita has a higher occlusal caries rate than Arruda (14.3% of lower molar occlusal surfaces versus 7.3% for Arruda),

even despite the higher rate of attrition in Moita molars (see also Meiklejohn, Wyman & Schentag, 1992).

Our dental material indicates Neolithic diversity over space and time (Lubell & Jackes, 1988; Jackes & Lubell, 1992). This might be expected, since we are able to sample sites which, in comparison with those for the Mesolithic, range over a greater geographical area of Portugal (north to south, inland to coastal) and represent well over 2000 years. However, it contradicts both the hypothesis that Neolithic dental pathology is always more frequent than Mesolithic, and the evidence of homogeneity provided by the stable isotope analyses.

Unfortunately, we do not have the full range of sites represented among the stable isotopes values: we have no data from Furninha. Nevertheless, all indications are of Neolithic homogeneity in stable isotopes suggesting that the Neolithic diet was much less varied than that of the Mesolithic population, with an early established reliance on a limited range of foodstuffs. The Mesolithic diet based on hunting and gathering is to be compared with a Neolithic diet limited by the constraints of stricter sedentism and by reliance on domesticates. This Neolithic diet did, however, apparently allow movement into a broader area of Portugal coupled with an increase in population.

Furthermore, dental pathology indicates that there must have been variations in Neolithic diets which are indiscernible by stable isotope analyses. Such variations cannot be explained away as due only to geochemical differences among sites since, for example,

Table 2. Mesolithic and Neolithic dental pathologies based on erupted permanent lower molars

Site	Occlusal caries/ total occlusal surfaces		Approximal caries/ total approximal surfaces		Occlusal/Approximal ratio	Premortem loss/ total sockets	
	N	%	N	%		N	%
Moita	26/182	14.3	16/344	4.6	2.8	31/198	15.7
Arruda	18/246	7.3	22/369	6.0	1.2	36/297	12.1
Casa da Moura	9/283	3.1	22/566	3.9	0.75	35/376	9.3
Melides*	8/75	10.7	8/150	5.3	2.2	19/124	15.3
Furninha	4/84	4.8	7/161	4.3	1.25	57/250	22.8
Feteira 1 & 2	6/54	11.1	2/108	1.8	5.5	3/43	7.0
Feteira 3	3/22	13.6	1/44	2.3	7.0	4/20	20.0
Fontainhas	0/61	0.0	4/122	3.3	0.0	2/74	2.7

\*All dentitions from Melides are recorded as from Zambujal.

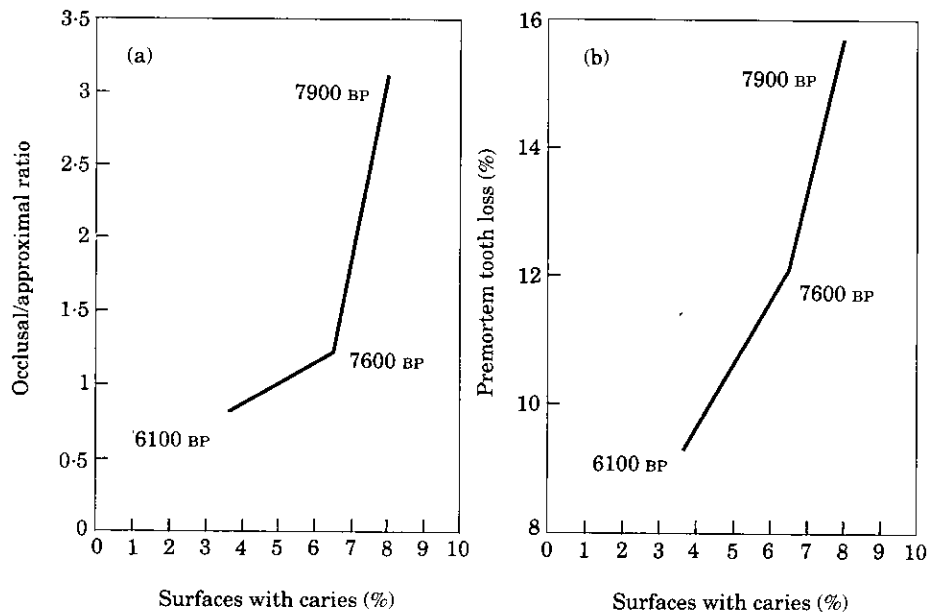


Figure 9. Changes through time in mandibular molar pathology: in the ratio of occlusal to approximal caries (a) and the percent of premortem tooth loss (b) plotted against the percentage of carious surfaces. Calibrated mean radiocarbon years are shown.

Feteira and Casa da Moura are located within a few kilometres of each other and yet are divergent in dental pathology (Table 2).

Two complicating factors must be taken into account when considering Table 2. Firstly, our demographic studies demonstrate that the Mesolithic samples are more likely to contain older individuals than the Neolithic ones. We have shown that the demography of the Mesolithic sites is characteristic of stable populations with death rates that are low (relatively speaking) for archaeological sites (Jackes, 1992a). Casa da Moura, on the other hand, probably has a higher death rate with a greater proportion of juvenile dead because the population was increasing (Jackes, 1988). Therefore, we can expect Mesolithic samples to exhibit a great deal of age-dependent dental pathology. Secondly, dental pathology is absent in Mesolithic juveniles (Meiklejohn, Baldwin & Schentag,

1988; Meiklejohn & Zvelebil, 1991: 136). Neolithic populations, on the other hand, were quite likely to have dental pathology in childhood, and higher rates of pathology are seen in Neolithic permanent molars in the first stages of attrition (Lubell & Jackes, 1988: 243).

Rates of dental pathology do, however, clearly reflect the dietary changes of the Mesolithic–Neolithic transition confirmed by faunal studies, by the  $\delta^{13}\text{C}$  data and by dental attrition. To illustrate this we will use the samples from Moita, Arruda and Casa da Moura.

Analysis of Meiklejohn's data on lower molars from Moita and Arruda, in conjunction with Jackes' data on lower molars from Casa da Moura shows that the late Mesolithic decline in caries is accompanied by a decline in premortem tooth loss and in the number of carious tooth surfaces, but by an increase in the number of interproximal caries relative to caries on the occlusal

surface (Figure 9). It should be noted that pathology rates by attrition stage indicate that sample bias is not the operative factor here: in the oldest age groups, Moita dental pathology incidences are nearly double those of Arruda (Lubell & Jackes, 1988: 243).

Our conclusion is that dental pathology is not universally a good marker of the shift to agriculture. Rates of attrition decrease, but pathology rates are not generally higher in the Portuguese Neolithic than in the Mesolithic. It is evident that European domesticates were either not as cariogenic as maize proved to be in North America or that such cariogenic sources were less completely integrated into the diet. Secondly, fruits may have been available in southern Europe during the Mesolithic (e.g. figs: Powell, 1985: 313) which are highly cariogenic when dried and eaten constantly. It is possible that variations in caries rates indicate various levels of dependence on such fruits. A parallel case of divergent incidence of pathology apparently related to the contribution of dates, raisins and figs to the diet in one location but not at another (see Højgaard, 1980*a,b*) is of interest.

Caries of various types may have diverse aetiologies. Our data certainly indicate that approximal caries rates do not correlate with occlusal surface caries. We have grouped as “approximal caries” lesions initiated on the crown at or just below the interproximal facets and also lesions at the cemento-enamel junctions which are not crown, but root caries. It is impossible to distinguish approximal caries by the site of origin except in the earlier stages. In a sample of 19 Casa da Moura mandibular molar approximal caries, four were apparently initiated between the contact facet and the cemento-enamel junction, six at the cemento-enamel junction, five involved the interproximal facet and the occlusal surface (and may have started at the facet) and three were so extensive that the point of origin could not be determined.

Our detailed examination of Casa da Moura teeth suggests the possibility that cervical, as opposed to occlusal, crown caries are related to plaque deposition and to periodontal disease (see also Hillson, 1986: 299). As such they are likely to be more common in populations with large numbers of older adults. An extensive literature is now accumulating affirming that root lesions occur after age 40 or 50 (see e.g. Luan *et al.*, 1989), following the exposure of cementum by alveolar recession.

Interproximal caries on the crown, rather than on the root, do, however, occur in young individuals. They are related to the frequent ingestion of sweet foods (Burt *et al.*, 1988), and fructose is as strongly implicated as sucrose in the development of approximal caries (Rekola, 1989).

Approximal caries are difficult to observe and study, so that we would expect an underestimation of their rates. Our sample of over 4000 loose teeth from Casa da Moura has enabled us to examine interproximal surfaces microscopically in such detail that we can

usually differentiate among post-mortem erosional grooves, initial caries of several types and the toothpick grooves which are so often associated with interproximal caries, no doubt in attempts to alleviate discomfort.

Our study makes it clear that interproximal caries, both coronal and root, are probably under-reported (Jackes, Lubell & Meiklejohn, 1991; cf. Frayer, 1987), especially in matrix-obsured Mesolithic mandibles and in the loose Neolithic teeth in which the cemento-enamel junction area is often damaged by post-mortem erosion. The lack of correlation between occlusal and approximal caries could result from such under-reporting, but different aetiologies and ages of onset are also important factors.

In the later Portuguese Neolithic sites we see variable pathology rates: one site with a high carious surface rate, another with a high pre-mortem tooth loss rate, another with a fairly high rate of occlusal caries. The variations may be due to differences in fructose and starch intake, differences in trace elements in soils and groundwater, and differences in the age structures of the population.

## Conclusions

We have shown that there is stable isotopic evidence for a marked difference in diet between Mesolithic and Neolithic Portuguese human remains. The Mesolithic diet can be characterized as a mixture of terrestrial and marine foods, while the Neolithic population appears to have consumed only terrestrial foods (herbivore flesh and plant foods). The linear trend on a  $\delta^{15}\text{N}$ – $\delta^{13}\text{C}$  diagram (Figures 4 & 5) shows that the marine component of the Mesolithic diet was very homogeneous. While it appears to have been dominated by the flesh of a small variety of marine herbivores, it may also have been a culturally-defined mixture of marine foods whose proportions remained quite constant throughout the Mesolithic. Individual members of the Mesolithic population consumed quite varied proportions of the marine and terrestrial components, possibly in response to local availability determined by where they spent the majority of their lives. Note, however, that marine consumers of the Mesolithic period were very conservative in their choices of marine foods, as shown by the lack of dispersal in  $\delta^{15}\text{N}$  of the marine-dominant population (Figure 5, broken lines). This conservatism has been noted in other hunter–gatherer populations (see Schwarcz, 1991).

Although dental pathology is a complicated issue, we do see trends in pathology and in the rate and angle of molar attrition, showing a distinct difference in diet beginning in the Mesolithic and well established in the early Neolithic. The trend is toward a reduction in the age dependence of dental pathology, but we cannot simplify the complicated issue of the interaction of attrition, caries, tooth loss, caries location and age

distribution of the sample in order to make categorical statements about dietary changes. Nevertheless, dental data assure us of a change initiated before 7000 years ago. Dental data also suggest that diets were not homogeneous during the Neolithic.

While the transition from Mesolithic to Neolithic diets appears to have been relatively abrupt on the basis of our stable isotope data, the available dietary sources remained constant across this transition. The early Neolithic sample from Melides suggests that further evidence from coastal sites in southern Portugal may show the transition to have been less clear cut. The transition can be described as an abandonment of marine resources in favour of terrestrial ones, but we need further human and faunal remains from a variety of sites dated 7000–6000 BP in order to delineate the transition clearly.

Preliminary analyses of other osteological data provide several indications of change during the period between 8000–7500 BP (Meiklejohn & Schentag, 1988; Jackes & Lubell, 1992; Lubell & Jackes, 1985, 1988). Taken together with the evidence presented here, these suggest that the Portuguese Mesolithic was not a static, homogeneous period either biologically or culturally. The trend towards the Neolithic began in the Mesolithic, and can be discerned both by studies of human dentition and by analyses of the stable isotopic content of the human bone (see also Meiklejohn & Zvelebil, 1991).

We can thus show, for the first time, that the introduction of a Neolithic economy in Portugal was an intensification of a trend which started as an adjustment to problems of food supply during an earlier period of sea level, climatic and vegetational change.

## Acknowledgements

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