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Human Dietary Change [and Discussion]

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Human dietary change

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SUMMARY

The transition from hunting and gathering to agriculture and animal husbandry in the Near East and Mediterranean Region began some 12000 years ago. The ecological changes associated with this change are known to have been related to higher levels of stress from undernutrition and infectious disease. Certain pathologies found in human skeletal remains from this time are indicative of anaemia and osteoporosis, although it is not clear whether they had clear nutritional aetiologies. In this paper, dietary changes associated with changes in subsistence practices in this region are described. In addition, quantitative modelling of possible patterns of dietary and nutrient intakes of adult males before, and soon after, the establishment of agrarian economies is used to examine the proposition that the skeletal pathologies porotic hyperostosis, cribra orbitalia and porotic hyperostosis may have been due to nutritional deficiencies. The results suggest that protein deficiency was only likely if subjects were suffering from chronic energy deficiency (CED) and their diet contained no meat. Dietary calcium deficiency was possible after the transition to cultivation and animal husbandry, in the presence of moderate or severe CED. Anaemias, although present after the transition, were unlikely to have had dietary aetiologies, regardless of the severity of CED.

1. INTRODUCTION

The transition from hunting and gathering to agriculture and animal husbandry began in the Near East and Mediterranean Region some 12000 years before present (BP), with the deliberate growing of wild cereal crops and the taming of small mammals as means of expanding the food supply in response to population increase (Hillman *et al.* 1989). The Neolithic (10500–5750 years BP) was the period in prehistory in which a pattern of village settlement based on subsistence farming and stockbreeding became the basis of existence for communities throughout the Near East (Moore 1985), and was associated with greater physiological stress due to undernutrition and infectious disease (Cohen 1989).

Although there is a vast potential corpus of data about prehistoric human nutritional pathology, there are problems of interpretation (Armelagos 1987). The modelling of possible dietary and nutrient intakes under a variety of conditions provides an alternative way of examining and augmenting our knowledge of the nutritional ecology of past populations. In this paper, such a scheme is used to examine the proposition that the aetiologies of the skeletal pathologies, porotic hyperostosis, cribra orbitalia and osteoporosis found in human remains from the Near East and Mediterranean regions before and during the Neolithic, were due to nutritional deficiencies.

2. CHANGES IN SUBSISTENCE PRACTICES IN THE NEAR EAST AND THE MEDITERRANEAN

Locations in the Near East and Mediterranean at which diet and subsistence before and during the Neolithic have been studied include sites in the Jordan Rift Valley, Western Turkey, Israel, Iran, Syria and Iraq. Evidence for dietary usage comes from study of assemblages of animal bones, plant food and faecal remains at, or close to, sites of human habitation (Harris & Hillman 1989; Clutton-Brock 1989).

Between about 20000 and 12000 years BP the region provided a mosaic of so-called 'optimal' habitats in which semi-nomadic groups practised hunting and gathering (Bar-Yosef 1987). These 'optimal' habitats were separated by less favourable habitats that had

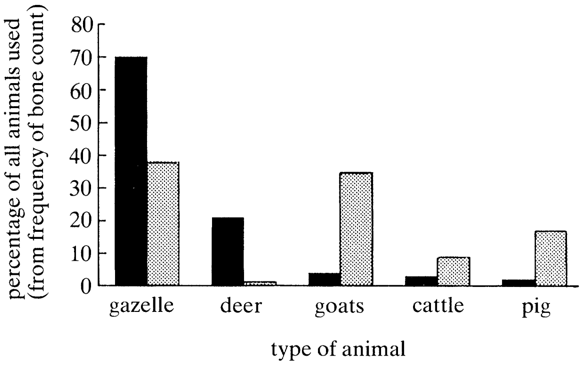

Figure 1. Ungulate faunal spectra in pre-Neolithic times (solid bars) and in the Neolithic (shaded bars). From Smith *et al.* (1984).

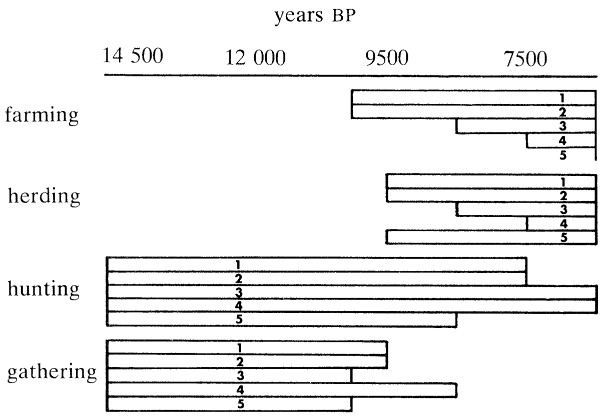

Figure 2. Tentative scheme of major subsistence activities in the Southern Levant. Regions: 1, Galilee, Mount Carmel, Judean Hills, Coastal Plain; 2, Jordan Valley; 3, Western Negev, Northern Sinai; 4, Southern Sinai; 5, Negev Highlands. After Smith *et al.* (1984).

lower carrying capacities and population densities of hunter–gatherers (Flannery 1969). Hunting of hoofed mammals including gazelle, antelope and deer was widespread (Flannery 1965; Jacobsen 1969), although the hunting or gathering of fish, crabs, molluscs and snails, partridges and migratory waterfowl increased with time (Flannery 1969). Gathered vegetable sources of food included root plants, wild pulses, almonds, pistachio and hazel nuts and fruits such as apples (Angel 1984). Wild cereal grains were also gathered, and these included wild strains of wheat and barley (Reed 1977).

By 11000 years BP wild sheep and goats were being domesticated (Butzer 1971; Reed 1977), and the domestication of cattle and pigs followed soon after (Angel 1984). The planting of wheat and barley was well underway before 9000 BP (Hopf 1969; Van Zeist & Bakker-Heeres 1979) as was that of pulses. The exploitation of fruits and nuts also shifted into systematic cultivation. Associated with this was a shift in the extent to which different species of animal were used as food (figure 1), and in an enormous reduction in the extent of meat consumption (Angel 1984).

The shift from hunting and gathering to cultivation and domestication was not an immediate and direct one; during the transition human groups probably varied in the extent to which they practised each strategy. In addition, the time at which farming and herding took precedence over hunting and gathering varied from site to site (figure 2), although by 7000 years BP the transition from one mode of subsistence to another was more or less complete.

3. PALAEOPATHOLOGIES AT THE ORIGINS OF AGRICULTURE

Evidence in support of the view that the transition from hunting and gathering to cultivation and animal husbandry in the Near East and Mediterranean was associated with an increase in disease and nutritional stress comes from various analyses of skeletal remains (Angel 1984; Smith *et al.* 1984). Estimates of the stature of adult males from femoral size by using the equations of Trotter & Gleser (1952) indicate a decline from an average of about 180 cm to about 170 cm between 32000–11000 years BP and 11000–9000 years BP (Angel 1984). This decline has been attributed to generalized undernutrition (Angel 1984), although other factors, such as increased stress from infectious disease in the more densely populated settlements at this time, or inbreeding in isolated communites might be equally important.

Specific bone pathologies which are related to nutritional or disease stress and have been identified in skeletal material from the region include porotic hyperostosis and cribra orbitalia. Porotic hyperostosis can be recognized by a thickened, porous, sievelike appearance of certain parts of the skeleton. Cribra orbitalia is porotic hyperostosis of the orbital surfaces of the skull. Both pathologies are diagnostic of anaemia, although it is not possible to give a specific aetiology on this basis alone (Huss-Ashmore *et al.* 1982).

Porotic hyperostosis has been reported to be present in skeletal remains from the Neolithic onward (Rathbun 1984). Although a primary dietary aetiology has been proposed (Moseley 1965), Stuart-Macadam (1991) has recently suggested that porotic hyperostosis in prehistoric populations is more likely to have been due to continuous or heavy pathogen loads than to iron deficiency. Cribra orbitalia may be due to dietary deficiency of iron or ascorbic acid, or to any infection which leads to chronic anaemia (Wing & Brown 1979). Its presence in the Neolithic Near East has been attributed to the effects of infectious disease on the bioavailability and utilization of iron rather than to dietary deficiency per se (Smith *et al.* 1984).

Osteoporosis specifically due to dietary calcium deficiency is rare in the modern world, but the possibility that it may have been more common in prehistoric populations cannot be discounted. In contemporary populations, osteoporosis is a condition where the bone density of an individual is lower than might be expected for their age, and may occur in the elderly population, as well as adults who are extremely inactive, or in women who are amenorrheic due to very high levels of physical activity (British Nutrition Foundation Task Force on Calcium 1989). Osteoporosis in skeletal material from past populations has often been ascribed to calcium deficiency by palaeoanthropologists, even though there is only a poor physiological basis on which to base this conclusion. Indeed, Kurth & Rohrer-Ertl (1981) found that long bones of 28 individuals from the Neolithic period in the Near East showed signs of osteoporosis, which they attributed to calcium deficiency. However, there is scant evidence of osteoporosis in skeletal material from earlier times (Smith *et al.* 1984).

Neolithic Near Eastern populations are known to have had high prevalences of anaemia and osteoporosis, but it is not clear whether these pathologies had specific dietary aetiologies, or were related to other factors. One way of evaluating the relative importance of dietary factors in the aetiology of these pathologies is to model dietary and nutrient intakes before, and during, the Neolithic, and to relate the latter to current

Table 1. *Physical activity levels for adult males engaged in a variety of subsistence practices*

group or district	country	subsistence type	physical activity level (TEE/BMR)	reference
Ache	Paraguay	hunter–gatherer	2.08^{a}	Hill *et al.* (1985)
Machiguenga	Peru	hunter–horticulturalist	2.09^{b}	Montgomery & Johnson (1974)
Wopkaimin	Papua New Guinea	hunter–horticulturalist	1.65^{b,c}	S. J. Ulijaszek & T. Brown (unpublished results)
Pari	Papua New Guinea	hunter–horticulturalist	1.42	Hipsley & Kirk (1962)
	Guatamala	maize cultivation	2.32	Viteri *et al.* (1971)
	Philippines	rice cultivation	2.25	de Guzman *et al.* (1974)
Varanin	Iran	wheat cultivation	2.10^{d}	Brun *et al.* (1979)
	Burma	rice cultivation	2.02^{b}	Tin-May-Than & Ba-Aye (1985)
	Gambia	rice and peanut cultivation	2.02^{b}	Fox (1953)
Tamil Nadu	India	rice cultivation	2.00^{d}	McNeill *et al.* (1987)
Sundanese	Indonesia	rice cultivation	1.96^{a}	Suzuki (1988)
	Burkina Faso	millet cultivation	1.89^{b}	Brun *et al.* (1981)
	Ivory Coast	mixed cultivation	1.68^{a}	Dasgupta (1977)
Lufa	Papua New Guinea	sweet potato cultivation	1.64^{a}	Norgan *et al.* (1974)
	Uganda	maize and plantain cultivation	1.63^{a}	Cleave (1970)
	Cameroun	millet cultivation	1.54^{a}	Guet (1960)
Kaul	Papua New Guinea	taro and plantain cultivation	1.52^{a}	Norgan *et al.* (1974)

[a] From estimates of BMR from body mass, and total energy expenditure from activity diaries.
[b] Average of two seasons.
[c] Estimate of total energy expenditure from activity diaries.
[d] Average of four seasons.

estimates of nutritional requirements (FAO/WHO 1974, FAO/WHO/UNU 1985).

4. MODELLING CHANGES IN NUTRIENT INTAKE

In this paper, model pre-Neolithic and Neolithic men are created, based on knowledge of stature at those times, and on current understanding of energy expenditures of contemporary hunter–gatherers and hunter–horticulturalists, and simple cultivators. Assuming that these men are in energy balance, intakes of protein, iron and calcium are calculated from dietary reconstructions based on evidence from the literature. Intakes of these nutrients are then estimated for the model Neolithic man, assuming that he is suffering from chronic energy deficiency (CED) at various levels of severity.

Dietary energy requirements are related to energy expenditure, which in turn is related to activity level and to basal metabolic rate (BMR) (FAO/WHO/UNU 1985). It is possible to express total daily energy expenditure (TEE) as a multiple of BMR (Waterlow 1986). In this way, differences in TEE due to differences in body size can be controlled for, giving a general measure of activity called the physical activity level (PAL) (James *et al.* 1988). Table 1 gives PALS obtained by a variety of means, for contemporary populations practising a number of subsistence strategies.

Hunter–gatherers and hunter–horticulturalists have PALS that range from 1.42 to 2.09 whereas the PAL of cultivators ranges from 1.52 to 2.32. On average, the difference in energy expenditure due to physical activity between groups practising these different types of subsistence is small, and it can be postulated that the switch from hunting and gathering to cultivation and animal husbandry involved little change in PAL. In the model to be elaborated, the pre-Neolithic man is assigned a PAL of 1.9, and the Neolithic man, 2.0.

Seasonal variation in activity levels, energy expenditure and therefore energy requirement almost certainly became exaggerated with the onset of agriculture. However, the pathologies with which this paper is concerned are due to chronic rather than acute stress, and seasonal variation in those stresses is unlikely to be of greater significance than the overall stress levels across the entire year.

Body mass index (BMI) is a crude index of body physique which has been recommended for use in the estimation of nutritional status in adults (James *et al.* 1988). BMI is body mass divided by height squared, and a scheme whereby this measure is used in association with PAL is given in table 2.

It is possible to model energy requirements of adult males in pre-Neolithic and Neolithic times at different

Table 2. *Body mass index and physical activity level* (PAL) *as markers for chronic energy deficiency* (CED) *in adults*

(From James *et al.* (1988).)

BMI	PAL[a]	presumptive diagnosis
> 18.5	—	normal
17.0–18.5	> 1.4	normal
	< 1.4	CED grade I
16.0–17.0	> 1.4	CED grade I
	< 1.4	CED grade II
< 16.0	—	CED grade III

[a] PAL = physical activity level (TEE/BMR).

Table 3. *Estimated mass, basal metabolic rate and total energy expenditure of adult males in pre-Neolithic times and the Neolithic*

	pre-Neolithic	Neolithic
height/cm	180	170
BMI/(kg m^{-2})	20.5	20.5
mass/kg	66.4	59.2
BMR/(MJ d^{-1})	7.08	6.63
TEE/(MJ d^{-1})	13.45	13.26

levels of energy nutritional status, assuming that subjects are in energy balance at different levels of BMI and PAL. Data from a variety of contemporary populations show that for hunter–gatherers and hunter–horticulturalists, BMIs of adult males range from 19.0 to 20.7 kg m^{-2}, whereas for simple cultivators, they range from 18.3 to 21.3 kg m^{-2}, respectively. In this analysis, both pre-Neolithic and Neolithic model men are assigned a BMI of 20.5 kg m^{-2}.

Body masses of the model men were calculated from their estimated heights and their assumed BMIs, and used to calculate BMR (Schofield 1985). The TEE of both men was then calculated from their respective BMR and PAL; daily energy requirement was assumed to be equal to energy expenditure. Estimates of BMR and TEE of adult males, based on assumed stature of 180 cm pre-Neolithic and 170 cm in the Neolithic, and on BMI of 20.5 kg m^{-2} at both times, are given in table 3.

TEE and daily energy requirements of both men are very similar, although their diets are likely to have been quite different. Qualitative descriptions of dietary change across the transition from hunting and gathering to agriculture and animal husbandry are numerous (Flannery 1965, 1969; Jacobsen 1969; Reed 1977; Angel 1984), but quantification is rather difficult. Estimates of the relative contribution of different animal species to the diet are far more accurate than those of different plant species, as existing methods in archaeology are more able to quantify the consumption of animal foods than plant foods. Angel (1971) has suggested that meat eating in the Neolithic may have been only 10–20% of the Palaeolithic norm. This may well have resulted in a decline in the contribution of animal foods to the diet from a level greater than 20% of the total daily energy intake, to below 10%.

There is little evidence of the relative contribution of different plant types to the diet of pre-Neolithic human groups. Despite this difficulty, an attempt has been made to estimate the proportion of dietary energy supplied by different plant and animal types, based on the descriptions of Flannery (1969), Jacobsen (1969), Reed (1977) and Angel (1984) (figure 3). It is assumed that wild grasses contributed half of the daily energy intake from plant sources in pre-Neolithic times, and

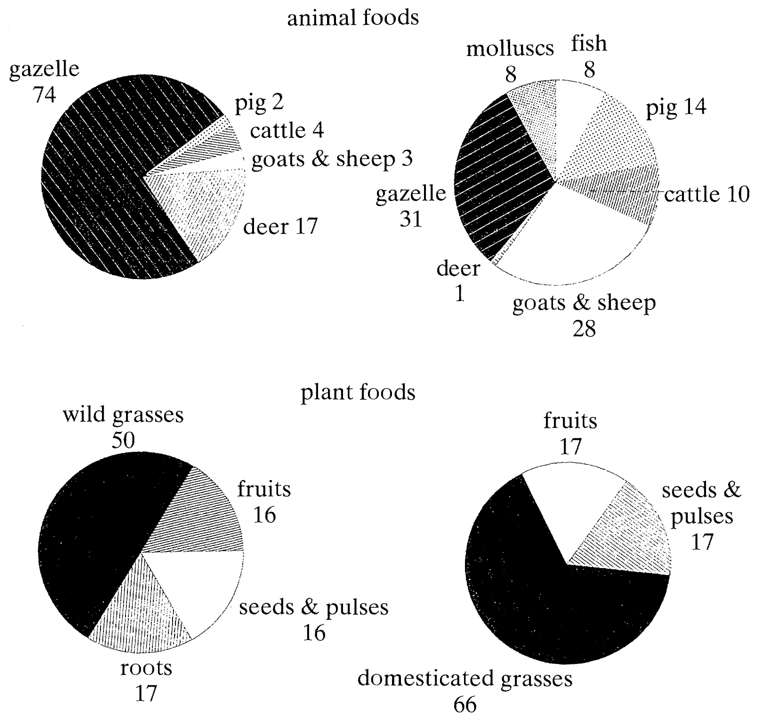

Figure 3. Proportion of total energy intake from different plant and animal sources.

Table 4. *Nutrient composition of animal and vegetable foods used in pre-Neolithic times and the Neolithic*

	nutrient composition (per 100 grams edible portion)			
	energy/ kJ	protein/ g	iron/ mg	calcium/ mg
animal foods				
pre-Neolithic	530	16.7	2.8	10
Neolithic	570	16.4	1.6	7
plant foods				
pre-Neolithic	310	2.8	0.7	9
Neolithic	400	3.2	0.4	7

that domesticated grasses (wheat and barley) supplied two thirds of plant food energy intake in the Neolithic. Although recent evidence suggests that the contributions of such grasses may have been considerably lower than this (G. C. Hillman, personal communication), adjusting the figures does not appreciably affect the analysis.

It is also assumed that milk does not contribute to the diet, since it is believed that domesticated animals were not widely used to produce milk for human consumption before the end of the Neolithic period (Bokonyi 1969).

The nutrient composition of edible portions of the animal and vegetable components of the diets at these two times, as estimated from food composition tables (FAO 1982; Paul & Southgate 1978) are given in table 4.

Although there is no direct evidence of the relative contributions of animal and plant sources of food to total energy intake at the periods in question, contemporary hunter–gatherers obtain between 12 and 86% of their dietary energy from animal sources (Hill

Table 5. *Estimates of daily nutrient intakes at varying levels of animal food intake*

proportion of dietary energy from animal sources (%)	daily intake of nutrients					
	energy density $(\mathrm{g/MJ^{-1}})$	energy/MJ	protein/g	PER[a] (%)	iron/mg	calcium/mg
pre-Neolithic						
80	206	13.45	384.6	47.9	64.7	271
35	258	13.45	267.0	33.3	49.7	325
20	282	13.45	196.0	24.4	42.6	350
15	291	13.45	172.5	21.5	40.4	359
Neolithic						
15	235	13.26	160.7	20.3	20.1	217
10	240	13.26	143.7	18.1	17.2	223
5	245	13.26	125.5	15.8	14.9	228
0	250	13.26	106.7	13.4	13.3	232

[a] Protein energy ratio is the proportion of dietary energy from protein.

Table 6. *Estimates of daily nutrient intakes in adult males in the Neolithic period, assuming different levels of chronic energy deficiency*

body mass index $(\mathrm{kg\ m^{-2}})$	physical activity level					
	2.0 × BMR			1.35 × BMR		
	protein/g	iron/mg	calcium/mg	protein/g	iron/mg	calcium/mg
	proportion of dietary energy from animal sources = 0%					
18.0	98.8	12.4	216	66.6	8.3	146
16.5	94.4	11.8	197	63.8	8.0	139
15.0	90.1	11.2	191	60.8	7.6	133
	proportion of dietary energy from animal sources = 5%					
18.0	116.7	13.9	211	78.7	9.4	143
16.5	111.5	13.2	202	75.3	9.0	137
15.0	106.4	12.7	193	71.8	8.6	130
	proportion of dietary energy from animal sources = 10%					
18.0	133.8	15.4	208	90.3	10.4	140
16.5	127.9	14.7	198	86.4	10.1	136
15.0	122.0	14.0	189	82.4	9.5	128
	proportion of dietary energy from animal sources = 15%					
18.0	149.6	18.7	202	100.9	12.6	136
16.5	143.0	17.9	193	96.5	12.1	130
15.0	136.3	17.1	184	92.1	11.5	124

1982). For contemporary agriculturalists, the range is between 1 (Rosetta 1988) and 27% (De Garine & Koppert 1988). Estimates of intakes of protein, iron and calcium based on diets in which animal foods supply different proportions of the energy intake in the two periods are given in table 5.

When the diet is adequate to sustain energy balance at a BMI of 20.5 kg m^{-2}, intakes of protein are high, for both model men. If the proportion of dietary energy from animal sources was 80% in pre-Neolithic times, the proportion of dietary energy from protein would have been very close to 50%, a level at which toxicity from excessive ingestion of nitrogenous compounds could ensue (Speth, this symposium). Lower levels of meat consumption would have resulted in considerably lower protein: energy ratios than this ceiling value.

An iron-rich intestinal environment may predispose human hosts to infection (Stockman 1981), and it is possible that human populations in the pre-Neolithic Near East and Mediterranean may have suffered from high levels of infection and intestinal infestation partly as a result of high intakes of iron. This could have been a contributing factor to certain disease pathologies observed in skeletal material from this region, and one which has not been considered by palaeoanthropologists. Iron intakes in the Neolithic model man are above the 5–9 mg per day recommended by FAO/WHO (1974) as the minimum to prevent anaemia in a population. The only possible way in which the anaemias reported by Angel (1984) could have been due directly to nutritional deficiencies of iron would have been if the intake of animal foods was nil, or very low indeed. Under such conditions, the intake of dietary iron, although superficially adequate, is overwhelmingly non-haem, and thus poorly absorbed. It is more likely that the pathologies described by various authors were due to anaemias which arose out of intestinal parasitism and other infectious agents and not nutritional shortfall, at least under conditions where subjects were not chronically energy deficient.

Calcium intakes of both model men are lower than the FAO/WHO (1974) recommended minimum values of 400–500 mg d^{-1} at all levels of meat consumption. Calcium balance can be maintained at a variety of levels of calcium intake, however. The highest figure recorded in the literature is 975 mg d^{-1} (Heaney *et al.* 1978), whereas the lowest is 200 mg d^{-1}, in a sample of 10 Peruvian men (Hegsted *et al.* 1952). Although there is enormous variation in absorptive efficiency of calcium, the smallest amount that needs to be absorbed by an adult male to stay in calcium homeostasis is about 100 mg d^{-1} (Stini 1990). This is approximately the amount that is lost daily in urine.

It is possible that the values for calcium intake reported here could be adequate to maintain calcium balance in both periods, if populations were extremely efficient in their absorption of this mineral. There are two reasons why this may not be the case, however. The first is that bioavailability of calcium is lower on high protein diets than on lower protein diets (Yuen *et al.* 1984, Kersetter & Lindsay 1990). This condition could have prevailed in pre-Neolithic times, if levels of meat consumption were high. The second is that the calcium in plant foods is not particularly well absorbed, due to the presence of phytate and oxalate, among other substances (McCance & Widdowson 1942; Cummings *et al.* 1979; Fincke & Sherman 1935). This condition is likely to have prevailed in the Neolithic, if the intake of animal foods was particularly low.

It is possible that the osteoporosis observed in the skeletal record from the Neolithic period could have been due to vitamin D deficiency or phosphorus excess, as well as primary calcium deficiency. Dietary intakes of vitamin D were probably low in both pre-Neolithic and Neolithic periods, as dairy foods played no part in the diet. Phosphorus intakes were more likely to be higher in pre-Neolithic times, if large amounts of meat were eaten. Therefore it might be expected that pre-Neolithic man would have suffered from osteoporosis in equal or greater measure than Neolithic man, if the condition was due primarily to dietary factors. The palaeopathological record does not support this assertion.

5. THE EFFECTS OF ENERGY UNDERNUTRITION ON THE AVAILABILITY OF DIETARY IRON AND CALCIUM

To examine the possible effects of CED on the availability of iron and calcium in the diet of subjects living in the Neolithic, the model was re-run under modified conditions. The following assumptions were made: (i) that the model man suffers from CED which is manifested in low BMI and possibly low PAL; (ii) that the types and relative proportions of foods eaten are the same as those in the previous run, at all levels of BMI; (iii) that in the estimation of PAL, there is no down-regulation of BMR due to CED; and (iv) that subjects are in energy balance at the lower levels of intake, where energy intake is equal to TEE. Results are given in table 6.

At the higher PAL (2.0 × BMR), levels of protein and iron intake are adequate to high, regardless of BMI or the proportion of the diet coming from animal foods. At low PAL (1.35 × BMR), protein intakes are lower but still adequate, whereas iron intakes are within the range of values recommended by FAO/WHO (1974) in the 0 and 5% animal foods categories, and above this range for the 10% animal foods group. It is possible, however, that at very low levels of animal food intake, the iron in the diet would have been poorly absorbed. Calcium intakes are consistently low, with values falling below 200 mg d^{-1} at PAL of 1.35 × BMR. This may be a level below which calcium balance cannot be sustained; if so, the osteoporosis observed in the Neolithic skeletal record can only be attributed to primary calcium deficiency under conditions of moderate or severe CED.

6. DISCUSSION

The transition from hunting and gathering to cultivation and animal domestication in the Near East and Mediterranean involved greater utilization of energy-rich plant foods to the detrement of energy-poor ones, and an enormous reduction in the consumption of animal foods. This dietary change has been associated with overall dietary deficiency, and specific deficiencies of protein (Angel 1984), calcium (Smith *et al.* 1984), and possibly iron (Rathbun 1984) by inference from the examination of skeletal material from pre-Neolithic and Neolithic times.

The modelling of dietary and nutritional intakes of an adult male in pre-Neolithic times and in the Neolithic has allowed the postulated association between dietary change and nutrient deficiencies in the Neolithic to be tested. The results suggest that protein deficiency was unlikely if CED was not being experienced; that is, if mass in relation to height was not low, even if adult males were short statured. If adult males suffered from CED, then dietary protein deficiency was only likely if the diet contained no meat. Deficiency of dietary calcium was possible in the Neolithic, if populations were experiencing moderate or severe CED. In the absence of CED, it is unlikely that dietary iron deficiency was a problem. Even if adult males in the Neolithic were suffering CED, it is unlikely that the anaemias identified by palaeoanthropologists had a specific dietary aetiology, although a more complex dietary aetiology is possible.

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REFERENCES

Angel, J. L. 1971 *The People of Lerna*. Washington D.C.: Smithsonian Institution.

Angel, J. L. 1984 Health as a crucial factor in the changes from hunting to developed farming in the Eastern Mediterranean. In *Palaeopathology at the origins of agriculture* (ed. M. N. Cohen & G. J. Armelagos), pp. 51–73. New York: Academic Press.

Armelagos, G. 1987 Biocultural aspects of food choice. In *Food and evolution. Toward a theory of human food habits* (ed. M. Harris & E. B. Ross), pp. 579–594. Philadelphia: Temple University Press.

Bar-Yosef, O. 1987 Late Pleistocene adaptations in the Levant. In *The Pleistocene Old World: regional perspectives* (ed. O. Soffer), pp. 219–236. New York: Plenum Press.

Bokonyi, S. 1969 Archaeological problems and methods of recognising animal domestication. In *The Domestication and exploitation of plants and animals* (ed. P. J. Ucko and G. W. Dimbleby), pp. 219–229. London: Duckworth.

British Nutrition Foundation Task Force on Calcium. 1989 London: British Nutrition Foundation.

Brun, T., Bleiberg, F. & Goihman, S. 1981 Energy expenditure of male farmers in dry and rainy seasons in Upper-Volta. *Br. J. Nutr.* **45**, 67–75.

Brun, T. A., Geissler, C. A., Mirbagheri, I., Hormozdiary, H., Bastani, J. & Heydayat, H. 1979 The energy expenditure of Iranian agricultural workers. *Am. J. clin. Nutr.* **32**, 2154–2161.

Butzer, K. W. 1971. *Environment and archaeology: an introduction to Pleistocene geography*. Chicago: Aldine.

Cleave, J. H. 1970 *Labour in the development of African agriculture: the evidence of farm surveys*. Ph.D. thesis, Stanford University.

Clutton-Brock, J. 1989 *The walking larder. Patterns of domestication, pastoralism, and predation*. London: Unwin Hyman.

Cohen, M. N. 1989 *Health and the rise of civilisation*. New Haven: Yale University Press.

Cummings, J. H., Hill, M. J., Houston, M. N., Branch, W. J. & Jenkins, D. J. A. 1979 The effect of meat protein and dietary fiber on colonic function and metabolism. 1. Changes in bowel habit, bile acid excretion and calcium absorption. *Am. J. clin. Nutr.* **32**, 2086–2093.

Dasgupta, B. 1977 *Village society and labour use*. Delhi: Oxford University Press.

De Garine, I. & Koppert, G. 1988 Coping with seasonal fluctuations in food supply among savanna populations: the Massa and Mussey of Chad and Cameroon. In *Coping with uncertainty in food supply* (ed. I. de Garine & G. A. Harrison), pp. 210–259. Oxford University Press.

FAO 1982 *Food composition tables for the Near East* (FAO Food and Nutrition Paper No. 26). Rome: Food and Agriculture Organisation.

FAO/WHO 1974 *Handbook on human nutritional requirements*. Geneva: World Health Organisation.

FAO/WHO/UNU 1985 *Energy and protein requirements* (Technical Report Series 724). Geneva: World Health Organisation.

Fincke, M. L. & Sherman, H. C. 1935 The availability of calcium from some typical foods. *J. biol. Chem.* **110**, 421–428.

Flannery, K. V. 1965 The ecology of early food production in Mesopotamia. *Science, Wash.* **147**, 1247–1256.

Flannery, K. V. 1969 Origins and ecological effects of early domestication in Iran and the Near East. In *The domestication and exploitation of plants and animals* (ed. P. J. Ucko & G. W. Dimbleby), pp. 73–100. London: Gerald Duckworth & Co. Ltd.

Fox, R. H. 1953 *A study of the energy expenditure of Africans engaged in various activities, with special reference to some environmental and physiological factors which may influence the efficiency of their work*. Ph.D. thesis; University of London.

Guet, G. 1960 *Dario: village de Haute-Sangha*. Paris: Bureau d'Etudes et de Recherches du Plan.

de Guzman, P. E., Dominguez, S. R., Kalaw, J. M., Basconcillo, R. O. & Santos, V. F. 1974 A study of the energy expenditure, dietary intake, and pattern of daily activity among various occupation groups. I. Laguna rice farmers. *Philippine J. Sci.* **103**, 53–65.

Harris, D. R. & Hillman, G. C. 1989 *Foraging and farming. The evolution of plant exploitation*. London: Unwin Hyman.

Heaney, R. P., Recker, R. R. & Saville, P. D. 1978 Menopausal changes in calcium balance performance. *J. Lab. clin. Med.*, **92**, 953–963.

Hegsted, D. M., Muscoso, I. & Collazos, C. 1952 Study of minimum calcium requirements of adult men. *J. Nutr.* **46**, 181–201.

Hill, K. 1982 Hunting and human evolution. *J. hum. Evol.* **11**, 521–544.

Hill, K., Kaplan, H., Hawkes, K. & Hurtado, A. M. 1985 Men's time allocation to subsistence work among the Ache of Eastern Paraguay. *Hum. Ecol.* **13**, 1, 29–47.

Hillman, G. C., Colledge, S. M. & Harris, D. R. 1989 Plant food economy during the Epipalaeolithic period at Tell Abu Hureyra, Syria: dietary diversity, seasonality, and modes of exploitation. In *Foraging and farming. The evolution of plant exploitation* (ed. D. R. Harris & G. C. Hillman), pp. 240–268. London: Unwin Hyman.

Hipsley, E. H. & Kirk, N. E. 1962 *Studies of dietary intake and the expenditure of energy by New Guineans* (South Pacific Commision Technical Paper No. 147). Noumea.

Hopf, M. 1969 Plant remains and early farming in Jericho. In *The domestication and exploitation of plants and animals* (ed. P. J. Ucko & G. W. Dimbleby), pp. 355–359. London: Duckworth.

Huss-Ashmore, R. A., Goodman, A. H. & Armelagos, G. J. 1982 Nutritional inference from paleopathology. *Adv. Archaeol. Meth. Theory* **5**, 395–474.

Jacobsen, T. W. 1969 Excavations at Porto Cheli and vicinity, preliminary report. II. The Franchthi Cave, 1967–1968. *Hesperia* **38**, 343–381.

James, W. P. T., Ferro-Luzzi, A. & Waterlow, J. C. 1988 Definition of chronic energy deficiency in adults. *Eur. J. clin. Nutr.* **42**, 969–981.

Kersetter, J. E. & Lindsay, H. A. 1990 Dietary protein increases urinary calcium. *J. Nutr.* **120**, 134–136.

Kurth, G. & Rohrer-Ertl, O. 1981 On the anthropology of the Mesolithic to Chalcolithic human remains from the Tell es-Sultan in Jericho, Jordan. In *Excavations at Jericho*, Vol. III (Ed. K. M. Kenyon), pp. 407–499. Jerusalem: British School of Archaeology.

McCance, R. A. & Widdowson, E. M. 1942 Mineral metabolism of healthy adults on white and brown bread dietaries. *J. Physiol.* **101**, 44–85.

McNeill, G., Payne, P. R. & Rivers, J. P. W. 1987 *Patterns of adult energy nutrition in a South Indian village*. (Department of Human Nutrition Occasional Paper No. 11.) London School of Hygiene and Tropical Medicine.

Montgomery, E. & Johnson, A. 1974 Machiguenga energy expenditure. *Ecol. Food Nutr.* **6**, 97–105.

Moore, A. T. 1985 The development of Neolithic societies in the Near East. *Adv. World Archaeol.* **4**, 1–70.

Moseley, J. E. 1965 The paleopathologic riddle of symmetrical osteoporosis. *Am. J. Roentgenology* **95**, 135–143.

Nathan, H. & Haas, N. 1966 Cribra orbitalia. A bone condition of the orbit of unknown nature. *Israel J. Med. Sc.* **2**, 171–191.

Norgan, N. G., Ferro-Luzzi, A. & Durnin, J. V. G. A. 1974 The energy and nutrient intake and the energy expenditure of 204 New Guinean adults. *Phil. Trans. R. Soc. Lond.* B **268**, 309–348.

Paul, A. A. & Southgate, D. A. T. 1978 *McCance and Widdowson's The Composition of Foods*. London: HMSO.

Rathbun, T. A. 1984 Skeletal pathology from the Paleolithic through the metal ages in Iran and Iraq. In *Paleopathology at the origins of agriculture* (ed. M. N. Cohen & G. J. Armelagos), pp. 137–167. New York: Academic Press.

Reed, C. A. 1977 A model for the origin of agriculture in the Near East. In *Origins of agriculture* (ed. C. A. Reed), pp. 543–567. The Hague: Mouton.

Rosetta, L. 1988 Seasonal variations in food consumption by Serere families in Senegal. *Ecol. Food Nutr.* **20**, 275–286.

Schofield, W. N. 1985 Predicting basal metabolic rate, new standards and review of previous work. *Hum. Nutr. Clin. Nutr.* **39**C (Suppl. 1), 5–41.

Smith, P., Bar-Yosef, O. & Sillen, A. 1984 Archaeological and skeletal evidence for dietary change during the late Pleistocene/early Holocene in the Levant. In *Paleopathology at the origins of agriculture* (ed. M. N. Cohen & G. J. Armelagos), pp. 101–136. New York: Academic Press.

Stini, W. A. 1990 'Osteoporosis': etiologies, prevention, and treatment. *Yb. phys. Anthropol.* **33**, 151–194.

Stockman, J. A. 1981 Infections and iron. *Am. J. Dis. Child.* **135**, 18–20.

Stuart-Macadam, P. L. 1991 Anemia in past human populations. *Am. J. phys. Anthropol.* **85**, 170–171.

Suzuki, S. 1988 Villagers' daily life and the environment. In *Health ecology in Indonesia* (ed. S. Suzuki), pp. 13–22. Tokyo: Gyosei Corporation.

Tin-May-Than & Ba-Aye 1985 Energy intake and energy output of Burmese farmers at different seasons. *Hum. Nutr. Clin. Nutr.* **39**C, 7–15.

Trotter, M. & Gleser, G. C. 1952 Estimation of stature from long bones of American whites and negroes. *Am. J. phys. Anthropol.* **10**, 463–514.

Ulijaszek, S. J. 1987 *Nutrition and anthropometry – with special reference to populations in Papua New Guinea and the United Kingdom*. Ph.D. thesis, University of London.

Van Zeist, W. & Bakker-Heeres, J. A. H. 1979 Some economic and ecological aspects of the plant husbandry of Tell Aswad. *Paleoorient* **5**, 161–169.

Viteri, F. E., Torun, B., Garcia, J. C., & Herrera, E. 1971 Determining energy costs of agricultural activities by respirometer and energy balance techniques. *Am. J. clin. Nutr.* **24**, 1418–1430.

Waterlow, J. C. 1986 Notes on the new estimates of energy requirements. *Proc. Nutr. Soc.* **45**, 351–360.

Wing, E. S. & Brown, A. B. 1979 *Paleonutrition. Method and theory in prehistoric foodways*. New York: Academic Press.

Yuen, D. E., Draper, H. H. & Trilok, G. 1984 Effect of dietary protein on calcium metabolism in man. *Nutr. Abs. Rev.* **54**, 447–459.

Discussion

G. Hillman (*Department of Human Environment, Institute of Archaeology, University College London, U.K.*). At the start of his paper, Dr Ulijaszek made reference to the possible role of phytates in limiting the uptake of calcium and thereby contributing to osteoporosis and other pathologies. However, he eventually concluded that dietary factors are unlikely to have contributed to these pathologies.

I am not a nutritionist and cannot comment on any links between calcium malabsorbtion and osteoporosis. However, I am familiar with the existing evidence for changes in the plant-based components of diet which seem to have accompanied the shift from foraging to farming in Dr Ulijaszek's study area (Southwest Asia). My present reading of this evidence strongly suggests that the shift to cultivation would have involved a dramatic increase in the consumption of phytate-rich foods (probably as year-round staples), and presumably, therefore, a correspondingly increased risk of chronic calcium malabsorption.

S. J. Ulijaszek. Phytate intakes were not incorporated into the model, because the phytate content of only a limited range of foods has been thus far estimated. Certainly, higher intakes of phytate in the Neolithic, in association with marginal intakes of calcium, may have played an important part in the aetiology of osteoporosis at this time.

J. L. Boldsen (*Department of Community Health, University of Odense, Denmark*). I think that the height of the Neolithic people has been overestimated by using mainstream regression formulae (Trotter & Gleser 1952). Would Professor Ulijaszek comment on the effect on calcium and iron balance of the human height of the neolithic populations being 165 cm instead of 170 cm?

S. J. Ulijaszek. At a smaller body size, the Neolithic model man would maintain energy balance at lower levels of food intake, and this would result in lower levels of intake of both iron and calcium. It is unlikely that iron intakes would be low enough to cause iron deficiency anaemia, unless the model man were suffering chronic energy deficiency. However, the possibility of primary calcium deficiency would be greater than that suggested in the presentation.

C. J. Henry (*School of Biology, Oxford Polytechnic, U.K.*). Much of Dr. Ulijaszek's discussion has centred around calcium intake in early man. What relevance does the lack of vitamin D have on calcium metabolism in the Neolithic man? Could vitamin D have also been a limiting micronutrient thus influencing calcium metabolism in this population?

S. J. Ulijaszek. Certainly, dietary intakes of vitamin D would have been low in the Neolithic, because dairy products played little or no part in the diet. However, this vitamin can be synthesized in the skin from 7-dehydrocholesterol by the action of ultraviolet light. Climatological evidence indicates that overall rainfall in the Near East and Mediterranean region was lower in the Neolithic than in present times, suggesting a drier, sunnier clime. It is probable that on average, human groups received plentiful exposure to sunlight in the course of work, making the possibility that vitamin D deficiency was a major contributing factor to osteoporosis unlikely.