NUTRITION AND AGEING
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Although frank malnutrition has been largely eliminated from most sections of our population it is still occasionally found amongst the elderly. In addition a much larger number of old people may have marginal malnutrition and there is little agreement on the nutritional requirements to maintain the elderly in a state of optimum nutrition. Nutritional status in old age is determined not only by current dietary intakes but also by the operation of factors in earlier life and sometimes even in childhood. Since the elderly segment of the population makes greater demands on health care than any other age group it is important to reduce causes of impaired function and ill health associated with aging. According to Munro (1981) an area which has not received adequate systematic study is the role of nutrition.

Physiology of Aging and Nutrition

Aging is associated with a decline in average values for many physiological functions. Shock and his colleagues of the Gerontology Research Centre, Baltimore, have investigated the changes which occur between the ages of 30 and 80 years (Shock, 1972). Thus resting cardiac output showed a decrement of 30%, renal blood flow was reduced by 50% and the maximum breathing capacity and maximum oxygen uptake declined by 60-70% over the age span of 30 to 80 years. Nevertheless a wide range of values was found among different subjects at each age decade and in some instances the difference in physiological performances became greater with advancing age. Thus the effects of age are highly individual and chronological age alone is a poor index of physiological function.

When extra demands are imposed on an organ system the age differences are more pronounced than when the measurements are made under resting conditions. Older individuals show a greater displacement and a slower rate of recovery in physiological function compared with the young. In consequence the greatest age decrements are found in tests which impose a stress on the organism and require the co-ordinated activity of a number of organ systems, for example, in physical exercise. As homeostatic mechanisms become increasingly impaired, the precarious physiological balance may be upset by the operation of environmental and medical hazards to which the elderly are prone. Thus some cases of overt malnutrition which are seen in old people may be the result of stress of pathological processes in those individuals whose nutrition is only marginally adequate.

Metabolic Rate

The total energy production per square metre of body surface area falls progressively with advancing age. According to Shock et al (1963) there is an average decrement of about 12 Cals/M²/hour between the ages of 20 and 90 years. The fall is believed to be due to a loss of metabolizing tissue with age since animal experiments show that there is no decrease in oxygen uptake of tissue slices, homogenates or isolated mitochondria from rat heart, liver and kidney (Barrows, 1966); nor is there any evidence that the thyroid gland shows any reduction in its capabilities to produce or release thyroxine with advancing age.

The total energy production per 24 hours is the sum of the basal energy production and that required for daily activities. McGandy and his colleagues (1966) have investigated the changes which occur with age in energy expenditure for daily activities and have related total energy...
production to calorie intake. The subjects studied were 167 men whose ages ranged from 20 to 99 years. The total caloric intake fell from a mean of 2688 Cals/day in subjects aged 20-34 years to 2093 Cal/day in the group aged 75-99 years. There was found to be a fairly close agreement between the caloric intakes and the energy expenditure at all ages. The calories required for activities fell more than the basal calories especially among the group of 80 year old subjects. Thus the reduction in the energy metabolism of older subjects is a reflection of tissue loss and to greater extent, especially in the very old, of reduction in physical activity.

The importance of exercise is clearly seen in Durnin's study of elderly farmers (Durnin et al, 1966). The lowest energy output was 2200 Cals/day and the highest was 4200 Cals/day. Thus in this small group of men from the same socio-economic background engaged in the same occupation one man could expend almost twice as much energy as another. The considerable differences in energy expenditure observed in very old people can often be accounted for by complicating factors in that disease and disability have an increasing prevalence above the age of 75 and these affect the capacity for exercise. The main causes are degenerative joint disease and disorders of the respiratory and cardiovascular systems.

**Epidemiological Nutrition Studies**

Most of the nutritional surveys which have been made of the elderly populations have been on the basis of cross-sectional studies. Age differences have been established by the comparison of the results of measurements made on individuals of various age groups. These surveys have usually revealed that a proportion of subjects have low intakes of certain nutrients. In order to assess the effects on health of these low intakes serial investigations on the same individual are required. Moreover such longitudinal studies are the only means of clearly identifying the changes which are due to aging. Ideally the repeated measurements (which must include dietary intake, medical examination and laboratory investigations) should be made on the same person at standardised intervals of time over as long a period as possible; for obvious reasons there have been few studies of this kind.

**Aims of Epidemiological Studies**

The type of epidemiological study undertaken will largely be dictated by its purpose. Some of the more important aims are:

1. To assess the nutritional status of the elderly population and to ascertain to what extent this differs from that of younger adults.
2. To identify malnutrition and the factors involved in its causation.
3. To investigate the effects of aging on nutritional status and on nutritional requirements in old age.
4. To formulate recommendations for dietary allowances in old age.
5. To ascertain the range of "normal" biochemical and haematological values in old age with particular relevance to those related to nutrition.
6. To investigate the effects of nutrition on morbidity and mortality in the elderly and in particular to investigate the role of nutritional factors in the etiology of specific diseases, for example, osteoporosis and ischemic heart disease.
7. To determine whether the health of the elderly can be improved by dietary modifications.

**Cross-sectional Studies**

Although cross-sectional surveys are useful in establishing "normal" values or reference ranges for biochemical, haematological, anthropometric and other data they do not describe accurately the course of development or aging of individuals since the observed age differences may be due to the operation of several factors. These include the effects of aging (i.e. true age changes), the effects of disease (pathological aging), and the effects of change in the social and economic environment (pseudo-aging). From the results of cross-sectional studies it is rarely possible to ascertain the relative contribution of each of these variables. The most
The intrusion of cohort effects:

(i) Some of the differences are due to differences in date of birth of the subjects surveyed—in developing societies people aged twenty and people aged seventy are from very different cultural backgrounds and it is known that dietary patterns are profoundly influenced by socioeconomic and cultural factors.

(ii) Some of the age effects may be obscured by "the survival of the fittest"; for example, the older age groups may show an increase in some survey variable even when the overall trend with age is downwards.

In a survey sponsored by the King Edward's Hospital Fund for London (Exton-Smith and Stanton, 1965) an investigation was made of the diets of old people living alone at home in two North London Boroughs. The participants were 60 women whose ages ranged from 70 to 80 years (with the exception of three aged 89, 90 and 94 years). The mean daily intakes of nutrients were satisfactory and are shown in Table 1.

Few instances of malnutrition were revealed by the survey, but a proportion of the subjects had intakes of nutrients which were less than the recommended allowances, especially for iron and vitamin C. There was a striking correlation between diet and health; nearly all the subjects whose diet was better than average were judged on clinical assessment to be better than average in health. Although a good diet is undoubtedly one of the factors responsible for good health it is probably more likely that better health and greater physical activity are associated with good appetite and a larger intake of food.

When the sixty subjects were arranged in groups according to their ages a striking decrease in intakes of all nutrients with advancing age was found. Table 2 shows the percentage falls in mean intake for subjects in their late seventies compared with those in their early seventies.

The age differences in intake revealed by this cross-sectional study might be the result of several factors:

1. Reduction in basal metabolic rate and lean body mass leading to a fall in physiological requirements with advancing age. Thus the decrease in intake may represent true age changes affecting all individuals.

2. A reduction in appetite and energy expenditure in some of the older subjects due to the development of disease or disability as they enter the second half of the eighth decade. It is known that there is a striking increase in the prevalence of incapacity in the elderly population after the age of 75 (Sheldon, 1948).

3. Failure of certain individuals, notably the obese, to reach extreme old age. Thus the dietary intake of the thinner individuals of the late 70s group would be expected to be less.

4. Secular differences between the two groups in that the lifelong dietary pattern of the older group may have been different from that of the early seventies group. Indeed it is possible that the habitual dietary pattern may have been one of the factors responsible for the longevity of those who reach extreme old age.

Of these four factors the most important was...
believed to be the influence of disease and disability affecting particularly the older subjects. Further evidence that low intakes of nutrients are associated with impairment of health in old age was obtained from a study of the nutrition of housebound elderly people (Exton-Smith, Stanton and Windsor, 1972). The intakes of the housebound were compared with age-matched active people, and for women the differences amounted to 15 per cent less for carbohydrate to 46 per cent less for vitamin C. For the housebound group as a whole there was no decline in intake with advancing age. This is because for the housebound, in contrast with the active group, disability was just as severe in the younger as in the older people. It can be concluded that disability has a greater influence on nutrient intake than the effects of increasing age alone.

**Longitudinal Studies**

The 60 women who participated in the first King Edward’s Hospital Fund Survey were followed up to form a longitudinal study and the 22 women who were still alive and could be traced were re-examined 6½ years later (Stanton and Exton-Smith, 1970). It was found that for those subjects who maintained their health (as assessed on clinical examination and by a scoring system recording physical disabilities) the intakes of nutrients in the two surveys were remarkably similar. But for those women whose health had declined there was considerable fall in intake amounting on average to 20 per cent for protein and 17 per cent for calories. From this limited study it was confirmed that nutrient intakes in old age are usually maintained provided the person remains active and fit, and that physical disability is the most likely cause of declining intakes in the elderly.

Apart from expense these are other disadvantages of the longitudinal approach:

(i) During the interval between surveys economic or social changes can take place and produce effects that cannot be separated from the effects due to aging.

(ii) There is the risk that using the same sample more than once may bias the results as the subjects may change their behaviour and eating habits as the result of the survey.

(iii) Bias of the sample can also occur through the selective loss from the cohort by death, migration or non-cooperation. Non-response is a more serious problem in longitudinal studies than in cross-sectional because it is cumulative as the data from a particular subject who is a respondent in the first survey but not subsequently cannot be used. Moreover non-response over time may be related to the changes which we are attempting to study.

**Prediction of Mortality**

When subjects participating in epidemiological studies can be followed up for a period of five years or more it is possible by examination of data derived from the study to predict those factors which are related to mortality in the sample. Hodkinson and Exton-Smith (1976) have examined the factors which best predict mortality within five years in a random community sample of 852 people over the age of 65 in whom physical, medical, biochemical, haematological and nutritional assessments were made. Of the variables associated with 5 year outcome multiple regression analysis showed that two nutritional factors were significant predictors: low serum pyridoxine in women (p<0.01) and low vitamin C intake in men (p<0.02). Caution is required in interpretation of these findings since they may not represent true nutritional deficiencies. Although leucocyte ascorbic acid has been shown to be a predictor of mortality of patients admitted to a geriatric department (Wilson et al, 1973) it appeared to be an effect related to severity of illness and not an expression of vitamin C deficiency for supplementation had no influence on survival. The relationship between vitamin C intake and mortality may be an epiphenomenon due possibly to the fact that the fittest men who are more likely to survive tend to select diets which are particularly rich in vitamin C. Another important use of this
method is the assessment of risk factors in relation to a specific disease. It is the operation of these factors during the premorbid period which is important and ideally subjects should be free from the disease at the time of the initial epidemiological study since many illnesses themselves influence dietary patterns. If the subject subsequently develops the disease in question precise diagnosis often depends upon the accuracy of death certification.

Skeletal Development, Bone Loss and Osteoporosis

The influence on nutrition in old age of factors operating in earlier life is difficult to assess. The nature of this problem may be illustrated by reference to the patterns of development and loss of bone with age. These patterns have been studies by calculation of the amount of bone in the second metacarpal (Exton-Smith et al, 1979 and Gryfe et al, 1971). Percentile ranking curves for the ratio cortical area/surface area of the normal population of males and females between the ages of 2 and 85 years are shown in Figure 1.

Patterns of Changes in Bone Mass

Examination of the percentile ranking curves shows that some of the characteristics are:

1. The curves remain roughly parallel with age; that is, the variance remains unchanged with age and the distribution at each age group is normal.
2. There is a rapid increase in the amount of bone during the period of growth (up to the age of 18) but the increase continues at a slower rate for another 12 years or so and maturity is reached at about the age of 30.
3. The amount of bone in earlier life is greater in males than in females. At the age of 18 in relation to bodyweight females have 20% less bone than males.
4. Loss of bone is steady after about the age of 45 occurring more rapidly in women than in men.
5. There are some individuals aged 80 who have more bone than others at the age of 30.

Interpretation of Patterns

The interpretation of these results based on cross-sectional studies must be made with caution but the following comments can be made:

a) If there is a critical level for the amount of bone at which manifestations of osteoporosis appear (Newton-John and Morgan, 1968) then this level will be reached at an earlier age for those individuals with a bone mass in the lower percentile ranges than those individuals with greater amounts of bone who can better withstand the loss of bone with age. The likelihood of developing osteoporosis in old age therefore depends on:
   i) Skeletal status at maturity.
   ii) Loss of bone with age after maturity. The higher frequency of osteoporosis in females than in males is due to poorer skeletal status at maturity for females and their more rapid rate of loss of none after the age of 45.

b) The diminution in the amount of bone during the second half of life may be due to:
   i) True age changes occurring in men and women; the atrophy of bone tissue corresponding with that occurring in other bodily organs with advancing age.
   ii) Hormonal influences: the more rapid loss of bone in females after the menopause is due to lack
of oestrogens.

iii) Nutritional influences, particularly status of calcium and vitamin D nutrition. Thus it has been found possible to relate the loss of bone with age to the levels of serum 25 (OH) vitamin D (Exton-Smith, Nordin, Horsman et al, 1979). The rate of loss is minimal when 25 OHD) levels are within the range of 19–63 ng/ml; levels below 19 ng/ml and above 62 ng/ml are associated with more rates of bone loss.

iv) In part the loss of bone with age may be more apparent than real due to the intrusion of cohort effects. Thus the skeletal status of the present 75 year olds at maturity may have been inferior to that of 25–30 year olds today. It has been shown (Exton-Smith, 1970) that the length of the second metacarpal for men aged 75 is on average 1.5 mm less than that for men aged 25–30 years. This corresponds to a difference in height of about 4 cm. Thus the present generation of 75 year olds were in earlier life 4 cm shorter than those aged 25 today. This estimate is close to that reported by Khosla and Lowe (1968) who found that there has been an increase in mean height of the adult male population in the United Kingdom of 2.5 cm. per generation since the beginning of this century. It also corresponds with the accelerated growth in childhood which has occurred during the last 50 years (Tanner, Whitehouse and Tamaishi, 1966). This more rapid growth has been attributed to improvement in nutritional status generally, but Nordin (1976) has pointed out that the proportionate increase in calcium intake has been very much greater than that of calories and protein suggesting that calcium nutrition may be playing a more important role.

According to Greaves and Hollingsworth (1966) the mean calcium intake in the United Kingdom population has risen from 600 ng/day in 1909 to 1150 ng/day in 1960 whereas the protein intake has changed very little and the mean calorie intake by less than 10%.

The increase in height in Japanese children has been even more remarkable. In about 1950 the importance of calcium, nutrition was recognised and bread was fortified with calcium, free milk was issued to school children and attempts were made to increase the production and consumption of milk generally. As a result of these measures the intake of calcium increased threefold from 1950 to 1970 but there was little change in protein and calorie intakes. Twelve year old school boys are now 10 cm taller than boys of the same age 10 years age (Japanese Statistical Year Book, 1970). It can be expected, although it is not yet proven, that this better skeletal development in children will protect against the effects of loss of bone with age and lead to a lower prevalence of osteoporosis in the elderly.

c) The percentile ranking curves for men show that there is an apparent increase in bone mass for men over the age of 80 compared with those aged 75. This reversal of a general downward trend can be ascribed to the 'survival of the fittest'. Men over the age of 80 form a highly selected group and they represent the biological elite; not only do they have better developed bones but their sustained health and physical vigour have enabled them to outlive their former contemporaries.

Clinical Significance of Bone Loss

The major consequences of loss of bone tissue with age are fractures, especially of the femoral neck, and loss of height with age in part due to compression of vertebral bodies.

A. Femoral Neck Fracture

After the age of 60 in both males and females there is an exponential increase of femoral neck fractures. Comparison of the amount of bone in the metacarpal in cases of fracture of the proximal femur with that of the general population without fracture shows that over one-third of the female patients have an amount of bone below the 20th percentile and 40 per cent of the male patients an amount of bone below the 10th percentile (Cook, Exton-Smith, Brocklehurst and Lempert Barber, 1981). This finding clearly demonstrates the importance of osteoporosis in the etiology of femoral neck fracture. Additional factors are the
presence of greater amounts of osteoid due to vitamin D deficiency in femoral neck fracture cases (Faccini, Exton-Smith and Boyde, 1976) and the greater frequency of falling in subjects who subsequently sustained fractures (Cook et al., 1981).

B. Loss of Height

Reduction in height with advancing age is so common that it is often regarded as a typical characteristic of aging. By measurements made of the second metacarpal length and of the height of individuals aged 20 to 25 it is possible to calculate a ratio which can be used to predict height. When measurements of the second metacarpal are made on old people it is possible to calculate their height at maturity (predicted height). Figures 2 and 3 show the relationship between predicted height and measured height for males and females respectively. The majority of old people of either sex have a measured height which is less than their predicted height (Exton-Smith et al.—to be published). Further examination of the data shows that the loss of height (measured height—predicted height) is highly correlated with the amount of bone as determined by metacarpal morphometry (see Figures 4 and 5). Thus elderly individuals who show the greatest reduction in height have the lowest amount of bone in old age. At present it is uncertain whether the loss of height can be attributed entirely to osteoporotic vertebral collapse; in part it could be due to reduced mass of the spinal musculature which is known to correlate with reduced density of the vertebral bodies.

Conclusions

The follow-up of patients participating in a
nutrition survey has provided evidence for variables both nutritional and clinical which are significantly associated with mortality within a five-year period. Similar studies are required using fracture as the end point rather than mortality to determine the influence of factors which lead to osteoporosis and fractures. When the contribution of these variables has been assessed it should be possible by means of intervention studies to determine whether the fracture rate in the elderly population can be influenced by nutritional or other means.

References
2) Cook PJ, Exton-Smith AN, Brocklehurst JC, Lempert-Barber SM (1981) Fracture of the Proximal Femur: The contribution of Falls and

Fig. 4  Predicted change in height by metacarpal index (Men 80 years & over).

Fig. 5  Predicted change in height by metacarpal index (Women 80 years & over).

Bone Disorders (In Press).