

Calcium, micronutrients and physical activity to maximize bone mass during growth

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A large body of evidence relates nutrition in the early stages of life to health later in life. Osteoporosis, a disease affecting several million older people worldwide, is a condition that must be prevented from childhood. Bone grows longitudinally and cross-sectionally during childhood and adolescence, with the largest accumulation of skeletal tissue (50 percent of the total mass) taking place during the adolescent growth spurt. In the third decade of life, the growth and development of the skeleton is complete. The bone consolidates: there is an increase in bone density but no increase in height. After this time, bone mass decreases progressively and becomes increasingly fragile until a threshold is reached. At this stage, fractures are very likely, even as a result of minor injuries. Having a large skeletal mass in early adulthood postpones the time in life when this threshold is reached. A 20 percent variation in the skeletal mass (corresponding to approximately 1 SD [standard deviation] of skeletal mass of the population) leads to 50 to 100 percent variation in the risk of fractures in different sites of the vertebral column (Hui, Slemenda and Johnston, 1989).

Both the formation and the subsequent maintenance of skeletal mass are determined by environmental, hormonal and genetic factors. Studies of twins have indicated that approximately 80 percent of the mass is decided by genetics (Slemenda *et al.*, 1991), while the remaining 20 percent can be manipulated with environmental interventions such as modifications of diet and physical activity. Other studies have suggested that environmental factors such as physical activity and calcium intake can each contribute 40 percent of the variance in bone density (Kelly, Eisman and Sambrook, 1990). This large discrepancy suggests that there is a considerable overlap and interaction of the different factors, since the genetic background modulates nutrient absorption and utilization and also affects muscle mass, thus indirectly influencing the level of mechanical stimulation of the bone.

CALCIUM

Intake

Approximately 70 percent of bone weight is accounted for by calcium phosphate crystals. Thus, calcium is regarded as

the first nutrient to be provided to ensure optimal bone growth. Extreme calcium deprivation, experimentally induced in laboratory animals with diets containing as little as 0.3 to 0.5 mg calcium per gram of food, results in gross retardation of longitudinal growth and marked reduction of bone density. Calcium deprivation affects bone density earlier than it affects growth: in calcium-deprived rats the rate of growth declines only when bone mineral has decreased to 30 percent or less of the control values (Moore *et al.*, 1963). In cases in which infants had very low calcium intakes (below 200 mg per day) and normal vitamin D levels, there was radiographic appearance of rickets (Root, 1990). Another study compared five-year-old children in China, who had calcium intakes of less than 250 mg per day, with children of the same age in Hong Kong, who received more than twice that amount. The bone mineral content of the first group was 14 percent less and the height was 4 percent less than those of children in the second group (Lee *et al.*, 1993). Prolonged dietary deficiency of calcium has not been studied in humans; however, it is known that the bones of the malnourished are very thin and fragile (Himes, 1978).

Worldwide, there is quite a wide spectrum of calcium intakes among different populations. According to some studies, the dimensions, composition and density of bones from populations with low calcium supplies are similar to those of groups with higher calcium intake levels (Walker, 1972). Other studies show that calcium consumption during infancy and adolescence is related to bone density in adulthood (Matkovic, 1991).

Results from recent supplementation trials indicate that an increase in calcium intake leads to greater bone density. In a study of twins aged 6 to 14 years, the diet was supplemented with 1 000 mg of calcium citrate malate for three years. It was found that calcium enhanced the rate of increase in bone density (Johnston *et al.*, 1992). Research with adolescent girls involving an 18-month trial with calcium citrate supplements of 500 mg per day also led to a significant increase in total bone density (Lloyd *et al.*, 1993). In Hong Kong, a group of seven-year-old Chinese children with an initial calcium intake of approximately 500 mg per day were given elemental calcium supplements of 300 mg per

day for 18 months, and this led to a 4 percent increase in lumbar-spinal bone mineral content and a 2 percent increase in lumbar-spinal area (Lee *et al.*, 1995).

Absorption and retention

A possible explanation for this variety of findings, which is reflected in differences in the recommended dietary allowances (RDAs) for calcium, is that calcium intake is just one component of the complex dynamics regulating calcium balance. Calcium absorption is regulated by a number of dietary and individual factors. Calcium from dairy products is more available for absorption in the small intestine, but calcium from plant foods may become available for absorption in the colon (James, Branch and Southgate, 1978). Calcium absorption is enhanced when calcium is limited in the diet and is higher when the needs are greater, such as during infancy. In infants up to 50 percent of dietary calcium can be absorbed, while in adults 25 to 35 percent is absorbed (Heaney *et al.*, 1989). Protein-energy malnutrition reduces the efficiency of calcium absorption (Younoszai and Ghishan, 1979), while recovery from malnutrition can enhance calcium retention up to 87 percent (de Portela *et al.*, 1982). In addition, other factors in the diet, namely protein (Kerstetter and Allen, 1994) and sodium (Nordin and Need, 1994), impair calcium balance by increasing urinary excretion. High phosphorus intake also impairs the regulation of calcium balance in individuals with low-calcium diets (Calvo, 1994).

The list of factors affecting calcium excretion should be extended to all factors that regulate the balance between bone formation and bone resorption. In other words, calcium balance is related to the bone tissue deposited. Even when the conditions for calcium retention are favourable, the mineral may not be deposited in the bone simply because, for a number of reasons, bone is not being made. Two important factors regulating bone deposition during growth and development are micronutrient intake and physical activity.

MICRONUTRIENTS

Are diets balanced and rich enough in all the micronutrients to meet the requirements for manufacturing a sufficient amount of good-quality bone? There are questions as to whether the provision of some micronutrients is adequate worldwide. At present, there is little information about the nutrient contents of foods, let alone population intakes.

Minerals

Minerals other than calcium are involved in skeletal growth, some of them as matrix constituents, such as magnesium and fluoride, and others as components of

enzymatic systems involved in matrix turnover, such as zinc, copper and manganese. Insufficient supplies of these nutrients from the diet result in reduced bone growth or in the formation of defective bone. The adequacy of the intake of these minerals should be verified if all the benefits of a good calcium intake are to be gained.

Zinc deficiency is typically characterized by the arrest of growth. The bones of zinc-deficient animals are very thin and fragile, with a marked reduction of all the cellular elements. Bone formation is depressed, while bone-resorbing cells are stimulated (Holloway *et al.*, 1996) and the concentration of parathyroid hormone, an activator of bone resorption, is increased (Roth and Kirchgessner, 1989). Marginal deficiency of zinc may be common in developing countries (Gibson, 1994), and supplementation studies indicate that the developed world might be affected as well (Sandstead, 1995).

Copper is important for the mechanical characteristics of the bone matrix; the bones of copper-deficient animals are less resistant to mechanical stress (Jonas *et al.*, 1993). In ovariectomized rats that are made copper deficient, osteoporosis progresses more quickly (Yee *et al.*, 1995).

Manganese deficiency causes reduced growth and skeletal abnormalities in animals and in humans (Fincham, van Rensburg and Maras, 1981), with decreased bone turnover.

In studies of postmenopausal women, the supplementation of a conventional low-boron diet led to a decrease of urinary calcium excretion (Nielsen *et al.*, 1987).

Fluoride is involved in the formation of hydroxyapatite crystals. In experiments, fluoride deficiency led to a delay in skeletal development in animals (Schwarz and Milne, 1972). Sodium fluoride supplements, in addition to calcium, are used as an alternative to oestrogen replacement therapy or bisphosphonate in the treatment of osteoporosis.

Vitamins

In addition to vitamin D, vitamins C and K are required for optimal bone metabolism. Vitamin C (ascorbic acid) is required for the synthesis of type I collagen, the main organic component of bone; for the subsequent extracellular modification that allows the formation of collagen cross-links; and for the synthesis of other important matrix constituents, such as glycosaminoglycans. Vitamin K is required for the synthesis of functional osteocalcin, an important structural protein of the bone matrix.

PHYSICAL ACTIVITY

The functional demand imposed on bone is a major determinant of its structural characteristics. Biomechanical studies indicate that stress applied to a skeletal segment

affects the geometry of the bone, the microarchitecture and the composition of the matrix (Carter, van der Meulen and Beaupré, 1996). Clinical studies have shown that physical activity leads to greater bone density in children and adolescents and, to a minor extent, in adults (Parfitt, 1994). Weight-bearing activities, such as walking, have a greater positive effect than non-weight-bearing activities, such as cycling and swimming (Forwood and Burr, 1993). On the other hand, bedrest and the absence of gravity experienced during space flights lead to bone loss; loss of total bone calcium may be 0.3 to 0.4 percent per month (*British Medical Journal*, 1980). Immobility during foetal development, which may result from neuromuscular diseases, leads to reduced skeleton size, with smaller bone cross-section (Rodriguez *et al.*, 1988).

A sustained level of activity leads to greater peak bone mass, as demonstrated by a 15-year longitudinal study in the Netherlands in which physical activity over time was correlated with the lumbar bone mineral density at the age of 27 years (Welten *et al.*, 1994). Interestingly, the daily intake of calcium was not correlated with peak bone mass at age 27, although it was noted that the calcium intake met the Netherlands RDA of 900 to 1 200 mg per day.

There is an important interaction between mechanical demands and the availability of nutrients to manufacture bone tissue. A meta-analysis of 16 studies carried out in postmenopausal women showed that the increase in bone density was positively related to calcium intake when

IMPACT OF EXERCISE ON THE BONE MASS OF ITALIAN BOYS

At the National Institute of Nutrition in Italy, a study was carried out with 36 prepubertal boys to examine the combined effect of calcium intake and physical activity on bone mass and turnover. Twenty-six of the boys (10 ± 1.4 years of age) were involved in gymnastic training, spending about three hours per day in active games or sport and three hours in sedentary activities such as watching television or reading. The other ten boys (10.4 ± 0.6 years) spent less than one hour per day in active games or sport and more than four hours in sedentary activities.

Both groups of boys were consuming a diet adequate in calcium, although they had a calcium:phosphorus ratio below one. Controlling for height, bone area and maturational stage, it was found that the bone mineral density of the arms and legs of the sedentary boys was significantly lower than that of the active children. Time spent in weight-bearing activities was significantly related to bone density at axial and appendicular sites, and each hour of weight-bearing activity increased total bone density by 2 percent. Physical activity appeared to be more important than calcium intake in determining bone density, possibly because all the boys had adequate calcium intake (F. Branca, M. Marzia, A. Andreoli, L. Rossi, L. Callazi, S. Cianferani, S. Vitali, A. De Lorenzo and M.G. Giampietro, in preparation).

calcium supplementation was accompanied by a physical exercise programme (Specker, 1996). On the other hand, when mechanical demands are low, such as during immobilization, intestinal calcium absorption is reduced (Yeh and Aloia, 1990).

CONCLUSIONS

The available scientific evidence indicates that a sufficient amount of calcium should be provided in the diet to ensure the achievement of a peak bone mass and to allow individuals to reach their genetic potential. Frank osteopaenia during growth has been observed only at very low levels of calcium intake, below 500 mg per day, thanks to the adaptive capacity of absorption and excretion. However, higher intakes appear to be advisable. Other conditions also need to be satisfied; these include adequate intake of other nutrients needed for bone formation, such as vitamins C and K, zinc and copper, and a high mechanical demand on the skeleton through an adequate level of weight-bearing exercise. This observation leads to the general recommendation that individuals consume a balanced healthy diet, combined with physical activity, to prevent osteoporosis as well as other chronic diseases. ♦

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Calcium, micronutrients and physical activity to maximize bone mass during growth

Nutrition during the early stages of life can influence an individual's health decades later. Bone growth and development are completed during the first 30 years of life, with the largest accumulation of skeletal tissue taking place during the adolescent growth spurt. Maximizing bone mass during youth can delay the loss of bone mass and reduce the risk of fracture in later years. Physical exercise and diet, in addition to genetic and hormonal factors, can influence bone density.

Research studies disagree about the effects of low calcium intakes on bone growth. The fact that calcium intake is just one component of the complex dynamics regulating calcium balance may explain the differences in research findings. Micronutrient intakes and physical activity also determine bone deposition during growth and development.

In addition to calcium, other micronutrients involved in skeletal growth include magnesium and fluoride, which are matrix constituents, and zinc, copper and manganese, which are components of enzymatic systems involved in matrix turnover. Insufficient dietary supply of these nutrients results in reduced bone growth or in the formation of defective bone.

The functional demand imposed on bone is a major determinant of its structural characteristics. At the National Institute of Nutrition in Italy, the combined effects of calcium intake and physical activity on bone mass and turnover were studied among two groups of boys. After controlling for height, bone area and stage of maturation, the bone mineral density of the arms and legs of the sedentary group was found to be significantly lower than that of the active group. Physical activity appeared to be more important than calcium intake in determining bone density, possibly because all the subjects had an adequate calcium intake. There is an important interaction between mechanical demands and the availability of nutrients to manufacture bone tissue.

Importance du calcium, des micronutriments et de l'activité physique pour maximiser la masse osseuse durant la croissance

La nutrition au cours de la prime enfance peut avoir une influence sur la santé d'un individu des décennies plus tard. La croissance et le développement osseux sont complétés durant les 30 premières années et c'est à l'adolescence, au moment de l'accélération de la croissance, que se constitue la plus grande partie du tissu osseux. Une maximalisation de la masse osseuse pendant la jeunesse peut retarder le phénomène de perte enregistré plus tard et réduire le risque de fracture chez les personnes âgées. Outre les facteurs génétiques et hormonaux, l'activité physique et l'alimentation peuvent influer sur la densité osseuse.

Les résultats des recherches donnent des avis divergents quant aux effets d'une carence en calcium sur les os car l'apport en calcium n'est qu'un des éléments d'une dynamique complexe de l'équilibre calcique. Les apports de micronutriments et l'activité physique jouent également un rôle essentiel dans l'ostéogenèse.

Outre le calcium, d'autres micronutriments ont une incidence sur le développement du squelette: le magnésium et le fluor en tant que constituants matriciels; et le zinc, le cuivre et le manganèse en tant que composants de systèmes enzymatiques associés au renouvellement de la matrice. Une disponibilité alimentaire insuffisante de ces nutriments se traduit par une diminution de la croissance osseuse et par une ossification défective.

La demande fonctionnelle imposée à un os est un facteur déterminant de ses caractéristiques structurelles. En Italie, l'Institut national de la nutrition a étudié, sur deux groupes de garçons, les effets conjugués de l'apport en calcium et de l'activité physique sur la masse et le métabolisme osseux. En vérifiant la grandeur, la section osseuse et le stade de maturation, on a constaté que la densité minérale osseuse des bras et des jambes du groupe sédentaire était nettement inférieure à celle du groupe actif. L'activité physique, plus que l'apport en calcium, semble intervenir sur la densité osseuse: les sujets des deux groupes bénéficiaient en effet d'un apport calcique approprié. Il existe une interaction importante entre les contraintes mécaniques et la disponibilité de nutriments pour créer le tissu osseux.

Calcio, micronutrientes y actividad física para aumentar al máximo la masa ósea durante el crecimiento

La nutrición que recibe una persona durante las fases iniciales de su vida puede influir en su salud decenios más tarde. El crecimiento y desarrollo de los huesos se completa en el curso de los 30 primeros años de vida, registrándose la mayor acumulación de tejido óseo durante el estirón de la adolescencia. Aumentando al máximo la masa ósea durante la juventud, es posible retrasar la pérdida de dicha masa y reducir el riesgo de fracturas entre los ancianos. El ejercicio físico y la alimentación, además de factores genéticos y hormonales, pueden influir en la densidad ósea.

Los resultados de investigaciones relativas a los efectos de ingestas bajas de calcio sobre el crecimiento de los huesos son contradictorios. El hecho de que la ingesta de calcio sea sólo uno de los componentes de la compleja dinámica que regula el equilibrio del calcio puede explicar las diferencias en las conclusiones de las investigaciones. La ingesta de micronutrientes y la actividad física determinan también el depósito en los huesos durante el crecimiento y el desarrollo. En el crecimiento del esqueleto intervienen otros micronutrientes además del calcio: el magnesio y el flúor son componentes de la matriz; y el zinc, el cobre y el manganeso forman parte de los sistemas enzimáticos que intervienen en el ciclo metabólico de la matriz. Un suministro alimentario insuficiente de estos nutrientes se traduce en una reducción del crecimiento óseo o en la formación de huesos defectuosos.

Las exigencias funcionales impuestas a los huesos determina en gran medida sus características estructurales. En el Instituto Nacional de Nutrición de Italia, se estudiaron los efectos conjuntos de la ingesta de calcio y la actividad física sobre la masa ósea y su ciclo metabólico en dos grupos de muchachos. Controles del peso, la superficie ósea y la etapa de maduración revelaron que la densidad mineral de los huesos de los brazos y la piernas del grupo sedentario era considerablemente inferior a la del grupo activo. La actividad física era al parecer más importante que la ingesta de calcio como determinante de la densidad ósea, posiblemente porque dicha ingesta era suficiente en todos los sujetos. Existe una interacción importante entre las exigencias mecánicas y la disponibilidad de nutrientes para la elaboración del tejido óseo. ♦