Adolescence, the optimum time to maximize bone mass through calcium & vitamin D

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Osteoporosis is a major public health problem in the world. As the average age of the world’s population shifts upward, the number of osteoporotic hip fractures occurring in the world each year will rise, from 1.7 million in 1990 to 6.3 million by the year 2050. Osteoporotic hip fracture is an important cause of death and disability, particularly in the developed regions of the world. In Canadian women over 50 y of age, prevalence of osteoporosis is 16%. Annual costs of hip fracture in Canada are expected to rise from $650 million (1995-96) to $2.4 billion by 2041, hence justifying an urgent need for preventive strategies.

Since bone loss is a normal consequence of aging, development of bone mass during adolescence is thought to be a major determinant of vulnerability to osteoporotic fractures in such a way that an increase by 10% in peak bone mass would reduce the fracture risk by 50%.

Bone Mass Development

Time of peak bone mineral content velocity (PBMCV)
The dramatic increase in bone mineral content (BMC) during adolescence is a function of maturation. Approximately 90-95% of an adult’s bone mineral is achieved by the end of adolescence and the final 5-10% may be added over the next 10 years. BMC is closely correlated with height in children until the occurrence of the adolescent growth spurt. Peak height velocity (PHV) is achieved at age 11.8 y in girls and 13.4 y in boys and it is attained ~2 years earlier in girls compared to boys. There is over a 0.7 y year lag time between PHV and PBMCV (Figure 1). The prolonged bone maturation period in boys results in increasing bone size and cortical thickness.

Factors affecting bone mass development
Bone mass accumulation is influenced by heredity, gender, diet, hormones, mechanical forces, and exposure to risk factors which affect bony tissue. Although genetics is the most prominent factor, it is well established that nutrition influences bone mass accrual during adolescence. Nutrients including protein, vitamins C, D and K, and the minerals Cu, Mn, and Zn are involved in cellular activities such as synthesis of bone matrix. Phosphorus is important both for cellular activities and for mineral deposition. Furthermore, the skeleton serves as a very large nutrient reserve for calcium and phosphorus. The North American diet can provide sufficient amounts of most nutrients. However, calcium intake is well below the current recommendation in adolescents.

Role of calcium in maximizing bone mass during PBMCV
The high velocity of bone mineral accumulation during puberty requires a greater intake of calcium compared to childhood and young adulthood. The increase in the plasma level of 1,25-dihydroxy D₃ (1,25D3) and the stimulation of the renal tubular reabsorption of inorganic phosphate are two adaptive mechanisms to cope with increased bone mineral demand of calcium during pubertal growth spurt. Insulin-like growth hormone-1 (IGF-1) presumably is the main hormone responsible for activating those adaptive mechanisms. It has been shown in girls that during puberty, calcium absorption and bone calcium deposition rate increase resulting in more calcium absorption and less overall calcium excretion than adults with the same calcium intake.

Recommended intakes of calcium at puberty
The Panel for the Dietary Reference Intakes (DRI) for calcium could not establish “estimated average requirement” (EAR) for calcium due to lack of precise data. Currently, only an adequate intake (AI) of 1300 mg/d calcium has been set for adolescent boys and girls aged 9-18 y. Therefore the ability of nutritionists to provide dietary advice and to assess nutrient intake is limited.

In setting AI for calcium in adolescence, the DRI panel used the values of calcium retention from the cross-sectional analysis of bone mineral accrual within 2 y of peak bone mineral content accrual. Using longitudinal rather than cross-sectional data, we provided a more accurate picture of BMC accrual. We subsequently estimated that during the 2 years of peak bone accretion calcium requirements increase to 1500 mg for girls and 1700 mg for boys. According to our calculation, during the whole span of adolescence (9-18 y), calcium requirements are 1000 and 1200 mg/day for girls and boys, respectively. These data can be proposed for setting recommended dietary allowance (RDA) for calcium.

Calcium has threshold behaviour. This means there is skeletal accumulation that increases as calcium intake increases, but only up to a threshold level. Above the threshold, skeletal accrual is steady, irrespective of further increases in calcium intake. Therefore, calcium retention in bony tissue is not optimal at intakes below the threshold level.

Dietary sources of calcium
Natural calcium-rich foods, calcium fortified foods, or supplements are dietary sources of calcium. Natural calcium-rich foods are ideal sources of calcium, since they provide a variety of nutrients which are necessary for bone health. In a sample of Canadian adolescents, milk products were the major source of calcium intake, followed by bread and cereals (19%) and other foods (21%) which is close to data from the United States. Fluid milk is the main source of calcium in North America. However, as other beverages such as carbonated and non-carbonated soft drinks and fruit juice, become the favorite beverages of adolescents the intake of fluid milk has decreased over time. Hence, calcium fortification of high quality beverages such as orange juice or soy drinks can be an effective approach for increasing calcium intakes.

Calcium Supplementation
A variety of compounds including calcium acetate, carbonate, citrate, citrate malate, gluconate, lactate, and tricalcium phosphate are available in the market place. In healthy individuals, calcium carbonate is the most widely used supplement with adequate absorbability, when consumed with meals. Calcium supplements provide additional alkalai salts and since the maintenance of acid-base balance is crucial to preserving bone health, calcium supplements may be important for also providing additional alkali salts.

Although most studies are of short duration, they suggest that calcium supplementation improves bone mass accrual by up to 5% during growth years. The optimal time period to intervene is not clearly established. Two studies of calcium supplementation for 1 year, one in post- and the other in pre-menarcheal girls both indicated that there was a sustained effect on total body bone mineral density (BMD) after 3.5 years post-supplement. There is evidence that calcium supplementation in adolescent girls sustained some of the benefits of increased BMD of the forearm and metacarpals of some subjects into young adulthood.

Role of vitamin D in maximizing bone mass during PBMCV
The major calcitropic function of vitamin D is providing calcium for bone growth and homeostasis by increasing intestinal calcium absorption. During the critical time of PBMCV, when the calcium requirement is high, vitamin D status as an adaptive mechanism influences bone mineral accrual. The major source of vitamin D is exposure of skin to sunlight. However, cultural, environmental, and physiological factors can impair sunlight-induced production of vitamin D, hence, it is important to consider dietary intake of vitamin D.

Although North Americans probably have one of the highest vitamin D intakes in the world from both food and supplements, a seasonal insufficiency of vitamin D has been reported in adults, adolescents and children. There are no nationally representative vitamin D intakes for Canada however studies indicate the same seasonal variation as the US in serum 25-hydroxy vitamin D (25(OH)D) concentrations. Even vitamin D insufficiency in Canada may be worse than in the US due to greater absence of cutaneous vitamin D synthesis during long winters. Current vitamin D fortification practices may not be sufficient to prevent poor vitamin D during winter. However, dietary vitamin D intake per kg body weight was the most important predictor of 25(OH)D concentration at the end of winter in Edmonton, when adolescents and children were at risk of vitamin D insufficiency.
The current dietary recommendation for vitamin D was set in 1997 by the Institute of Medicine and it has not changed much from the RDA value first determined in the 1940s. There was not sufficient evidence to set an RDA, instead an Adequate Intake (AI) was determined. Higher than recommended current vitamin D requirements and status have been more surmise than science. During time of PMBCV, the vitamin D requirement is likely more than other age groups due to accelerated bone mineralization but this is not reflected in a higher AI for adolescents, which is the same for all age groups below 51 y in both genders at 5 μg/dL (200 IU/d).

Since 1997, much has been learned regarding the calcitocorticotropic and noncalcitocorticotropic functions, and the metabolism of vitamin D. In addition to the critical role of vitamin D in maximizing peak bone mass, there are links between vitamin D insufficiency and chronic diseases. Furthermore, it is well known that without assurance of sun exposure, requirement and recommendation for vitamin D would be far higher than what is currently set to EAR and RDA values for vitamin D to facilitate planning and nutrition education initiatives.

Dietary sources of vitamin D

There are few natural food sources of vitamin D: primarily fish and liver oils. Since these foods are not commonly consumed, in North America most of the vitamin D intake comes from foods fortified with vitamin D, and in Canada, the food that provides fortification with vitamin D are milk (100 IU per 250-mL) and margarine (53 IU/g) currently. Currently, no other foods fortified with vitamin D is permitted. Vitamin D supplementation should be considered to meet vitamin D needs when skin synthesis is not possible.

Conclusion

Nutrition is a critical factor in achieving genetically determined peak bone mass. Calcium and vitamin D are the two key nutrients in this regard. Behavioral changes during puberty affect nutritional choices of adolescents. Fluid milk as the main source of dietary vitamin D has been substituted in adolescents by other beverages.25,26 By promoting healthy eating behaviors, including consuming foods containing these nutrients, and when appropriate supplementing with calcium and vitamin D, adolescents can optimize their calcium and vitamin D intake hence, maximizing their bone mass.

Figure 1: Total body mineral content velocity during adolescence. Age of peak height velocity (PHV) is 11.8 y in girls and 12.4 y in boys. Peak bone mineral content velocity (PBMWV) is achieved 0.7 year after PHV.

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Editor: Wyeth Consumer Healthcare Inc.

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