Calcium and dairy intake in bone health during adolescence

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Introduction

Adolescence, as defined by the World Health Organization (WHO), is the period in human growth and development that occurs after childhood and before adulthood, from ages ten to 19 years. Adolescence is the critical period for bone accrual and the development of peak bone mass (PBM). PBM, the maximum amount of bone acquired at skeletal maturity, will determine fracture risk and in turn be a determining factor for osteoporosis later in life. It has been said that 60% of the risk for osteoporosis can be explained by the amount of bone mineral laid down in the early years of life, and 40 - 60% of adult bone mass is acquired during the pubertal growth spurt; with 25% PBM acquired during the two years surrounding peak height velocity. Bone density and bone growth are dependent on various factors that affect the development of PBM. Approximately 60-80% of the PBM that is developed is genetically determined. The remaining 20-40% is determined by diet, physical activity, hormones and medications. The promotion of healthy bones is essential in the short-term to prevent fractures, but also in the long-term prevention of osteoporosis in the elderly.

To ensure adequate bone mineral density (BMD) and bone mineral content (BMC), adequate dietary intake of key nutrients involved in bone metabolism such as calcium, iron, zinc, vitamin D and other key nutrients, and sufficient physical activity levels are of the essence.

Nutrition

Nutrition is a critical determining and modifiable factor of bone growth and density. Macro and micronutrients are involved in bone metabolism, and include protein, calcium, phosphate, vitamin D, sodium, iron, potassium, zinc, phosphorus, fluoride, copper, boron, manganese, vitamin C, vitamin A, B vitamins and magnesium. Female adolescents with conditions such as anorexia nervosa are at a high risk for fractures and osteoporosis since their overall dietary intake is very poor. Adolescents who are overweight or obese may also not consume an adequate amount of calcium and vitamin D as the diet is often high in energy from fat and carbohydrates.

The typical dietary patterns and food choices of the rural as well as urban black population in South Africa have changed over the years from a prudent to a Westernised diet that is high in sugar and fat and low in fiber and essential nutrients involved in bone health and metabolism. The Medical Research Council of South Africa published research investigating the dietary intakes of the South African population from 1995-2005, that has shown that the intake of dairy in rural children above the age of ten years is 31g/day, vegetables 101g/day, fruit and legumes 36g/day, whereas their urban counterparts consumed 109g/day, 85g/day, 83g/day and 34g/day, respectively.

It is very important to emphasise the fact that a diverse diet, rich in micronutrients, with a variety of foods including lean proteins, complex carbohydrates, fruits, vegetables, nuts and low fat dairy products is needed to ensure normal weight gain and micronutrient levels. An adequate dietary intake, together with physical activity to ensure proper growth and development is essential, and the focus should not be placed on one nutrient or one lifestyle factor alone.

Calcium and dairy intake in bone metabolism will be discussed in more detail.
Calcium

Calcium is one of the primary bone-forming minerals that has been associated with a greater PBM and has a protective effect against fractures.2,5,6,13 The skeleton contains 99% of the calcium in the body, but its functions are not limited to it. At birth the infant has approximately 20-30g of calcium in the body, and by the stage of maturity approximately 1200g which is found in the teeth and bones (99%).14 Calcium in the body fluids also exerts metabolic functions, binds to proteins, operates as a signal and is required for muscle contraction, nerve transmission and blood clotting. Extracellular calcium levels are tightly controlled to ensure its functions.15,16 When extracellular fluid calcium concentration is not sufficient, bone is resorbed to release calcium, therefore optimal intake is important as well as optimal absorption.16

The Institute of Medicine (IOM) has published the latest RDA for calcium and this is endorsed by the American Academy of Paediatrics (AAP). The RDA for adolescents nine to 13 years is 1300mg with an upper level (UL) of 3000mg/day. This RDA meets the requirements for 97.5% of the population.4,17 Data on calcium toxicity are not available in this age group yet, but a very high calcium intake may increase the risk of zinc and iron deficiency as calcium affects the absorption of these minerals.15 Calcium intakes for ages above eleven years, typically fail to meet the adequate intake (AI), especially among females as reported by the United States Nutrition and health Status Survey (NHANES) data from 2007.18

Calcium can be obtained from foods including milk, cheese, yogurt and sardines.18,19 Calcium is mostly found as complexes with other food components, thus the calcium must be ionised to a soluble form once in the body. When the calcium-containing food enters the stomach, the acidity from the gastric acid assists with the solubility of the complexes, since most of the enzymes that facilitate the digestion are pH dependent.20 Once the calcium is in a soluble form, it is absorbed through two pathways, i.e. transcellular and paracellular transport.21,22,23 The transcellular pathway (mainly regulated by 1,25(OH2)D3) is a process which involves the entry of luminal Ca2+ across the membrane of the microvilli into the enterocyte, after which it moves through the cytosol and gets actively extruded from the enterocyte into the lamina propria and ultimately into the general circulation. The intracellular Ca2+ diffusion is facilitated by a cytosolic calcium-binding protein (CBP) namely calbindin D9K, which synthesis is dependent on 1,25(OH2)D3. Calbindin D9K facilitates the diffusion of Ca2+ across the cell by acting as an intracellular calcium carrier. The active extrusion of Ca2+ at the basolateral membrane is mediated by Ca-ATPase and takes place against an electrochemical gradient. The entry of Ca2+ across the membrane of the enterocyte is heavily electrochemically favoured due to the concentration of Ca2+ within the cell. This means that the movement of Ca2+ across the apical membrane does not require energy expenditure. Each step in the transcellular movement is dependent on 1,25(OH2)D3. However calbindin D9K is the rate-limiting molecule in vitamin D-induced transcellular calcium transport. This passive movement of calcium takes place in the jejunum and ileum.21,22,23

The paracellular route is a passive and non-saturable. This route is dependent on the calcium concentration levels, not on nutritional or physiological regulation. The small intestine is where most calcium absorption takes place in humans, with very little colonic absorption. Therefore when dietary calcium is abundant, the paracellular pathway can be predominant as opposed to when dietary calcium is limited, the 1,25(OH2)D3 dependent transcellular pathway is predominant.21,23
Furthermore, the duodenum contains the calcium-binding protein (CaBP) that, in combination with low pH, explains why the calcium absorption in the duodenum is greater than in the other parts of the intestine.  

Oxalate, fiber, alcohol, fat and phytates decrease the absorption of calcium, whereas sodium, caffeine and animal protein acid producing foods, increase calciuria. Lactose and medium chain triglycerides (MCT) increase the absorption. Potassium and bicarbonate found in fruits and vegetables have a reduced calcium excretion effect in the kidneys.

Interestingly Pettifor discusses the adaptation that children make when they have consistently low calcium intakes. The renal system adapts by reducing urinary calcium excretion. This adaptation to calcium homeostasis is said to be present when diets are high in phytates and oxalates.

Evidence shows that non-digestible oligosaccharides, especially inulin-type fructans, enhance the absorption of calcium. A randomised controlled trial done by Abrams et al in 2005 found that in nine to 13 year boys and girls, those supplemented with inulin-type fructan, had significantly higher calcium absorption than those in the placebo control group who only received maltodextin. In addition to this, it was shown that the additional calcium absorbed was retained in the body for use by skeletal tissue. The experimental group had a greater increment in both BMC and BMD than the control group.

A study done in 1979 by Pettifor et al in South Africa, investigated the calcium intake and associated urine and blood levels of rural children and found that those with a low calcium intake had low levels, and when supplemented with 500mg of calcium daily, the status improved dramatically. The study mentioned the availability of milk was a concern in rural areas as only those households with cows had milk whereas the urban areas have more access to milk. More recently, MacKeown et al investigated the macro and micronutrient intake from the children in the Birth to Twenty Cohort. They started investigating the nutrient intakes when the children were five, seven, nine and ten years in 1995, 1997, 1999 and 2000 respectively. At every time period calcium was below the RDA; 673mg/day, 583mg/day, 606mg/day and 494mg/day, respectively. In another published article MacKeown et al investigated the intakes at the year 2000 and 2003 respectively, and found similar results. Calcium intakes were below the RDA for every intercept. Pedro et al reported the variety of foods reported in the same group and from the 40 most commonly consumed foods, full cream milk was ranked 8th and the only other calcium foods were custard (32nd), ice cream (35th) and low fat yogurt (37th). This suggests that for eight years these children have had a low calcium intake which places them at risk for low PBM and BMD.

Several trials have found an increase in BMD in adolescents who were supplemented with calcium. A study done by Wosje et al in South Dakota in 2000, reviewed randomised control trials of calcium supplementation. They found that the highest BMD increase was found to be in the cortical bone sites of those who had low baseline calcium intakes. They found that BMD was increased in children and adolescents as calcium intakes increased. In a double-blind randomised control trial conducted in Switzerland in 1997, pre-pubertal girls were supplemented with calcium. Their BMC and BMD were measured, and it was found that the BMD was increased in the radial metaphysis and diaphysis as well as the femoral neck, trochanter and diaphysis sites. Increased BMC was also seen together with increased bone size and statural height. Nieves et al estimated that an increase in calcium intake from 800 to 1200mg in the teenage years would increase hip bone density by 6% by the age...
of 39 years. In 2006 Winzenberg et al conducted a meta-analysis of the effects of calcium supplementation on bone density in healthy children. They studied 19 calcium intervention studies that were all randomised controlled trials that involved 2859 children. The supplemented doses varied between 300 and 1200mg per day. There was no effect of supplementation on BMD of the femoral neck or lumbar spine. There was a small effect on total body BMC and upper limb BMD. Only the effect in the upper limb persisted after supplementation ceased. A calcium supplementation study was done in the Gambia where pre- or early-pubertal children received calcium supplementation of 1000 mg/day for 5 days a week. These children had habitual calcium intakes of 340mg/day. The supplementation resulted in a 4-5% increase in radial BMC as compared to the controls over a 12 month period. The authors made the conclusion that the increase in BMC was a result of a reduction in bone remodeling space rather than an actual increase in bone.

It is important to note data suggesting that if calcium is supplemented for short periods, it may not have long-term benefits in attaining and maintaining maximum PBM. Calcium in the form of supplements is more effectively absorbed in doses less than 500mg. In the state of fasting, calcium in the form of calcium citrate is better absorbed than from calcium carbonate whereas calcium carbonate is better absorbed when taken with food. The IOM recommends taking supplements with food to reduce the risk of kidney stone development. When supplementing with calcium, it is important to note that calcium has a threshold which means that the benefits discussed is related to those with a low intake. Once intake is adequate, additional supplementation will not provide additional benefit. Though calcium intake in the form of milk is still recommended for adolescents, it is often a challenge.

Milk Intake and bone growth

Adolescents, especially females, consume far less than the recommended intake for calcium from foods such as milk. Dairy foods are a complex source of nutrients, including protein, carbohydrates, calcium, phosphorus, fatty acids, potassium and magnesium. It has been suggested that the health benefits are not due to individual nutrients, but the greater sum of it all. As mentioned before, protein plays an essential role in bone health and milk provides a good quality protein together with calcium, vitamin D and other nutrients such as iron, magnesium and zinc that play a role in bone formation. Milk contains lactoferrin which stimulates osteoblasts and inhibits the work of the osteoclasts, thereby directly contributing to bone formation.

A study published by Feskanich in 2014 investigated the milk consumption during teenage years and risk of hip fractures in older adults. They found that those men and women who consumed more milk were taller than those who consumed less. A higher milk consumption during the teenage years was not associated with a lower risk of hip fractures in women. Interestingly, the men had a higher risk of fractures with higher milk intake, but this was attenuated when height was accounted for.

Unfortunately, there are various barriers to optimal milk intake in adolescents that should be considered. Western literature reports that girls especially show suboptimal protein and calcium intake as they see dairy products as fattening. It can also be related to lactose intolerance and the fact that milk is replaced by soft drinks, flavoured water and fruit juice where only 10% of adolescent girls achieved a calcium intake of 1300mg per day as reported by a descriptive study done in the United States by Suitor et al. Parental influences are also important when it comes to adolescent milk consumption.
Milk and milk products may provide a better sustained accrual of bone mass as opposed to that obtained from calcium supplements. The nutrient profile of the products differ, e.g. choosing dairy intake as fluid milk or yogurt instead of cheese or cream can increase intake of vitamin D, potassium and vitamin A, and decrease intake of sodium, saturated fatty acids cholesterol. Milk has the largest ratio of calcium to sodium, whereas the calcium from yogurt has a higher bioavailability of calcium as a result of the acidity of the yogurt which facilitates calcium absorption. On the other hand, cheese has a high sodium and polyphosphate levels and may not be as advantageous. Cream has a very low nutrient density and may even be disadvantageous to bone health.

A study reported in 2013 by Sahni et al investigated the associations of milk, cheese, cream yogurt, most dairy (total dairy without cream), and fluid dairy (milk and yogurt) with BMD at femoral neck, trochanter, and spine, and with incident hip fracture over a twelve year follow-up in the Framingham Offspring Study. They reported that most dairy intake was positively associated with spine and hip BMD. The intake of fluid dairy and milk was related with hip but not spine BMD. Yogurt intake was associated with TR-BMD alone. Cream and cheese intakes were not associated with BMD. They concluded that milk and yogurt intakes were associated with hip but not spine BMD, while cream may adversely influence BMD. Therefore it is clear that not all dairy products provide equal benefits for the skeleton.

Conclusion

Adolescence is a critical time for achieving PBM and bone density that is critical for the prevention of fractures and osteoporosis in the long-term. The South African population has moved toward a more Westernised dietary pattern, characterised by a high intake of foods that are energy dense and high in sugar, fat and salt. This dietary pattern is already present from the adolescent years and follows into adulthood. This type of dietary pattern may lead to macro and micronutrient malnutrition, specifically a low intake of nutrients involved in bone metabolism. A low intake of these nutrients contributes to the development of weak and brittle bones and ultimately osteoporosis. Underweight, overweight and obesity negatively impact bone density and are directly influenced by dietary intake.

An adequate dietary intake of nutrients involved in bone metabolism is essential during this critical period of bone accrual. Nutrients including protein, calcium, phosphate, vitamin D, potassium and zinc are actively involved in bone modeling and remodelling. Together with physical activity, these nutrients ensure proper bone mineralisation and ultimately the attainment of PBM. Regular physical activity of varying intensities is needed to stimulate osteogenesis, but also to maintain a healthy body weight.

Intake of milk and other dairy products remain a crucial strategy to ensure bone health and development during adolescence. Financial and social barriers result in reduced milk intake and often increased intake of soft drinks which negatively impact bone health. Dietary assessment, together with anthropometry and body composition assessment play a crucial role in identifying children at risk for low bone density.

We have a responsibility as health care professionals to promote bone health by investigating areas of, and contributing factors to poor dietary intake of calcium and dairy products. This creates a dire need for insight that can lead to appropriate cultural specific interventions.
REFERENCES


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