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Review Article

A review on dietary approaches to enhance calcium intake among adolescents

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ABSTRACT

Adolescence is one of the most important milestones in the life cycle stages, in which each individual undergoes various physiological and psychological changes. This period is considered one of the important stages of nutritional vulnerability. Calcium needs are elevated due to intensive bone and muscular development. Calcium acts as one of the vital minerals for bone mineralization during childhood and adolescence that primarily needs to be driven through adequate dietary sources. Globally, calcium intake in all age groups including adolescents has lowered due to changing food patterns which have highly tilted towards a high intake of ultra-processed foods. This review draws attention to enhanced calcium intake through healthy dietary measures.

Keywords: Adolescents, Bone health, Calcium requirement, Calcium intake, Calcium absorption

INTRODUCTION

Adolescence is a transitional period between childhood and adulthood characterized by rapid physical, cognitive, emotional, and social development. It is typically marked by the onset of puberty, but it encompasses a broader range of changes and is predominantly driven by testosterone and estrogen hormones in boys and girls respectively.[1,2] Bone mineralization initiates in the first weeks of the life cycle phase and this gets stabilized around 25 years of age, however, the intensity of bone remodeling is observed to be high in the second decade of life which is around 20 years of age.[3]

The greatest intensity of accretion occurs six months after peak growth velocity, during the pubertal spurt, and continues until the final height is reached. In the case of girls, this phenomenon occurs about a year before menarche.[4] Rapid physical changes like augmented growth including skeletal and muscular change and onset of menarche, and psychological changes in adolescents elevate the nutrient demands. For healthy bone accretion and calcium homeostasis, micronutrients like calcium, phosphorous, and vitamin D play a vital role. Calcium is also required for basic regulatory functions like nerve impulse transmission, a cascade of blood coagulation, muscular contraction, and relaxation, stimulation of hormonal secretion including enzyme activation, and so on in the human body.[5] Adolescents throughout the world are at risk due to dietary pattern changes and other lifestyle factors as nicotine and alcohol, which are part of most adolescent lifestyle that interferes with the body's use of calcium.

Nicotine is known to cause inhibition of osteoblast production.[6] Alcohol, action on the liver, brings metabolic changes that further affect the bioavailability of micronutrients. In many adolescents, decreased calcium intake is observed due to the substitution of soft drinks in place of milk which acts as one of the contributing factors for reduced intake of dietary calcium. Optimization of lifestyle factors is an important strategy known to influence calcium intake. Hence, adequate calcium intake through dietary sources along with other lifestyle modifications during this period helps in attaining the

required bone mass and muscle growth, which protects against osteoporosis in the later period.[7]

Recommended calcium intake for adolescents

The recommendation of specific nutrients is the required level of nutrients for a specific age and stage, which helps to meet the adequacy of nutrients that prevents the risk of deficit or excess. In general, a gradient of biological effects related to nutrient intake is considered while considering nutrient requirements. The scientific panel considers several points of view while recommending the specific nutrient requirement in each life cycle stage.

The primary strategies used to determine the daily loss of a given nutrient, growth requirements, adjusted fractional absorption in a given life cycle phase and intake to achieve maximal nutrient retention factors are established by published randomized studies, controlled trials and factorial approaches. Dietary calcium intake is of concern for adolescents, where the typical requirement of calcium given by different health supporting agencies and organizations is presented in (table 1).

Calcium intake among adolescents

From the literature, it was revealed that calcium intake among adolescents is low, and since the past decade, intake is still reducing. Globally, calcium intake in all age groups including adolescents has lowered due to changing food patterns which have highly tilted towards high intake of ultra-processed foods. The available literature on calcium intake among adolescents from the last decade is presented in (table 2) and has shown a clear indication of lower calcium intake. Cereals are the staple food of the majority of Indian adolescents which are rich in oxalic acid and phytins, known to reduce the bioavailability of calcium.[13] Most of the researchers revealed the increased pervasiveness of faulty food habit patterns in adolescents.

One Brazilian research revealed that the dietary patterns of adolescents is changing as there is an increasing trend in high-calorie foods consumption as sugary drinks, sweets, and cookies and saturated fats consumption has increased and sodium intake also increased due to high consumption of processed foods. Dietary intake assessment among adolescents in Pokhara Valley, Nepal reported a highly remarkable increase in junk food intake in both public school and private school adolescents. The easy availability and ready-to-use packaging or convenience have increased junk food consumption among adolescents.[14]

Dietary approaches to enhance calcium intake

Certain foods contain compounds like oxalic acid and phytic acid that prevent the absorption of calcium by producing unabsorbable salt. Dietary sodium intake has been identified as a contributor to increased urinary calcium loss, necessitating elevated calcium requirements for individuals with high sodium intakes. Contrary to previous beliefs, recent studies suggest that high-protein diets may not adversely affect the calcium balance.[25] Dietary sources like milk and milk products, dark-colored green vegetables, certain types of fish and nuts, finger millet, dried forms of curry leaves and drumstick leaves, and spinach are considered good sources of calcium. Milk and milk products are considered good sources of calcium, however, increased unsafe hormonal dosage in dairy animals for milk production created a dilemma for milk and milk products choice.

In Kale, broccoli and watercress calcium content ranges between 100 and 150 mg per 100 g.[26] Despite the broad spectral availability of different food sources, various factors like the accessibility of these foods, socio-economic status, individual food preference, religion, physiological conditions such as food intolerance and lack of nutritional knowledge among adolescents and parents have been shown to affect the total intake of calcium among adolescents. Calcium absorption and percent bioavailability of calcium from different foods are considered as other contributory factors for calcium deficiency prevalence among adolescents.

Approximately around 20 to 60 percent of dietary calcium is absorbed in the duodenum and jejunum, and is stimulated by calcitriol, the biologically active form of vitamin D. From numerous research studies it was revealed a positive correlation between low levels of vitamin D3 with decreased calcium absorption. Vitamin D and its metabolites are known to play a crucial part in the endocrine system which aids in the control of calcium homeostasis.[27] Hence, vitamin D intake from different food sources and exposure to sunlight need to be considered to enhance calcium levels.

Awareness and consideration of different food sources of calcium, inhibitory and enhancing factors for calcium bioavailability among adolescents plays a crucial role in the enhancement of calcium intake. Different dietary sources for calcium are presented in (table 3) and the inclusion of these food ingredients in daily diet helps in the enhancement of dietary intake of calcium. Fortification of commonly consumed foods also can become one of the possible solutions to enhance calcium intake. However, issues related to the availability of calcium salts for the fortification of food, ethical considerations, consumer acceptance and bioavailability of fortified salts need to be considered while planning the food fortification.

Factors affecting absorption and bioavailability of calcium

Calcium absorption and bioavailability are the major concerns that need to be considered while selecting the food. The bioavailable calcium fraction from dietary sources is potentially absorbable by the intestine and gets utilized for physiological functions, particularly bone

mineralization or to help in limiting bone loss. Calcium absorption occurs through both transcellular and paracellular pathways. In the duodenum, the transcellular pathway dominates, but in the jejunum and ileum, the paracellular pathway accounts for the bulk of calcium absorption.[36] Factors affecting absorption and bioavailability of calcium need to be considered to make effective availability of dietary calcium intake. Although the calcium absorption in the body is specific to each person and derived from different genetical makeup, qualitative and quantitative composition of external factors (e.g., dietary source) consideration also plays a vital role.[37]

Several factors affect the calcium absorption and bioavailability, such as physiological and environmental factors and physical form and property of food. The low pH in the stomach is critical for solubilization and ionization of calcium salts present in foods, although calcium oxalate complexes remain insoluble and thus cause poor absorption.[38,39] Calcium absorption is enhanced when the needs are greater, such as in infancy and adolescence. Fractional calcium absorption is highest in infancy (60%), decreases in childhood, then rises with puberty (34%), stabilizes in adulthood (25% in young adults) and progressively decreases with aging.[40]

Vitamin D

Vitamin D consumption is another important factor that improves the absorption of calcium. Vitamin D plays a vital role in facilitating the active, transcellular pathway for intestinal calcium absorption, contributing significantly to the maintenance of normal calcium levels and bone mineralization. The adequacy of dietary calcium is in part, contingent upon the individual's vitamin D status. In most adult populations, vitamin D deficiency is unlikely to hinder calcium absorption, unless there are extremely low concentrations of 25-hydroxyvitamin D (25(OH)D), which have been linked to impaired calcium absorption.[41,42] Sun exposure evidenced the endogenous synthesis of vitamin D. Meanwhile, as high as possible calcium intakes should be achieved through a balanced diet and can also be facilitated by the consumption of fortified foods. Dietary factors impairing positive calcium balance (mainly animal protein and sodium) should be minimized.

Vitamin D and calcium collaboratively regulate parathyroid hormone (PTH), with the suppression of PTH to normal concentrations contingent upon sufficient calcium intake and adequate vitamin D status, as indicated by serum 25-hydroxyvitamin D (25(OH)D) levels.[27] Populations deficient in vitamin D may experience elevated PTH levels, leading to increased bone turnover and heightened calcium requirements. In South Korea, where average calcium intake is low (around 485 mg/day), the 2009–2010 Korea National Health and Nutrition Examination Survey revealed an inverse correlation between PTH levels and calcium intake.

This association observed for both lower (<50 nmol/l) and higher (>75 nmol/l) 25(OH)D levels.[41] Conversely, in Iceland, where calcium intake is higher (mean intake >1000 mg/day), a cross-sectional study involving 944 healthy participants found that calcium intake of 800 mg/day was significantly linked to elevated serum PTH in individuals with low 25(OH)D (<25 nmol/l). Notably, in individuals without vitamin D deficiency, calcium intake did not show a significant relationship with PTH levels.[42] These findings are representative of observational studies demonstrating an inverse correlation between calcium intake and PTH when calcium intakes are low, particularly in the context of low vitamin D status. Certain foods contain compounds like oxalic acid and phytic acid that prevent the absorption of calcium by producing unabsorbable salt.[43]

Dietary sodium intake has been identified as a contributor to increased urinary calcium loss, necessitating elevated calcium requirements for individuals with high sodium intakes. Contrary to previous beliefs, recent studies suggest that high-protein diets may not adversely affect the calcium balance.[25] Research reviews on factors affecting the absorption of calcium is presented in (table 4) and these need to be consider for the improvement of calcium intake. The negative effect of fiber on calcium absorption is mainly due to the phytates that are frequently associated with dietary fiber.[44] Some indigestible carbohydrates and hard-to-digest oligosaccharides have been shown to increase calcium absorption in the distal intestine by enhancing bacterial fermentation, thereby lowering the pH.[45]

Food processing techniques

Fermentation technique can be used for the reduction of antinutritional factors such as phytic acid, oxalate, tannins, and various protein complexes which in turn helps in enhancing the mineral absorption in addition to microbial production of digestive enzymes.[46] In one of the research studies on calcium bioavailability from fermented Moringa oleifera in rat revealed effective release of calcium and increased bioavailability of calcium. The mixture of bacterial microflora of Lactobacillus reuteri, Lactobacillus acidophilus and Candida utilis fermentation has shown the 2.4-fold of elevation of calcium in Moringa oleifera.[47] Due to the desirable benefits, fermentation is considered as an effective tool in reducing the mineral deficiency across populations, by enhancing the bioavailability of minerals especially from whole cereals and/or pulses.[48]

The germination process facilitates mineral absorption by releasing bound minerals from legumes and reducing phytic acid, thereby enhancing their bioavailability and nutritional value. Studies by Greiner & Konietzny and Lonnerdal reveal that germination releases bound

minerals such as calcium, zinc and iron, potentially increasing their bioavailability.[63,64] Similarly, few more studies demonstrate that phytic acid reduction during germination enhances mineral absorption, contributing to the nutritional value of legumes.[65] In addition to germination, cooking methods play a crucial role in enhancing legume nutrition. pressure cooking method which is a common practice in Chinese households, effectively reduces antinutritional factors, further improving the nutritional quality of legumes.[66]

Table 1: Recommended calcium intake for adolescents.

Recommended calcium intake (mg/day)	Reference
960	AR, Europe-2021
1000	RDA, Southeast Asia-2021
1000	EAR, Brazil-2000
1100	EAR, United States/Canada-2011
800	EAR, India-2021
1040	FAO/WHO-2006

AR-Average Requirement, EAR-Estimated Average Requirement, RDA-Recommended Dietary Allowance, FAO/WHO-Food and Agriculture Organization/World Health Organization.

Table 2: Calcium intake (mg/day) in adolescents.

Population size	Study design	Country/place	Calcium intake (mg/day)	Reference
290 (girls)	Cross-sectional study	Delhi, India	707	Marwaha et al[15]
3127 (girls)	Cross-sectional study	Delhi, India	685	Puri et al[16]
486 (boys)	The study was based on national data	Denmark,	1286	Weichselbaum et al[17]
233 (boys)	Cross-sectional study	Italy	773	Leclercq et al[57]
66 (girls)	Cross-sectional study	Brazil	700	Rodrigues et al[18]
160 (girls)	Cross-sectional study	Brazil	682	Peters et al[19]
203 (boys)	Study data are derived from Catalan Nutritional Surveys	Spain	959	Majem et al[20]
507 (girls)	Cross-sectional study	Brazilian state	396	Santos et al[21]
100 (boys)	A cross-sectional study	Pune, India	893	Sanwalka et al[22]
99 (boys)	Cohort study	Malaysia	356	Suriawati et al[23]
190 (girls)	Cohort study	Malaysia	387	Suriawati et al[23]
428 (Boys and Girls)	Data are derived from National Teens Food Survey II- Irish	Irish	767	Cashman et al[24]

Table 3: Calcium rich different food sources.

Food	Calcium (mg/100 g)
Finger millet	364
Whole milk (buffalo)	121
Jaggery	107
Sesame seeds (white)	1283
Sesame seeds (black)	1664
Paneer	476
Almonds	228
Curry leaves	659
Poppy seeds	1372
Garden cress	318

Source: IFCT – Indian food composition tables 2017

Table 4: Dietary factors affecting calcium absorption.

Factors	Increases	Decreases	Reference
Vit D	✓		Francis et al
Protein	✓		Giannini et al
Lysine	✓		Civitelli et al
Carbohydrate	✓		Aragon et al
Phytate		✓	Heaney et al
Oxalates		✓	Pius et al
Caffeine		✓	Heaney 2002
Fiber		✓	Pius et al
Alcohol		✓	Sampson et al
Tannin		✓	Pius et al

CONCLUSION

Prioritizing sufficient dietary calcium intake during adolescence is paramount for optimal growth and development. The pervasive lack of awareness regarding recommended calcium levels poses a significant public health concern, particularly among economically disadvantaged adolescents. Addressing disparities in calcium consumption, especially in lower economic classes, is essential for attaining optimal peak bone mass. The review highlights the intricate factors influencing calcium requirements, encompassing physiological, dietary, and absorption considerations. Diverse strategies, including educational initiatives and dietary diversification, are recommended to enhance calcium intake, with the consideration of adolescents' preferences and constraints.

Recognizing fortified foods and supplementation as viable alternatives, particularly for those facing dietary challenges, underscores the need for a multifaceted approach. Implementing comprehensive strategies, encompassing educational efforts, public health initiatives, and practical interventions, is crucial to bridge awareness gaps and promote sustained bone health. Ultimately, a holistic approach is vital to ensure the well-being of adolescents, laying the foundation for a healthier adulthood and mitigation of the long-term burden of osteoporosis and related health issues in later periods.

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