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REVIEW ARTICLE

The importance for growth of dietary intake of calcium and vitamin D

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Abstract

Objective: To investigate the role of dietary calcium and vitamin D in the process of growth and development of children and adolescents, focusing in particular on the prevention and treatment of delayed growth caused by nutritional deficiency.

Sources: Information was gathered from articles published in the last 2 decades, from searches on the databases SciELO, PubMed and Medline, technical books and publications of international organizations.

Summary of the findings: Growth is influenced by intrinsic (genetic and metabolic) and extrinsic factors (environmental factors such as diet, health, hygiene, housing and access to health services). Among the nutritional factors are vitamin and oligoelement deficiencies which may be associated with malnutrition or caused by insufficient absorption. Since calcium is one of the main mineral components of bone tissue, it is essential for adequate bone formation and, considering that vitamin D plays an important role in calcium metabolism, a diet with insufficient quantities of these nutrients can impact on the formation of the skeleton and on the process of growth and development.

Conclusions: In children and adolescents, low intake or low absorption of calcium and vitamin D may limit their statural growth, and it is necessary to supply sufficient quantities of both during the critical growth phases.

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Introduction

Normal somatic growth is a complex process controlled by cellular factors, genetic interactions and external factors such as physical activity, infections, psychosocial and economic factors, chronic diseases, metabolic and hormonal factors and, finally, nutrition.[1] In general, all people are born with a given genetic potential for growth, which may or may not be realized, depending on the living conditions to which they are subjected. Thus, it can be stated that the final height of a person is the result of interactions between their genetic load and those environmental factors that allow them to express their genetic potential to a greater or lesser extent.[2,3]

Restricted growth may manifest clinically as shorter stature than that expected for the family potential, shorter stature than that expected for the general population or as slower than expected growth velocity, based on sex, chronological age and puberty stage of the child. Therefore, children are defined as having short stature if they are below the third percentile, i.e., two standard deviations on the growth curves based on the average height of the general population.[4,5]

Therefore, just as normal growth is dependent on interaction between several different factors, short stature can also be the result of a variety of causes, including causes of a genetic, endocrine or nutritional nature, or may be secondary to chronic diseases.

Infections and inadequate dietary intake are well-established causes of short stature.[6,7] Notwithstanding, attention has recently been directed to the possibility that deficiencies of some micronutrients may play a role in delayed growth. This is because certain micronutrients are essential

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Table 1 - Dietary factors that affect calcium balance

	Reduces	Increases
Absorption	Fiber	Intake
	Phytates	Lactose
	Oxalates	Carbohydrates
	Caffeine	Lysine
	Fat	Fat
	Phosphorous	-
	Iron	-
Excretion	Phosphorous	Protein
	Alkaline ash	Sodium
	-	Chloride
	-	Acid ash

for physical growth, sexual maturity, neuromotor development and to the integrity and function of the immune system. Therefore, a child's capacity to realize its full genetic potential for physical growth and mental development may also be compromised due to subclinical micronutrient deficiencies.[8]

One condition of note that results in short stature and is characterized by deficiency of a micronutrient is rickets caused by vitamin D deficiency. This is a disease that results in retarded growth, muscle weakness, skeletal deformities, hypocalcemia and tetany. An epidemic during the 19th century was almost completely eradicated by encouraging people to expose themselves to sunlight and fortifying milk with vitamin D. However, vitamin D deficiency has once more become epidemic among children and rickets has become a worldwide health issue. In addition to vitamin D deficiency, calcium deficiency also causes rickets.[9]

Furthermore, we believe that, even before the development of rickets, dietary calcium and vitamin D deficiencies can compromise growth and development. This review article summarizes the role of calcium and vitamin D and their importance for maintaining good health in general and for the health, growth and development of children and adolescents.

Calcium

Calcium is an element that is a fundamental part of the body and its importance is related to the functions it performs in bone mineralization, primarily related to bone health, which include formation and maintenance of the structure and rigidity of the skeleton.[10,11]

Calcium absorbed from the diet is dependent on the balance between intake, absorption (intake less losses in feces) and excretion. Several different factors have an influence on these mechanisms, as shown in Table 1.[11,12]

Nutritional recommendations for calcium

The nutritional recommendations for calcium vary throughout people's lives, with higher requirements during periods of rapid growth, such as during childhood and adolescence, during pregnancy and lactation, in cases of calcium deficiency, when practicing forms of exercise that result in high bone density and increased calcium absorption and in old age.[13] The ideal calcium intake is that which results in adequate peak bone mass when a children and adolescent, that maintains it during adulthood and minimizes losses when elderly.[14]

The Standing Committee on the Scientific Evaluation of Dietary Reference Intakes, the Food and Nutrition Board and the Institute of Medicine - National Academy of Science have defined dietary calcium recommendations for a range of age groups. The calcium requirements were established based on three indicators: risk of fracture, measures of muscle mass and maximum calcium retention[12,15] (Table 2).

However, although there is agreement between developed countries on dietary calcium recommendations, there are doubts with respect to their applicability in developing countries, such as Brazil, since all of these tables are based on data from white populations in developed countries, and do not take into account differences in ethnicity, geography and cultural and dietary habits observed in different countries.[10] We therefore emphasize the need to develop dietary

Table 2 - Nutritional recommendations for calcium – Dietary Reference Intake[15]

Age group*	AI (mg/day)
Infants	
0 to 6 months	210
7 to 12 months	270
Children	
1 to 3 years	500
4 to 8 years	800
Adolescents	
9 to 13 years	1,300
14 to 18 years	1,300
Adults	
19 to 30 years	1,000
31 to 50 years	1,000
51 to 70 years	1,200
> 70 years	1,200
Pregnant women	
≤ 18 years	1,300
19 to 50 years	1,000
Lactating women	
≤ 18 years	1,300
19 to 50 years	1,000

AI = adequate intake. This is an estimation that is determined experimentally from the intake of nutrients of specific groups of healthy people. The AI is used when scientific investigations have not been able to establish an estimated average requirement (EAR). It evaluates the prevalence of inadequate intake within a group. For healthy infants fed on breastmilk, the AI is an estimated average intake.
* All groups except pregnant and lactating women apply to both males and females.

recommendations specifically for our population, taking into consideration the extremely diverse regional variations of our country.

Since it cannot be produced endogenously, calcium can only be acquired by means of a daily intake of foods that contain it.[14] Among foods rich in calcium, of note are milk and its byproducts (yoghurt and cheese) with low levels of fats.[16]

The high bioavailability of calcium in dairy products is related to their vitamin D content and to the presence of lactose, which increase calcium absorption in the intestine.[17] Furthermore, since milk has an alkaline pH, calcium is kept in suspension due to formation of calcium caseinate, calcium citrate and a complex with lactose. Therefore, the lactose, caseinate and citrate in milk and dairy products appear to explain their better calcium absorption in relation to other dietary calcium sources.[14] Although cheese contains little lactose, the calcium it contains is freely available.[10]

Recently, lactose intolerance has been diagnosed with greater frequency which demands special care with ensuring that patients maintain an adequate calcium intake. This hypothesis is supported by results published by Medeiros,[17] who found that calcium intake was lower q ($p < 0.001$) among children on diets free from cow's milk and dairy products.[18]

Nevertheless, it is not only milk and dairy products that contribute to people's calcium intake. Vegetables with dark

Table 3 - Foods rich in calcium

Food	Portion	Calcium (mg)
Whole milk	1 teacup	290
Semi-skimmed milk	1 teacup	297
Skimmed milk	1 teacup	302
White cheese	Slice (30 g)	205
Yellow cheese	Slice (20 g)	120
Processed cheese spread	Level tablespoon (15 g)	84.75
Natural yoghurt	Pot (200 g)	228
Curd cheese	Pot (200 g)	130
Sardines in brine	100 g	402
Fish	Filet or steak	50-60
Boiled soy beans	1 cup	175
Boiled broccoli	100 g	113
Boiled collard greens	1 cup	148
Chopped cabbage	1 cup	94
Baked potato	1 medium potato	115
Orange	1 orange	96
Papaya	1 medium papaya	62
Watermelon	1 large slice	22

green leaves, such as collard greens, kale, mustard leaves, broccoli leaves and turnip leaves are also sources of calcium, but the calcium they contain has low bioavailability. Sardines, bivalve mollusks, oysters, salmon and pulses, such as soy, also contain calcium in the quantities listed in Table 3.[10,19,20]

Dietary calcium intake

Until recently, it was believed that a low calcium intake did not result in damage to health. Nowadays, it is thought that global variations in prevalence rates of calcium deficiency may affect the bone distribution and dietary habits of different populations, in response to genetic, ethnic and geographic (latitude) differences and related to cultural and lifestyle factors.[11]

We can cite some studies that have demonstrated low consumption of foods containing calcium, especially at ages when physical development occurs, which could cause future growth deficits or even bone diseases.

Rajeshwari et al. followed a group of children from 10 years of age until adulthood and demonstrated that calcium intake was reduced at this age, despite the increased energy expenditure. Furthermore, they found that there was a considerable reduction in total calcium intake in childhood (54% below the recommended level) to adulthood (77% below the recommended level).[21]

In another study, Salamoun et al. evaluated the calcium and vitamin D intake of children and adolescents living in Mediterranean countries and found that intake of both nutrients was below optimum levels (mean calcium intake was 816±776.8 mg/day and mean vitamin D intake was 129±116.1 IU/day). Just 12% had adequate daily calcium intake, and 16% for vitamin D.[22]

In Brazil, Lerner et al. evaluated the calcium intake of adolescents in public schools in Osasco, SP, and found that mean daily calcium intake did not differ significantly between boys and girls, and was around 50% of recommended in both cases (mean calcium intake of 628.85±353.82 mg/day among the

Table 4 - Nutritional recommendations for vitamin D – Dietary Reference Intake[15]

Age group*	AI (μg/day)†‡
Infants (0 to 12 months)	5
Children (1 to 8 years)	5
Adolescents (9 to 18 years)	5
Adults	
19 to 50 years	5
51 to 70 years	10
> 70 years	15
Pregnant women	5
Lactating women	5

* All groups except pregnant and lactating women apply to both males and females. Recommended by Institute of Medicine, National Academy of Sciences.
† As cholecalciferol. 1 μg of cholecalciferol = 40 IU of vitamin D.
‡ In the absence of sufficient exposure to sunlight.

boys and 565.68±295.43 mg/day among the girls). Just 6.2% of the boys and 2.8% of the girls had adequate calcium intake, in common with studies carried out in other countries.[21-23]

Vitamin D

The 1,25-$(OH)_2D_3$ molecule is a hormone that regulates calcium and phosphorous metabolism. This being so, its primary function is to maintain serum calcium and phosphorus levels in a normal state that is capable of providing the conditions for the majority of metabolic functions, including bone mineralization.[9,16] Because it is involved in growth of the skeleton, vitamin D is essential during childhood and adolescence.[24]

Normal serum vitamin D levels determine absorption of 30% of dietary calcium and more than 60-80% during periods of growth, due to the high demand for calcium.[25] This is why vitamin D deficiency during childhood can cause delayed growth and bone abnormalities, increasing the risk of fractures in adulthood.[26]

Nutritional recommendations for vitamin D

Daily nutritional recommendations for vitamin D are difficult to establish with precision, since it is produced endogenously and deposited in adipose tissues for long periods of time, and because the body's requirements also depend on dietary intake of calcium and phosphorous, on age, sex, skin pigmentation and exposure to sunlight. Historically, a tablespoon of fish oil was defined as containing a sufficient quantity of vitamin D to prevent rickets. Even today there is not sufficient evidence on which to base recommendations, but the adequate daily intake has been established[26,27,15] (Table 4).

The skin has a large capacity to synthesize vitamin D, since it is estimated that exposure to sunlight long enough to cause mild redness to the skin of children and adults wearing swimwear is equivalent to 15 times the daily vitamin D recommendation, and that mild redness of 6% of the body is equal to an intake of 15-25 μg of cholecalciferol.[26,28]

Even so, it is difficult to determine the quantity of exposure to sunlight (the surface area of skin exposed for a given time) necessary to prevent vitamin D deficiency and rickets in childhood. Furthermore, there is growing concern with relation to exposure to UVB radiation at this stage of life and its relationship with skin cancer in adulthood, since there is a positive correlation between the occurrence of malignant melanoma among adults and quantity of exposure to sunlight during childhood.[29]

Although vitamin D is produced by exposure of the skin to sunlight, when exposure to sunlight is insufficient to meet the requirements it becomes essential to eat foods containing vitamin D. This situation has become common, particularly among people resident in urban centers who are exposed to less than the optimum level of sunlight[27,30,31] (Table 5).

However, there are few foods which are sources of vitamin D, as egg yolk, liver, butter and milk are. Furthermore, these are foods that are eaten less nowadays as because of the high levels of cholesterol.[32] In general, lean fish and meat contain only traces of this vitamin, with the highest concentrations being found in herring and mackerel.[16] Oil from the

Table 5 - Risk factors for hypovitaminosis D[30]

Under exposure to UVB radiation
Excessive clothing
Countries with little sunlight (high latitudes)
Low quantities of UVB light penetrating the atmosphere during winter
Use of sunscreen
Confinement in places where there is no exposure to UVB light
Dark skin
Reduced capacity to synthesize vitamin D in the skin
Aging
Type of skin
Yellow race
Diseases that affect metabolism of 25-OH-D_3 or 125-$(OH)_2D_3$
Cystic fibrosis
Diseases of the gastrointestinal tract
Hematological diseases
Kidney disease
Heart failure
Immobility
Reduction in the availability of vitamin D
Obesity
Breastfeeding

liver of fish such as tuna and sole, cod in particular and fish such as salmon, mackerel, sardines, eels, herring and tuna are rich in vitamin D[19,33] (Table 6).

Another possible source is mushrooms, which naturally contain small quantities of vitamin D, but this food is also eaten infrequently and subject to great seasonal variation in terms of vitamin D content.[32]

Unfortunately, there is little published literature relating to the bioavailability of this vitamin. Certain dietary factors have been indicated as increasing or reducing vitamin D bioavailability. It is known that if milk is drunk at the same time as natural vitamin D food sources are eaten, it can increase absorption by three to 10 times, which can be explained by the presence of lactalbumin. Long chain fatty acids also facilitate vitamin D absorption, when compared with pharmacological doses of this vitamin. In contrast, ethanol and fiber reduce its bioavailability, since they provoke biliary excretion.[34]

Thus, exposure to solar radiation can guarantee vitamin D supply during childhood, but with an increased risk of skin cancer; additionally, dietary sources of this vitamin restricted. This being so, a safer way of meeting dietary requirements during growth is to use dietary supplements, either in pharmaceutical presentations or through fortifying foods with vitamin D.[27,35]

Dietary vitamin D intake

It is assumed that a healthy diet should be sufficient to provide abundant vitamin D, however, as we have seen before, this does not always take place. This is the reason why vitamin D deficiency has become common among children and adolescents during growth phases in the United States and Europe.[27,25]

Docio et al. conducted a study to determine desirable 25-OH-D_3 levels in children and to observe whether these levels were maintained all year long. They decided that the lower limit for desirable 25-OH-D_3 levels in children is somewhere between 12 and 20 ng/mL. However, 31% of the 51 normal children investigated during the winter exhibited levels below 12 ng/mL, and 80% had levels below 20 ng/mL. When their diets were analyzed, it was found that mean calcium intake was 790±156 mg/day and vitamin D intake was 160±80 IU/day, both below the recommended level.[36]

Gordon et al. performed a study at an urban hospital in Boston, assessing the prevalence of serum vitamin D deficiency in 307 healthy adolescents. They identified 24.1% of

Table 6 - Foods rich in vitamin D[33]

Food	Domestic measures /g	μg
Tuna	2 medium (90 g)	3.68
Raw sardines	100 g	5.20
Tinned sardines	100 g	17
Fish oil	1 tablespoon	40.3
Butter	1 heaped tablespoon	0.45
Cow's liver	100 g	1.12
Chicken liver	100 g	1.25
Egg, yolk, raw, fresh	100 g	0.53
Egg, whole, raw, fresh	100 g	0.875
Whole milk	1 glass (240 mL)	0.17
Mushrooms	100 g	0.62

the sample as deficient in vitamin D, 4.6% of whom were severely deficient. The season of the year (winter and spring), ethnicity (African Americans), milk intake, body mass index (BMI) and physical activity were independent and significant factors for hypovitaminosis D.[24]

Studies with preadolescents have also demonstrated deficiencies in vitamin D serum concentrations and intake. Rajakumar et al. evaluated the proportion of vitamin D deficiency among African-American preadolescents aged six to 10 years in the United States. Forty-nine percent had insufficient serum 25-OH-D_3 levels (24±10.5 ng/mL). Their mean vitamin D intake was 277±146 IU/day, and 39% did not reach the adequate daily vitamin D intake.[37]

To date, few studies have been carried out into the prevalence of hypovitaminosis D in Brazil. Due to its climate, Rio Grande do Sul is the state where deficiencies are most likely. In a study carried out at the Hospital de Clínicas de Porto Alegre (HCPA), Premaor & Furlanetto found low serum 25-OH-D_3 levels in patients admitted by the internal medicine teams. Nevertheless, these were adult patients and they had several risk factors for the disease, and so the true extent of this disorder in our country remains unknown.[30]

Dietary calcium and vitamin D and growth

Reduced intake of calcium and vitamin D during periods of growth can have a negative influence on bone development, causing not only rickets, which is the final result of vitamin D deficiency, but also interfering with attainment of genetically programmed height.[25]

During puberty and adolescence, calcium requirements are greater than at any other stage of life, due to the accelerated muscular, skeletal and endocrine development.[11] bone mineral deposition during pubertal growth appears to depend on dietary absorption of calcium, and on reducing its excretion, and this is dependent on adequate vitamin D status. Despite this, understanding of the relationship between calcium absorption and vitamin D and growth is limited.[38]

Abrams et al. compared the heights of 315 girls between 5 and 15 years old with their dietary calcium absorption and found a positive relationship ($r = 0.18$; $p = 0.001$), demonstrating that an increase in absorption efficiency is, in part, regulated in order to meet the requirements of the final skeletal size. Nevertheless, this relationship remains uncertain, and may be due to genetic components or ethnic differences. Another hypothesis is that calcium absorption is directly related to the greater intestinal surface area of taller individuals. These findings were dependent on puberty stage and independent of the girls' heights, since an increase in calcium absorption was observed during the onset of puberty.[38]

Prentice et al. evaluated the effect on bone acquisition and bone growth of supplementation with calcium carbonate (1,000 mg/day) vs. placebo in 143 boys, aged 16 to 18 years, over 13 months. The intervention resulted in improved total bone mineral content, which increased 1.3% ($p = 0.02$), combined with an increase in height of 0.4% ($p = 0.0004$), equivalent to 7 mm. The same association could not be detected in a study with younger children and with girls in the same age group.[39] Although there are studies investigating calcium supplementation, studies relating dietary calcium and growth are scarce, and the same is true of vitamin D.

Results published by Black et al. confirmed the view that children with long histories of low milk intake have low dietary calcium intake (443±230 mg/day) and poor bone health (bone mineral content 0.45 g less; $p < 0.01$) compared with children who drink milk. It also adds support to the hypothesis that children who do not drink cow's milk have a shorter stature than those who consume milk regularly (0.65 cm shorter; $p < 0.01$). In addition to these results, the z score for total bone mineral content correlated positively with dietary calcium intake ($r = 0.38$; $p < 0.006$). In this study, dietary calcium intake of children who did not drink milk did not provide the large quantities of calcium needed to supply the demands of pubertal growth.[40]

Conclusions

We can therefore conclude that, during growth, adequate supplies of calcium and vitamin D are considered critically important to bone development and, if a child is going to fulfill their genetic potential for growth and peak bone mass, their diet must include a sufficient quantity of these nutrients. The low dietary intake of calcium and vitamin D among children and adolescents also became clear, as did the fact that this has had deleterious effects on their skeletal health and bone metabolism. It is necessary to investigate the causes of low calcium and vitamin D intake among people in growth phases, such as childhood and adolescence, to establish nutritional strategies to increase their dietary intake and to make it possible for populations at nutritional risk to access foods rich in these nutrients.

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