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Chapter

Vitamin D3 Deficiency: The Missing Component in the Physical Activity and Lifelong Health of Children and Adolescents in Sub-Sahara Africa?

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Abstract

Urbanization in Africa has led to lifestyles changes that undermine physical activity. These behavioral changes are also linked to spending less time in the Sun. Vitamin D is primarily synthesized dermally when sun rays directly strikes exposed skin. Vitamin D deficiency and insufficiency is now recognized as a global issue impairing the health of more than 1 billion people Worldwide. Serum Vitamin D levels in children in Sub-Sahara Africa (SSA) has been linked to inadequate exposure to sunlight, despite it straddling the equator that affords almost yearlong overhead sunshine. Vitamin D deficiency is associated with several health challenges, which in turn undermines normal growth, development, and potential physical and mental function likely to compromise performance of physical activity and sports. This chapter highlights the role of Vitamin D, its deficiency and implications on physical activity and sports performance with particular focus on children and adolescents, who are at a prime age for foundational development of motor function, skills and performance. While parents, healthcare professionals, coaches and caregivers of children in SSA need to promote sun exposure as the primary source of vitamin D, this perhaps also calls for further attention on Vitamin D supplementation, to support health and sports performance.

Keywords: vitamin D, deficiency, physical activity, sports, fitness, health, children, Sub-Sahara Africa

1. Introduction

Sub-Sahara Africa (SSA) is an expansive area about 23,852,823 square kilometers in size that lies between latitudes 16° N and 35° S. Its population was estimated at 1.1 billion in 2019 by the United Nations Department of Economic and Social Affairs [1], with more than 40% of this population estimated to be below the age of 15 years.
The World Bank in 2020 estimated urbanization in this region to be above 45% with the highest rate at 90% in Gabon and 17% in Malawi [1]. Urbanization is known to offer numerous conveniences that tend to improve the standard of living in general. However, it is also associated with lifestyles that undermine engagement in sports and physical activity in children and adolescents due to numerous factors; motorized transportation, a built environment devoid of parks or social amenities for exercising, air pollution, and long hours in traffic while commuting to and from school. In general, children living in such an environment spend less time in the Sun resulting in impaired dermal Vitamin D synthesis: a key component of not only bone metabolism but also for maintaining immune homeostasis, activation of genes influencing muscle growth and differentiation, all critical factors in physical activity and sports performance.

This chapter seeks to highlight the role of Vitamin D, its deficiency and implications on physical activity and sports performance. We appreciate that effects of Vitamin D deficiency cut across all athletes but we choose to focus on children and adolescents, who are at a prime age for foundational development of motor function, skills and performance. Surprisingly, evidence on children in SSA may suggest that Africa could be the continent with one of the highest frequency of severe vitamin D deficiency [2]. This chapter appreciates that while Sun exposure is the main source for Vitamin D, it should be the primary focus for advocacy compared to prescription of supplements among athletes especially in economic-resource deprived settings such as those in Sub-Saharan Africa.

2. Sports and fitness activities among children and youth in SSA

There is a perception that children are ‘naturally’ active [3], and as previously witnessed in Africa, they would take advantage of every opportunity and space to play, given adequate time and an enabling environment regardless of availability of equipment or the ideal facility. Sports, active play and fitness activities among children and youth in SSA usually take place in the school settings (during PE classes, school sports programmes and recess time activities), home environment (active play at home and in the neighborhood with siblings and friends) and at the leisure and recreation centres (organized club activities and outdoor pursuits programmes). Activities among children and adolescents range from organized/formal sports activities (such as ball games, racket and batting sports, athletics, swimming and martial arts) and fitness programmes to informal active play characterized with fun, less stringent rules and improvisation of equipment and facilities. These are excellent opportunities to develop and nurture motor abilities and skills linked to enhanced fitness, necessary for health and performance. There is also evidence that such physical activity behavior and resulting active lifestyles tracks from childhood through adolescence and into adulthood [4].

Notably, most of these activities (especially in SSA) are designed to take place in the outdoors where participants not only interact with the built and social environment but also engage in nature-based learning, survival and experiential learning, characterized by physical engagement and active transportation. In the process, participants gained the much needed direct exposure to sunshine for Vitamin D. We are now witnessing an increase in indoor-based programmes with rapid digitization of education materials, an influx of motorized and digitized equipment and play gadgets, leading to minimized energy expenditure, overdependence on screen-based sedentary activities [5] and less sun exposure.
3. Vitamin D

While Vitamin D is widely known for its role in bone metabolism, the past two decades have seen a plethora of research pointing to its endocrine effects such as regulating calcium and phosphorous in the body i.e. its skeletal role. However, Vitamin D is increasingly being appreciated for its paracrine, autocrine and exocrine functions in the body as it directly affects a broad range of cells in the body, in addition to this, it regulates expression of genes involved in cell growth, protein synthesis and immune function [6].

3.1 Vitamin D metabolism

Vitamin D is primarily synthesized dermally by the action of UVB radiation of between 250 and 300 nm wavelengths when it directly strikes the exposed skin. This is then picked up by 7-dehydrocholesterol and transported in the blood to the liver where it is hydroxylated by the enzyme CYP2R1 into 25 hydroxycholecalciferol before it’s transportation in the blood to the kidneys for further hydroxylation with the help of CYP27B1, where it is converted into the active metabolite 1,25 dihydroxycholecalciferol (Calcitriol), a potent steroid hormone. Calcitriol then enters the different target cells bound to Vitamin D Receptors (VDR) [7] found widely in the human body.

Cutaneous synthesis of Vitamin D via UVB solar radiation is however not possible on a year round basis for individuals living at latitudes further away from the Equator due to seasonal changes that result from the shifting of the Earth on its axis. Secondly, even in regions enjoying overhead UVB radiation on a year round basis, failure to expose oneself to the Sun’s rays in a state of near or total undress when the UV index is above 3, anything below this predisposes one to Vitamin D deficiency. Thirdly, darker skinned people have less cutaneous vitamin D synthesis as a result of higher levels of melanin which absorbs UVB and therefore require three to five times longer duration of skin exposure to sunlight [8], this is particularly important given that 50–90% of Vitamin D is synthesized through the skin [9]. Extenuating circumstances such as these require supplementation with vitamin D to optimize serum levels of Vitamin D.

Vitamin D (Vitamin D3/Cholecalciferol) can be derived from foods of animal origin: animal fat, oily fish, liver and pastured eggs, while foods from plant sources such as mushrooms and fortified cereals provide ergocalciferol/ vitamin D2, however this form of vitamin D has been found to be less effective at raising serum 25(OH)D levels [10].

3.2 Vitamin D status

Vitamin D status is determined by measuring serum levels of circulating 25(OH)D, on account of its half-life of about 2–3 weeks [11]. Classification of vitamin D status is not universally agreed upon; the Institute of Medicine (IOM) classifies a serum level of 20 ng/mL as adequate [12] while the Endocrine Society suggests a serum concentration of ≥ 30 ng/mL as sufficient [13]. The difference arising from the former’s recommendations were exclusively based on skeletal integrity while the latter’s was based on a broader range of studies examining associations between vitamin D deficiency with immune dysfunction, pregnancy and cancers alongside a decline in serum parathyroid hormone (PTH) reaching its nadir asymptotically with 25(OH)D levels in adults at 30–40 ng/mL [12].
3.3 Vitamin D deficiency

The ubiquity of Vitamin D Receptors (VDR) in numerous tissues in the human body points to the body’s widespread need for 25(OH)D, where it therefore follows that deficiency or insufficiency of the same is associated with several diseases. Vitamin D deficiency and insufficiency is now recognized as a global issue impairing the health of more than 1 billion children and adults in the World [13].

3.3.1 Vitamin D3 deficiency in SSA

A study on vitamin D deficiency in 3880 African children aged 0–8 years drawn from four African countries: Kenya, Burkina Faso, Uganda and South Africa, found a relatively low prevalence of Vitamin D deficiency at 0.7% when using cut-off of less than 30 nmol/L and 7.4% prevalence when using a cut-off of less than 50 nmol/L [14]. This was in stark contrast to a meta-analysis by the same investigators on the Vitamin D status of 21,474 individuals living in 23 African countries that concluded that about 18% of these had severe vitamin D deficiency using a cut-off of <30 nmol/l, “suggesting that Africa could be the continent with the highest frequency of severe vitamin D deficiency” [2]. Perhaps, the noted low prevalence of vitamin D deficiency among the children was due to the use of IOM cut-offs focused on skeletal integrity rather than the Endocrine Society’s cut-offs. Ironically, the vitamin D deficiency study on young African children found that 35.4% of these children had serum concentrations between 50 and 70 nmol/L (20-28 ng/mL) clearly pointing to a 35.5% prevalence of Vitamin D3 deficiency when evaluated using the Endocrine Society’s cut-off of at least 70 nmol/L (30 ng/mL) linked with better health outcomes [12].

4. Risk factors for vitamin D deficiency in children and adolescents

Risks associated with Vitamin D deficiency can be traced all the way from fetal development and at birth. Children born of Vitamin D deficient mothers tend to: be born prematurely, have low birth-weight, be at risk of allergies, develop asthma and impaired neurodevelopment. Achievement of a serum vitamin D concentration of greater than 100 nmol/L (40 ng/ml) by gravid mothers has been linked with prevention of some of these health risks [15]. Maternal serum vitamin D levels have been associated with fetal femur length, femur volume, cross-sectional area of the distal metaphysis and the ratio between the former and latter in offspring as measured using ultrasound exacerbating the risk of skeletal dysplasia and shorter stature at birth [15]. Such risks likely disadvantage physical development and lead to physiological limitations in sports performance in children and adolescents years later.

Serum Vitamin D levels in children and adolescents in SSA have been linked to inadequate exposure to sunlight, despite it straddling the equator as this affords almost yearlong overhead sunshine: a UVB wavelength advantage suitable for dermal Vitamin D synthesis. In two studies focusing on Vitamin D deficiency and rickets in low income informal settlements in Nairobi, Kenya, reported both low serum Vitamin D during pregnancy and in breast milk at delivery further raising the risk of rickets in their offspring. Similarly lengthy hours indoors during infancy in daycare facilities, as mothers work during the day, further compounded the risk of rickets. In addition to this finding, about 1% of the infants had as little as 3 hours of Sunshine exposure weekly [16–18].
In the southern most region of SSA; South Africa, seasonal variation and latitude have been identified as factors influencing Vitamin D status [17, 18]. Other non-pathological factors affecting Vitamin-D status in this region have been identified as: urban lifestyles, obesity, skin pigmentation and age demographics [18], while afebrile malaria has been associated with low serum vitamin D in SSA Children and adolescents.

5. Implications of vitamin D3 deficiency on health, physical activity and sports performance

Vitamin D deficiency in children and adolescents is associated with several health and metabolic challenges, which in turn undermine normal growth, development and potential physical and mental function. Negative effects of Vitamin D deficiency that are likely to compromise the performance of physical activity and sports are noted in the following functions:

5.1 Cardiac function

VDR are abundant in the myocardium, vasculature, myocytes and cardiac fibroblasts, suggesting the importance of Vitamin D in myocardial function. Calcitriol, the active form of Vitamin D, has been shown to participate in structural remodeling of cardiac muscle and vascular tissue, activates myocyte contractility and in turn up-regulating myocardial force [19]. This highlights the role of Vitamin D deficiency as a negative myocardial inotrope leading to poorer contractility, the result of which is reduced cardiac output. This negative effect on myocardial function is further compounded by an increase in cardiac collagen content resulting from Vitamin D deficiency.

Abnormal electrocardiographic and echocardiographic findings suggestive of dilated cardiomyopathy, heart failure and left ventricular dysfunction, have all been found present in vitamin D deficient infants diagnosed with rickets, and such findings have returned to normal upon treatment of rickets, [20, 21].

Scientific literature indicates that Vitamin D deficiency up-regulates production of Parathyroid hormone (PTH) and that this can in turn lead to pathological enlargement of the left ventricle (LVH) and subsequently modifies the filling capacity of the left ventricle and ejections fraction, the sequela of this being hypoxic muscle tissue posing a physiological limitation to physical activity or sports performance [22–24]. Vitamin D deficiency is also associated with atherogenesis, arterial stiffness and endothelial dysfunction, and these changes in vascular function undermine vascular competence. Optimal performance in sports and physical activity is not feasible with pathological structural or functional changes in the myocardium, thus the importance of optimal serum vitamin D in children and adolescents is therefore a key component of sports and physical activity performance.

5.2 Muscular function

The importance of Vitamin D in muscle growth and function can be understood when viewed from the perspective that Vitamin D receptors are located in both the cytoplasm and the nucleus of muscle fibers to regulate their genomic or non-genomic actions [25]. In addition to this, muscle cell proliferation, differentiation and the
interaction between myosin and actin filaments in the sarcomere of muscle cells are all dependent on adequate serum Vitamin D which serves to improve the concentration of adenosine triphosphate (ATP), the energy fuel reserve in the cell [26–29].

Low vitamin D is associated with atrophy of muscle fibers, fatty infiltration and fibrotic factors that all slow peak muscle contraction subsequently impeding generation of force [30, 31]. Vitamin D is one of several hormones known to influence the structure and function of striated muscles during all stages of life [32]. Vitamin D deficiency in children and adolescents may present as muscular pain, weakness or heaviness in the legs, these are important symptoms that parents, pediatric clinicians, sports coaches and caregivers would do well to keep in mind as they interact with this population. In this regard, Vitamin D deficiency is therefore antithetical to optimal physical activity and sports performance.

5.3 Lung function

Vitamin D deficiency is associated with lower lung function, altered lung structure, wheezing, increased asthma exacerbations and use of corticosteroids [33, 34] due to deprivation of oxygen to tissues in the lung as a results of inflammation of the alveolar, damaged epithelia and impaired regeneration of endothelial barriers [35, 36], with this easily progressing to and exacerbating asthma and respiratory infections. Vitamin D deficiency is therefore at the heart of all stages of respiratory infections and severity, however, adequate vitamin D lowers susceptibility to these types of respiratory infections via production of antimicrobial cathelicidins and defensins both of which are antibacterial and antiviral in their expression [36].

Given that optimal lung function is a primary factor in extraction of oxygen from inhaled air, for delivery to the lungs and then transportation via blood to the myocardium for onward delivery to muscles during physical activity and sports performance, Vitamin D deficiency in children and adolescence would likely have an adverse effect engendering sedentary lifestyles and an increased risk of chronic obstructive pulmonary disease over the long haul.

5.4 Skeletal effects of vitamin D

Vitamin D is thought to facilitate bone metabolism through its effects in promoting calcium and phosphate absorption, both of which are critical factors for both bone development and maintenance. A second pathway by which vitamin D maintains bone Calcium levels occurs by its regulation of serum Parathyroid hormone (PTH) to prevent hypocalcemia and hypophosphatemia [37] which would otherwise result in bone loss and fracture, manifesting in bone diseases such as osteomalacia and osteoporosis in old age, however among children and adolescents, a low serum Vitamin D levels manifest in rickets.

Rickets is a bone disease marked by deformities of wrists, legs, delayed closure of the soft membranous gaps between the cranial bones in infants, as well as fraying, metaphyseal cupping and widening of the growth plate as a result of vitamin D deficiency [38], while rickets can also be caused by calcium deficiency. A case control study on rickets in children in a slum in Nairobi, comparing rickets cases to controls (children without rickets or acute malnutrition) determined biochemically and phenotypically that the pathogenesis of rickets in this cohort was a result of vitamin D deficiency and not Calcium deficiency [39]. With an estimated 18% of the population in Sub-Saharan Africa having a severely deficient serum Vitamin D level of less than
30 nmol/L (12 ng/mL) [18]. The implication of this has significant negative ramifications on bone development, structural stability, bone length in children and adolescence but also in their ability to engage in physical activity and sports performance at all levels even in future.

6. Conclusion

The purpose of our review was to relate the relevance of vitamin D to physical activity and sports performance. We reviewed recent advances in this field and novel insights about vitamin D: its deficiency and implications on physical activity and sports performance.

Low vitamin D status could negatively impact the health and training efficiency of athletes regardless of their age and developmental level. Research to date suggests that certain athletes are at risk for suboptimal vitamin D status, which may increase risks for stress fractures, acute illness, and suboptimal muscle function.

The emerging evidence about vitamin D and sports performance suggests the need to determine vitamin D concentration in athletes but further research is necessary to characterize the true vitamin D status by simply measuring free vitamin D rather than total 25-OHvitD.

In relation to the prevention of vitamin D deficiency, parents, healthcare professionals, coaches, caregivers of children and adolescents need to be aware that Sun exposure is the primary means of vitamin D synthesis, unfortunately, this may not be feasible for all demographics on account of distance from the Equator, pollution or skin pigmentation, however, this demographic can benefit from Vitamin D supplementation alongside minerals and vitamins that aid its absorption, activation or metabolism such as Magnesium and Vitamin K2. The importance of optimal vitamin D in myocardial, skeletal, pulmonary and immune functions is a critical component in physical activity and lifelong health of children and adolescents in Sub-Saharan Africa. This perhaps also calls for further investigation of the efficacy of Vitamin D supplementation in this demographic on health, physical activity and sports performance outcomes.

Conflict of interest

The authors declare no conflict of interest.
References


