Less than adequate vitamin D status and intake in Latin America and the Caribbean: A problem of unknown magnitude

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Abstract

Background. *The prevalence of vitamin D deficiency in Latin America and the Caribbean is unknown.*

Objective*. To examine the prevalence data available on vitamin D deficiency in Latin America and the Caribbean.*

Methods. *A systematic review was conducted in 2011. Studies using biochemical biomarkers and dietary intake estimation were included. Studies conducted in apparently healthy individuals, independently of age, latitude, skin pigmentation, and season of the year at the time of blood collection, were included.*

Results. *A total of 243 studies were identified. The final number of selected studies was 28, including two National Health Surveys (Mexico and Argentina). There are studies that report the vitamin D status of specific subgroups conducted in Argentina, Brazil, Chile, Colombia, Ecuador, Guatemala, and Mexico. However, the small sample sizes in these studies and thus the low national representativeness of the reported data do not allow for an accurate assessment of vitamin D status at the regional level. In the majority of the countries with available data, we observed that vitamin D insufficiency was classified as a mild, moderate, or severe public health problem. The only country with a nationally representative sample was Mexico, which found 24%, 10%, 8%, and 10% prevalence rates of vitamin D insufficiency (25-hydroxyvitamin D < 50 nmol/L) in preschoolers, schoolchildren, adolescents, and adults, respectively. The prevalence of vitamin D deficiency (25-hydroxyvitamin D < 20 nmol/L) was less than 1% for all groups.*

Conclusions*. There is some indication that vitamin D insufficiency may be a public health problem in Latin America and the Caribbean, but the exact magnitude is currently unknown.*

Key words: Caribbean, deficiency, 25-hydroxyvitamin D, Latin America, micronutrients, vitamin D

Introduction

Vitamin D (calciferol), which comprises a group of fat-soluble sterols, is an essential micronutrient for calcium and phosphorus homeostasis [1]. Moreover, promising new effects of vitamin D on health have been described in relation to obesity, type 2 diabetes, and cardiovascular disease [2–7]. Humans obtain vitamin D primarily from two sources: photosynthesis in the skin by the action of solar ultraviolet B (UVB) radiation, and dietary intake. In free-living individuals, the majority of circulating 25-hydroxyvitamin D (25 OHD) originates from UVB exposure [8]. The efficiency of vitamin D synthesis in the skin depends on the number of UVB photons that penetrate into the epidermis [8]. An increase in skin melanin pigmentation [9] and the topical application of sunscreen [10] can markedly reduce the synthesis of vitamin D in the skin [11]. Vitamin D can be found naturally in many forms, but the two major physiologically relevant forms for humans are vitamin D_2 (ergocalciferol), which is obtained from plant sources, and vitamin D_3 (cholecalciferol), which is synthesized in the skin or obtained from animal sources. In addition, fortified foods and

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dietary supplements usually contain either vitamin D_2 or vitamin D_3 [1]. Once vitamin D is obtained, either absorbed from the diet or synthesized in the skin by the action of sunlight, it is metabolized in the liver to 25 OHD and then in the kidney to 1,25-dihydroxyvitamin D (1,25 OH_2D) [12].

Vitamin D deficiency has long been known to have adverse effects on health. This deficiency is characterized by inadequate mineralization or demineralization of the skeleton. In children it causes rickets, and in adults it can precipitate and exacerbate osteopenia, osteoporosis, and bone fractures [1]. Intervention studies have shown that vitamin D therapy increases muscle strength in vitamin D–deficient subjects [13]. Epidemiological research has associated vitamin D deficiency with increased risks of certain common cancers, autoimmune diseases, hypertension, and infectious diseases [14–16]. Despite observed associations between vitamin D status and cancer, especially with colon cancer, the International Agency for Research on Cancer (IARC) has concluded that the relationship between vitamin D status and colorectal cancer, cardiovascular diseases, and all-cause mortality should be tested in appropriately designed randomized, controlled trials. IARC considers that the current evidence for the association between vitamin D and breast cancer is weak and that the observational evidence does not support a beneficial role of vitamin D in reducing the risk of prostate cancer [17]. The plasma concentration of 25 OHD has been regularly used to identify individuals at risk for vitamin D deficiency and, on a population basis, to estimate the adequacy of vitamin D. However, presently there is no global consensus on the cutoff point for defining vitamin D status [18]. Vitamin D deficiency has the potential to be a public health problem [19]. The magnitude of this deficiency in Latin America and the Caribbean is unknown. The purpose of this systematic review was to examine the prevalence data currently available on vitamin D deficiency in Latin America and the Caribbean.

Methods

Identification and selection of studies

A systematic review was conducted between July and August 2011. Evidence regarding vitamin D deficiency in Latin America and the Caribbean since the year 2000 was included. A thorough search of published research articles in PubMed, LILACS, and SciELO was performed, where combinations of the term "vitamin D" and the names of all the countries of the region in Spanish, Portuguese, and English were used as key words. In addition, some review articles were used to identify potential studies [20, 21].

Eligibility criteria

Most of the studies conducted in Latin America and the Caribbean report vitamin D status using biochemical biomarkers. Nevertheless, we identified several studies that had estimated the dietary intake of vitamin D in different population subgroups. Therefore, this systematic review included both sources of information in order to achieve a better understanding of vitamin D status in countries located in Latin America and the Caribbean. Studies conducted in apparently healthy individuals, independently of potential confounding factors such as age, latitude, skin pigmentation, and season of the year at the time of blood collection, were included. Studies were included based on identification of data regarding the prevalence of vitamin D status in the region. Studies were not excluded on the basis of language.

Indicator used to assess vitamin D status

In the studies reviewed, the primary indicator used to assess vitamin D status was 25 OHD. The values reported in the present review were standardized to nmol/L (1 ng/mL = 2.5 nmol/L) to facilitate comparison. The cutoff points used to define deficient, insufficient, and inadequate values of 25 OHD varied widely. The majority of the studies defined vitamin D deficiency as 25 OHD < 25 nmol/L, vitamin D insufficiency as 25 OHD between 25 and 50 nmol/L, and vitamin D inadequacy as 25 OHD between 50 and 75 nmol/L. Since no standard threshold exists, cutoff values expressed by each author were included when there was not sufficient information to classify according to the criteria mentioned above.

Dietary intake assessment

Most studies reporting dietary intake assessment expressed vitamin D intake in international units (IU) and defined Adequate Intakes (AI) based on the Dietary Reference Intakes (DRI) of the United States Institute of Medicine (IOM) 2004 [22]. In the present article we also compare reported intakes with the Estimated Average Requirements (EAR) as defined by the IOM in 2004 and 2011 [23].

Results

A total of 243 studies were identified. The number of preselected studies was 178, after exclusion of 65 due to duplicate identification. After reviewing the titles and abstracts, 156 studies were excluded because the information was not relevant for the purpose of the present review, leaving the number of early selected studies to 22. Two National Health Surveys (Argentina and

Mexico) and 12 references that had not been identified during the bibliographical search and were provided by colleagues were included afterward. The final number of selected studies was 28, after a detailed review of all the aforementioned references and the exclusion of 8 more articles that had insufficient or absent criteria for assessment of vitamin D status or that included patients with severe clinical conditions or under pre- or postoperative care (**fig. 1**). **Appendix 1** shows studies in Latin America and the Caribbean that assessed the frequency of vitamin D deficiency using 25 OHD. **Figure 2** illustrates this information in a map. **Table 1** shows studies estimating the intake of vitamin D in Latin America and the Caribbean countries.

Argentina

The 2004/05 Argentinean National Health Survey only included information regarding vitamin D status for a subsample of young children aged 6 to 23 months from the Patagonia region. In this group, only 3% were vitamin D deficient (25 OHD < 25 nmol/L) [26–28]. A small study (n = 24) showed that 33% of adults had low levels of vitamin D (25 OHD < 50 nmol/L) [24], while a study in postmenopausal women showed that 6% of subjects had 25 OHD levels lower than 25 nmol [30]. In 2003, a study in elderly subjects comparing vitamin D status in different seasons showed a prevalence of vitamin deficiency (25 OHD < 25 nmol/L) of 16% in winter and 0% in summer [29]. A second study in the elderly showed that the prevalence rates of vitamin D deficiency (25 OHD < 25 nmol/L) in this group in the northern, middle, and southern regions of this country were 2%, 11%, and 14%, respectively [25].

Brazil

A study of stunted children and adolescents showed that 9% of them presented with 25 OHD concentrations lower than 50 nmol/L [34]. A study published in 2011 showed that 10% of young adults had 25 OHD levels lower than 50 nmol/L [31]. Unger et al. showed that in winter 14% of adult subjects had vitamin D insufficiency (25 OHD < 38 nmol/L), compared with only 4% in summer [32]. A study conducted in postmenopausal women showed a 7% prevalence of vitamin D deficiency (25 OHD < 25 nmol/L) in 29 healthy subjects used as controls in a trial evaluating the effect of calcium and vitamin D supplementation [33]. On the other hand, a study conducted in adults and elderly with low bone mineral density showed a 2% prevalence of vitamin D deficiency (25 OHD < 25 nmol/L) [35]. Also in the elderly, a study showed 82% to 94% of subjects with 25 OHD levels lower than 70 nmol/L [36]. In the same age group, another study showed that the prevalence of vitamin D deficiency (25 OHD < 25 nmol/L) was 16% in ambulatory subjects [37].

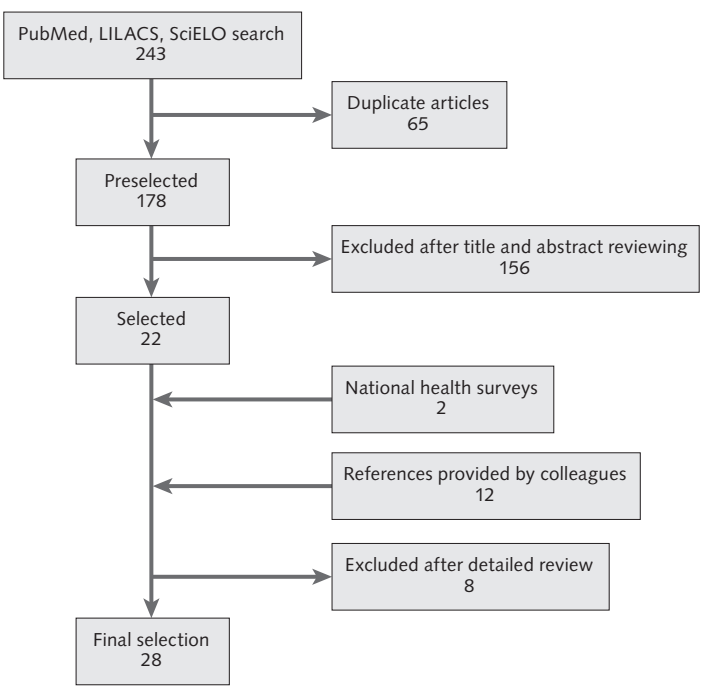

FIG. 1. Flow diagram of identification of studies

FIG. 2. Vitamin D status in Latin America and the Caribbean

TABLE 1. Studies estimating vitamin D intake in Latin America and the Caribbean

Country	Age group	Age (yr)	*n*	Mean vitamin D intake (IU/day)	Adequate intake IU/day (IOM 2004)	EAR-RDA IU/day (IOM 2011)	Adequacy in relation to EAR 2011	Observations
Brazil 2011 [31]	Adolescents and young adults	16–20	160	124.0 ± 28.0	200	400–600	100% inadequacy	
Brazil 2010 [34]	Children and adolescents	12 ± 4 (mean) 4–18	58	72.5 (Median) 37–145.6 (Interquartile range)	200	400–600	64% inadequacy (IOM 2004)	Short-stature subjects
Brazil 2010 [33]	Post-menopausal women	62 ± 8	29	112.0 ± 56.0	400	400–600	100% inadequacy	
Brazil 2009 [47]	Adults	> 40	2,420	72–88 32–144 (range)	400	400–600	100% inadequacy	
Brazil 2009 [48]	Adult women	50 ± 10	24	60.7 ± 56.9	200–400	400–600	N/A	Women with normal bone mineral density
Costa Rica 2005 [49]	Adolescents	16 ± 0	159	185 ± 7.6	200	400–600	N/A	
Costa Rica 2005 [49]	Adults	57 ± 1	159	176 ± 8.4	200	400–600	N/A	

EAR, estimated average requirement; IOM, Institute of Medicine; IU, international unit; N/A, not available; RDA, Recommended Dietary Allowance

Chile

A study conducted in premenopausal women showed a 0% prevalence of vitamin D deficiency, defined as 25 OHD < 23 nmol/L [39]. On the other hand, there are several studies in postmenopausal women showing 0% to 12% prevalence of vitamin D deficiency (25 OHD < 23 nmol/L) and between 5% and 60% prevalence of vitamin D insufficiency, depending on the cutoff value used [38–40].

Colombia

Two studies conducted in schoolchildren showed between 10% and 12% prevalence of vitamin D insufficiency (< 50 nmol/L) [41, 42].

Ecuador

A study published in 2008 showed a 19% prevalence of vitamin D insufficiency (25 OHD < 40 nmol/L) in elderly men, whereas in elderly women the prevalence was 9% [43].

Guatemala

A study conducted in indigenous Guatemalans showed 46% of subjects with 25 OHD levels lower than 50 nmol/L [44].

Mexico

The 2006 Mexican National Health Survey showed in a national representative sample of preschool children, schoolchildren, adolescents, and adults prevalence rates of vitamin D insufficiency (25 OHD < 50 nmol/L) of 24%, 10%, 8%, and 10%, respectively [46]. The prevalence of vitamin D deficiency (25 OHD < 20 nmol/L) was less than 1% for all groups [46]. A study assessing vitamin D deficiency among obese and nonobese children showed that the prevalence of vitamin D insufficiency (25 OHD < 50 nmol/L) was 27% and 13%, respectively [45].

Dietary intake estimation

A study conducted in Brazilian stunted children and adolescents showed that only 36% of children and adolescents had an adequate intake of vitamin D [34]. As shown in **table 1**, studies performed in Brazil in adolescents, young adults, adults, and women showed that the dietary intake of vitamin D was lower than recommended [31, 33, 47, 48]. In Costa Rica, another study showed that the median intake of vitamin D was 185 ± 7.6 IU, which is lower than the IOM 2004 recommendation (200 international units/day) [49].

Discussion

This review intended to provide some indication of the magnitude of vitamin D deficiency in Latin America and the Caribbean. In the majority of the countries with available data, we observed that vitamin D deficiency either was not a public health problem (prevalence < 5%) or could be classified as a mild public health problem (prevalence between 5% and 19.9%). On the other hand, vitamin D insufficiency is classified in most countries as a mild, moderate (prevalence between 20% and 39.9%), and, in some, severe public health problem (≥ 40%). However, the data reviewed do not allow us to accurately assess vitamin D status at the regional level, given that there are no nationally representative data and the few scientific studies available within each country usually have a low number of subjects in their samples. It is therefore difficult to draw any definitive conclusions on the extent of vitamin D deficiency in the region.

The present systematic review indicates that there are scientific studies assessing the prevalence of vitamin D deficiency in Argentina, Brazil, Chile, Colombia, Ecuador, Guatemala, and Mexico. Most of these studies assessed the association between vitamin D deficiency and bone mineral health in children, adolescents, adults, postmenopausal women, and the elderly. In general, these studies showed a considerable prevalence of vitamin D insufficiency in different age groups. The only nationally representative sample was from Mexico. In addition, studies in Brazil and Costa Rica reporting dietary intake of vitamin D show that the intake for several age groups is lower than current recommendations. However, it is possible that these studies underestimate usual intake, depending on whether the food composition tables used include the content of vitamin D for all foods.

Vitamin D status has been studied in all continents and most countries around the world. However, population-based data that include prevalence assessments of vitamin D status are not available for most of the countries [50]. One of the largest representative samples available is the National Health and Nutrition Examination Survey (NHANES) in the United States [51]. From 1988–94 (n = 18,641) to 2001–06 (n = 23,424), this survey showed a decrease in the geometric mean serum 25 OHD level by 9% in all participants. During 2006–11, the overall prevalence rates of vitamin D deficiency (25 OHD < 25 nmol/L) and vitamin D insufficiency (25 OHD < 50 nmol/L) were 5% and 32%, respectively. The nationally representative sample from Mexico showed that the prevalence rates of vitamin D insufficiency (25 OHD < 50 nmol/L) in preschoolers (2 to 5 years) and schoolchildren (6 to 12 years) were 24% and 10%, respectively. These values are higher in preschoolers and lower in schoolchildren

than the values reported by NHANES 2001–06 using the same cutoff (11% and 16%, respectively). In the case of adolescents and adults (16 to 50 years), NHANES 2001–06 reported rates of vitamin D insufficiency (25 OHD < 50 nmol/L) of 33% to 37%. Results from research studies conducted in the region showed a large range in the prevalence of vitamin D insufficiency, from 5% to 55%, depending on the 25 OHD cutoff used. NHANES 2001–06 showed a 5% prevalence of vitamin D deficiency (25 OHD < 25 nmol/L) and a 34% prevalence of vitamin D insufficiency (25 OHD < 50 nmol/L) in subjects over 70 years of age. In Latin America, some individual studies conducted in older people showed a higher prevalence of vitamin D deficiency (25 OHD < 25 nmol/L) than NHANES, reaching 16% in Brazil and Argentina. In the same context, a 73% prevalence of vitamin D insufficiency (25 OHD between 25 and 50 nmol/L) was observed in Argentina and Brazil. Nevertheless, it is important to highlight that there are several factors affecting an appropriate comparison between the results obtained in research studies conducted in Latin America and the Caribbean and NHANES data, such as differences among these studies in the laboratory techniques used to determine 25 OHD [52].

It is necessary to be cautious with preliminary conclusions from this systematic review, because the available data are limited and do not reflect what occurs at a national level within each country. In addition, there are other factors that affect the interpretation of the data, such as season, skin pigmentation, degree of sun exposure (latitude and altitude, no direct estimation of sunlight exposure), use of sunscreens for skin cancer prevention, possible use of vitamin D supplements (indeterminate), dietary intake of vitamin D, differences in laboratory techniques, and lack of consensus regarding the threshold of the blood concentrations of 25 OHD. In this sense, the use of diverse cutoffs in the reviewed studies could have led to under- or overestimations if other cutoffs were used.

It is important to emphasize that most of the studies were conducted in older individuals, because of their decreased vitamin D absorption and age-related skin thinning and functional changes in skin capacity. The concentration in the skin of 7-dehydrocholesterol, a precursor of vitamin D synthesis, is 50% higher in 20-year-olds than in 80-year-olds [53].

25 OHD provides the single best assessment of vitamin D status. There are several methods available to determine this metabolite. Results may vary among methods, among commercially available versions of the same method, and among laboratories [52]. In the present article, most of the studies determined 25 OHD by radioimmunoassay (Diasorin). It has been reported that the intra- and interassay coefficients of variability are less than 8% and less than 12%, respectively, indicating that it is an effective assay to determine vitamin D status [54, 55]. However, a liquid chromatography/mass spectrometry method to measure 25 OHD is currently a preferred technique. This technique has the ability to separate and accurately quantify both vitamin D_2 and vitamin D_3, as compared with radioimmunoassay [56, 57].

In the present review, some studies evaluated vitamin D status in an obese population or compared obese with nonobese subjects, showing a lower vitamin D status in those subjects with obesity. Vitamin D is thought to play an important role in adipogenesis and the prevention of a variety of diseases, including cancer and diabetes. Low vitamin D levels are associated with increased overall and cardiovascular mortality and increased risks of secondary hyperthyroidism and insulin resistance [58–62].

This is the first systematic review assessing the prevalence of vitamin D deficiency in Latin America and the Caribbean. In our opinion, the main issues that need to be addressed to obtain a better understanding of the magnitude of vitamin D deficiency in the region are as follows: national population-based studies designed specifically to assess vitamin D status should be encouraged; information is needed from all populations, not just those considered at risk, such as children, postmenopausal women, and elderly people. Vitamin D deficiency can be a problem at any life stage, and therefore research should encompass various populations and physiological states. Consensus is needed on the best cutoff to determine vitamin D status using 25 OHD, based on the biological implication of vitamin D deficiency, using this cutoff in different ages and physiological groups, and for monitoring responses to interventions for their prevention and control, including the relationship with dietary intake of vitamin D and sun exposure habits.

The present computer-based systematic search of studies, complemented by national health surveys and studies delivered by colleagues in the region, was performed to identify the majority of the available evidence. However, we cannot rule out the possibility that some available evidence was not identified in our search. This article is useful as a first step to recognize that vitamin D deficiency could be a major problem in Latin America and the Caribbean. It is important to note that we could find no studies assessing vitamin D status in the Caribbean. In children, vitamin D deficiency can cause rickets, and in adults it affects bone metabolism and muscle strength, as well as many other metabolic and immune functions, as suggested by the occurrence of the vitamin D receptor in over 30 different human tissues [2]. We believe it is urgent to develop more and better nationally representative data to clarify the true magnitude of this deficiency in Latin America and the Caribbean.

Conclusions

There is some indication that vitamin D insufficiency may be a public health problem in Latin America, but the extent of the magnitude is currently unknown.

Authorship

A.B. designed the research; A.B. and M.F.M. analyzed the data; H.C., M.O., G.C., and D.L.dR. assisted with data interpretation; A.B. wrote the paper; and A.B. had primary responsibility for the final content. All authors read and approved the final manuscript.

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Appendix 1. Studies determining vitamin D deficiency in Latin America and the Caribbean

Country	Age group	Age	Sex	*N*	Vitamin D level (nmol/L)	Vitamin D deficiency (%)	Cutoff (nmol/L)	Vitamin D insufficiency (%)
Argentina 2009 [24]	Adult	> 50 yr	15 F 9 M	24	61.3 (mean)	N/A	N/A	33
Argentina 2004 [25]	Elderly	> 65 yr 70 ± 5 yr	N/A	58	51.8 ± 18.5	2	< 25	50
Argentina 2004 [25]	Elderly	> 65 yr 72 ± 6 yr	N/A	193	44.8 ± 20.5	11	< 25	53
Argentina 2004 [25]	Elderly	> 65 yr 71 ± 5 yr	N/A	88	35.5 ± 14.0	14	< 25	73
Argentina 2004–05 [26–28]	Young children	6–23 mo	N/A	N/A	67.5 10.5–178 (range)	3	< 25	21
Argentina 2003 [29]	Elderly	> 65 yr 72 ± 4	37 F 12 M	49	43.3 ± 18.8	14	< 25	51
Argentina 2003 [29]	Elderly	> 65 yr 72 ± 8 yr	25 F 9 M	34	71.5 ± 25.0	0	< 25	15
Argentina 2003 [29]	Adult	30 ± 7 yr	N/A	44	42.8 ± 20.3	16	< 25	55
Argentina 2003 [29]	Adult	30 ± 7 yr	30 F 2 M	32	81.3 ± 32.0	0	< 25	16
Argentina 2001 [30]	Postmenopausal women	37–87 yr 61 ± 9 yr	198 F	198	50.0 ± 18.0 12.3–105.3 (range)	6	< 25	46
Brazil 2012 [31]	Adolescents and young adults	16–20 yr	82 F 78 M	160	72.5 ± 22.3	N/A	N/A	10
Brazil 2010 [32]	Adult and elderly	48 ± 13 yr	485 F 118 M	603	53.5 (median)	N/A	N/A	N/A
Brazil 2010 [32]	Adult and elderly	18–90 yr	178 F 31 M	209	55.0 (41.5–72.3) (median) (p25–p75)	N/A	N/A	14
Brazil 2010 [32]	Adult and elderly	18–90 yr	178 F 31 M	209	85.0 (65.5–109) (median) (p25–p75)	N/A	N/A	4
Brazil 2010 [33]	Postmenopausal women	63 ± 8 yr	29 F	29	53.0 ± 21.0	7	< 25	50
Brazil 2010 [34]	Children and adolescents	4–18 yr 12 ± 4 yr	18 F 40 M	58	76.8 ± 28	N/A	N/A	9
Brazil 2010 [35]	Postmenopausal women	66 ± 7 yr 51–84 yr	93 F	93	28.8 ± 14.8	8	< 38	24
Brazil 2009 [36]	Adult and elderly	50–85 yr	251 F	251	72.0 ± 26.5 15.0 –215 (range)	2	< 25	63
Brazil 2009 [36]	Elderly	72 ± 4 yr	226 F	226	52.0 ± 27.0	N/A	N/A	N/A
Brazil 2009 [36]	Elderly	75 ± 6 yr	189 F	189	42.0 ± 21.0	N/A	N/A	N/A

Cutoff (nmol/L)	Vitamin D inadequacy (%)	Cutoff (nmol/L)	Latitude	Technique	Observations
< 50	50	Between 50 and 75	N/A	HPLC	
Between 25 and 50	46	Between 50 and 100	26°–27°S	Radioimmunoassay (RIA-IDS)	Subjects from northern region of Argentina
Between 25 and 50	35	Between 50 and 100	33°–34°S	Radioimmunoassay (RIA-IDS)	Subjects from middle region of Argentina
Between 25 and 50	13	Between 50 and 100	41°–55°S	Radioimmunoassay (RIA-IDS)	Subjects from southern region of Argentina
Between 25 and 50	40	Between 50 and 75	N/A	Radioimmunoassay Diasorin	Children from Patagonia
Between 25 and 50	37	Between 50 and 100	34°S	Radioimmunoassay INCSTAR RIE	Study performed in winter
Between 25 and 50	65	Between 50 and 100	34°S	Radioimmunoassay INCSTAR RIE	Study performed in summer
Between 25 and 50	27	Between 50 and 100	34°S	Radioimmunoassay INCSTAR RIE	Study performed in winter
Between 25 and 50	56	Between 50 and 100	34°S	Radioimmunoassay INCSTAR RIE	Study performed in summer
Between 25 and 50	N/A	N/A	34°S	Competitive protein-binding assay	
< 50	52	Between 50 and 75	23°S	Radioimmunoassay (DiaSorin)	
N/A	77	< 75	N/A	Radioimmunoassay (DiaSorin)	
< 38	63	Between 38 and 75	N/A	Radioimmunoassay (DiaSorin)	Study performed in winter
< 38	33	Between 38 and 75	N/A	Radioimmunoassay (DiaSorin)	Study performed in summer
Between 25 and 50	41	Between 50 and 75	N/A	Radioimmunoassay (DiaSorin)	
<50	48	Between 51 and 73	30°S	HPLC (Chromsystems. solid phase extraction)	Stunted
< 50	N/A	N/A	20–30°S	Radioimmunoassay (DiaSorin)	
Between 25 and 50	N/A	N/A	N/A	Radioimmunoassay (DiaSorin)	Women with low bone mineral density
N/A	82	< 75	23°S	Radioimmunoassay (DiaSorin)	
N/A	94	< 75	23°S	Radioimmunoassay (DiaSorin)	Women with vertebral fractures

continued

Country	Age group	Age	Sex	*N*	Vitamin D level (nmol/L)	Vitamin D deficiency (%)	Cutoff (nmol/L)	Vitamin D insufficiency (%)
Brazil 2007 [37]	Elderly	79 ± 6 yr	168 F 75 M	243	49.5 ± 28.5	16	< 25	28
Chile 2007 [38]	Postmenopausal women	58 yr (mean) 55–84 (range)	555 F	555	42.0 ± 17.0	N/A	N/A	48
Chile 2007 [39]	Premenopausal women	33 ± 7 yr	30 F	30	N/A	0	< 23	27
Chile 2007 [39]	Postmenopausal women	64 ± 10 yr	60 F	60	N/A	12	< 23	60
Chile 2001 [40]	Postmenopausal women	61 ± 5 yr 50–74 yr (range)	40 F	40	80.6 ± 31.1 35–175 (range)	N/A	N/A	5
Colombia 2011 [41]	Schoolchildren	9 ± 2 yr	242 F	242	71.0 ± 18.3 (plasma)	N/A	N/A	12
Colombia 2010 [42]	Schoolchildren	5–12 yr	250 F 229 M	479	73.3 ± 19.8 (plasma)	N/A	N/A	10
Ecuador 2008 [43]	Elderly	76 ± 7 yr	125 M	125	57.0 ± 15.8	N/A	N/A	19
Ecuador 2008 [43]	Elderly	74 ± 6 yr	224 F	224	49.3 ± 13.5	N/A	N/A	9
Guatemala 2010 [44]	Elderly	69 ± 7 yr	54 F 54 M	108	53.3 ± 15.0	N/A	N/A	46
Mexico 2010 [45]	Children	9 ± 2 yr	49 F 50 M	99	57.5 ± 12.5	N/A	N/A	27
Mexico 2010 [45]	Children	9 ± 2 yr	49 F 50 M	99	65.0 ± 15	N/A	N/A	13
Mexico 2006 [46]	Preschool children	2–5 yr	216 F 150 M	366	78.0 ± 37	N/A	N/A	24
Mexico 2006 [46]	Schoolchildren	6–12 yr	270 F 389 M	659	106.0 ± 51.0	N/A	N/A	10
Mexico 2006 [46]	Adolescents	13–19 yr	163 F 250 M	513	105 (96–114) 102 (93–110)	— 0.5	< 20	8
Mexico 2006 [46]	Adults	≥ 20	547 F 417 M	964	97 (92–103) 98 (92–104)	2.2 0.2	< 20	10

ELISA, enzyme-linked immunosorbent assay; HPLC, high-performance liquid chromatography; N/A, not available

Cutoff (nmol/L)	Vitamin D inadequacy (%)	Cutoff (nmol/L)	Latitude	Technique	Observations
Between 25 and 50	N/A	N/A	N/A	Radioimmunoassay (Nichols Institute Diagnostics)	Outpatients
< 43	N/A	N/A	33°S	N/A	
Between 25 and 50	N/A	N/A	33°S	Radioimmunoassay (DiaSorin)	Performed in winter and half in summer
Between 25 and 50	N/A	N/A	33°S	Radioimmunoassay (DiaSorin)	Performed in winter and half in summer
< 38	N/A	N/A	33°S	Radioimmunoassay (DiaSorin)	Women with low bone mineral density
< 50	51	Between 50 and 75	N/A	Enzyme immunoassay (Immunodiagnostic Systems)	
< 50	46	Between 50 and 75	4°34'N	Enzyme immunoassay (Immunodiagnostic Systems)	
< 40	N/A	N/A	N/A	N/A	
< 40	N/A	N/A	N/A	N/A	
< 50	N/A	N/A	14° N	Radioimmunoassay (Immuno Diagnostics Kit)	Study performed in summer in indigenous people
< 50	64	Between 51 and 73	25° N	Radioimmunoassay (DiaSorin)	Obese children
< 50	59	Between 51 and 73	25° N	Radioimmunoassay (DiaSorin)	Nonobese children
< 50	6	Between 50 and 75	N/A	ELISA (Immunodiagnostik AG)	Nationally representative sample
< 50	8	Between 50 and 75	N/A	ELISA (Immunodiagnostik AG)	Nationally representative sample
< 50	23	< 75	N/A	ELISA (Immunodiagnostik AG)	Nationally representative sample
< 50	20	< 75	N/A	ELISA (Immunodiagnostik AG)	Nationally representative sample

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