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Worldwide status of vitamin D nutrition☆

P. Lips*

VU University Medical Center, Department of Internal Medicine, Section Endocrinology, P.O. Box 7057, 1007 MB Amsterdam, The Netherlands

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ABSTRACT

The vitamin D status depends on the production of vitamin D3 in the skin under the influence of ultraviolet radiation and vitamin D intake through the diet or vitamin D supplements. The serum 25-hydroxyvitamin D (25(OH)D) concentration is the parameter of choice for the assessment of vitamin D status. Low serum levels of calcium and phosphate and an elevated level of alkaline phosphatase can also point to vitamin D deficiency. Usually, between 50% and 90% of vitamin D in the body is coming from the production in the skin and the remainder is from the diet. The production of vitamin D3 in the skin depends on sunshine exposure, latitude, skin-covering clothes, the use of sun block and skin pigmentation. In general, serum 25(OH)D is lower with higher latitudes and with darker skin types, but there are exceptions. Vitamin D deficiency (serum 25(OH)D < 25 nmol/l) is highly prevalent in India and China while vitamin D status is better in Japan and South-East Asia. Vitamin D deficiency is very common in the Middle-East and there is a relationship with skin covering clothes and staying outside of the sun. A poor to moderate vitamin D status is also common in Africa, probably caused by the dark skin types and cultural habits of staying outside of the sunshine. Vitamin D status is much better in North America where vitamin D deficiency is uncommon but vitamin D insufficiency (serum 25(OH)D between 25 and 50 nmol/l) is still common. In the United States and Canada milk is usually supplemented with vitamin D and the use of vitamin supplements is relatively common. Vitamin D status in Latin America usually is reasonable but there are exceptions and vitamin D insufficiency still occurs quite often. In Australia and New Zealand a poor vitamin D status was seen in the elderly who were often vitamin D deficient and also in immigrants from Asia. Vitamin D deficiency also occurred in children when the mother was vitamin D deficient. Within Europe, vitamin D status usually is better in the Nordic countries than around the Mediterranean. This may be due to a lighter skin and sun seeking behaviour and a high consumption of cod liver oil in the Northern countries while in Southern Europe people stay out of the sunshine and have a somewhat darker skin. A very poor vitamin D status was observed in non-western immigrants, especially in pregnant women.

In conclusion, vitamin D deficiency and insufficiency are globally still very common especially in risk groups such as young children, pregnant women, elderly and immigrants.

1. Introduction

Vitamin D status in different European countries has been assessed in numerous studies in great detail. The same is true for North America, Asia and Oceania, but studies on vitamin D status in Latin America and Africa are scant. One recent report by the International Osteoporosis Foundation summarizes one available study [1]. Studies are not always comparable, since different assays have been used and the interlaboratory variation still is considerable [2]. The problem of vitamin D deficiency in many countries is reflected by the high prevalence of rickets in countries such as Mongolia, Tibet and Ethiopia, shown in Table 1 [3]. Western countries also feature on this list associated with people using special diets or with non-western immigrants. This paper focuses on worldwide vitamin D status and its determinants, risk groups and implications. Currently the best parameter for vitamin D status is the serum concentration of 25-hydroxyvitamin D (25(OH)D). For this review, the required serum 25(OH)D for all ages is set at 50 nmol/l. However, consensus has not been obtained at this point, and many investigators have the opinion that the required serum level should be 75 or 80 nmol/l or even higher.

2. Vitamin D status in different continents

One of the first review articles comparing different continents concluded that Vitamin D status was better in North America than in Europe and within Europe it was better in the Nordic countries [4].

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* Tel.: +31 20 444 0530; fax: +31 20 444 0502.
E-mail address: p.lips@vumc.nl.

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Table 1
Worldwide prevalence of rickets.

Asia, Middle East and Africa		%
Mongolia	1998	70
Tibet	1994	66
Ethiopia	1997	42
Yemen	1987	27
Turkey	1998	10
Nigeria	1998	9
Europe		
The Netherlands (macrobiotics)	1990	55
UK–Manchester (minorities)	2002	1.6

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2.1. Europe

The Euronut-Seneca study has compared vitamin D status in a population sample of older persons including latitudes from 35° to more than 60°. The mean serum 25(OH)D ranged from 20 to 60 nmol/l, but the concentration increased from southern European countries (e.g. Portugal, Greece) to Northern Europe (Scandinavia), while the reverse should be expected based on sunshine and ultraviolet prevalence throughout the year [5]. The study also shows that vitamin D deficiency is very common in older persons in southern Europe. The National Diet and Nutrition Survey includes population data of persons from 18 to 85 years and over, including institutionalized people, analyzed in a central laboratory [3]. It shows high prevalences of 15–25% of vitamin D deficiency (serum 25(OH)D < 25 nmol/l) in adolescents and young adults and again of 20 to more than 35% in those over 85 years and the institutionalized (Fig. 1). When looking at serum 25(OH)D lower than 50 nmol/l, percentages range from 40% to 80% in different adult age groups.

While serum 25(OH)D was lower than 25 nmol/l in less than 5% of children under 10 years, it was much more common, more than 25% in British Asian children [3]. The Longitudinal Aging Study Amsterdam (LASA) comprises a population sample from the Netherlands of 55 years and older. Serum 25(OH)D was lower than 25 nmol/l in 13% and lower than 50 nmol/l in 48% of persons older than 65 years. Levels were about 5 nmol/l lower in women than in men, and decreased from 60 to 48 nmol/l with increasing fat percentage (20–35%) in men, and from 55 to 40 nmol/l with increasing fat percentage (32–51%) in women, making body fat or BMI a major determinant [6]. A survey on ethnic minorities from general practices in four large cities in the Netherlands showed a serum 25(OH)D lower than 25 nmol/l in 41% of Turkish, 36% of Moroccan, 48% of Surinam and 19% of sub-Saharan African adults, compared to 6% of indigenous Dutch adults [7]. A similar survey in midwife practices in The Hague showed a serum 25(OH)D lower than 25 nmol/l in 84% of Turkish and 81% of Moroccan pregnant women compared with 8% of pregnant women from western countries [8].

In France, the Suvimax study in more than 1500 women and men between 35 and 65 years showed the expected south-north gradient with mean serum 25(OH)D going from 94 nmol/l in the south-west to 43 nmol/l in the north of France. Serum 25(OH)D in the Mediterranean part was 68 nmol/l, with still 7% lower than 30 nmol/l, while this was 29% in the north [9]. In Italy, vitamin D status was studied in 700 women of 60–80 years. Mean serum 25(OH)D was 27 nmol/l. Serum 25(OH)D was below 12.5 nmol/l in 27%, below 25 nmol/l in more than 50% and below 50 nmol/l in almost 90% [10]. Baseline data of the MORE study on the effect of raloxifene vs placebo in postmenopausal women with osteoporosis confirmed the reversed south-north gradient with mean serum 25(OH)D of 55 and 60 nmol/l in Italy and Spain respectively, while it was 86–89 nmol/l in Norway and Sweden and 71 nmol/l in Finland [2]. A central laboratory facility was used in this study, excluding interlaboratory variation as a cause of the observed differences. A strong positive correlation was observed between serum 25(OH)D and latitude ($r^2 = 0.42$, $P < 0.001$). The high serum 25(OH)D in Norway may be explained by the high vitamin D intake with cod liver oil. In Tromso at 70° latitude mean serum 25(OH)D was lower than 50 nmol/l in 15% only and mean vitamin D intake was 356 IU per day [11].

2.2. Middle East and Asia

Several surveys showed a very poor vitamin D status in the Middle East and a strong relationship with clothing style. Mean serum 25(OH)D in Turkish women with veil (hijab) was 32 nmol/l, while it was only 9 nmol/l when they were completely covered (niqab). On the other side, Turkish women with western style clothing had a mean serum 25(OH)D of 56 nmol/l [12,13]. Similar data were reported from Jordan with mean serum 25(OH)D in western style women of 37 nmol/l, with hijab 28 nmol/l and with niqab 24 nmol/l, while in men mean serum 25(OH)D was 44 nmol/l [14]. Saudi Arabia showed the lowest values, around 10 nmol/l in students and older persons [15].

In India, generally low serum 25(OH)D concentrations have been reported. In a survey in hospital staff mean serum 25(OH)D was 30 nmol/l [16]. In pregnant women mean serum 25(OH)D was

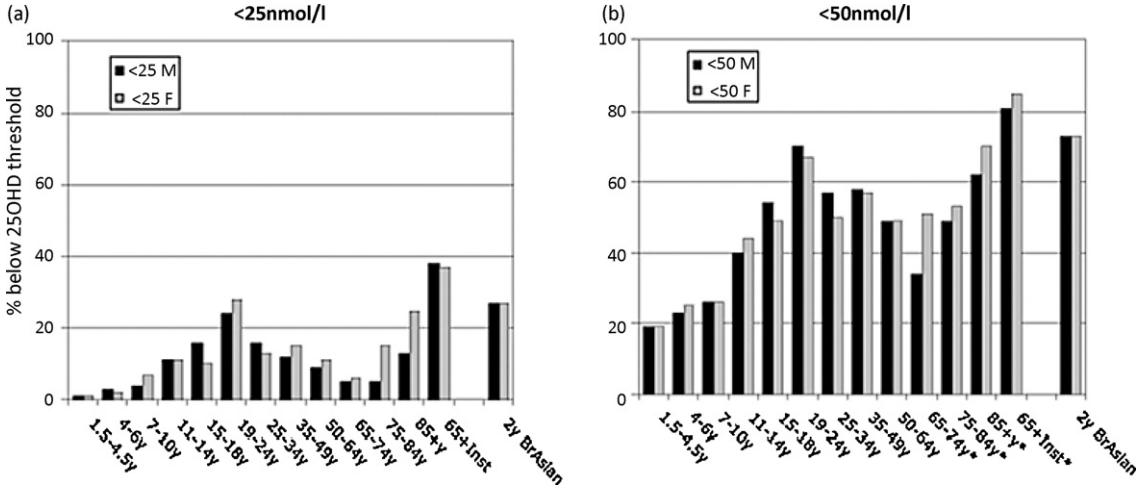

Fig. 1. Vitamin D status in the United Kingdom. Serum 25(OH)D according to sex and age groups showing the lowest levels in young adults, subjects older than 85 years, the institutionalized and British Asian children. Data from a national survey. Reproduced from Prentice A. et al., Nutr Rev 2008;66(Suppl. 2):S153–S164.

35 nmol/l [17], and in postmenopausal women it was 36 nmol/l [18]. In Jekaterinburg (Siberia) mean serum 25(OH)D was 22 nmol/l in hip fracture patients and 28 nmol/l in elderly controls [19]. In Mongolia mean serum 25(OH)D was 7 nmol/l in rachitic children [20], and the prevalence of rickets was as high as 70% [3]. Healthy Mongolian children had a mean serum 25(OH)D of 41 nmol/l, and in pregnant women it was 26 nmol/l. In Beijing, China, mean serum 25(OH)D in adolescent girls was 36 nmol/l when participating in sports and 30 nmol/l when not participating [21]. In South East Asia vitamin D status generally is better. In a study in premenopausal women in Jakarta and Kuala Lumpur, the mean serum 25(OH)D was 48 nmol/l [22]. In Japan, a low mean serum 25(OH)D of 34 nmol/l was observed in women younger than 30 years and of 30 nmol/l in immobile older persons [23].

2.3. North America

Recent data on vitamin D status in the United States have become available from the National Health and Nutrition Examination Survey (NHANES) in 20,000 men and 18,000 women collected between 2000 and 2004 [24]. Mean serum 25(OH)D was about 65 nmol/l in non-hispanic whites, but only 40 nmol/l in non-hispanic blacks and in between in Mexican-Americans. Values were slightly higher in men than in women. There was a downward secular trend between NHANES III (1990–1994) and NHANES 2000–2004, being significant in men even when corrected for changes in the 25(OH)D assay. Serum 25(OH)D decreased significantly with increasing BMI, with the use of sun protection and with low milk intake. The latter is an important source of vitamin D in the US as it is fortified with 400 IU per quart. A poor vitamin D status was observed in older persons admitted to hospital [25], and recently the MrOS study showed that a serum 25(OH)D below 50 nmol/l was present in 26% of older men. Vitamin D deficiency was associated with winter and spring, age and BMI [26].

A recent survey in Canada in children and adults of all ages showed a mean serum 25(OH)D of 65.7 in males and 68.0 in females. The lowest values were observed in adolescents and young adults [27,28].

2.4. Latin America

Data on vitamin D status in Latin America are scarce and population studies are not available. A study in postmenopausal women with osteoporosis showed a mean serum 25(OH)D of 65 nmol/l in Mexico, 81 nmol/l in Brazil and 75 nmol/l in Chile [29]. Percentages below 50 nmol/l were 29%, 15% and 19% respectively. In a study in Argentina, serum 25(OH)D decreased from 52 nmol/l in the north, at lower latitude, to 36 nmol/l in the south at higher latitude [30].

2.5. Africa

Vitamin D studies in Africa have recently been reviewed [31]. This study showed a high variation in vitamin D status throughout the continent. Low serum 25(OH)D levels were observed in Algeria in pregnant women (mean summer 11.8, winter 9.0 nmol/l), in Egypt (healthy children 25.3 nmol/l, children with rickets 9.2 nmol/l), in Ethiopia (men and non-pregnant women 23.5 nmol/l). In Tunisia veiled women showed a lower mean serum 25(OH)D than non-veiled women (35.7 vs 42.5 nmol/l). Vitamin status was studied in Gambian women from 25 to 75+ years. Mean serum 25(OH)D was maximal, 113 nmol/l, in women 45–49 years, and lowest in 75+ women, 72 nmol/l. Healthy men in Zaire had a mean serum 25(OH)D of 65 nmol/l. Vitamin D status in children in South Africa generally was adequate with mean serum 25(OH)D between 72 and 123 nmol/l. However, mean serum 25(OH)D was 44 nmol/l in South African patients with hip fracture [32].

2.6. Oceania

In Australia, mean serum 25(OH)D was 70 nmol/l in postmenopausal women with osteoporosis [29]. However, a study in residential care facilities showed a low serum 25(OH)D (<39 nmol/l) in 77% of the residents [33]. In a study in older people in Sydney, the prevalence of vitamin D deficiency (serum 25(OH)D < 25 nmol/l) in older persons of Middle Eastern origin was four times as high as in older persons of European descent [34]. Vitamin D deficiency also was common in older persons originating from Vietnam [35]. In Tasmania, serum 25(OH)D was lower than 40 nmol/l in 23% of people from the community compared to 34% of patients with multiple sclerosis [36]. In New Zealand, a study of vitamin D status in a national sample showed a mean serum 25(OH)D of 47 nmol/l in women and 52 nmol/l in men. Maori and Pacific subjects had lower mean levels than persons of European descent (42 and 37 vs 51 nmol/l). People on the South Island had lower levels than those on the North Island. Other determinants were season, age and BMI [37]. The National Children's Nutrition Survey in New Zealand showed similar mean serum 25(OH)D in girls and boys (47 and 52 nmol/l). Values were lower in Maori and Pacific children than in those of European descent (43 and 36 vs 53 nmol/l) and the former groups were more often vitamin D deficient [38]. Girls between 11 and 14 years had the lowest values in all ethnic groups (Maori 35, Pacific 32 and European 45 nmol/l).

3. Global studies

Some global studies on vitamin D status have been performed, using one central laboratory facility for the measurement of all 25(OH)D samples. These studies usually done in postmenopausal women enable a comparison between countries and continents. The MORE study in postmenopausal women with osteoporosis showed higher serum 25(OH)D in Northern than in Southern European countries, higher levels in the US than in Europe, and higher levels in Canada than in the US [2]. An international comparative study showed similar data with the lowest values in the Middle East and South Korea [29]. The baseline data of the bazedoxifene study in postmenopausal women with osteoporosis showed decreasing serum 25(OH)D with increasing latitude as expected, but a reverse trend in Europe with higher levels in Northern than in Southern Europe [39]. The latter study also showed a relationship between serum 25(OH)D and affluence.

4. Risk groups

Studies from different continents and countries cannot exactly be compared due to differences in laboratory assessment of serum 25(OH)D. Nevertheless, general patterns can be recognized. Older persons generally are at risk of vitamin D deficiency and especially those in residential care or nursing homes. Older children, adolescents and young adults also had low serum 25(OH)D when data were available, e.g. in the UK and in New Zealand. Ethnicity is a strong determinant of vitamin D status, which may be due to skin pigmentation or cultural habits, such as clothing style or staying in the shadow. The very poor vitamin D status in the Middle East has a cultural and religious base and directly relates to clothing style. Season is a strong determinant almost everywhere. Obesity also is an important determinant, and the trend of increasing BMI in the western world may further decrease vitamin D status. Nutrition and supplement use also influence vitamin D status, as is evident in the US, where vitamin D status relates to milk consumption, milk being fortified with vitamin D), and Norway, where the use of cod liver oil prevents vitamin D deficiency.

5. Implications

In many countries throughout all continents, mean serum 25(OH)D is around 50 nmol/l, which implicates that vitamin D insufficiency exists in around 50% of those populations. This has important implications for prevention. The population should be made aware of the problem, sunshine exposure might be stimulated, as well as the consumption of fatty fish. Food fortification might be encouraged. Vitamin D supplementation for risk groups usually is necessary.

6. Conclusion

The prevalence of inadequate vitamin D status (serum 25(OH)D < 50 nmol/l) is high. Men have a better vitamin D status than women. Adolescents, young adults and older persons, especially the institutionalized, carry a high risk for vitamin D insufficiency.

Latitude and socio-economic status are important determinants. Vitamin D status is particularly poor in the Middle East and India. Non-western immigrants in western countries carry a high risk for overt vitamin D deficiency. The high prevalence of rickets in countries such as Mongolia, India and Ethiopia is of particular concern. Vitamin D deficiency in pregnant women increases the risk for rickets in their offspring. The trend to decreasing serum 25(OH)D levels in the United States and possibly in other affluent countries may be due to increasing adiposity, decreasing mobility and fear of sunshine. Moderate sunshine exposure and food fortification with vitamin D can improve the vitamin D status of the population. In order to rise serum 25(OH)D to 50 nmol/l (20 ng/ml) or higher, a large part of the population will need vitamin D supplementation in winter or all year long.

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