



**International Osteoporosis
Foundation**

ARCHIVES OF OSTEOPOROSIS

August 2012 revised

A GLOBAL REPRESENTATION OF VITAMIN D STATUS IN HEALTHY POPULATIONS

Wahl DA, Cooper C, Ebeling PR, Eggersdorfer M, Hilger J, Hoffmann K, Josse R, Kanis JA, Mithal A, Pierroz DD, Stenmark J, Stöcklin E and Dawson Hughes B*

*Corresponding author

B. Dawson-Hughes

Department of Agriculture Human Nutrition,

Research Center on Aging, Tufts University,

711 Washington Street,

Boston, MA 02111, USA

Email: bess.dawson-hughes@tufts.edu

Author affiliations

D.A. Wahl, D.D. Pierroz and J. Stenmark
International Osteoporosis Foundation, Nyon, Switzerland

C. Cooper
MRC Lifecourse Epidemiology Unit, University of Southampton and NIHR Musculoskeletal Biomedical Research Unit, University of Oxford, UK

P.R. Ebeling
NorthWest Academic Centre, University of Melbourne, Western Health, St. Albans, Victoria, Australia

M. Eggersdorfer and E. Stöcklin
Nutrition Science & Advocacy and Research & Development Human Nutrition, DSM Nutritional Products, Kaiseraugst, Switzerland

J. Hilger and K. Hoffmann
Mannheim Institute of Public Health, Social and Preventive Medicine, Mannheim Medical Faculty, Heidelberg University, Mannheim, Germany

R. Josse
Division of Endocrinology and Metabolism, University of Toronto, St Michael's Hospital Health Centre, Toronto, Canada

A. Mithal
Medanta Medicity, Sector 38, Gurgaon, India

J.A. Kanis
WHO Collaborating Centre for Metabolic Bone Diseases, University of Sheffield Medical School, UK

B. Dawson-Hughes *
Jean Mayer USDA Human Nutrition Research Center on Aging at Tufts University, Boston, USA

Abstract

Purpose This paper visualizes the available data on vitamin D status on a global map, examines the existing heterogeneities in vitamin D status and identifies research gaps.

Methods A graphical illustration of global vitamin D status was developed based on a systematic review of the world wide literature published between 1990 and 2011. Studies were eligible if they included samples of randomly selected males and females from the general population and assessed circulating 25-hydroxyvitamin D (25OHD) levels. Two different age categories were selected: children and adolescents (1-18 years) and adults (>18 years). Studies were chosen to represent a country based on a hierarchical set of criteria.

Results In total, 200 studies from 46 countries met the inclusion criteria, most coming from Europe. Forty-two of these studies (21%) were classified as representative. In children, gaps in data were identified in large parts of Africa, Central and South America, Europe, and most of the Asia/Pacific region. In adults, there was lack of information in Central America, much of South America, and Africa. Large regions were identified for which mean 25OHD levels were below 50 nmol/L.

Conclusions This study provides an overview of 25OHD levels around the globe. It reveals large gaps in information in children and adolescents and smaller but important gaps in adults. In view of the importance of vitamin D to musculoskeletal growth, development, and preservation, and of its potential importance in other tissues, we strongly encourage new research to clearly define 25OHD status around the world.

Keywords: vitamin D status, vitamin D deficiency, 25OHD, IOF

Introduction

Vitamin D status in an individual is dependent on numerous genetic, lifestyle and geographical factors that include age, gender, skin pigmentation, sunlight exposure, latitude, the use of sunscreen, dietary habits and supplement intake [1]. It is best measured by serum concentration of 25-hydroxyvitamin D levels, also known as 25OHD levels [2].

Very low levels of 25OHD have been documented in different subgroups of the population worldwide [1, 3-6], which have clinical implications. Vitamin D plays an important role in the skeletal growth and development, and in bone health throughout life. It promotes calcium absorption [7] and reduces bone loss through the regulation of parathyroid hormone levels [8]. As a consequence, vitamin D deficiency has been linked to reduced bone mineral density [9, 10] and higher risk of osteoporotic fractures [11]. Although further investigation is necessary, vitamin D supplementation may reduce the risk of other diseases, such as colorectal cancer [12], diabetes [13], infection [14] and it may help to decrease fractures and falls [15] [16]. The loss of muscle mass and strength observed in vitamin D deficient individuals puts them at higher risk of falls and therefore fragility fractures.

The International Osteoporosis Foundation took the initiative to describe the vitamin D status in the general population in different countries based on a systematic review and to present the data on a global map. The aims of the study were to provide a general overview of vitamin D status in countries for which data were available, examine the existing heterogeneities in vitamin D status, and identify research gaps.

Methods

The data used in this project are based on a systematic literature review conducted by the Mannheim Institute of Public Health, Germany. The methods used generally follow the PRISMA Statement (Preferred Reporting Items for Systematic reviews and Meta-Analyses) [17]. Here, we provide a short summary of the methods used in this review. The methods are described in more detail elsewhere [18].

Eligible criteria

A systematic search was conducted in PubMed/Medline and EMBASE to identify articles on vitamin D status in the global population. Eligible studies included samples of randomly selected persons from the general population in countries throughout the world. The outcome of interest was the mean or median 25OHD level measured in serum or plasma. There were no limitations based on the type of assay used. Studies were required to have a cross-sectional design or to include a population-based cohort. Other study types like clinical trials, case-control studies, case reports or case series, reviews or qualitative studies were excluded. Articles had to be written in English and published between Jan 1st 1990 and 28th Feb 2011.

Abstract and full publication screening

2,566 articles were identified from both databases. Two independent researchers screened the articles were by with a good agreement for excluding studies (kappa coefficient of 0.719). Disagreements were discussed and resolved. After review, 273 articles were eligible and included in a large database which provided, in part, the following information: mean or median 25OHD levels, population characteristics, study location, assay type, number of participants and age groups.

Data filtering

In a second review process, studies on institutionalized elderly only, those on newborn babies and those having an age range that largely overlapped the two age categories (1-18 years and > 18 years) were removed. When published repeatedly, the same cohort was not presented more than once. In contrast, studies reporting sub-analysis of a cohort (number of participants and age range different from the root

paper) were retained. Studies originating from England, Northern Ireland and Scotland were grouped as United Kingdom. In the end, our database included 200 studies from 46 countries.

After examination of the database, two different age categories were selected: children and adolescents (1-18 years) and adults (>18 years). Mean serum or plasma 25OHD levels were extracted and reported as gender-specific means weighted by sample size where possible. Median levels of 25OHD were included when mean levels were not reported in a study. When data were classified by specific seasons, winter values were chosen. Values in ng/ml were converted to nmol/L by a multiple of 2.496.

Four colour codes according to mean (or median) 25OHD levels were used:

GREEN	>75 nmol/L
YELLOW	50-74 nmol/L
ORANGE	25-49 nmol/L
RED	<25 nmol/L

For each study, the mean or median vitamin D levels (nmol/L) were reported from the literature and a study colour code was assigned.

Rationale for the colour coding of countries

For both age categories, the rationale for assigning a colour code to a specific country was based on the following hierarchical selection criteria:

1. Representative of the entire country, population-based, and based on a weighted mean of these studies
2. Representative of a region/city of the country, population-based, based on a weighted mean of these studies
3. Based on a weighted mean of multiple studies, non-population-based
4. Based on a single study

Country colour was based on the 25OHD level (either weighted mean or median) of one or more representative studies, if available. If not available, it was based on one or more studies fitting the second criterion cited above, and so forth. A study was considered representative if it represented the entire population for a certain age and sex group in a certain country, region or city. Studies with a selection bias, which excluded individuals for example on the basis of health status, ethnicity, physical abilities, language, smokers and social economic status, were classified as non-representative. However, for some studies such information was not described in the text.

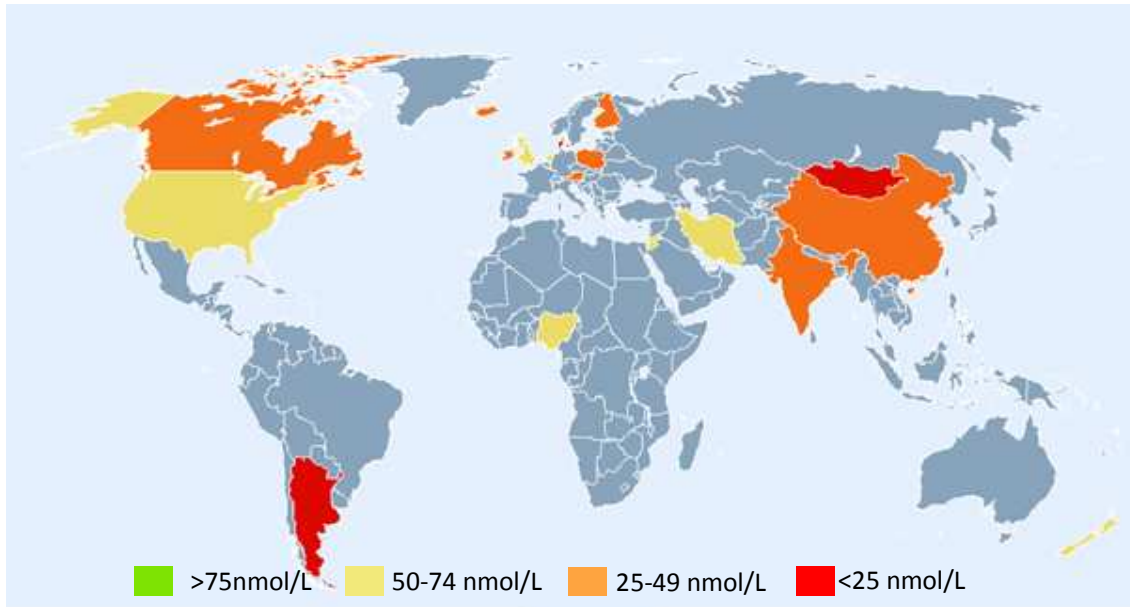
Design of the figures

The software FlashWorldMap.com was used to produce the maps

Results

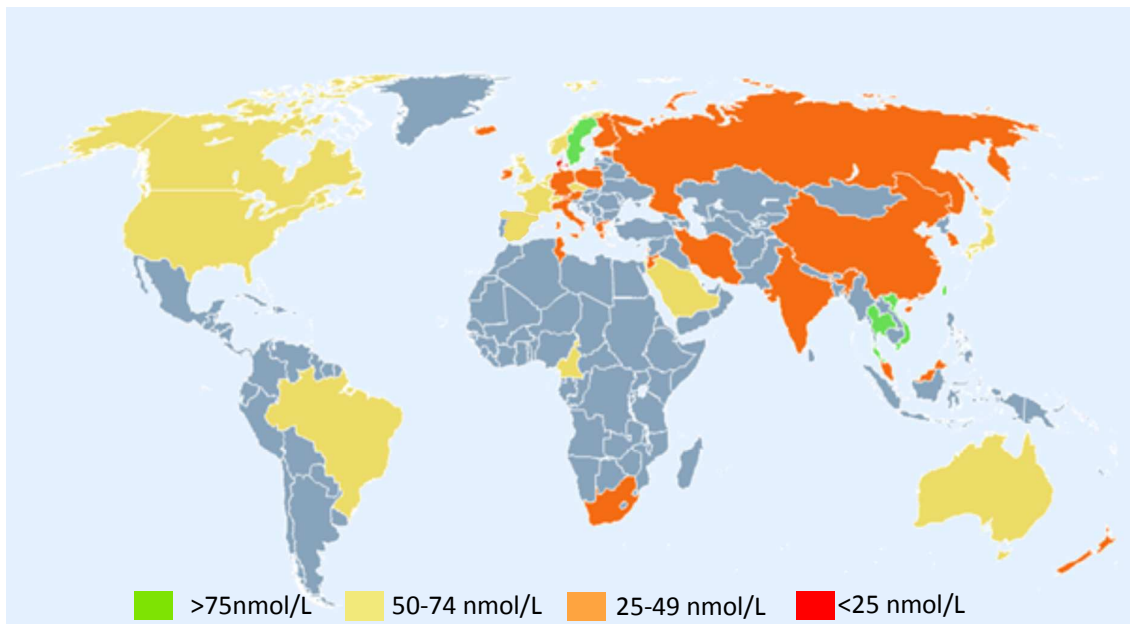
This analysis involves 200 studies from 46 countries. Forty two of the 200 studies (21%) were considered representative. Details of these studies for each contributing country are provided in Tables 1 (children and adolescents) and 2 (adults). The largest number of studies was conducted in Europe (48.0%), followed by North America (27%) and the Asia-Pacific region (16.5%). Of the 46 countries contributing data, 20 (43%) had at least one study that was classified as representative. Fig 1 and Fig 2 show the vitamin D status in children and adolescents, and adults, respectively, in different countries. The countries are colour-coded according to the serum levels of 25OHD reported in Table 1 (children and adolescents) and Table 2 (adults) and the ranges of 25OHD represented by each colour are described in the two figures.

Fig 1 Vitamin D status in children and adolescents (1-18 years) around the world



when available, winter values were used to calculate the mean 25OHD levels.

Fig 2 Vitamin D status in adults (> 18 years) around the world



when available, winter values were used to calculate the mean 25OHD levels.

Discussion

This project provides a 'snap shot' or summary of 25OHD levels around the globe, as identified in publications since the year 1990. The maps form a core or platform upon which additional information can and should be added. The number of published papers describing 25OHD levels is escalating and the geographic diversity of incoming data is broadening. As a result, we can anticipate having a more comprehensive picture of global vitamin D status in coming years. Updating of the accompanying tables, in which information from each country is ordered chronologically, will also allow for a qualitative assessment of secular trends in 25OHD since 1990, within regions and overall. We can expect to see rises in 25OHD levels as awareness and concern about vitamin D deficiency grows, and as recommendations for vitamin D supplementation appear in more and more government documents, position statements and clinical practice guidelines for bone health [19-21]. This trend would only be accelerated should vitamin D be proven to modify risk of non-musculoskeletal diseases, such as diabetes, infection, or cancer, as has been suggested by many observational studies [22].

Examination of the current maps enables one to identify regions where information on 25OHD levels is lacking. The most striking gap is in children and adolescents. The systematic search did not identify studies in this age range in Central America, northern and central regions of South America, most of Africa, much of Europe, and in Australia. This information gap needs attention in view of the importance of vitamin D in bone and muscle growth and development. In regions where data were available, the predominant colour code for children and adolescents was orange, indicating mean 25OHD levels in the 25 to 49 nmol/l range. These values are below those recommended by the Institute of Medicine (50 nmol/L) the International Osteoporosis Foundation and the US Endocrine Society (75 nmol/L) [19-21].

Among adults, most regions offer some data and their colour codes are approximately evenly split between orange (25 to 49 nmol/L) and yellow (50 to 74 nmol/L). Areas where information was not identified include Central America, South America (with the exception of Brazil), and much of Africa. With the known role of vitamin D in preserving bone health, it is important to fill these gaps so that appropriate measures can be implemented to correct inadequate 25OHD levels. Information gaps in both age groups would ideally be filled with survey data based on random sampling of a country or region. In the meantime, any and all data from specific regions will make some contribution to defining vitamin D status globally.

Despite using data from a systematic literature review, the maps have limitations. One limitation is that adequate information is not available. An extreme example is that for a few countries, one single small study confined to a limited region of the country and to a narrow age range was used to colour the country (e.g., Argentina). This is of course not a complete picture of the country. Other countries have many studies, representative and non-representative. For example, New Zealand is coloured orange based on the one available representative sample of subjects residing in the city of Auckland. As indicated in the table, other studies from this country involving healthy populations and subjects measured in summer consistently reported higher 25OHD levels in the range of yellow and green. In view of the diversity in quantity and quality of data used in this study, it is important that the tables be used in conjunction with the maps and that the maps are interpreted with caution.

Several limitations are inherent in the way that the published data were presented. For example, 25OHD measurements were sometimes made in specific seasons (i.e., winter or summer) and at other times made without reference to season. When the option was available, we used the winter measurement, representing the worst case scenario, for the map colouration; however 25OHD levels by season, when available, are provided in the table. There was inconsistency across studies in the age groupings, such that we were not always able to break out the levels by our predefined age categories of children and adolescents 1-18 years and adults >18 years. Another limitation is that some of the studies represented small regions within large countries with diverse latitudes; thus they did not fairly represent the whole

nation with respect to the contribution of sun exposure (skin synthesis) to 25OHD levels. Additionally, information on body size, clothing habits, and skin pigmentation was not consistently available.

An important limitation of this project and of any inter-study comparison of 25OHD levels is the well described variability in 25OHD assays. Since the first 25OHD assay was developed 30 years ago [23], the analytical options have expanded from the original competitive protein binding assay to include radioimmunoassay, chemiluminescent assay, high-performance liquid chromatography and liquid chromatography mass spectrometry/mass spectrometry. Unfortunately, serum 25OHD levels vary by up to 20 to 40%, depending upon which assay is used [24-27]. Part of the variability can be attributed to the fact that not all of the assays detect 25OHD₂ as effectively as they detect 25OHD₃. As a result, in those regions where vitamin D₂ is used in most supplements, total 25OHD levels will tend to be underestimated.

To address the assay problem, many laboratories around the world participate in a quarterly quality assurance and surveillance program, the Vitamin D External Quality Assessment Scheme (DEQAS) which we strongly encourage. Standard reference material consisting of known amounts of 25OHD₂ and 25OHD₃ in human serum is now available through the U.S. National Institute of Standards and Technology (NIST; SRM972; www.NIST.gov/srm). The use of this material should make inter-laboratory comparisons more readily interpreted and allow for the detection of intra-laboratory changes over time. An important initiative, the vitamin D standardization program (VDSP), is currently under way to make the measurement of 25OHD accurate and comparable over time, location and laboratory [28]. The first goal of VDSP is to standardize 25OHD values currently being measured in national health surveys to the NIST standards. Australia, Canada, Germany, Ireland, Mexico, South Korea, United Kingdom and the U.S. are participating in this process. A second goal is to design studies to cross-calibrate data from national surveys in which 25OHD measurements have already been completed. The longer range goal is to enable the use of standardized 25OHD values in individual research laboratories and in clinical care.

Conclusion

In conclusion, this study provides an overview of 25OHD status around the globe. It reveals large gaps in information in children and adolescents and smaller but important gaps in adults. In view of the importance of vitamin D to overall musculoskeletal health and of its potential importance in other tissues, we strongly encourage new research worldwide to define 25OHD status. Deficiency must first be identified before it can be appropriately addressed. Knowledge of specific data gaps may help to motivate regional policy makers and granting agencies to define the vitamin D status of their population as they decide how to allocate scarce research resources.

Acknowledgments

The authors would like to thank the invaluable advice from Professors Noriko Yoshimura, Edith Lau, Jean-Philippe Bonjour, Sunil Wimalawansa, Steven Boonen, Paul Lips and the late Philip Sambrook from the IOF Committee of Scientific Advisors; Professor Peter Weber, Doctors Angelika Friedel and Franz Roos from the DSM Nutrition Science & Advocacy for their intellectual input; and DSM for supporting the work through an unrestricted educational grant.

Disclosure

Drs Manfred Eggersdorfer and Elisabeth Stöcklin are employed by DSM Nutritional Products Ltd. Professor Cyrus Cooper has received honoraria and consulting fees from Amgen, Eli Lilly, Medtronic, Merck, Novartis and Servier. All the other authors have nothing to disclose.

Table 1 Country colour codes of vitamin D status in children and adolescents

Country	Refs	Representative	Age	Sex	N	25OHD (nmol/L)*	Season	Study colour code ^{&}	Country colour code ^{&}	Country colour code rationale
Argentina	[29]	No	8.5	M+F	42	24.5	Winter	RED	RED	Based on a single study
Austria	[30]	NA	4-19	M+F	1143	26.4 (+)	NA	ORANGE	ORANGE	Based on a single study
Canada	[31]	Yes	3-5	M+F	282	48.3	Mixed	ORANGE	ORANGE	Representative of a region/city of the country, population-based
	[32]	No	9-16	M F	878 867	45.9 45.9	Mixed	ORANGE ORANGE		
China	[33]	Yes	12-14	M	649	33.4	Winter	ORANGE	ORANGE	Representative of a region/city of the country, population-based
	[34]	NA	1-2	F F	131 119	42.3 25.5	Mixed	ORANGE ORANGE		
Denmark	[35]	No	12.5	F	59	24.4	Winter	RED	RED	Based on a single study
Finland	[36]	NA	11.4	F	64	39.9	Mixed	ORANGE	ORANGE	Based on a weighted average
	[35]	No	12.8	F	60	29.2	Winter	ORANGE		
Iceland	[37]	No	16-20	F	259	43.9	Winter	ORANGE	ORANGE	Based on a single study
India	[38]	No	11-14	M	64	40.8	Winter	ORANGE	ORANGE	Based on a single study
				F	75	46.8		ORANGE		
Iran	[39]	No	7-18	M	424	116.3	Winter	GREEN	YELLOW	Based on a weighted average of females [#]
				F	539	60.4		YELLOW		
	[40]	NA	11-15	F	414	74.9	Mixed	YELLOW		
	[41]	No	14-18	M F	153 165	93.2 41.9	Winter	GREEN ORANGE		
Ireland	[42]	NA	11-13	F	15	39.0	Winter	ORANGE	ORANGE	Based on a single study
Israel	[43]	Yes	0-20	M+F	195	57.3	Mixed	YELLOW	YELLOW	Representative of the entire country, population based
Jordan	[44]	NA	4-5	M+F	93	55.8	Mixed	YELLOW	YELLOW	Based on a single study
Mongolia	[45]	No	1-3	M+F	79	24.5 (+)	NA	RED	RED	Based on a single study
Netherlands	[46]	No	8-13	M+F	307	69.7	NA	YELLOW	YELLOW	Based on a single study
New Zealand	[47]	No	5-14	M+F	1585	50.0	Mixed	YELLOW	YELLOW	Based on a weighted average
	[48]	NA	1-2	M+F	193	52.0	Mixed	YELLOW		
	[49]	NA	1-2	M+F	233	53.3 (+)	Mixed	YELLOW		
Nigeria	[50]	NA	0.6-3.9	M+F	218	66.9	Mixed	YELLOW	YELLOW	Based on a single study
Poland	[35]	No	12.6	F	61	30.6	Winter	ORANGE	ORANGE	Based on a single study
UK	[51]	Yes	Childs	M+F	854	65.5	Mixed	YELLOW	YELLOW	Representative of the Entire country, population-based
	[52]	Yes	12, 15	M F	505 510	62.3 58.3	Mixed	YELLOW YELLOW		
	[53]	Yes	12-15	M+F	1015	64.3	Mixed	YELLOW		
USA	[54]	Yes	1-19	M+F	8541	66.8 (+)	Mixed	YELLOW	YELLOW	Representative of the entire country, population-based, and based on a weighted average
	[55]	Yes	1-11	M+F	4558	68	Mixed	YELLOW		
	[56]	Yes	12-19	M+F	3528	62.0	NA	YELLOW		
	[57]	Yes	6-21	M+F	382	69.9	Mixed	YELLOW		
	[58]	No	4-8	F	168	93.8	Mixed	GREEN		
	[59]	NA	9-11	F	22	74.4	Mixed	YELLOW		
	[60]	NA	7-18	M+F	735	66.2	NA	YELLOW		
	[61]	NA	4-8	F	76	88.2	Mixed	GREEN		
	[62]	NA	12-18	F	370	53.7	Mixed	YELLOW		

(M) Males; (F) Females; (M+F) Combined data for males and females; (NA) No information available.

*Published 25OHD means (or medians if means not available) are presented with the exception of studies marked with a (+). For these studies, the 25OHD level is a mean weighted for sample size. If weighted means couldn't be calculated, a simple mean was taken.

& Colour codes: RED, < 25nmol/L; ORANGE 25-49nmol/L; YELLOW 50-74nmol/L; GREEN ≥75nmol/L

Male data from references 38 and 40 were considered outliers and were excluded from the weighted mean 25OHD levels.

Table 2 Country colour codes of vitamin D status in adults.

Country	Refs	Representative	Age	Sex	N	25OHD (nmol/L)*	Season	Study colour code ^a	Country colour code ^a	Country colour code rationale
Australia	[63]	No	60+	M	437	70.2 (+)	NA	YELLOW	YELLOW	Based on a weighted average
	[64]	No	20-92	F	861	70.3	Mixed	YELLOW		
	[65]	No	51-77	M+F	253	72.2	NA	YELLOW		
	[66]	NA	51-79	M+F	880	52.8	NA	YELLOW		
	[67]	No	78	M+F	70	33	NA	ORANGE		
Austria	[30]	NA	65-85	M+F	78	9.5	NA	RED	ORANGE	Based on a weighted average
	[68]	No	21-76	M+F	1089	52.2	Winter	YELLOW		
Belgium	[69]	No	70-90	F	245	56.4	NA	YELLOW	YELLOW	Based on a weighted average
	[70]	No	70-87	F	129	43.2	NA	ORANGE		
	[71]	NA	20+	M	270	71.5	NA	YELLOW		
					272	73.5		YELLOW		
	[72]	No	21-65	M+F	126	48.2	Winter	ORANGE		
	[73]	No	40-60	M+F	401	35.0	NA	ORANGE		
Brazil	[74]	Yes	65+	M+F	250	52.4	Mixed	YELLOW	YELLOW	Representative of the entire country, population-based
Cameroon	[75]	No	60-86	M+F	152	52.7	NA	YELLOW	YELLOW	Based on a single study
Canada	[76]	Yes	20-79	M+F	3458	67.7 (+)	Mixed	YELLOW	YELLOW	Representative of the entire country, population-based
	[77]	No	27-89	M+F	188	57.3	Winter	YELLOW		
	[78]	No	68-82	M+F	195	66.7	Mixed	YELLOW		
	[79]	No	46.8	F	741	64.9	Winter	YELLOW		
China	[80]	NA	40-70	M+F	2018	31.7	Mixed	ORANGE	ORANGE	Based on a weighted average
	[81]	NA	40-65	M+F	720	33.1	Mixed	ORANGE		
	[82]	No	19-40	F	16	43.9	NA	ORANGE		
Czech Republic	[83]	No	62.3	F	47	58.2	NA	YELLOW	YELLOW	Based on a single study
Denmark	[84]	Yes	35-65	M+F	125	25.5	Mixed	ORANGE	ORANGE	Representative of a region/city of the country, population-based
	[85]	NA	50-82	F	315	57.0	NA	YELLOW		
	[86]	NA	17-87	F	2316	62.0	Mixed	YELLOW		
	[87]	No	45-58	F	510	24.0	NA	RED		
	[35]	No	71.6	F	53	47.8	Winter	ORANGE		
	[88]	No	20-29	M	700	64.9	Mixed	YELLOW		
	[89]	NA	70-74	M+F	669	47.6	Mixed	ORANGE		
Estonia	[90]	Yes	25-70	M+F	367	43.7	Winter	ORANGE	ORANGE	Representative of a region/city of the country, population-based
Fidji Islands	[91]	NA	15-44	F	511	76.0	Winter	GREEN	GREEN	Based on a single study
Finland	[92]	Yes	30+	M+F	6937	42.9	NA	ORANGE	ORANGE	Representative of the entire country, population-based, and based on a weighted average
	[93]	Yes	30+	M+F	6219	43.4	Mixed	ORANGE		
	[94]	No	30-97	M	2736	45.1	NA	ORANGE		
					3299	45.2		ORANGE		
	[95]	No	30+	M+F	6241	45.1	Mixed	ORANGE		
	[96]	NA	40-69	M+F	4097	43.6	Mixed	ORANGE		
	[97]	NA	31-43	M	126	45.0	Mixed	ORANGE		
					202	47.0		ORANGE		
[98]	NA	20-64	M	138	34.0	Mixed	ORANGE			
				358	35.0		ORANGE			
France	[99]	NA	35-65	M+F	1569	61.0	Winter	YELLOW	YELLOW	Based on a weighted average
	[100]	NA	35-65	M+F	1191	79.5	Winter	GREEN		
	[101]	No	18-62	M	70	80.9 (+)	Mixed	GREEN		
					94	71.5 (+)		YELLOW		
	[102]	No	18-76	F	248	64.1	NA	YELLOW		
Gambia	[103]	No	25+	F	112	91.3 (+)	NA	GREEN	GREEN	Based on a single study
Germany	[104]	Yes	18-79	M	1763	45.2	NA	ORANGE	ORANGE	Representative of the entire country,
				F	2267	44.7		ORANGE		

	[148]	No	55.6 67.5	M F	50 50	91.0 67.0	NA	GREEN YELLOW			
	[149]	NA	46-89	F	116	54.0	NA	YELLOW			
	[150]	No	18+	M+F	273	51.0	Mixed	YELLOW			
Norway	[151]	NA	38-61	M+F	32	67.2	NA	YELLOW	YELLOW	Based on a weighted average	
	[152]	No	44-59	F	300	56.9	Mixed	YELLOW			
	[153]	No	45-60	M F	302 278	74.1 75.9	Mixed	YELLOW GREEN			
	[154]	No	45-75	M+F	869	74.8	Mixed	YELLOW			
	[155]	NA	25-74	M+F	6932	58.9	NA	YELLOW			
	[156]	No	25-84	M+F	2668	55.3	NA	YELLOW			
Poland	[157]	Yes	60-90	F	274	33.5	Winter	ORANGE	ORANGE	Representative of the entire country, population-based	
	[35]	No	71.6	F	65	32.5	Winter	ORANGE			
Russia	[158]	No	45-79	F	122	29.1	NA	ORANGE	ORANGE	Based on a single study	
Saudi Arabia	[159]	No	20-45	F	1557	66.0	Mixed	YELLOW	YELLOW	Based on a single study and on a weighted average	
			62.4	F	568	55.7		YELLOW			
South Africa	[160]	No	65-92	M+F	173	37.0	NA	ORANGE	ORANGE	Based on a single study	
Spain	[161]	Yes	15-70	M	126	52.7	Mixed	YELLOW	YELLOW	Representative of a region/city of the country, population-based	
	[162]	No	65-93	F	127	49.9	Winter	ORANGE			
	[163]	No	35	M+F	237	42.9		Mixed			ORANGE
					M	227	23.4				RED
				F	164	21.3		RED			
Sweden	[164]	No	75-76	F	986	95.0	Mixed	GREEN	GREEN	Based on a weighted average	
	[165]	No	72.9	F	350	91.0	Mixed	GREEN			
	[166]	No	56-67	M	34	90.0	NA	GREEN			
	[167]	NA	61-86	F	116	69.0	Winter	YELLOW			
	[168]	No	61-83	F	100	72.0	Winter	YELLOW			
	[169]	NA	71	M	1194	68.7	NA	YELLOW			
	[170]	NA	71	M	958	69.0	NA	YELLOW			
	[171]	No	79-95	M F	23 81	70.0 65.0	Mixed	YELLOW YELLOW			
Switzerland	[172]	Yes	25-74	M+F	3276	50.0	Mixed	YELLOW	YELLOW	Representative of the entire country, population-based	
	[173]	No	66-95 62-86	M F	203 109	91.7 67.5	Mixed	GREEN YELLOW			
Taiwan	[174]	No	40-72	W	262	76.5	Mixed	GREEN	GREEN	Based on a single study	
Thailand	[175]	Yes	20-84	M	126	133.5	NA	GREEN	GREEN	Representative of a region/city of the country, population-based	
	[176]	NA	20-80	F M	125 108	102.7 126.9	NA	GREEN GREEN			
	[177]	NA	60-92	F	121	92.8		Mixed			GREEN
	[178]	NA	60-97	F	106 446	83.3 67.6	NA				GREEN YELLOW
Tunisia	[179](e)	No	20-60	F	261	40.3	Mixed	ORANGE	ORANGE	Based on a single study	
United Kingdom	[180]	Yes	65+	M	322	56.2	Mixed	YELLOW	YELLOW	Representative of the entire country, population-based	
	[181]	Yes	65+	F	320	48.4	Mixed	ORANGE			
				M	950	53.0		YELLOW			
	[182]	No	65+	M+F	1120	48.0	NA	ORANGE			
	[183]	No	18-45	M+F	32	49.5	NA	ORANGE			
	[184]	NA	40-69	M+F	524	25.5	NA	ORANGE			
	[185]	No	40-65	M	524	60.2	NA	YELLOW			
					F	458	56.4 (+)	NA			YELLOW
					F	599	50.1 (+)				YELLOW
	[186]	NA	65-75	M+F	96	23.1	Winter	RED			
	[187]	No	65+	M+F	924	49.7 (+)	Mixed	ORANGE			
[188]	No	45-54	F	3133	54.0	Mixed	YELLOW				
[189]	No	61.7	F	325	53.3	Mixed	YELLOW				
[187] (d)	No	65+	M+F	924	43.5	Mixed	ORANGE				
USA	[190]	Yes	20+	M	3184	70.4 (+)	Winter	YELLOW	YELLOW	Representative of the entire country, population-based, and based on a weighted average of these studies	
				F	3383	62.4 (+)		YELLOW			
	[54]	Yes	20+	M+F	11009	59.6 (+)	Winter	YELLOW			
	[191]	Yes	20+	M+F	1654	62.4	NA	YELLOW			
	[192]	Yes	20+	M+F	15068	73.7	Mixed	YELLOW			
	[11]	Yes	20+	M+F	9961	62.6	Mixed	YELLOW			
	[193]	Yes	20-49	M	3474	68.0	Mixed	YELLOW			

			50+	M	1912	69.0		YELLOW		
			20-49	F	3947	60.0		YELLOW		
			50+	F	1869	61.0		YELLOW		
	[194]	Yes	20+	M+F	8421	74.0	Mixed	YELLOW		
	[195]	Yes	20+	M+F	948	65.1	Mixed	YELLOW		
	[196]	Yes	20+	M	6097	78.0	Mixed	GREEN		
				F	6547	73.0		YELLOW		
	[197]	Yes	40+	M	1273	54.2	NA	YELLOW		
	[198]	No	65+	M+F	1917	71.9	Mixed	YELLOW		
	[199]	No	35+	M+F	3890	93.0	Mixed	GREEN		
	[200]	NA	67-95	M	290	82.0	NA	GREEN		
				F	469	69.8		YELLOW		
	[201]	No	59.6	M+F	808	47.4	Mixed	ORANGE		
	[202]	No	35-89	M	843	49.0	Mixed	ORANGE		
				F	919	49.2		ORANGE		
	[203]	No	67-90	M+F	341	72.0	NA	YELLOW		
	[204]	No	69-90	M+F	328	75.0	NA	GREEN		
	[205]	NA	80-89	M+F	68	75.1	Mixed	GREEN		
	[206]	No	20+	M+F	8351	61.0	NA	YELLOW		
	[207]	No	20+	F	1881	54.0	NA	YELLOW		
	[208]	No	20+	M+F	4495	49.75	NA	ORANGE		
	[209]	No	17+	M+F	-	67.4	Mixed	YELLOW		
	[210]	No	20+	M	6950	78.0	Mixed	GREEN		
				F	7729	71.6		YELLOW		
	[211]	No	65+	M+F	3408	66.0	Mixed	YELLOW		
	[212]	No	18+	M+F	16603	74.0	Mixed	YELLOW		
	[213]	No	20+	M+F	15088	75.0	Mixed	GREEN		
	[214]	No	20+	M	2939	78.8	Mixed	GREEN		
				F	3289	72.6		YELLOW		
	[215]	No	18+	M	7286	78.7	Mixed	GREEN		
				F	8104	71.1		YELLOW		
	[216]	No	55-96	M+F	654	103.7	Mixed	GREEN		
	[217]	No	74	M+F	1073	105.0	Mixed	GREEN		
	[218]	NA	50-97	M+F	615	102.0	Mixed	GREEN		
	[219]	NA	65-87	M	182	82.4	Mixed	GREEN		
				F	209	68.9		YELLOW		
	[220]	No	82.4	M+F	77	113.1	NA	GREEN		
	[221]	No	57-89	F	136	52.8	Mixed	YELLOW		
	[222]	No	55+	F	1179	71.8	Mixed	YELLOW		
	[223]	No	20-30	F	20	75.0	NA	GREEN		
			55+	F	20	85.0		GREEN		
	[224]	NA	20-88	M+F	198	70.9	Mixed	YELLOW		
	[225]	No	20-80	F	410	54.2	Mixed	YELLOW		
	[226]	NA	21-54	F	138	77.6	NA	GREEN		
	[227]	No	64-92	M	142	67.5	NA	YELLOW		
			64-93	F	195	57.7		YELLOW		
	[228]	No	18-68	F	50	55.7	Mixed	YELLOW		
	[229]	NA	35-46	F	182	72.3	NA	YELLOW		
Vietnam	[230]	Yes	18-87	M	205	92.0	Mixed	GREEN	GREEN	Population-based data for a region/city of the country
				F	432	75.3		GREEN		

(M) males; (F) females; (M+F) combined data for males and females; (NA) No information available.

*Published 25OHD means (or medians if means not available) are presented with the exception of studies marked with a (+). For these studies, the 25OHD level is a mean weighted for sample size. If weighted mean couldn't be calculated, a simple mean was taken.

& Colour code: RED, < 25nmol/L; ORANGE 25-49nmol/L; YELLOW 50-74nmol/L; GREEN ≥75nmol/L

(a) A previous study of the same cohort [231] reported median 25OHD levels of 20.6 nmol/L. This does not affect the colour of the overall country.

(b) Unknown number per gender – overall study population is 976.

(c) Unknown number – subset of 1311 people measured in winter

(d) Unknown number – the entire cohort for the 4 regions in the UK represented 924 individuals.

(e) Mean 25OHD was not stated in the publication but it was calculated using the information provided.

References

1. Mithal A, Wahl DA, Bonjour JP, Burckhardt P, Dawson-Hughes B, Eisman JA, El-Hajj Fuleihan G, Josse RG, Lips P, Morales-Torres J (2009) Global vitamin D status and determinants of hypovitaminosis D. *Osteoporos Int* 20:1807-1820
2. Lips P (2001) Vitamin D deficiency and secondary hyperparathyroidism in the elderly: consequences for bone loss and fractures and therapeutic implications. *Endocr Rev* 22:477-501
3. Lips P (2010) Worldwide status of vitamin D nutrition. *J Steroid Biochem Mol Biol* 121:297-300
4. McKenna MJ (1992) Differences in vitamin D status between countries in young adults and the elderly. *Am J Med* 93:69-77
5. Prentice A (2008) Vitamin D deficiency: a global perspective. *Nutr Rev* 66:S153-164
6. van Schoor NM, Lips P (2011) Worldwide vitamin D status. *Best Pract Res Clin Endocrinol Metab* 25:671-680
7. Heaney RP, Dowell MS, Hale CA, Bendich A (2003) Calcium absorption varies within the reference range for serum 25-hydroxyvitamin D. *J Am Coll Nutr* 22:142-146
8. Steingrimsdottir L, Gunnarsson O, Indridason OS, Franzson L, Sigurdsson G (2005) Relationship between serum parathyroid hormone levels, vitamin D sufficiency, and calcium intake. *JAMA* 294:2336-2341
9. Dawson-Hughes B, Dallal GE, Krall EA, Harris S, Sokoll LJ, Falconer G (1991) Effect of vitamin D supplementation on wintertime and overall bone loss in healthy postmenopausal women. *Ann Intern Med* 115:505-512
10. Ooms ME, Roos JC, Bezemer PD, van der Vijgh WJ, Bouter LM, Lips P (1995) Prevention of bone loss by vitamin D supplementation in elderly women: a randomized double-blind trial. *J Clin Endocrinol Metab* 80:1052-1058
11. Bischoff-Ferrari HA, Kiel DP, Dawson-Hughes B, Orav JE, Li R, Spiegelman D, Dietrich T, Willett WC (2009) Dietary calcium and serum 25-hydroxyvitamin D status in relation to BMD among U.S. adults. *J Bone Miner Res* 24:935-942
12. Gorham ED, Garland CF, Garland FC, Grant WB, Mohr SB, Lipkin M, Newmark HL, Giovannucci E, Wei M, Holick MF (2005) Vitamin D and prevention of colorectal cancer. *J Steroid Biochem Mol Biol* 97:179-194
13. Pittas AG, Harris SS, Stark PC, Dawson-Hughes B (2007) The effects of calcium and vitamin D supplementation on blood glucose and markers of inflammation in nondiabetic adults. *Diabetes Care* 30:980-986
14. Urashima M, Segawa T, Okazaki M, Kurihara M, Wada Y, Ida H (2010) Randomized trial of vitamin D supplementation to prevent seasonal influenza A in schoolchildren. *Am J Clin Nutr* 91:1255-1260
15. Bischoff-Ferrari HA, Willett WC, Orav EJ, et al. (2012) A pooled analysis of vitamin D dose requirements for fracture prevention. *N Engl J Med* 367:40-49
16. Bischoff-Ferrari HA, Willett WC, Orav JE, Kiel DP, Dawson-Hughes B (2011) Fall prevention with vitamin D. *BMJ* 342:d2608
17. Moher D, Liberati A, Tetzlaff J, Altman DG (2009) Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. *PLoS Med* 6:e1000097
18. Hilger J, Friedel A, Herr R, Ruasch T, Roos F, Wahl DA, Pierroz DD, Weber P, Hoffmann K (2012) A systematic review of vitamin D status in populations worldwide. *British J of Nutrition* submitted
19. (2011) Dietary reference intakes for calcium and vitamin D. The National Academies Press, Washington, DC
20. Dawson-Hughes B, Mithal A, Bonjour JP, Boonen S, Burckhardt P, Fuleihan GE, Josse RG, Lips P, Morales-Torres J, Yoshimura N (2010) IOF position statement: vitamin D recommendations for older adults. *Osteoporos Int* 21:1151-1154

21. Holick MF, Binkley NC, Bischoff-Ferrari HA, Gordon CM, Hanley DA, Heaney RP, Murad MH, Weaver CM (2011) Evaluation, treatment, and prevention of vitamin D deficiency: an Endocrine Society clinical practice guideline. *J Clin Endocrinol Metab* 96:1911-1930
22. Rosen CJ, Adams JS, Bikle DD, Black DM, Demay MB, Manson JE, Murad MH, Kovacs CS (2012) The nonskeletal effects of vitamin d: an endocrine society scientific statement. *Endocr Rev* 33:456-492
23. Haddad JG, Chyu KJ (1971) Competitive protein-binding radioassay for 25-hydroxycholecalciferol. *J Clin Endocrinol Metab* 33:992-995
24. Binkley N, Krueger D, Cowgill CS, Plum L, Lake E, Hansen KE, DeLuca HF, Drezner MK (2004) Assay variation confounds the diagnosis of hypovitaminosis D: a call for standardization. *J Clin Endocrinol Metab* 89:3152-3157
25. Binkley N, Krueger D, Gemar D, Drezner MK (2008) Correlation among 25-hydroxy-vitamin D assays. *J Clin Endocrinol Metab* 93:1804-1808
26. Hypponen E, Boucher BJ, Berry DJ, Power C (2008) 25-hydroxyvitamin D, IGF-1, and metabolic syndrome at 45 years of age: a cross-sectional study in the 1958 British Birth Cohort. *Diabetes* 57:298-305
27. Stepman HC, Vanderroost A, Van Uytendange K, Thienpont LM (2011) Candidate reference measurement procedures for serum 25-hydroxyvitamin D3 and 25-hydroxyvitamin D2 by using isotope-dilution liquid chromatography-tandem mass spectrometry. *Clin Chem* 57:441-448
28. Sempos CT, Vesper HW, Phinney KW, Thienpont LM, Coates PM (2012) Vitamin D status as an international issue: national surveys and the problem of standardization. *Scand J Clin Lab Invest Suppl* 243:32-40
29. Oliveri MB, Ladizesky M, Mautalen CA, Alonso A, Martinez L (1993) Seasonal variations of 25 hydroxyvitamin D and parathyroid hormone in Ushuaia (Argentina), the southernmost city of the world. *Bone Miner* 20:99-108
30. Koenig J, Elmadfa I (2000) Status of calcium and vitamin D of different population groups in Austria. *Int J Vitam Nutr Res* 70:214-220
31. El Hayek J, Egeland G, Weiler H (2010) Vitamin D status of Inuit preschoolers reflects season and vitamin D intake. *J Nutr* 140:1839-1845
32. Delvin EE, Lambert M, Levy E, O'Loughlin J, Mark S, Gray-Donald K, Paradis G (2010) Vitamin D status is modestly associated with glycemia and indicators of lipid metabolism in French-Canadian children and adolescents. *J Nutr* 140:987-991
33. Du X, Greenfield H, Fraser DR, Ge K, Trube A, Wang Y (2001) Vitamin D deficiency and associated factors in adolescent girls in Beijing. *Am J Clin Nutr* 74:494-500
34. Strand MA, Perry J, Zhao J, Fischer PR, Yang J, Li S (2009) Severe vitamin D-deficiency and the health of North China children. *Matern Child Health J* 13:144-150
35. Andersen R, Molgaard C, Skovgaard LT, et al. (2005) Teenage girls and elderly women living in northern Europe have low winter vitamin D status. *Eur J Clin Nutr* 59:533-541
36. Viljakainen HT, Palssa A, Karkkainen M, Jakobsen J, Cashman KD, Molgaard C, Lamberg-Allardt C (2006) A seasonal variation of calcitropic hormones, bone turnover and bone mineral density in early and mid-puberty girls - a cross-sectional study. *Br J Nutr* 96:124-130
37. Kristinsson JO, Valdimarsson O, Sigurdsson G, Franzson L, Olafsson I, Steingrimsdottir L (1998) Serum 25-hydroxyvitamin D levels and bone mineral density in 16-20 years-old girls: lack of association. *J Intern Med* 243:381-388
38. Harinarayan CV, Ramalakshmi T, Prasad UV, Sudhakar D (2008) Vitamin D status in Andhra Pradesh : a population based study. *Indian J Med Res* 127:211-218
39. Rabbani A, Alavian SM, Motlagh ME, Ashtiani MT, Ardalan G, Salavati A, Rabbani B, Shams S, Parvaneh N (2009) Vitamin D insufficiency among children and adolescents living in Tehran, Iran. *J Trop Pediatr* 55:189-191
40. Dahifar H, Faraji A, Yassobi S, Ghorbani A (2007) Asymptomatic rickets in adolescent girls. *Indian J Pediatr* 74:571-575
41. Moussavi M, Heidarpour R, Aminorroaya A, Pournaghshband Z, Amini M (2005) Prevalence of vitamin D deficiency in Isfahani high school students in 2004. *Horm Res* 64:144-148

42. McCarthy D, Collins A, O'Brien M, Lamberg-Allardt C, Jakobsen J, Charzewska J, Kiely M, Flynn A, Cashman KD (2006) Vitamin D intake and status in Irish elderly women and adolescent girls. *Ir J Med Sci* 175:14-20
43. Oren Y, Shapira Y, Agmon-Levin N, Kivity S, Zafrir Y, Altman A, Lerner A, Shoenfeld Y (2010) Vitamin D insufficiency in a sunny environment: a demographic and seasonal analysis. *Isr Med Assoc J* 12:751-756
44. Gharaibeh MA, Stoecker BJ (2009) Assessment of serum 25(OH)D concentration in women of childbearing age and their preschool children in Northern Jordan during summer. *Eur J Clin Nutr* 63:1320-1326
45. Lander RL, Enkhjargal T, Batjargal J, Bailey KB, Diouf S, Green TJ, Skeaff CM, Gibson RS (2008) Multiple micronutrient deficiencies persist during early childhood in Mongolia. *Asia Pac J Clin Nutr* 17:429-440
46. van Summeren MJ, van Coeverden SC, Schurgers LJ, Braam LA, Noirt F, Uiterwaal CS, Kuis W, Vermeer C (2008) Vitamin K status is associated with childhood bone mineral content. *Br J Nutr* 100:852-858
47. Rockell JE, Green TJ, Skeaff CM, et al. (2005) Season and ethnicity are determinants of serum 25-hydroxyvitamin D concentrations in New Zealand children aged 5-14 y. *J Nutr* 135:2602-2608
48. Houghton LA, Szymlek-Gay EA, Gray AR, Ferguson EL, Deng X, Heath AL (2010) Predictors of vitamin D status and its association with parathyroid hormone in young New Zealand children. *Am J Clin Nutr* 92:69-76
49. Grant CC, Wall CR, Crengle S, Scragg R (2009) Vitamin D deficiency in early childhood: prevalent in the sunny South Pacific. *Public Health Nutr* 12:1893-1901
50. Pfitzner MA, Thacher TD, Pettifor JM, Zoakah AI, Lawson JO, Isichei CO, Fischer PR (1998) Absence of vitamin D deficiency in young Nigerian children. *J Pediatr* 133:740-744
51. Davies PS, Bates CJ, Cole TJ, Prentice A, Clarke PC (1999) Vitamin D: seasonal and regional differences in preschool children in Great Britain. *Eur J Clin Nutr* 53:195-198
52. Cashman KD, Hill TR, Cotter AA, et al. (2008) Low vitamin D status adversely affects bone health parameters in adolescents. *Am J Clin Nutr* 87:1039-1044
53. Hill TR, Cotter AA, Mitchell S, et al. (2008) Vitamin D status and its determinants in adolescents from the Northern Ireland Young Hearts 2000 cohort. *Br J Nutr* 99:1061-1067
54. Looker AC, Pfeiffer CM, Lacher DA, Schleicher RL, Picciano MF, Yetley EA (2008) Serum 25-hydroxyvitamin D status of the US population: 1988-1994 compared with 2000-2004. *Am J Clin Nutr* 88:1519-1527
55. Mansbach JM, Ginde AA, Camargo CA, Jr. (2009) Serum 25-hydroxyvitamin D levels among US children aged 1 to 11 years: do children need more vitamin D? *Pediatrics* 124:1404-1410
56. Reis JP, von Muhlen D, Miller ER, 3rd, Michos ED, Appel LJ (2009) Vitamin D status and cardiometabolic risk factors in the United States adolescent population. *Pediatrics* 124:e371-379
57. Weng FL, Shults J, Leonard MB, Stallings VA, Zemel BS (2007) Risk factors for low serum 25-hydroxyvitamin D concentrations in otherwise healthy children and adolescents. *Am J Clin Nutr* 86:150-158
58. Stein EM, Laing EM, Hall DB, Hausman DB, Kimlin MG, Johnson MA, Modlesky CM, Wilson AR, Lewis RD (2006) Serum 25-hydroxyvitamin D concentrations in girls aged 4-8 y living in the southeastern United States. *Am J Clin Nutr* 83:75-81
59. Sullivan SS, Rosen CJ, Halteman WA, Chen TC, Holick MF (2005) Adolescent girls in Maine are at risk for vitamin D insufficiency. *J Am Diet Assoc* 105:971-974
60. Hill KM, McCabe GP, McCabe LD, Gordon CM, Abrams SA, Weaver CM (2010) An inflection point of serum 25-hydroxyvitamin D for maximal suppression of parathyroid hormone is not evident from multi-site pooled data in children and adolescents. *J Nutr* 140:1983-1988
61. Breen ME, Laing EM, Hall DB, et al. (2011) 25-hydroxyvitamin D, insulin-like growth factor-I, and bone mineral accrual during growth. *J Clin Endocrinol Metab* 96:E89-98
62. Harkness LS, Cromer BA (2005) Vitamin D deficiency in adolescent females. *J Adolesc Health* 37:75e71-75e75
63. Center JR, Nguyen TV, Sambrook PN, Eisman JA (1999) Hormonal and biochemical parameters in the determination of osteoporosis in elderly men. *J Clin Endocrinol Metab* 84:3626-3635

64. Pasco JA, Henry MJ, Nicholson GC, Sanders KM, Kotowicz MA (2001) Vitamin D status of women in the Geelong Osteoporosis Study: association with diet and casual exposure to sunlight. *Med J Aust* 175:401-405
65. Ngo DT, Sverdlov AL, McNeil JJ, Horowitz JD (2010) Does vitamin D modulate asymmetric dimethylarginine and C-reactive protein concentrations? *Am J Med* 123:335-341
66. Ding C, Cicuttini F, Parameswaran V, Burgess J, Quinn S, Jones G (2009) Serum levels of vitamin D, sunlight exposure, and knee cartilage loss in older adults: the Tasmanian older adult cohort study. *Arthritis Rheum* 60:1381-1389
67. Brock K, Wilkinson M, Cook R, Lee S, Bermingham M (2004) Associations with Vitamin D deficiency in "at risk" Australians. *J Steroid Biochem Mol Biol* 89-90:581-588
68. Kudlacek S, Schneider B, Peterlik M, Leb G, Klaushofer K, Weber K, Woloszczuk W, Willvonseder R (2003) Assessment of vitamin D and calcium status in healthy adult Austrians. *Eur J Clin Invest* 33:323-331
69. Boonen S, Lesaffre E, Aerssens J, Pelemans W, Dequeker J, Bouillon R (1996) Deficiency of the growth hormone-insulin-like growth factor-I axis potentially involved in age-related alterations in body composition. *Gerontology* 42:330-338
70. Boonen S, Cheng XG, Nijs J, Nicholson PH, Verbeke G, Lesaffre E, Aerssens J, Dequeker J (1997) Factors associated with cortical and trabecular bone loss as quantified by peripheral computed tomography (pQCT) at the ultradistal radius in aging women. *Calcif Tissue Int* 60:164-170
71. Richart T, Thijs L, Nawrot T, Yu J, Kuznetsova T, Balkestein EJ, Struijker-Boudier HA, Staessen JA (2011) The metabolic syndrome and carotid intima-media thickness in relation to the parathyroid hormone to 25-OH-D(3) ratio in a general population. *Am J Hypertens* 24:102-109
72. MacFarlane GD, Sackrison JL, Jr., Body JJ, Ersfeld DL, Fenske JS, Miller AB (2004) Hypovitaminosis D in a normal, apparently healthy urban European population. *J Steroid Biochem Mol Biol* 89-90:621-622
73. Moreno-Reyes R, Carpentier YA, Boelaert M, El Mounni K, Dufourny G, Bazelmans C, Leveque A, Gervy C, Goldman S (2009) Vitamin D deficiency and hyperparathyroidism in relation to ethnicity: a cross-sectional survey in healthy adults. *Eur J Nutr* 48:31-37
74. Saraiva GL, Cendoroglo MS, Ramos LR, Araujo LM, Vieira JG, Kunii I, Hayashi LF, Correa MP, Lazaretti-Castro M (2005) Influence of ultraviolet radiation on the production of 25 hydroxyvitamin D in the elderly population in the city of Sao Paulo (23 degrees 34'S), Brazil. *Osteoporos Int* 16:1649-1654
75. Njemini R, Meyers I, Demanet C, Smits J, Sosso M, Mets T (2002) The prevalence of autoantibodies in an elderly sub-Saharan African population. *Clin Exp Immunol* 127:99-106
76. Langlois K, Greene-Finestone L, Little J, Hidiroglou N, Whiting S (2010) Vitamin D status of Canadians as measured in the 2007 to 2009 Canadian Health Measures Survey. *Health Rep* 21:47-55
77. Rucker D, Allan JA, Fick GH, Hanley DA (2002) Vitamin D insufficiency in a population of healthy western Canadians. *CMAJ* 166:1517-1524
78. Barake R, Weiler H, Payette H, Gray-Donald K (2010) Vitamin D supplement consumption is required to achieve a minimal target 25-hydroxyvitamin D concentration of > or = 75 nmol/L in older people. *J Nutr* 140:551-556
79. Sinotte M, Diorio C, Berube S, Pollak M, Brisson J (2009) Genetic polymorphisms of the vitamin D binding protein and plasma concentrations of 25-hydroxyvitamin D in premenopausal women. *Am J Clin Nutr* 89:634-640
80. Chen W, Dawsey SM, Qiao YL, Mark SD, Dong ZW, Taylor PR, Zhao P, Abnet CC (2007) Prospective study of serum 25(OH)-vitamin D concentration and risk of oesophageal and gastric cancers. *Br J Cancer* 97:123-128
81. Abnet CC, Chen W, Dawsey SM, Wei WQ, Roth MJ, Liu B, Lu N, Taylor PR, Qiao YL (2007) Serum 25(OH)-vitamin D concentration and risk of esophageal squamous dysplasia. *Cancer Epidemiol Biomarkers Prev* 16:1889-1893
82. Chan EL, Lau E, Shek CC, MacDonald D, Woo J, Leung PC, Swaminathan R (1992) Age-related changes in bone density, serum parathyroid hormone, calcium absorption and other indices of bone metabolism in Chinese women. *Clin Endocrinol (Oxf)* 36:375-381
83. Zofkova I, Hill M (2008) Biochemical markers of bone remodeling correlate negatively with circulating TSH in postmenopausal women. *Endocr Regul* 42:121-127

84. Rudnicki M, Thode J, Jorgensen T, Heitmann BL, Sorensen OH (1993) Effects of age, sex, season and diet on serum ionized calcium, parathyroid hormone and vitamin D in a random population. *J Intern Med* 234:195-200
85. Rejnmark L, Vestergaard P, Heickendorff L, Mosekilde L (2008) Plasma 1,25(OH)₂D levels decrease in postmenopausal women with hypovitaminosis D. *Eur J Endocrinol* 158:571-576
86. Rejnmark L, Vestergaard P, Heickendorff L, Mosekilde L (2011) Determinants of plasma PTH and their implication for defining a reference interval. *Clin Endocrinol (Oxf)* 74:37-43
87. Brot C, Jorgensen N, Madsen OR, Jensen LB, Sorensen OH (1999) Relationships between bone mineral density, serum vitamin D metabolites and calcium:phosphorus intake in healthy perimenopausal women. *J Intern Med* 245:509-516
88. Frost M, Abrahamsen B, Nielsen TL, Hagen C, Andersen M, Brixen K (2010) Vitamin D status and PTH in young men: a cross-sectional study on associations with bone mineral density, body composition and glucose metabolism. *Clin Endocrinol (Oxf)* 73:573-580
89. Dalgard C, Petersen MS, Schmedes AV, Brandslund I, Weihe P, Grandjean P (2010) High latitude and marine diet: vitamin D status in elderly Faroese. *Br J Nutr* 104:914-918
90. Kull M, Jr., Kallikorm R, Tamm A, Lember M (2009) Seasonal variance of 25-(OH) vitamin D in the general population of Estonia, a Northern European country. *BMC Public Health* 9:22
91. Heere C, Skeaff CM, Waqatakirewa L, Vatucawaqa P, Khan AN, Green TJ (2010) Serum 25-hydroxyvitamin D concentration of Indigenous-Fijian and Fijian-Indian women. *Asia Pac J Clin Nutr* 19:43-48
92. Kilkinen A, Knekt P, Heliovaara M, Rissanen H, Marniemi J, Hakulinen T, Aromaa A (2008) Vitamin D status and the risk of lung cancer: a cohort study in Finland. *Cancer Epidemiol Biomarkers Prev* 17:3274-3278
93. Kilkinen A, Knekt P, Aro A, Rissanen H, Marniemi J, Heliovaara M, Impivaara O, Reunanen A (2009) Vitamin D status and the risk of cardiovascular disease death. *Am J Epidemiol* 170:1032-1039
94. Kauppi M, Impivaara O, Maki J, Heliovaara M, Marniemi J, Montonen J, Jula A (2009) Vitamin D status and common risk factors for bone fragility as determinants of quantitative ultrasound variables in a nationally representative population sample. *Bone* 45:119-124
95. Partti K, Heliovaara M, Impivaara O, Perala J, Saarni SI, Lonqvist J, Suvisaari JM (2010) Skeletal status in psychotic disorders: a population-based study. *Psychosom Med* 72:933-940
96. Mattila C, Knekt P, Mannisto S, Rissanen H, Laaksonen MA, Montonen J, Reunanen A (2007) Serum 25-hydroxyvitamin D concentration and subsequent risk of type 2 diabetes. *Diabetes Care* 30:2569-2570
97. Lamberg-Allardt CJ, Outila TA, Karkkainen MU, Rita HJ, Valsta LM (2001) Vitamin D deficiency and bone health in healthy adults in Finland: could this be a concern in other parts of Europe? *J Bone Miner Res* 16:2066-2073
98. Parviainen MT, Kumpusalo E, Halonen P, Neittaanmaki L, Pekkarinen H (1992) Epidemiology of vitamins A, E, D and C in rural villages in Finland: biochemical, nutritional and socioeconomical aspects. *Int J Vitam Nutr Res* 62:238-243
99. Chapuy MC, Preziosi P, Maamer M, Arnaud S, Galan P, Hercberg S, Meunier PJ (1997) Prevalence of vitamin D insufficiency in an adult normal population. *Osteoporos Int* 7:439-443
100. Malvy DJ, Guinot C, Preziosi P, Galan P, Chapuy MC, Maamer M, Arnaud S, Meunier PJ, Hercberg S, Tschachler E (2000) Relationship between vitamin D status and skin phototype in general adult population. *Photochem Photobiol* 71:466-469
101. de Carvalho MJ, Guillard JC, Moreau D, Boggio V, Fuchs F (1996) Vitamin status of healthy subjects in Burgundy (France). *Ann Nutr Metab* 40:24-51
102. Blain H, Jaussent A, Thomas E, et al. (2009) Low sit-to-stand performance is associated with low femoral neck bone mineral density in healthy women. *Calcif Tissue Int* 84:266-275
103. Aspray TJ, Yan L, Prentice A (2005) Parathyroid hormone and rates of bone formation are raised in perimenopausal rural Gambian women. *Bone* 36:710-720
104. Hintzpeter B, Mensink GB, Thierfelder W, Muller MJ, Scheidt-Nave C (2008) Vitamin D status and health correlates among German adults. *Eur J Clin Nutr* 62:1079-1089

105. Scharla SH, Scheidt-Nave C, Leidig G, Woitge H, Wuster C, Seibel MJ, Ziegler R (1996) Lower serum 25-hydroxyvitamin D is associated with increased bone resorption markers and lower bone density at the proximal femur in normal females: a population-based study. *Exp Clin Endocrinol Diabetes* 104:289-292
106. Woitge HW, Scheidt-Nave C, Kissling C, Leidig-Bruckner G, Meyer K, Grauer A, Scharla SH, Ziegler R, Seibel MJ (1998) Seasonal variation of biochemical indexes of bone turnover: results of a population-based study. *J Clin Endocrinol Metab* 83:68-75
107. Woitge HW, Knothe A, Witte K, Schmidt-Gayk H, Ziegler R, Lemmer B, Seibel MJ (2000) Circaannual rhythms and interactions of vitamin D metabolites, parathyroid hormone, and biochemical markers of skeletal homeostasis: a prospective study. *J Bone Miner Res* 15:2443-2450
108. Papapetrou PD, Triantaphyllopoulou M, Karga H, Zagarelou P, Aloumanis K, Kostakioti E, Vaiopoulos G (2007) Vitamin D deficiency in the elderly in Athens, Greece. *J Bone Miner Metab* 25:198-203
109. Sigurdsson G, Franzson L, Steingrimsdottir L, Sigvaldason H (2000) The association between parathyroid hormone, vitamin D and bone mineral density in 70-year-old Icelandic women. *Osteoporos Int* 11:1031-1035
110. Goswami R, Kochupillai N, Gupta N, Goswami D, Singh N, Dudha A (2008) Presence of 25(OH) D deficiency in a rural North Indian village despite abundant sunshine. *J Assoc Physicians India* 56:755-757
111. Masoompour SM, Sadegholvaad A, Larijani B, Ranjbar-Omrani G (2008) Effects of age and renal function on vitamin D status in men. *Arch Iran Med* 11:377-381
112. Hosseinpanah F, Rambod M, Hossein-nejad A, Larijani B, Azizi F (2008) Association between vitamin D and bone mineral density in Iranian postmenopausal women. *J Bone Miner Metab* 26:86-92
113. Omrani GR, Masoompour SM, Sadegholvaad A, Larijani B (2006) Effect of menopause and renal function on vitamin D status in Iranian women. *East Mediterr Health J* 12:188-195
114. Hossein-Nezhad A, Khoshniat Nikoo M, Maghbooli Z, Karimi F, Mirzaei K, A. H, Larijani B (2009) Relationship between serum vitamin D concentration and metabolic syndrome among Iranian adults population. *DARU* 17 (Suppl 1):1-5
115. Niafar M, Bahrami A, Aliasgharzadeh A, Aghamohammadzadeh N, Najafipour F, Mobasser M (2009) Vitamin D status in healthy postmenopausal Iranian women. *J Res Med Sci* 14:171-177
116. Hashemipour S, Larijani B, Adibi H, et al. (2006) The status of biochemical parameters in varying degrees of vitamin D deficiency. *J Bone Miner Metab* 24:213-218
117. Keane EM, Healy M, O'Moore R, Coakley D, Walsh JB (1995) Hypovitaminosis D in the healthy elderly. *Br J Clin Pract* 49:301-303
118. Hill T, Collins A, O'Brien M, Kiely M, Flynn A, Cashman KD (2005) Vitamin D intake and status in Irish postmenopausal women. *Eur J Clin Nutr* 59:404-410
119. Hill TR, O'Brien MM, Lamberg-Allardt C, Jakobsen J, Kiely M, Flynn A, Cashman KD (2006) Vitamin D status of 51-75-year-old Irish women: its determinants and impact on biochemical indices of bone turnover. *Public Health Nutr* 9:225-233
120. Semba RD, Houston DK, Bandinelli S, Sun K, Cherubini A, Cappola AR, Guralnik JM, Ferrucci L (2010) Relationship of 25-hydroxyvitamin D with all-cause and cardiovascular disease mortality in older community-dwelling adults. *Eur J Clin Nutr* 64:203-209
121. Lauretani F, Bandinelli S, Russo CR, et al. (2006) Correlates of bone quality in older persons. *Bone* 39:915-921
122. Houston DK, Cesari M, Ferrucci L, Cherubini A, Maggio D, Bartali B, Johnson MA, Schwartz GG, Kritchevsky SB (2007) Association between vitamin D status and physical performance: the InCHIANTI study. *J Gerontol A Biol Sci Med Sci* 62:440-446
123. Hicks GE, Shardell M, Miller RR, Bandinelli S, Guralnik J, Cherubini A, Lauretani F, Ferrucci L (2008) Associations between vitamin D status and pain in older adults: the Invecchiare in Chianti study. *J Am Geriatr Soc* 56:785-791
124. Vezzoli G, Soldati L, Arcidiacono T, et al. (2005) Urinary calcium is a determinant of bone mineral density in elderly men participating in the InCHIANTI study. *Kidney Int* 67:2006-2014
125. Maggio D, Cherubini A, Lauretani F, et al. (2005) 25(OH)D Serum levels decline with age earlier in women than in men and less efficiently prevent compensatory hyperparathyroidism in older adults. *J Gerontol A Biol Sci Med Sci* 60:1414-1419

126. Adami S, Viapiana O, Gatti D, Idolazzi L, Rossini M (2008) Relationship between serum parathyroid hormone, vitamin D sufficiency, age, and calcium intake. *Bone* 42:267-270
127. Carnevale V, Modoni S, Pileri M, Di Giorgio A, Chiodini I, Minisola S, Vieth R, Scillitani A (2001) Longitudinal evaluation of vitamin D status in healthy subjects from southern Italy: seasonal and gender differences. *Osteoporos Int* 12:1026-1030
128. Nakamura K, Nashimoto M, Yamamoto M (2001) Are the serum 25-hydroxyvitamin D concentrations in winter associated with forearm bone mineral density in healthy elderly Japanese women? *Int J Vitam Nutr Res* 71:25-29
129. Kwon J, Suzuki T, Yoshida H, Kim H, Yoshida Y, Iwasa H (2007) Concomitant lower serum albumin and vitamin D levels are associated with decreased objective physical performance among Japanese community-dwelling elderly. *Gerontology* 53:322-328
130. Suzuki T, Kwon J, Kim H, Shimada H, Yoshida Y, Iwasa H, Yoshida H (2008) Low serum 25-hydroxyvitamin D levels associated with falls among Japanese community-dwelling elderly. *J Bone Miner Res* 23:1309-1317
131. Nakamura K, Nashimoto M, Hori Y, Yamamoto M (2000) Serum parathyroid hormone in healthy Japanese women in relation to serum 25-hydroxyvitamin D. *Int J Vitam Nutr Res* 70:287-292
132. Kim MK, Il Kang M, Won Oh K, Kwon HS, Lee JH, Lee WC, Yoon KH, Son HY (2010) The association of serum vitamin D level with presence of metabolic syndrome and hypertension in middle-aged Korean subjects. *Clin Endocrinol (Oxf)* 73:330-338
133. Arabi A, Baddoura R, El-Rassi R, El-Hajj Fuleihan G (2010) Age but not gender modulates the relationship between PTH and vitamin D. *Bone* 47:408-412
134. Gannage-Yared MH, Chemali R, Yaacoub N, Halaby G (2000) Hypovitaminosis D in a sunny country: relation to lifestyle and bone markers. *J Bone Miner Res* 15:1856-1862
135. Rahman SA, Chee WS, Yassin Z, Chan SP (2004) Vitamin D status among postmenopausal Malaysian women. *Asia Pac J Clin Nutr* 13:255-260
136. Kuchuk NO, Pluijm SM, van Schoor NM, Looman CW, Smit JH, Lips P (2009) Relationships of serum 25-hydroxyvitamin D to bone mineral density and serum parathyroid hormone and markers of bone turnover in older persons. *J Clin Endocrinol Metab* 94:1244-1250
137. van Schoor NM, Visser M, Pluijm SM, Kuchuk N, Smit JH, Lips P (2008) Vitamin D deficiency as a risk factor for osteoporotic fractures. *Bone* 42:260-266
138. Visser M, Deeg DJ, Puts MT, Seidell JC, Lips P (2006) Low serum concentrations of 25-hydroxyvitamin D in older persons and the risk of nursing home admission. *Am J Clin Nutr* 84:616-622; quiz 671-612
139. Buizert PJ, van Schoor NM, Lips P, Deeg DJ, Eekhoff EM (2009) Lipid levels: a link between cardiovascular disease and osteoporosis? *J Bone Miner Res* 24:1103-1109
140. de Jongh RT, Lips P, Rijs KJ, van Schoor NM, Kramer MH, Vandenbroucke JP, Dekkers OM (2011) Associations between vitamin D receptor genotypes and mortality in a cohort of older Dutch individuals. *Eur J Endocrinol* 164:75-82
141. Hoogendijk WJ, Lips P, Dik MG, Deeg DJ, Beekman AT, Penninx BW (2008) Depression is associated with decreased 25-hydroxyvitamin D and increased parathyroid hormone levels in older adults. *Arch Gen Psychiatry* 65:508-512
142. Wicherts IS, van Schoor NM, Boeke AJ, Visser M, Deeg DJ, Smit J, Knol DL, Lips P (2007) Vitamin D status predicts physical performance and its decline in older persons. *J Clin Endocrinol Metab* 92:2058-2065
143. Lowik MR, Schrijver J, Odink J, van den Berg H, Wedel M, Hermus RJ (1990) Nutrition and aging: nutritional status of "apparently healthy" elderly (Dutch nutrition surveillance system). *J Am Coll Nutr* 9:18-27
144. Al-Delaimy WK, Jansen EH, Peeters PH, van der Laan JD, van Noord PA, Boshuizen HC, van der Schouw YT, Jenab M, Ferrari P, Bueno-de-Mesquita HB (2006) Reliability of biomarkers of iron status, blood lipids, oxidative stress, vitamin D, C-reactive protein and fructosamine in two Dutch cohorts. *Biomarkers* 11:370-382
145. Pilz S, Dobnig H, Nijpels G, Heine RJ, Stehouwer CD, Snijder MB, van Dam RM, Dekker JM (2009) Vitamin D and mortality in older men and women. *Clin Endocrinol (Oxf)* 71:666-672

146. Scragg R, Holdaway I, Jackson R, Lim T (1992) Plasma 25-hydroxyvitamin D₃ and its relation to physical activity and other heart disease risk factors in the general population. *Ann Epidemiol* 2:697-703
147. Bolland MJ, Grey AB, Ames RW, Mason BH, Horne AM, Gamble GD, Reid IR (2007) The effects of seasonal variation of 25-hydroxyvitamin D and fat mass on a diagnosis of vitamin D sufficiency. *Am J Clin Nutr* 86:959-964
148. Bolland MJ, Grey AB, Ames RW, Horne AM, Mason BH, Wattie DJ, Gamble GD, Bouillon R, Reid IR (2007) Age-, gender-, and weight-related effects on levels of 25-hydroxyvitamin D are not mediated by vitamin D binding protein. *Clin Endocrinol (Oxf)* 67:259-264
149. Bolland MJ, Grey AB, Ames RW, Horne AM, Gamble GD, Reid IR (2006) Fat mass is an important predictor of parathyroid hormone levels in postmenopausal women. *Bone* 38:317-321
150. Rockell JE, Skeaff CM, Venn BJ, Williams SM, Green TJ (2008) Vitamin D insufficiency in New Zealanders during the winter is associated with higher parathyroid hormone concentrations: implications for bone health? *N Z Med J* 121:75-84
151. Brustad M, Sandanger T, Aksnes L, Lund E (2004) Vitamin D status in a rural population of northern Norway with high fish liver consumption. *Public Health Nutr* 7:783-789
152. Brustad M, Alsaker E, Engelsen O, Aksnes L, Lund E (2004) Vitamin D status of middle-aged women at 65-71 degrees N in relation to dietary intake and exposure to ultraviolet radiation. *Public Health Nutr* 7:327-335
153. Holvik K, Meyer HE, Sogaard AJ, Selmer R, Haug E, Falch JA (2006) Biochemical markers of bone turnover and their relation to forearm bone mineral density in persons of Pakistani and Norwegian background living in Oslo, Norway: The Oslo Health Study. *Eur J Endocrinol* 155:693-699
154. Meyer HE, Falch JA, Sogaard AJ, Haug E (2004) Vitamin D deficiency and secondary hyperparathyroidism and the association with bone mineral density in persons with Pakistani and Norwegian background living in Oslo, Norway, The Oslo Health Study. *Bone* 35:412-417
155. Grimnes G, Almaas B, Eggen AE, et al. (2010) Effect of smoking on the serum levels of 25-hydroxyvitamin D depends on the assay employed. *Eur J Endocrinol* 163:339-348
156. Jorde R, Sneve M, Hutchinson M, Emaus N, Figenschau Y, Grimnes G (2010) Tracking of serum 25-hydroxyvitamin D levels during 14 years in a population-based study and during 12 months in an intervention study. *Am J Epidemiol* 171:903-908
157. Napiorkowska L, Budlewski T, Jakubas-Kwiatkowska W, Hamzy V, Gozdowski D, Franek E (2009) Prevalence of low serum vitamin D concentration in an urban population of elderly women in Poland. *Pol Arch Med Wewn* 119:699-703
158. Sapir-Koren R, Livshits G, Kobylansky E (2003) Genetic effects of estrogen receptor alpha and collagen IA1 genes on the relationships of parathyroid hormone and 25 hydroxyvitamin D with bone mineral density in Caucasian women. *Metabolism* 52:1129-1135
159. Ardawi MS, Maimani AA, Bahksh TA, Rouzi AA, Qari MH, Raddadi RM (2010) Reference intervals of biochemical bone turnover markers for Saudi Arabian women: a cross-sectional study. *Bone* 47:804-814
160. Charlton KE, Labadarios D, Lombard CJ, Louw ME (1996) Vitamin D status of older South Africans. *S Afr Med J* 86:1406-1410
161. Gomez JM, Maravall FJ, Gomez N, Navarro MA, Casamitjana R, Soler J (2004) Relationship between 25-(OH) D₃, the IGF-I system, leptin, anthropometric and body composition variables in a healthy, randomly selected population. *Horm Metab Res* 36:48-53
162. Almirall J, Vaqueiro M, Bare ML, Anton E (2010) Association of low serum 25-hydroxyvitamin D levels and high arterial blood pressure in the elderly. *Nephrol Dial Transplant* 25:503-509
163. Muray S, Marco MP, Craver L, Rue M, Valdivielso JM, Fernandez E (2006) Influence of mineral metabolism parameters on pulse pressure in healthy subjects. *Clin Nephrol* 66:411-417
164. Gerdhem P, Ringsberg KA, Obrant KJ, Akesson K (2005) Association between 25-hydroxy vitamin D levels, physical activity, muscle strength and fractures in the prospective population-based OPRA Study of Elderly Women. *Osteoporos Int* 16:1425-1431
165. Salminen H, Saaf M, Ringertz H, Strender LE (2008) The role of IGF-I and IGFBP-1 status and secondary hyperparathyroidism in relation to osteoporosis in elderly Swedish women. *Osteoporos Int* 19:201-209

166. Lind L, Hanni A, Lithell H, Hvarfner A, Sorensen OH, Ljunghall S (1995) Vitamin D is related to blood pressure and other cardiovascular risk factors in middle-aged men. *Am J Hypertens* 8:894-901
167. Burgaz A, Akesson A, Oster A, Michaelsson K, Wolk A (2007) Associations of diet, supplement use, and ultraviolet B radiation exposure with vitamin D status in Swedish women during winter. *Am J Clin Nutr* 86:1399-1404
168. Burgaz A, Akesson A, Michaelsson K, Wolk A (2009) 25-hydroxyvitamin D accumulation during summer in elderly women at latitude 60 degrees N. *J Intern Med* 266:476-483
169. Melhus H, Snellman G, Gedeberg R, et al. (2010) Plasma 25-hydroxyvitamin D levels and fracture risk in a community-based cohort of elderly men in Sweden. *J Clin Endocrinol Metab* 95:2637-2645
170. Hagstrom E, Hellman P, Larsson TE, et al. (2009) Plasma parathyroid hormone and the risk of cardiovascular mortality in the community. *Circulation* 119:2765-2771
171. Melin AL, Wilske J, Ringertz H, Saaf M (1999) Vitamin D status, parathyroid function and femoral bone density in an elderly Swedish population living at home. *Aging (Milano)* 11:200-207
172. Burnand B, Sloutskis D, Gianoli F, Cornuz J, Rickenbach M, Paccaud F, Burckhardt P (1992) Serum 25-hydroxyvitamin D: distribution and determinants in the Swiss population. *Am J Clin Nutr* 56:537-542
173. Theiler R, Stahelin HB, Kranzlin M, Tyndall A, Bischoff HA (1999) High bone turnover in the elderly. *Arch Phys Med Rehabil* 80:485-489
174. Tsai KS, Hsu SH, Cheng JP, Yang RS (1997) Vitamin D stores of urban women in Taipei: effect on bone density and bone turnover, and seasonal variation. *Bone* 20:371-374
175. Chailurkit LO, Pongchaiyakul C, Charoenkiatkul S, Kosulwat V, Rojroongwasinkul N, Rajatanavin R (2001) Different mechanism of bone loss in ageing women and men in Khon Kaen Province. *J Med Assoc Thai* 84:1175-1182
176. Chailurkit LO, Piaseu N, Rajatanavin R (2002) Influence of normal ageing on mechanism of bone loss in women and men in Bangkok. *J Med Assoc Thai* 85:915-921
177. Soontrapa S, Boonsiri P, Khampitak T (2009) The prevalence of hypovitaminosis D in the elderly women living in the rural area of Khon Kaen Province, Thailand. *J Med Assoc Thai* 92 Suppl5:S21-25
178. Chailurkit LO, Kruavit A, Rajatanavin R (2011) Vitamin D status and bone health in healthy Thai elderly women. *Nutrition* 27:160-164
179. Meddeb N, Sahli H, Chahed M, et al. (2005) Vitamin D deficiency in Tunisia. *Osteoporos Int* 16:180-183
180. Hirani V, Primatesta P (2005) Vitamin D concentrations among people aged 65 years and over living in private households and institutions in England: population survey. *Age Ageing* 34:485-491
181. Hirani V, Tull K, Ali A, Mindell J (2010) Urgent action needed to improve vitamin D status among older people in England! *Age Ageing* 39:62-68
182. Elia M, Stratton RJ (2005) Geographical inequalities in nutrient status and risk of malnutrition among English people aged 65 y and older. *Nutrition* 21:1100-1106
183. Sadideen H, Swaminathan R (2004) Effect of acute oral calcium load on serum PTH and bone resorption in young healthy subjects: an overnight study. *Eur J Clin Nutr* 58:1661-1665
184. Forouhi NG, Luan J, Cooper A, Boucher BJ, Wareham NJ (2008) Baseline serum 25-hydroxy vitamin d is predictive of future glycemic status and insulin resistance: the Medical Research Council Ely Prospective Study 1990-2000. *Diabetes* 57:2619-2625
185. Wareham NJ, Byrne CD, Carr C, Day NE, Boucher BJ, Hales CN (1997) Glucose intolerance is associated with altered calcium homeostasis: a possible link between increased serum calcium concentration and cardiovascular disease mortality. *Metabolism* 46:1171-1177
186. Hegarty V, Woodhouse P, Khaw KT (1994) Seasonal variation in 25-hydroxyvitamin D and parathyroid hormone concentrations in healthy elderly people. *Age Ageing* 23:478-482
187. Bates CJ, Carter GD, Mishra GD, O'Shea D, Jones J, Prentice A (2003) In a population study, can parathyroid hormone aid the definition of adequate vitamin D status? A study of people aged 65 years and over from the British National Diet and Nutrition Survey. *Osteoporos Int* 14:152-159
188. Macdonald HM, Mavroei A, Barr RJ, Black AJ, Fraser WD, Reid DM (2008) Vitamin D status in postmenopausal women living at higher latitudes in the UK in relation to bone health, overweight, sunlight exposure and dietary vitamin D. *Bone* 42:996-1003

189. Mavroei A, O'Neill F, Lee PA, Darling AL, Fraser WD, Berry JL, Lee WT, Reid DM, Lanham-New SA, Macdonald HM (2010) Seasonal 25-hydroxyvitamin D changes in British postmenopausal women at 57 degrees N and 51 degrees N: a longitudinal study. *J Steroid Biochem Mol Biol* 121:459-461
190. Looker AC, Dawson-Hughes B, Calvo MS, Gunter EW, Sahyoun NR (2002) Serum 25-hydroxyvitamin D status of adolescents and adults in two seasonal subpopulations from NHANES III. *Bone* 30:771-777
191. Reis JP, von Muhlen D, Miller ER, 3rd (2008) Relation of 25-hydroxyvitamin D and parathyroid hormone levels with metabolic syndrome among US adults. *Eur J Endocrinol* 159:41-48
192. de Boer IH, Ioannou GN, Kestenbaum B, Brunzell JD, Weiss NS (2007) 25-Hydroxyvitamin D levels and albuminuria in the Third National Health and Nutrition Examination Survey (NHANES III). *Am J Kidney Dis* 50:69-77
193. Dietrich T, Joshipura KJ, Dawson-Hughes B, Bischoff-Ferrari HA (2004) Association between serum concentrations of 25-hydroxyvitamin D3 and periodontal disease in the US population. *Am J Clin Nutr* 80:108-113
194. Ford ES, Ajani UA, McGuire LC, Liu S (2005) Concentrations of serum vitamin D and the metabolic syndrome among U.S. adults. *Diabetes Care* 28:1228-1230
195. Kant AK, Graubard BI (2008) Ethnic and socioeconomic differences in variability in nutritional biomarkers. *Am J Clin Nutr* 87:1464-1471
196. Scragg R, Sowers M, Bell C (2007) Serum 25-hydroxyvitamin D, ethnicity, and blood pressure in the Third National Health and Nutrition Examination Survey. *Am J Hypertens* 20:713-719
197. Skinner HG, Schwartz GG (2009) The relation of serum parathyroid hormone and serum calcium to serum levels of prostate-specific antigen: a population-based study. *Cancer Epidemiol Biomarkers Prev* 18:2869-2873
198. Looker AC, Mussolino ME (2008) Serum 25-hydroxyvitamin D and hip fracture risk in older U.S. white adults. *J Bone Miner Res* 23:143-150
199. Cheng S, Massaro JM, Fox CS, et al. (2010) Adiposity, cardiometabolic risk, and vitamin D status: the Framingham Heart Study. *Diabetes* 59:242-248
200. Jacques PF, Felson DT, Tucker KL, Mahnken B, Wilson PW, Rosenberg IH, Rush D (1997) Plasma 25-hydroxyvitamin D and its determinants in an elderly population sample. *Am J Clin Nutr* 66:929-936
201. Liu E, Meigs JB, Pittas AG, McKeown NM, Economos CD, Booth SL, Jacques PF (2009) Plasma 25-hydroxyvitamin D is associated with markers of the insulin resistant phenotype in nondiabetic adults. *J Nutr* 139:329-334
202. Shea MK, Benjamin EJ, Dupuis J, et al. (2009) Genetic and non-genetic correlates of vitamins K and D. *Eur J Clin Nutr* 63:458-464
203. Hannan MT, Felson DT, Dawson-Hughes B, Tucker KL, Cupples LA, Wilson PW, Kiel DP (2000) Risk factors for longitudinal bone loss in elderly men and women: the Framingham Osteoporosis Study. *J Bone Miner Res* 15:710-720
204. Kiel DP, Myers RH, Cupples LA, et al. (1997) The Bsm1 vitamin D receptor restriction fragment length polymorphism (bb) influences the effect of calcium intake on bone mineral density. *J Bone Miner Res* 12:1049-1057
205. Johnson MA, Davey A, Park S, Hausman DB, Poon LW (2008) Age, race and season predict vitamin D status in African American and white octogenarians and centenarians. *J Nutr Health Aging* 12:690-695
206. Kim DH, Sabour S, Sagar UN, Adams S, Whellan DJ (2008) Prevalence of hypovitaminosis D in cardiovascular diseases (from the National Health and Nutrition Examination Survey 2001 to 2004). *Am J Cardiol* 102:1540-1544
207. Badalian SS, Rosenbaum PF (2010) Vitamin D and pelvic floor disorders in women: results from the National Health and Nutrition Examination Survey. *Obstet Gynecol* 115:795-803
208. Forrest KY, Stuhldreher WL (2011) Prevalence and correlates of vitamin D deficiency in US adults. *Nutr Res* 31:48-54
209. Freedman DM, Looker AC, Abnet CC, Linet MS, Graubard BI (2010) Serum 25-hydroxyvitamin D and cancer mortality in the NHANES III study (1988-2006). *Cancer Res* 70:8587-8597
210. Chonchol M, Scragg R (2007) 25-Hydroxyvitamin D, insulin resistance, and kidney function in the Third National Health and Nutrition Examination Survey. *Kidney Int* 71:134-139

211. Ginde AA, Scragg R, Schwartz RS, Camargo CA, Jr. (2009) Prospective study of serum 25-hydroxyvitamin D level, cardiovascular disease mortality, and all-cause mortality in older U.S. adults. *J Am Geriatr Soc* 57:1595-1603
212. Kendrick J, Targher G, Smits G, Chonchol M (2009) 25-Hydroxyvitamin D deficiency is independently associated with cardiovascular disease in the Third National Health and Nutrition Examination Survey. *Atherosclerosis* 205:255-260
213. Martins D, Wolf M, Pan D, Zadshir A, Tareen N, Thadhani R, Felsenfeld A, Levine B, Mehrotra R, Norris K (2007) Prevalence of cardiovascular risk factors and the serum levels of 25-hydroxyvitamin D in the United States: data from the Third National Health and Nutrition Examination Survey. *Arch Intern Med* 167:1159-1165
214. Scragg R, Sowers M, Bell C (2004) Serum 25-hydroxyvitamin D, diabetes, and ethnicity in the Third National Health and Nutrition Examination Survey. *Diabetes Care* 27:2813-2818
215. Zadshir A, Tareen N, Pan D, Norris K, Martins D (2005) The prevalence of hypovitaminosis D among US adults: data from the NHANES III. *Ethn Dis* 15:S5-97-101
216. Reis JP, von Muhlen D, Michos ED, Miller ER, 3rd, Appel LJ, Araneta MR, Barrett-Connor E (2009) Serum vitamin D, parathyroid hormone levels, and carotid atherosclerosis. *Atherosclerosis* 207:585-590
217. Jassal SK, Chonchol M, von Muhlen D, Smits G, Barrett-Connor E (2010) Vitamin d, parathyroid hormone, and cardiovascular mortality in older adults: the Rancho Bernardo study. *Am J Med* 123:1114-1120
218. von Muhlen DG, Greendale GA, Garland CF, Wan L, Barrett-Connor E (2005) Vitamin D, parathyroid hormone levels and bone mineral density in community-dwelling older women: the Rancho Bernardo Study. *Osteoporos Int* 16:1721-1726
219. Dawson-Hughes B, Harris SS, Dallal GE (1997) Plasma calcidiol, season, and serum parathyroid hormone concentrations in healthy elderly men and women. *Am J Clin Nutr* 65:67-71
220. Avery E, Kleppinger A, Feinn R, Kenny AM (2010) Determinants of living situation in a population of community-dwelling and assisted living-dwelling elders. *J Am Med Dir Assoc* 11:140-144
221. Ilich JZ, Brownbill RA, Tamborini L (2003) Bone and nutrition in elderly women: protein, energy, and calcium as main determinants of bone mineral density. *Eur J Clin Nutr* 57:554-565
222. Lappe JM, Davies KM, Travers-Gustafson D, Heaney RP (2006) Vitamin D status in a rural postmenopausal female population. *J Am Coll Nutr* 25:395-402
223. Mirza FS, Padhi ID, Raisz LG, Lorenzo JA (2010) Serum sclerostin levels negatively correlate with parathyroid hormone levels and free estrogen index in postmenopausal women. *J Clin Endocrinol Metab* 95:1991-1997
224. Sabetta JR, DePetrillo P, Cipriani RJ, Smardin J, Burns LA, Landry ML (2010) Serum 25-hydroxyvitamin d and the incidence of acute viral respiratory tract infections in healthy adults. *PLoS One* 5:e11088
225. Arunabh S, Pollack S, Yeh J, Aloia JF (2003) Body fat content and 25-hydroxyvitamin D levels in healthy women. *J Clin Endocrinol Metab* 88:157-161
226. Khosla S, Atkinson EJ, Melton LJ, 3rd, Riggs BL (1997) Effects of age and estrogen status on serum parathyroid hormone levels and biochemical markers of bone turnover in women: a population-based study. *J Clin Endocrinol Metab* 82:1522-1527
227. Iannuzzi-Sucich M, Prestwood KM, Kenny AM (2002) Prevalence of sarcopenia and predictors of skeletal muscle mass in healthy, older men and women. *J Gerontol A Biol Sci Med Sci* 57:M772-777
228. Alvarez JA, Ashraf AP, Hunter GR, Gower BA (2010) Serum 25-hydroxyvitamin D and parathyroid hormone are independent determinants of whole-body insulin sensitivity in women and may contribute to lower insulin sensitivity in African Americans. *Am J Clin Nutr* 92:1344-1349
229. Chai W, Maskarinec G, Cooney RV (2010) Serum 25-hydroxyvitamin D levels and mammographic density among premenopausal women in a multiethnic population. *Eur J Clin Nutr* 64:652-654
230. Ho-Pham LT, Nguyen ND, Lai TQ, Eisman JA, Nguyen TV (2011) Vitamin D status and parathyroid hormone in a urban population in Vietnam. *Osteoporos Int* 22:241-248
231. Hashemipour S, Larijani B, Adibi H, et al. (2004) Vitamin D deficiency and causative factors in the population of Tehran. *BMC Public Health* 4:38

Figure 1

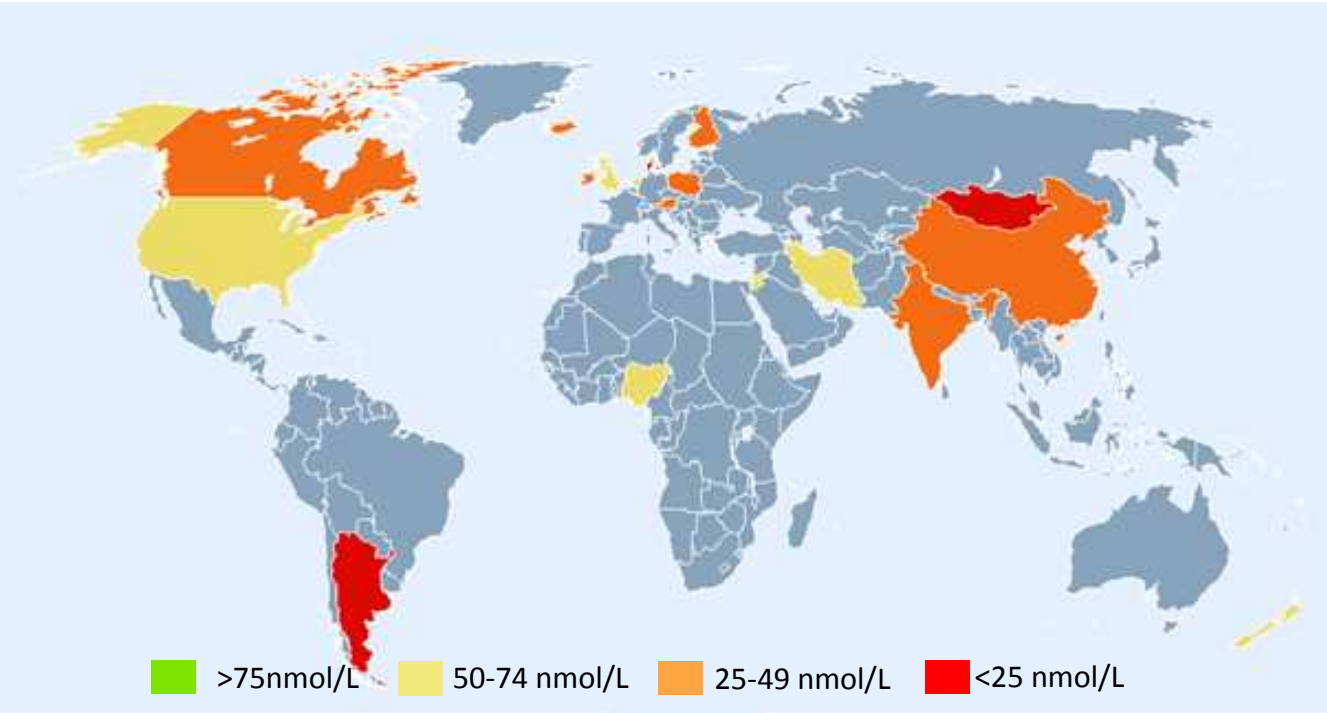


Figure 2

