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Geographical differences in vitamin D status, with particular reference to European countries

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Vitamin D is produced endogenously when the skin is exposed to sunlight and can be obtained exogenously from a few natural food sources, from food fortification and from supplements. Generally, vitamin D intake is low ≤ 2–$3\ \mu g/d$ in Europe. Casual exposure to sunlight is thought to provide most of the vitamin D requirement of the human population. However, skin synthesis of vitamin D may not compensate for the low nutritional intake in Europe, even in countries with high supplies from food fortification and supplements. For assessment of vitamin D nutritional status the concentration of 25-hydroxyvitamin D (25(OH)D) in serum is considered to be an accurate integrative measure reflecting an individual's dietary intake and cutaneous production. A substantial percentage of the elderly and adolescents in Europe have a low concentration of 25(OH)D; in the elderly this percentage ranges from approximately 10 in the Nordic countries to approximately 40 in France. Low vitamin D status seems to be aggravated by disease and immobility, and by a low frequency of supplement use.

Vitamin D intake: Vitamin D recommendations: 25-Hydroxyvitamin D: Elderly: Adolescents: Europe

Vitamin D is produced endogenously when the skin is exposed to sunlight and is obtained exogenously from natural food sources, from food fortification and supplements. Vitamin D requires activation by two successive hydroxylation steps: first in the liver to form 25-hydroxyvitamin D (25(OH)D); then in the kidney to form 1,25-dihydroxyvitamin D (Parfitt *et al.* 1982). The 25-hydroxylation is very fast and almost unregulated in contrast to the 1-hydroxylation that is strictly regulated by parathyroid hormone (PTH; Shepard & DeLuca, 1980). Vitamin D status is commonly defined by the level of 25(OH)D in circulating blood. Inadequate vitamin D intake and/or insufficient sunlight exposure reduces serum 25(OH)D concentration causing secondary hyperparathyroidism, which increases the risk of osteoporosis (Aloia *et al.* 1985; Lips *et al.* 1987) and fractures in the elderly (von Knorring *et al.* 1982; Morris *et al.* 1984; Lips *et al.* 1985; Meller *et al.* 1985).

International comparison studies have shown that among adults serum concentrations of 25(OH)D vary between countries, but are often higher in the USA and Canada and in Scandinavia, compared with the rest of Europe (McKenna, 1992; Lips, 2001). Contrary to expectations the European Euronut SENECA Study found a positive association between latitude and mean serum 25(OH)D, with lower concentrations in Greece and Spain than in Norway (van der Wielen *et al.* 1995). These differences in vitamin D status must be accounted for by international differences, still largely unexplained, in contributions to the vitamin D supply from food, including the supply from fortification and supplements, and the extent of solar skin exposure.

As individuals age the concentration of 25(OH)D decreases, mainly because of a declining efficiency of skin to produce vitamin D (MacLaughlin & Holick, 1985). Also, the elderly may spend less time outdoors, especially if institutionalised, and their food intake (including fish intake) decreases, adding to the risk of vitamin D deficiency and consequently osteoporosis (Lips *et al.* 1987).

The present short review focuses on comparisons of vitamin D intake and frequency of low vitamin D status

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Abbreviations: PTH, parathyroid hormone; 25(OH)D, 25-hydroxyvitamin D.
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among healthy populations in Europe, with special emphasis on the vitamin D nutritional status in the elderly who, for the reasons given earlier, are at an increased risk of an insufficient vitamin D supply.

Vitamin D status

For assessment of vitamin D nutritional status the concentration of 25(OH)D in serum is considered as an accurate integrative measure reflecting an individual's dietary intake and cutaneous production (Parfitt, 1998).

Many studies have suggested that there is a value of 25(OH)D above which there is little further decrease in PTH (Ooms *et al.* 1995*b*; Chapuy *et al.* 1997; Reginster *et al.* 1998; Melin *et al.* 1999; Souberbielle *et al.* 2001). However, the threshold concentration of 25(OH)D that delimits deficiency from sufficiency, i.e. the lowest concentration defining the plateau level of PTH, differs between studies and ranges from 20 nmol/l to >100 nmol/l (Gloth *et al.* 1995; Ooms *et al.* 1995*b*; Chapuy *et al.* 1997; Dawson-Hughes *et al.* 1997; Holick, 1998; Thomas *et al.* 1998). Some studies, however, have shown a continuous decline in PTH with increasing 25(OH)D and no plateau (Bates *et al.* 2003; Kudlacek *et al.* 2003). Other studies have included bone resorption markers (hydroxyproline, pyridinoline and deoxypyridinoline) to derive a 25(OH)D concentration that distinguishes sufficiency from deficiency (Sahota *et al.* 1999; Jesudason *et al.* 2002). The concentration of 1,25-dihydroxyvitamin D, the biologically-active form of vitamin D, will usually be normal or even slightly elevated in vitamin D deficiency, and therefore provides no information on nutritional status (Hollis, 1996). The blood native vitamin D concentration of an individual reflects recent intake of vitamin D and/or exposure to sunlight, and therefore may vary greatly over a short time period.

Presently, there is no clear definition of an absolute value for 25(OH)D above which an individual is considered to be vitamin D replete. Alternatively, a gradual scale has been proposed in which hypovitaminosis D is defined as a 25(OH)D concentration of <100 nmol/l, vitamin D insufficiency as a 25(OH)D concentration of < 50 nmol/l and vitamin D deficiency as a 25(OH)D concentration of < 25 nmol/l (McKenna & Freaney, 1998).

The classical vitamin D-deficiency diseases, rickets in children and osteomalacia in adults, are caused by severe lack of vitamin D (Hutchison & Bell, 1992), usually with serum 25(OH)D concentrations < 10 nmol/l (and hypocalcaemia, hypophosphataemia and increased serum alkaline phosphatase). Rickets and osteomalacia are a major problem in some population groups in Europe, whether as a result of immobility or infirmity (Lips, 2001), or social or religious customs practised by certain immigrant groups (Meulmeester *et al.* 1990; Iqbal *et al.* 1994; Solanki *et al.* 1995; Glerup, 2000), especially those who are living in north western Europe where sunlight exposure is limited.

Solar exposure

The relationship between lack of sunlight and vitamin D deficiency has been recognised for many years. During exposure to sunlight u.v. B photons (wavelength 290 and 315 nm) photolyse epidermal stores of 7-dehydrocholesterol (provitamin D) to form previtamin D, which is unstable and subsequently undergoes isomerisation to the stable vitamin D (Holick *et al.* 1980). After its formation vitamin D slowly moves into the circulation.

Casual exposure to sunlight is thought to provide most of the vitamin D requirement of the human population (Holick, 1996). However, skin synthesis of vitamin D may not compensate for the low nutritional intake in Europe, because Europe is located at high latitude, from approximately 40°N (Madrid, Spain) to 64°N (Reykjavik, Iceland). Webb *et al.* (1988) in the USA demonstrated that in Boston, MA (latitude 42°N) photosynthesis of previtamin D is nearly impossible during the winter months (November–February) and in Edmonton, Canada (latitude 52°N) vitamin D synthesis is impaired from October to March. Model calculations also demonstrate the considerable contrast in skin production of vitamin D between sites of different latitude and that low vitamin D status is more likely to develop in locations where solar u.v. levels are low for much of the year (Kimlin *et al.* 2003).

A number of studies from many European countries have shown that vitamin D status exhibits a seasonal variation. Both serum concentrations of 25(OH)D (Juttmann *et al.* 1981; Tjellesen & Christiansen, 1983; Hegarty *et al.* 1994; Scharla *et al.* 1996; Brot *et al.* 2001) and biomarkers of bone turnover (Woitge *et al.* 1998) are elevated in late summer and decrease during winter, whereas PTH concentrations tend to increase during winter (Krall *et al.* 1989; Hegarty *et al.* 1994; Chapuy *et al.* 1996). The influence of sun exposure on vitamin D status is underlined in a large Danish study of 2016 post-menopausal females, which showed that those who sunbathed regularly had higher year-round serum 25(OH)D concentrations compared with those who reported that they usually avoided direct sun exposure (Brot *et al.* 2001).

However, the relationship between u.v. radiation and cutaneous vitamin D production is complex and, apart from time of day, latitude, altitude and season, depends on a large number of other factors, such as the amount of air pollution, cloud cover, concentration of O_3 in the atmosphere and stratosphere, surface albedo, age of the individual and the amount of clothing worn, sunscreen usage and skin pigmentation (Holick, 1995). Some of these factors specifically add to the increased risk of an insufficient vitamin D supply in the elderly across Europe, e.g. decreased outdoor activities because of immobility, decreased capacity of their skin to produce vitamin D because of age-related changes and use of clothing that diminishes the cutaneous production of vitamin D.

Dietary intake

Vitamin D is found naturally in only a few foods, mainly in fish and in lesser amounts in eggs (yolk) and meat products. Animal foods contributing to dietary vitamin D also contain 25(OH)D. Although this vitamin D metabolite has a higher activity than native vitamin D, its precise potency is not known (Ovesen *et al.* 2003).

Table 1 shows the intake of vitamin D in healthy elderly subjects based on results from representative dietary intake

Table 1. Mean dietary vitamin D intake in representative samples of independent elderly subjects and dietary vitamin D recommendations in some European countries (intake from supplements are not included)

			Intake (µg/d)					
Country	Survey	Method	Age (years)	Men	*n*	Women	*n*	Recommendation†
Denmark	The Danish Dietary Survey, 1995 (Danish Food Agency, 1996)	7 d record	65–74	3·3	103	4·1	122	Recommended dietary intake: ≥61 years 10 µg/d In DK subjects > 65 years are recommended 10 µg as supplement
			75–80	3·2	44	3·7	64	
Norway	Norkost 1997 (Johansen & Solvoll, 1999)	Food-frequency questionnaire	60–69	5·6	131	4·0	137	
			70–79	6·0	106	4·0	109	
Sweden	Riksmaten 1997–8 (Becker & Pearson, 2002)	7 d record	> 65	7·1	65	4·9	58	
France	INCA 1999 (Volatier, 2000)	7 d record	> 65		2·5	245*		Recommended dietary intake: Elderly 10 µg/d
The Netherlands	The Third Dutch National Food Consumption Survey 1997–8 (Hulshof *et al.* 1998)	2 d record	> 65	4·8	185	3·6	236	Adequate intake: 61–70 years 7·5 µg ≥71 years 12·5 µg Higher recommendations with limited exposure to sunlight and with dark skin colour
Germany	Ernärungsbericht 2000 (Deutsche Gesellschaft für Ernährung, 2000)	3 d record	65–74	3·7	361	3·1	503	Population reference intake: ≥66 years 10 µg
			75–84	3·5	126	3·0	285	
			> 65	4·1	23	2·6	73	
UK	National Diet and Nutrition Survey. People aged 65 years and over (Finch *et al.* 1998)	4 d record	65–74	4·3	271	3·0	256	Reference nutrient intake: > 65 years 10 µg 10 µg for those confined indoors, irrespective of age
			75–84	3·8	265	3·0	217	
			> 85	3·2	96	2·3	170	

DK, Denmark.

*Intake and no. of subjects for men and women combined.

†Different terms are used, e.g. recommended dietary allowance (RDA), recommended dietary intake, recommended nutrient intake or population reference intake. The recommended intake is defined as the intake of an essential nutrient considered as being adequate to meet known nutritional needs of practically all healthy individuals. The recommended intake is normally calculated as the average requirement + 2 SD. An adequate intake is set instead of an RDA if sufficient scientific evidence is not judged to be available to calculate an estimated average requirement. The average intake is based on observed or experimentally-determined estimates of average nutrient intake by a group of healthy individuals.

studies. Generally, vitamin D intake is low, approximately 2–3 µg/d, in Europe (except in Norway and Sweden where fish intake and the contribution from fortified foods are high). McKenna (1992) reported that the mean vitamin D intake is significantly ($P < 0·0001$) lower in Central Europe (2·5 µg/d) than in North America (6·2 µg/d) or Scandinavia (5·2 µg/d).

Direct comparison between countries is difficult, however, because different methods are used to estimate food intake. Furthermore, food tables differ in the way vitamin D content is expressed. Some food tables use values derived by imprecise bioassay techniques, while other tables use analytical data derived by more modern chemical methods for vitamin D determination that often do not include 25(OH)D (Deharveng *et al.* 1999). The imprecision is further augmented by the extreme paucity of systematic analytical data, and the uncertainty of the biological activity of 25(OH)D (Ovesen *et al.* 2003).

Dietary recommendations

There is some variation in dietary recommendations for vitamin D among European countries (Table 1). Evidently, the difficulty in setting daily recommendations for vitamin D arises from the dual nature of its supply, and as the amount of vitamin D that originate from endogenous production varies, a recommendation cannot be determined accurately (Prentice, 2002). In most countries the recommended daily intake is 5–10 µg/d, often at the higher intake levels in the elderly (and in infants) with less opportunity to produce vitamin D cutaneously. Some national committees recommend a higher intake for the elderly because they have a high risk of vitamin D deficiency. It should be noted that there is controversy about the daily intake of vitamin D required to meet or sustain ‘normal’ concentrations of 25(OH)D in the blood, and that some research groups advocate a much higher intake of vitamin D (50–100 µg/d) in populations that do not have substantial body stores of vitamin D (Malabanan *et al.* 1988; Vieth *et al.* 2001; Heaney *et al.* 2003).

Food fortification

While food fortification continues to be a widely-used mechanism for increasing vitamin D intake in many industrialised countries, prevailing attitudes, and relevant legislation, differ, and there is no general consensus on the extent to which vitamin D fortification should be practised (Nordic Council of Ministers, 1995). In some countries the addition of vitamin D is completely unregulated (e.g. UK, although it is mandatory in the case of margarine), while in the countries where there is most restriction (e.g. Scandinavia) fortification is permitted only after authorisation based on a scientifically-documented public health need. Some countries have instituted mandatory fortification of certain foodstuffs (the addition of vitamin D to margarine in the UK and The Netherlands), while other countries have a voluntary fortification programme (e.g. Finland allows addition of vitamin D to milk and margarine). The maximum amounts of vitamin D that can be added to foods differ widely between countries (e.g. in margarine from approximately 20 µg/kg to >100 µg/kg); however, in most countries the level is approximately 70–80 µg/kg. The level of fortification and the selection and extension of the range of foods fortified, as well as the actual intake of the target group, will determine the effect on vitamin D status, and will obviously differ between countries.

However, the effect of inclusion of fortified foods on vitamin D status of the most important target group, the frail elderly, has been modest. Studies of elderly subjects conducted in the UK have found small increases in 25(OH)D concentrations in those consuming fortified margarine (Scragg *et al*. 1995) and milk (Keane *et al*. 1992, 1998). Significant (compared with the control group; $P < 0{\cdot}001$) increases in 25(OH)D were observed in frail elderly Dutch subjects who every day consumed fortified dairy products that brought their intake of vitamin D up to recommended levels (from 3·2 µg/d to 11·6 µg/d; de Jong *et al*. 1999). In contrast, no increases in 25(OH)D were found in a Scottish study of long-stay residents of geriatric wards who received fortified foods (margarine, butter or milk) as part of their daily diet for a period of 0·5–1 year (Dunnigan *et al*. 1986).

Supplementation

The effect of vitamin D supplementation on the serum concentration of 25(OH)D has been demonstrated in several studies worldwide, but the wide variation among European countries in the use of vitamin D-containing supplements will affect vitamin D status. The use of supplements is generally much higher in the Scandinavian countries than in the rest of Europe. For example, studies of elderly subjects from Norway (Sem *et al*. 1987) and Denmark (Knudsen *et al*. 2002) showed that more than half used vitamin D supplements, while a study from Iceland reported that 83 % of the elderly took cod-liver oil or vitamin D supplements (Sigurdsson *et al*. 2000). In contrast in the UK about 16 % of the free-living elderly and only 3 % of the institutionalised elderly received vitamin D supplements (Bates *et al*. 2003).

Relative contributions of intake and solar exposure

During the past 20 years the measurement of serum 25(OH)D has been routinely available and many reports have been published that provide evidence for an association (within country) between vitamin D intake and the extent of solar exposure, and serum 25(OH)D. The British National Diet and Nutrition Survey of subjects aged >65 years found that in the non-institutionalised subjects there was a strong association (linear regression; $P < 0{\cdot}0001$) between 25(OH)D concentrations and vitamin D intake in autumn, winter and spring, but not in the summer season (Bates *et al*. 2003). This pattern was similar to that observed in preschool children for whom vitamin D intake was significantly associated (linear regression; $P < 0{\cdot}006$) with 25(OH)D in the winter but not in the summer months (Davies *et al*. 1999), suggesting a higher dependency on dietary vitamin D during seasons with low solar exposure.

Most European populations require regular sun exposure during the summer to build up sufficient stores to ensure adequate vitamin D status during winter and spring, even in younger individuals. An increased dependence on dietary vitamin D occurs when there is restricted skin exposure to sunlight (housebound or institutionalised subjects, individuals wearing protective clothing) and reduced capacity for endogenous synthesis (dark skin, habitual use of sunscreen).

Vitamin D status in Europe

McKenna (1992) reviewed vitamin D status based on serum concentrations of 25(OH)D in 117 studies from twenty-seven regions and found large regional variations in young adults and the elderly. When results were subsequently grouped according to three geographical regions (North America, Scandinavia and Central and Western Europe) serum concentrations of 25(OH)D were found to be markedly higher in the USA and Canada and in Scandinavia compared with the rest of Europe, a difference that could be explained, at least partly, by the higher intakes of vitamin D from fortification and supplements in North America and in Scandinavia.

However, conclusions of regional differences based on comparisons of 25(OH)D concentrations are questionable because of the lack of standardisation between methods. Until the early 1990s analytical methods were mainly competitive protein-binding assays with or without a chromatographic step to isolate 25(OH)D that were developed in-house. For the last 10 years commercial radioimmunoassays have been used, but the large discrepancies found in international studies between 25(OH)D measurements derived with different competitive protein-binding assays and radioimmunoassays prevent comparison between countries (Lips *et al*. 1999). An additional problem is that some immunoassays do not measure 25-hydroxyergocalciferol (25(OH)D_2), and therefore underestimate total 25(OH)D (subjects may have major amounts of the plant-derived 25(OH)D_2 in their blood, e.g. from pharmaceutical vitamin D preparations; Hollis, 2000).

Elderly

A large number of independent studies worldwide have shown that the elderly often have low serum concentrations of 25(OH)D coupled with high levels of PTH (Lips, 2001). Concentrations of 25(OH)D have been repeatedly found to be higher in independent healthy subjects compared with patients in hospitals and residents of nursing homes, indicating the increased reliance of the institutionalised elderly on vitamin D in food.

Within Europe mean 25(OH)D concentrations vary widely (Table 2). The lowest serum 25(OH)D concentrations are found in the Republic of Ireland and The Netherlands, with the highest concentrations in the Nordic countries and intermediate concentrations in other European

Table 2. Studies on vitamin D status in independent elderly populations from several European countries arranged according to latitude (north to south) (Mean values and standard deviations)

		Age (years)				Serum 25(OH)D (nmol/l)				
Country	Study	Mean	SD	Gender	*n*	Mean	SD	Lower reference limit (nmol/l)	Vitamin D deficiency (%)	Season
Iceland	Sigurdsson *et al.* (2000)	70		F	308	53	20	30	13	Winter
Sweden	Melin *et al.* (1999)	≥80		M	23	70	23	25	4	Winter
				F	81	65	30			
Denmark	Brot *et al.* (2001)	45–58*		F	2016	63		25	7	All the seasons
								50	40	
Republic of Ireland	McKenna *et al.* (1985)	69	5	M, F	30	21		25	21	Winter
The Netherlands	Lips *et al.* (1987)	76	4	M, F	74	33	14	20	16	All the seasons
Belgium	Boonen *et al.* (1997)	72	5	M	40	47	18	30	18	All the seasons
UK	Bates *et al.* (1999)	> 65		M, F	approx 800	56	27	12·5	2	All the seasons
								25	8	
Austria	Kudlacek *et al.* (2003)	> 60		M	40	57	31	25	26	Winter
				F	65	43	27			
Germany	Scharla *et al.* (1996)	50–80*		M, F	415	43	23	25	24	Winter
France	Chapuy *et al.* (1996)	80	3	F	440	43	25	30	39	Winter
Italy	Bettica *et al.* (1999)	59	8	F	570	45	20	30	28	All the seasons

25(OH)D, 25-hydroxyvitamin D.
*Range.

countries. The frequency of vitamin D deficiency obviously depends on the lower reference limit and the season. However, a substantial proportion of the independent elderly population of Europe is vitamin D deficient, and this proportion seems to be lower in the Nordic countries and UK compared with the rest of Europe.

Studies from The Netherlands (Ooms *et al.* 1995*a*) and Sweden (Toss *et al.* 1980) have shown that about one-third of the elderly in nursing homes and in homes for the elderly are vitamin D deficient (serum 25(OH)D < 20 nmol/l), and this number may be even higher in the Republic of Ireland where mean 25(OH)D concentrations of 9 nmol/l have been reported for nursing home residents (McKenna *et al.* 1985). In the UK 2·7 and 37 % of the institutionalised participants in the 1994–5 National Diet and Nutrition Survey of individuals ≥ 65 years had 25(OH)D concentrations < 12·5 and < 25 nmol/l respectively (Bates *et al.* 1999). Very low serum 25(OH)D concentrations were found for geriatric patients in the UK (Corless *et al.* 1975; Nayal *et al.* 1978; Vir & Love 1978), Spain (Quesada *et al.* 1989) and France (Fardellone *et al.* 1995); mean concentrations ranged from 3 nmol/l to 12 nmol/l and > 50 % had severe vitamin D deficiency (serum 25(OH)D < 12·5 nmol/l). In Denmark 44 % of geriatric patients had severe vitamin D deficiency (Egsmose *et al.* 1987). In Sweden vitamin D deficiency, defined as serum 25(OH)D < 30 nmol/l, was found in approximately 50 % of hospitalised women and 35 % of hospitalised men and in 20 % of the home-living elderly (Mowé *et al.* 1996). Severe vitamin D deficiency (serum 25(OH)D < 20 nmol/l) was found in 20 % of hospitalised elderly men and 26 % of hospitalised elderly women in Finland; for a comparable group of outpatients the respective prevalences were much lower, 6 % for men and 2 % for women (Kauppinen-Mäkelin *et al.* 2001).

The European Euronut SENECA Study was conducted in nineteen centres in eleven countries using a central laboratory facility (van der Wielen *et al.* 1995). Lowest mean winter serum 25(OH)D concentrations were found in study centres in Greece (21 nmol/l in women and 25 nmol/l in men) and the highest in Norway (48 nmol/l in women and 45 nmol/l in men). Serum 25(OH)D concentrations were positively associated with latitude. Low 25(OH)D concentrations could be explained by reduced sunlight exposure (time spent outdoors, clothing worn when exposed to sunlight), low intake of fish and low physical health status. The low concentrations of 25(OH)D in southern Europe might also be explained by limited fortification of foods with vitamin D and low frequency of supplement use.

Other adult age-groups

Low vitamin D status has also been demonstrated in the healthy adult population in Europe. In 328 Finnish adults aged 31–43 years low wintertime 25(OH)D concentrations (< 25 nmol/l) were found in 26·2 % of the women and 28·6 % of the men (Lamberg-Allardt *et al.* 2001). In a French urban population comprising 765 men aged 45–65 years and 804 women aged 35–60 years selected from twenty cities 14 % of the subjects had 25(OH)D concentrations < 30 nmol/l (Chapuy *et al.* 1997). In a representative sample (*n* 3276) of the general adult Swiss population 6 % were found to have 25(OH)D concentrations of 20 nmol/l (Burnand *et al.* 1992). Even in southern Italy a relatively high prevalence of vitamin D deficiency can be found among healthy young women (Carnevale *et al.* 2001). The prevalence of hypovitaminosis D, defined by concentrations of 25(OH)D < 30 nmol/l, was 27·8 % in winter and 3·4 % in summer.

Adolescents

Maximising the peak bone mass during adolescence and early adulthood is considered to be the best protection against age-related bone loss and later risk of osteoporosis (Heaney *et al*. 2000). Thus, adolescence becomes a critical period in skeletal development. However, in these stages of life the concentration of 25(OH)D considered necessary to achieve optimal bone mass is ill defined, partly because adolescence may be a time when physiological mechanisms other than the concentration of 25(OH)D play a role in regulating the secretion of PTH (Guillemant *et al*. 1995; Outila *et al*. 2001).

About 18 % of Icelandic 16–20-year-old girls had winter serum 25(OH)D concentrations of < 25 nmol/l (Kristinsson *et al*. 1998) and 14 % of Finnish females had winter serum 25(OH)D concentrations of < 20 nmol/l (Lehtonen-Veromaa *et al*. 1999). Other studies from Finland have shown a similar high frequency of low concentrations of 25(OH)D in female adolescents. Furthermore, low serum 25(OH)D concentration was associated with lower bone mineral density (Outila *et al*. 2001), and also higher bone resorption and lower gain in bone mass over 3 years (Lehtonen-Veromaa *et al*. 2002). A study from France demonstrated large differences in 25(OH)D values, ranging from high concentrations at the end of summer (58·5 (SD 18·0) nmol/l) to low concentrations at the end of winter (20·6 (SD 6·0) nmol/l), when almost all adolescents had a 25(OH)D concentration < 30 nmol/l (Guillemant *et al*. 1999). Finally, data from Spain have shown that in winter 31 % of adolescents had 25(OH)D concentrations below this cut-off level (Docio *et al*. 1998).

Conclusion

Very few of the population in Europe receive anywhere near the recommended dietary intake of vitamin D. A low vitamin D status, defined by a low 25(OH)D concentration in the blood, is found in a large proportion of the elderly in Europe, and may hasten the development of osteoporosis and increase fracture risk. Low vitamin D status is more frequent in southern Europe than in the Scandinavian countries, probably as a result of a higher intake of vitamin D from supplements in Scandinavia. Vitamin D deficiency is exacerbated by disease and immobility in the elderly. Low 25(OH)D concentrations are also found in the adult and adolescent population in Europe. However, the importance of vitamin D deficiency in these age-groups in relation to peak bone mass and the later development of osteoporosis is not known.

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