Vitamin D intake and status in Irish elderly women and adolescent girls

D McCarthy[1], A Collins[1], M O'Brien[1], C Lamberg-Allardt[3], J Jakobsen[4], J Charzewska[5], M Kiely[1], A Flynn[1], KD Cashman[1,2]

Dept of Food and Nutritional Sciences[1], Dept of Medicine[2], University College, Cork, Ireland; Calcium Research Unit[3], Division of Nutrition, Dept of Applied Chemistry and Microbiology, University of Helsinki, Finland; Danish Institute for Food and Veterinary Research[4], Denmark, National Food and Nutrition Institute[5], Warsaw, Poland

ABSTRACT

Aim To assess vitamin D status during summer and winter in Irish girls and elderly women, and to estimate vitamin D intake in these two age-groups.

Methods Ambulatory free-living, elderly Irish women (aged 70-76 years; n = 43) and girls (aged 11-13 years; n = 17) were recruited. Fasting serums were collected during August/September 2002 and February/March 2003 and analysed for 25 (OH) D by HPLC.

Results Mean daily intakes of vitamin D were 4.6 µg and 2.1 µg in elderly women and girls, respectively. Serum 25 (OH) D was significantly lower ($P<0.001$) during winter than summer in both age-groups. Eight (20%) and one (during late summer) and sixteen (37.2%) and eight (47%) (during late winter) of the elderly women and girls, respectively, had inadequate vitamin D status (serum 25 (OH) D <40 nmol/l).

Conclusion Inadequate vitamin D status during winter time is quite common in elderly women and adolescent girls in Ireland.

INTRODUCTION

Vitamin D is the major regulator of calcium metabolism and hence is an important determinant of bone health.[1,2] Prolonged and severe vitamin D deficiency leads to rickets in children and osteomalacia in adults,[3] whereas less severe vitamin D deficiency causes secondary hyperparathyroidism, increases bone turnover and bone loss (mainly from cortical sites such as the femoral neck),[4-8] thus increasing risk of osteoporotic fracture. Vitamin D deficiency in the elderly may also increase fracture risk, independently of its effects on bone mass and metabolism, via an alteration in muscle function, leading to increased body sway and risk of falling and falling-related fractures.[9] There is also growing evidence for the contribution of vitamin D insufficiency (i.e., serum 25 (OH) D levels below 50 nmol/l) to the development of various chronic diseases (e.g., some inflammatory and autoimmune diseases, some forms of cancer, hypertension, cardiovascular diseases and diabetes mellitus) which are frequent in Western societies.[9,10]

In humans, vitamin D is obtained primarily through cutaneous biosynthesis in the presence of UVB sunlight, but also from the diet.[4] Consequently, season is a major determinant of vitamin D status.[11] Vitamin D status is highest in Northern European populations around late summer (August-September) and lowest around late winter/early spring (February-March).[12,13] In Northern Europe (latitude 40-60°N), including Ireland (latitude 51-55°N), sunlight is too weak during the winter months to stimulate cutaneous vitamin D synthesis.[14,15] This creates an increased reliance on dietary sources during the winter months to help maintain adequate vitamin D status. However, the usual dietary vitamin D intake in Europe is not sufficient to maintain adequate vitamin D status especially during winter time.[16,17]

There are very few natural sources of vitamin D that are commonly consumed in Ireland. A recent analysis of the North/South Ireland Food Consumption Survey for vitamin intakes[18] estimated that the mean daily intake of vitamin D was 4.2 µg in adult men and women (aged 18-64 years) from all sources, including nutritional supplements. These data show that a considerable proportion of Irish adults have very low dietary intakes of vitamin D and are largely dependent on sunlight to maintain adequate vitamin D status. Recent preliminary results show that up to 36% of a group of 51-69-year-old Irish women had sub-optimal vitamin D status (defined as serum 25 (OH) D levels below 40 nmol/l) during winter time.[19]

A very high prevalence (50-100%) of severe vitamin D deficiency (serum 25 (OH) D levels <25 nmol/l) has also been reported in older studies of elderly (generally >65 years) Irish subjects, including sick elderly patients,[20] institutionalised subjects[21] as well as community-dwelling subjects from Dublin[21,22] and in two rural communities.[23] Vitamin D intake of this elderly age group within Ireland has been estimated to be only 1.3 to 2.6 µg/d,[21,24,25] placing a high demand on summer sunlight exposure to maintain adequate vitamin D status. However, Freaney et al. found that 32% of a group of free-living ambulatory elderly Irish subjects had severe vitamin D deficiency during summer time.[22]

Besides the elderly population, recent evidence suggests that sub-optimal vitamin D status may be common in European adolescent children during winter time.[17,26,27] This is of particular concern as adolescence is a critical period in terms of maximal skeletal development. Unfortunately, there are no data available on vitamin D status, or intake, in Irish adolescents. Therefore, the objectives of the present study were to assess vitamin D status during summer and winter time in Irish girls (aged 11-13 years) and in ambulatory, free-living elderly Irish women (aged 70-76 years), and to estimate vitamin D intake in these two age-groups. In addition, the impact of using vitamin D-containing supplements on vitamin D status was also assessed.

SUBJECTS AND METHODS

SUBJECTS

A convenience sample of 43 ambulatory, free-living elderly women (mean age 72.2 years (range 70-76 years)) and 17 girls (mean age 12.1 years (range 11-13 years)) were recruited by leaflet or direct contact from the Cork City area. The mean age, height, weight and body mass index (BMI) for both groups are provided in Table 1. None of the subjects were suffering from any condition likely to affect vitamin D status or parathyroid function. Otherwise, no other exclusion criteria were applied in this study. The girls and women were recruited as part of a pan-European study funded by the European Commission under Framework Programme V, in which the vitamin D intake and longitudinal exposure, as well as sunlight exposure are being assessed and compared in these population sub-groups across five different European countries (OPTIFORD Project QLK1-CT-2000-00623; see http://www.optiford.org).

ETHICAL CONSIDERATIONS

Before participation in this study, all subjects signed an informed consent document approved by the Clinical Research Ethics Committee of the Cork Teaching Hospitals.

DESIGN

This study was a longitudinal observational study of seasonal differences in vitamin D status in young girls (11-13 years) and elderly women (70-76 years). Each participant was invited to provide a fasting blood sample at the University on two separate occasions; February/March, 2002 (late winter/early spring) and August/September, 2002 (late summer). After an overnight fast, a blood sample (20 ml) was taken between 08.30 and 10.30 hours on both occasions. Blood was collected by venepuncture into vacutainer tubes containing no additive and processed to serum, which was immediately stored at -70°C until required. Food intake was assessed by a 14-day diet history and calcium and vitamin D intakes were quantified using a photographic food atlas of food portion sizes.[28] A general health and lifestyle questionnaire was also administered to each participant during each visit, which provided information on medical history, use of hormone replacement therapy, visits to hospital, fracture history and smoking history. The questionnaire also detailed sun holidays and the use of sun beds, medicines and nutritional supplements, including vitamin D-containing supplements. Of the 43 elderly women and 17 girls who participated at the first sampling point (late winter/early spring 2002), 40 and 15, respectively, returned for the second sampling point (late summer 2002).

EXPERIMENTAL TECHNIQUES

Serum parathyroid hormone (PTH)

Samples were analysed in duplicate for intact PTH with a chemiluminescent immunometric assay (IMMULITE®, Diagnostic Products Corporation, CA, USA).

Serum 25-hydroxyvitamin D (25 (OH) D)

Serum proteins were precipitated with ethanol, and deproteinized serum was subsequently applied to a MFC18 solid phase extraction column (Isolute®, International Sorbent Technology, Mid Glamorgan, UK) for elution of the 25 (OH) D fraction with ethylacetate: n-heptane. The extracted 25 OH D was injected onto an HPLC-system (Waters, Milford, MA, USA) equipped with a 600 controller and pump, a refrigerated 717_{PLUS} Autosampler, a 996 Diode Array Detector (set at 220-320 nm) for detection, and a 2487 Absorbance Detector (set at 265 nm) for quantification. The HPLC column used for separation was a cyano (Luna, Phenomenex, Torrance, CA, USA) in which 25 (OH) D2 and 25 (OH) D3 was eluted separately with 2-propanol:n-heptane. However, none of the samples contained 25 (OH) D2. The accuracy of the analysis was monitored by participation in the Vitamin D External Quality Assessment Scheme (DEQAS, Charing Cross Hospital, London, UK). There is no international consensus on cut-off levels for vitamin D deficiency

Table 1
CHARACTERISTICS OF THE GROUP OF APPARENTLY HEALTHY 11-13-YEAR-OLD GIRLS (N 17) AND 70-76-YEAR-OLD WOMEN (N 43) SELECTED FOR THE VITAMIN D STATUS OBSERVATIONAL STUDY

	WOMEN		GIRLS	
	Mean	SD	Mean	SD
Age (years)	72.4	2.2	12.1	0.8
Height (m)	1.57	0.12	1.52	0.10
Weight (kg)	65.1	11.7	49.7	12.8
BMI (kg/m²)	27.0	7.4	21.2	4.3

Table 2
MEAN DAILY INTAKES OF VITAMIN D AND CALCIUM FROM ALL SOURCES (INCLUDING SUPPLEMENTS) AND FROM FOOD SOURCES ONLY

	WOMEN		GIRLS	
	Mean	SD	Mean	SD
All sources				
Calcium (mg)	973	404	807	237
Vitamin D (µg)	11.25†	18.15	2.60	1.95
Food sources				
Calcium (mg)	892	380	794	248
Vitamin D (µg)	4.6	9.34	2.06	0.89

†Mean intake value from all sources significantly different from mean intake value from food sources only, Wilcoxan rank test, P<0.001.

Table 3
SERUM 25-HYDROXYVITAMIN D (25 (OH) D, NMOL/L) AND PARATHYROID HORMONE (PTH, PMOL/L) LEVELS IN 11-13-YEAR-OLD GIRLS AND 70-76-YEAR-OLD WOMEN

SEASON	Late winter				LATE-SUMMER			
ANALYTE	25 (OH) D		PTH		25 (OH) D		PTH	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Women (n 40)	47.3*	21.1	3.4	0.9	59.7	20.0	3.3	1.1
Girls (n 15)	39.0*	11.3	3.0†	1.1	64.0	11.5	2.3	0.5

**Mean value significantly lower than that during late summer, paired Student's t-test, P<0.0001.*
†Mean value tended to be higher than that during late summer, paired Student's t-test, P=0.058.

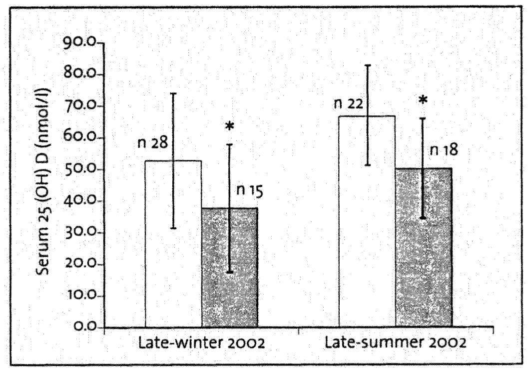

*FIGURE 1 — MEAN SERUM 25 (OH) D LEVELS DURING LATE-SUMMER AND Late winter 2002 IN 70-76-year-old WOMEN STRATIFIED BY VITAMIN D SUPPLEMENT USE. Open bars (supplement users) and hatched bars (supplement non-users). *Mean value significantly lower than that of vitamin D-containing supplement users, within a season; P<0.05.*

and vitamin D insufficiency.[29] In the present study, serum 25 (OH) D cut-off values for defining vitamin D status as adequate, marginally deficient or severely deficient were: >40 nmol/l, 25-40 nmol/l and <25 nmol/l, respectively.[30]

STATISTICAL ANALYSIS

Data are presented as means and standard deviations. With the exception of the vitamin D intake values, data for all variables were normally distributed and allowed for parametric tests of significance. Differences in serum 25 (OH) D and PTH levels between seasons, in each age group separately, were evaluated using paired Students t-tests. Differences in serum 25 (OH) D and PTH levels between vitamin D supplement users and non-users within a season, in each age group separately, were evaluated using unpaired Student's t-tests. Comparisons between vitamin D intakes from food sources and from all sources including nutritional supplements, within each age group, were made using Wilcoxan rank tests for vitamin D.

RESULTS

DIETARY INTAKES OF VITAMIN D

Mean daily intakes of vitamin D from food sources (excluding supplements) were 4.6 µg and 2.1 µg in 70-76-year-old Irish women and 11-13-year-old Irish girls, respectively (Table 2). The mean daily intake of vitamin D in the 70-76-year-old women was significantly higher (P<0.001) when vitamin D-containing supplements were accounted for (Table 2). Only three out of 17 girls (~18%) took vitamin D-containing supplements and this relatively low use of supplements did not significantly affect the group mean intake (Table 2).

SEASONAL VARIATION IN SERUM 25 (OH) D AND IMPACT ON SERUM PTH

Mean serum 25 (OH) D concentrations during late winter/early spring 2002 were significantly lower (P<0.0001) than in late summer 2002 in both the young girls and elderly women (Table 3). While serum PTH concentrations were similar during late late winter/early spring and late summer in elderly women, they tended to be higher (P=0.058) during late winter/early spring than late summer in the girls (Table 3).

SERUM 25 (OH) D LEVELS AND THE IMPACT OF VITAMIN D SUPPLEMENT USE

Twenty-six (60.5%) and twenty-two (55%) of the women took a vitamin D-containing supplement during late winter/early spring and late summer, respectively, whereas only three (17.6%) and two (13.3%) of the girls took a vitamin D-containing supplement during the same respective periods. The vitamin D content of the supplements used by the women ranged from 2.5-20 µg, with a mean content of 8.5 µg and 6.3 µg vitamin D for the two respective sampling points (further details of nature of the various vitamin D-containing supplements used by participants in the study are available from the authors upon request). The vitamin D content of the supplements used by the girls ranged from 2.5-10.0 µg, with a mean content of 7.5 µg for the two respective sampling points. Stratification of women and girls into vitamin D-containing supplement 'users' and 'non-users' revealed that mean serum 25 (OH) D levels were significantly higher (P<0.01) in supplement users than non-users at both time points in elderly women (Figure 1), but there was no difference between supplement users and non-users within the girls at either time point (data not shown). There was no effect of vitamin-containing supplements on serum PTH levels in either group at either sampling point (data not shown).

PREVALENCE OF VITAMIN D DEFICIENCY

During late summer 2002, one out of 40 elderly women and none of the girls had severe vitamin D deficiency, while seven (17.5%) of the women and one of the girls were marginally deficient. During late winter/early spring 2002, six (13.9%) and ten (23.2%) of elderly women were severely and marginally vitamin D deficient, respectively, while twenty-seven (62.8%) had adequate vitamin D status. At the same sampling point, three (17.6%) and five (29.4%) of young girls were severely and marginally vitamin D-deficient, respectively, while nine (52.9%) had adequate vitamin D status.

The prevalence of vitamin D deficiency in subjects stratified by vitamin D-containing supplement use was also examined in the elderly women, but not the young girls (as only three girls took supplements) in the current study. None of the vitamin D-containing supplement users had severe vitamin D deficiency, irrespective of sampling point. In non-users of vitamin D-containing supplements, one of the elderly women had severe vitamin D deficiency during late summer, whereas six (40%) of the elderly women had severe vitamin D deficiency during late winter/early spring.

In relation to the prevalence of marginal vitamin D deficiency, none of the vitamin D-containing supplement users had marginal deficiency during late summer, but five (17.9%) of the women had marginal vitamin D deficiency during late winter/early spring. In supplement non-users, one woman had marginal vitamin D deficiency during late summer and seven (46.7%) of the women had marginal vitamin D deficiency during late winter/early spring.

DISCUSSION

In the present study, mean daily vitamin D intakes of Irish girls (11-13 years old) and elderly women (70-76 years old) were 2.6 µg and 11.25 µg from all sources (i.e. food and nutritional supplements) and 2.1 µg and 4.6 µg from food sources only, respectively. The only other study to estimate vitamin D intake in Irish children reported intake estimates of 1.6 and 1.7 µg/d for 8-12 and 12-15-year-old girls, respectively.[31] The overall intake estimates for vitamin D in elderly Irish women in the present study appear to be much higher than those previously reported for middle-aged to elderly adult women. Hill et al. recently reported that mean daily vitamin D intakes of a nationally representative sample of Irish adult women (50-64 years old) was 5.1 µg from food and supplements and 3.4 µg from food sources only.[18] Hurson et al. reported that mean daily intake of vitamin D in elderly (mean age, 70 years) Irish women was 1.85 µg.[24] However, the proportion of the present group of elderly women who consumed vitamin D-containing supplements was 55-60%, which is a much higher figure than that reported previously in a nationally representative sample of 51-64-year old women (25%).[32] Thus, the current vitamin D intake estimate of 11.25 µg/day may not be representative of habitual intakes for this age group in the general population. Hill et al. also recently reported that 40-46% of 51-69-year-old Irish women (n 67) took vitamin D-containing supplements.[19] However, neither the present study nor that by Hill et al. were in a random sample.[19] The vitamin D intake from food sources only (i.e., excluding supplement use) by the women in the present study (4.6 µg) is close to that reported for a representative sample of 50-64-year-old Irish women (3.4 µg/d).[18]

The problem with establishing appropriate Dietary Reference Values (DRVs) for vitamin D has been a long-standing one. Determining the amount of vitamin D provided by sunlight is difficult. For this reason, an RDA of 0-15 µg/day was established for Irish 11-13-year-old girls and 10 µg/day for adults aged 65 year olds and older.[33] In the US, it is recommended that 70 year olds and older consume at least 15 µg vitamin D daily[34] to help counteract the slower rate of skin production with age, and thus to maintain adequate serum levels 25 (OH) D for bone health. Similarly, the FAO/WHO expert group on human vitamin and mineral requirements recommends 15 µg/day for adults 65 years and older.[35] The mean daily intake of vitamin D in the current sample of 70-76-year-old Irish women (11.2 µg/d) falls substantially short of this recommendation, with 80.5% failing to reach this intake level. Similarly, the mean daily intake of vitamin D from all sources in 11-13 year old Irish girls (2.6 µg/d) falls short of the US and FAO/WHO expert group recommendation of 5 µg/d, with 87% of girls failing to reach this intake level. These low values are consistent with vitamin D intake data from other European countries.[16,36,37]

Of particular interest in the current study was the much lower prevalence of sub-optimal vitamin D status in supplement users compared with non-users. For example, during late winter/early spring (a time at which vitamin D status is at its lowest) there was an absence of severe vitamin D deficiency and only about 18% had marginal vitamin D deficiency among elderly women who were supplement users, whereas 40% and about 47% of elderly women had severe and marginal vitamin D deficiency, respectively, among non-supplement users. These findings suggest that the use of vitamin D-containing supplements was protective of vitamin D status. The vitamin D content of the supplements used by the women ranged from 2.5-20 µg, with a mean content of 8.5 µg. Glerup et al. reported that vitamin D supplementation with 10 µg/d was insufficient to prevent winter time hypovitaminosis D in ethnic Danish Moslem women,[38] while Dawson-Hughes et al. reported that at least 20 µg/d are required to prevent osteoporosis.[39] In the present study, only 15% of the women had an intake of 20 µg/d, and only one woman was able to achieve a dietary intake ≥20 µg/d without using supplements.

In the elderly women, there was a seasonal variation in serum 25 (OH) D levels among both supplement users and non-users, suggesting that supplement use during summer time still, on average, conferred a benefit to vitamin D status. The seasonal variation in serum 25 (OH) D levels observed in young adolescent girls and elderly women in the present study has been reported in other studies of elderly Irish subjects[21,22] and in adult Irish women (aged 51-69 years),[19] as well as in various other European populations.[9,17]

The secretion of PTH has also been suggested as a biochemical marker for vitamin D deficiency.[8,29] Serum PTH concentration also exhibited a seasonal variation in adolescent girls, but not in elderly women. Hill et al. also reported a lack of effect of season on serum PTH in adult Irish women.[19] In addition to being influenced by serum 25 (OH) D levels, serum PTH is also affected by dietary calcium intake[40] as well as age and gender[41] and use of oestrogen.[42] The mean calcium intake in women in the present study was quite high (mean (SD) 973 (404) mg/d). Mean serum 25 OH D levels were much lower in young girls than elderly women during late winter/early spring in the present study, which may explain, at least in part, the difference in response of serum PTH to season in the two population sub-groups.

While there is no other report of serum 25 (OH) D levels in Irish children with which to compare the present findings, the prevalence of severe vitamin D deficiency (levels of 25 (OH) D below 25 nmol/l) during late winter/early spring in the entire group of elderly free-living women in the present study (14%) was much less than that reported in previous studies of ambulatory, free-living elderly Irish subjects during late winter/early spring. For example, Freaney et al. reported that 86% of elderly men and women (n 29; mean age, 74 y) had serum 25 (OH) D levels below 25 nmol/l.[22] McKenna et al. reported that 50% of healthy elderly people (n 30; mean age, 69 years) and 80% of elderly people attending a day-centre for elderly (n 49; mean age, 74 years) had serum 25 (OH) D levels below 25 nmol/l.[21] Meade et al. reported that 63% of patients in two rural areas in Ireland had undetectable levels of serum 25 (OH) D (i.e., less than 5 nmol/l).[23] However, vitamin D supplement use was an exclusion criterion in all of the above studies, bar that by McKenna et al., in which about 10% of subjects took a vitamin D-containing supplement.[21] In the present study, a large number of elderly women (>55%) took vitamin D-containing supplements and we suspect that the current results are a significant underestimation of the prevalence of vitamin D deficiency in the general population. However, the prevalence of

ORIGINAL PAPER

vitamin D deficiency during late winter/early spring was still only 40% in subjects not taking vitamin D-containing supplements, and this is still lower than the estimates of 50-80% reported previously. It should also be noted that comparison of prevalence of vitamin D deficiency (based on serum 25 (OH) D concentrations) in the present study and these older studies may be questionable due to lack of standardization between methods (an issue of less concern currently because of the establishment of the Vitamin D External Quality Assessment Scheme (DEQAS)) and other technical problems, such as the underestimation of total 25 (OH) D by some radioimmunoassays.[17]

Finally, while bone status measurements were not assessed in the present study, there is considerable evidence to suggest that vitamin D deficiency and insufficiency (defined as serum 25 (OH) D levels below 25 and 40 nmol/l, respectively) may be detrimental to bone health in adults [see reviews[9,17,34,35]]. Recent results from studies in adolescents provide evidence of a possible adverse effect of vitamin D deficiency and insufficiency for bone health in children.[26,43,44] For example, in a three-year longitudinal study of Finnish girls aged 9-15 years, Lehtonen-Veromaa et al. found that baseline 25 (OH) D levels were positively correlated with unadjusted three-year change in BMD at the lumbar spine ($r = 0.35$; $P<0.001$) and femoral neck ($r = 0.32$; $P<0.001$).[43] The difference from baseline-adjusted three-year BMD accumulation between those with severe hypovitaminosis D (serum 25 (OH) D <20 nmol/l) and those with a normal vitamin D status (serum 25 (OH) D ≥35 nmol/l) was 4% at the lumbar spine in the girls with advanced sexual maturation. In another study from Finland, Outila et al. showed that 13.5% and 62% of 14-16-year-old girls had severe and marginal vitamin D deficiency, respectively.[27] They also showed that subjects with serum 25 (OH) D levels less than 40 nmol/l had low mean forearm BMD values at both the radial ($P=0.04$) and ulnar ($P=0.08$) sites.[26]

CONCLUSION

The findings of the present study show that sub-optimal vitamin D status (serum 25 (OH) D levels below 40 nmol/l) is quite common in elderly Irish women, confirming previous reports. Although sub-optimal vitamin D status also occurs in adolescent girls in Ireland, these data are limited in number and also by sample selection and cannot be generalised to the wider population. In fact, it is likely that the prevalence in the population is higher than these data suggest. Hence, an investigation of vitamin D status in a representative sample of adolescents and elderly in the Irish population is required. Furthermore, the impact of this sub-optimal vitamin D status on bone health in both population subgroups needs to be investigated. Vitamin D supplementation was associated with the absence of severe deficiency and considerably lowered the prevalence of marginal deficiency of vitamin D in elderly Irish women in the present study. Vitamin D supplementation was also associated with improved vitamin D status in the elderly women during summer time, suggesting that summer sunlight exposure was not sufficient to optimise vitamin D status.

REFERENCES

1. Chapuy MC, Meunier PJ. Vitamin D insufficiency in adults and the elderly. In: Vitamin D, Eds Feldman D, Glorieux F, Pike JW, Academic Press, San Diego, CA 1997: 679-693.
2. Van Leeuwen JP, van den Bemd GJ, van Driel M, Buurman CJ, Pols HA. 24,25-Dihydroxyvitamin D(3) and bone metabolism. *Steroids* 2001; 66: 375-380.
3. Compston JE. Vitamin D deficiency: time for action. Evidence supports routine supplementation for elderly people and others at risk. *BMJ* 1998; 317: 1466-1467.
4. Parfitt AM, Gallagher JC, Heaney RP, Johnston CC, Neer R, Whedon GD. Vitamin D and bone health in the elderly. *Am J Clin Nutr* 1982; 36: S1014-S1031.
5. Lips P, Netelenbos JC, Jongen MJ, et al. Histomorphometric profile and vitamin D status in patients with femoral neck fracture. *Metab Bone Dis Relat Res* 1982; 4: 85-93.
6. Lips P, Van Ginkel FC, Jongen MJ, Rubertus F, Van Der Vijgh WJ, Netelenbos JC. Determinants of vitamin D status in patients with hip fracture and in elderly control subjects. *Am J Clin Nutr* 1987; 46: 1005-1010.
7. Ooms ME, Roos JC, Bezemer PD, van der Vijgh WJ, Bouter LM, Lips P. Prevention of bone loss by vitamin D supplementation in elderly women: a randomized double-blind trial. *J Clin Endocrinol Metab* 1995; 80: 1052-1058.
8. Chapuy MC, Preziosi P, Maamer M, et al. Prevalence of vitamin D insufficiency in an adult normal population. *Osteoporos Int* 1997; 7: 439-443.
9. Zittermann A. Vitamin D in preventative medicine: are we ignoring the evidence? *Br J Nutr* 2003; 9: 552-572.
10. Holick MF. Vitamin D: importance in the prevention of cancers, type 1 diabetes, heart disease and osteoporosis. *Am J Clin Nutr* 2004; 79: 362-71.
11. Stamp TCB, Round JM. Seasonal changes in human plasma levels of 25 (OH) vitamin D. *Nature* 1974; 247: 563-565.
12. McKenna MJ. Differences in vitamin D status between countries in young adults and the elderly. *Am J Clin Nutr* 1992; 93: 69-77.

13. Lips P, Duong T, Oleksik A, et al. A global study of vitamin D status and parathyroid function in postmenopausal women with osteoporosis: Baseline data from the multiple outcomes of raloxifene evaluation clinical trial. *J Clin Endocrinol Metab* 2001; 86: 1212-1221.

14. Webb AR, Kline LW, Holick MF. Influence of season and latitude on the cutaneous synthesis of vitamin D_3: exposure to winter sunlight in Boston and Edmonton will not promote vitamin D_3 synthesis in human skin. *J Clin Endocrinol Metab* 1988; 67: 373-378.

15. Department of Health Nutrition and Bone Health with Reference to Calcium and Vitamin D. Dietary Reference Values for Food Energy and Nutrients for the United Kingdom. Report in Health and Social Subjects no. 49. H.M. Stationery Office: London, 1998.

16. Van der Wielen RPJ, Lowik MRH, Van Den Berg H, et al. Serum vitamin D concentrations among elderly people in Europe. *Lancet* 1995; 346: 207-210.

17. Ovesen L, Andersen R, Jakobsen J. Geographical differences in vitamin D status, with particular reference to European countries. *Proc Nutr Soc* 2003; 62: 813-821.

18. Hill TR, O'Brien MM, Cashman KD, Flynn A, Kiely M. Vitamin D intakes in 18-64-year-old Irish adults. *Eur J Clin Nutr* 2004; 58: 1509-1517

19. Hill TR, Collins A, O'Brien MM, Kiely M, Flynn A, Cashman KD. Vitamin D intake and status in Irish postmenopausal women. *Eur J Clin Nutr.* 2005; 59: 404-410.

20. McKenna MJ, Freaney R, Keating D, Muldowney FP. The prevalence and management of vitamin D deficiency in an acute geriatric unit. *Ir Med J* 1981; 74: 336-338.

21. McKenna MJ, Freaney R, Meade A & Muldowney FP Hypovitaminosis D and elevated serum alkaline phosphatase in elderly Irish people. *Am J Clin Nutr* 1985; 41, 101-109.

22. Freaney R, McBrinn Y, McKenna MJ. Secondary hyperparathyroidism in elderly people: combined effect of renal insufficiency and vitamin D deficiency. *Am J Clin Nutr* 1993; 58: 187-91.

23. Meade A, Moloney M, O'Keeffe D. Prevalence of vitamin D deficiency in the elderly in two rural areas in Ireland. *Ir Med J* 1986; 79: 359.

24. Hurson M, Corish C, Sugrue S. Dietary intakes in Ireland of a healthy elderly population. *Ir J Med Sci* 1997; 166: 220-224.

25. Collins A, O'Brien MM, Flynn A, Cashman KD, Kiely M. Comparison of a 69-item food frequency questionnaire (FFQ) with a 14-day dietary history (DH) to estimate vitamin D intakes in 50-75-year-old Irish women. *Proc Nutr Soc* 2003; 62: 21A.

26. Outila TA, Karkkainen MU & Lamberg-Allardt CJ. Vitamin D status affects serum parathyroid hormone concentrations during winter in female adolescents: associations with forearm bone mineral density. *Am J Clin Nutr* 2001; 74: 206-10.

27. Guillemant J, Le HT, Maria A, Allemandou A, Peres G, Guillemant S. Winter time vitamin D deficiency in male adolescents: effect on parathyroid function and response to vitamin D3 supplements. *Osteoporos Int.* 2001;12: 875-879.

28. Ministry of Agriculture, Fisheries and Food *Food Portion Sizes*. The Stationary Office: London: 1997

29. McKenna MJ, Freaney R Secondary hyperparathyroidism in the elderly: means to defining hypovitaminosis D. *Osteoporos Int* 1998; 8: S3-6.

30. Vieth R. Vitamin D supplementation, 25-hydroxyvitamin D concentrations, and safety. *Am J Clin Nutr* 1999; 69: 842-856.

31. Irish Nutrition and Dietetic Institute, Irish National Nutrition Survey 1990. INDI: Dublin, 1990

32. Kiely M, Flynn A, Harrington KE, et al. The efficacy and safety of nutritional supplement use in a representative sample of adults in the North/South Ireland Food Consumption Survey. *Public Health Nutr* 2001; 4 1089-1097.

33. Food Safety Authority of Ireland Recommended Dietary Allowances for Ireland. Government Publications Sales Office: Dublin, 1999

34. Institute of Medicine, Dietary Reference Intakes. For Calcium, Phosphorus, Magnesium, Vitamin D and Fluoride. National Academy Press, Washington, DC, 1997; 1-448

35. FAO/WHO (1998) Human vitamin and mineral requirements: A report of the joint FAO/WHO expert consultation, Bangkok, Thailand. Food and Nutrition Division, Rome, 1998, http://ftp.fao.org/es/esn/nutrition

36. Rasmussen LB, Hansen GL, Hansen E, et al. Vitamin D: should the supply in the Danish population be increased? *Int J Food Sci Nutr* 2000; 51: 209-215.

37. Henderson L, Irving K, Gregory J, et al. The National Diet and Nutrition Survey: adults aged 19 to 64 years-Vitamin and mineral intake and urinary analytes, 2003 http://www.foodstandards.gov.uk/multimedia/pdfs/ndnsv3.pdf

38. Glerup H, Mikkelsen K, Poulsen L, et al. Commonly recommended daily intake of vitamin D is not sufficient if sunlight exposure is limited. *J Intern Med* 2000; 247: 260-268.

39. Dawson-Hughes B, Harris SS, Krall EA, Dallal GE. Effect of calcium and vitamin D supplementation on bone density in men and women 65 years of age or older. *N Engl J Med* 1997; 337: 670-676.

40. Karkkainen MU, Wiersma JW, Lamberg-Allardt CJ. Postprandial parathyroid hormone response to four calcium-rich foodstuffs. *Am J Clin Nutr* 1997; 65: 1726-1730.

41. Yan L, Prentice A, Zhang H, Wang X, Stirling DM, Golden MM. Vitamin D status and parathyroid hormone concentrations in Chinese women and men from north-east of the People's Republic of China. *Eur J Clin Nutr* 2000; 54: 68-72.

42. Riggs BL, Melton LJ 3rd. Evidence for two distinct syndromes of involutional osteoporosis. *Am J Med* 1983; 75: 899-901.

43. Lehtonen-Veromaa MK, Mottonen TT, Nuotio IO, Irjala KM, Leino AE, Viikari JS. Vitamin D and attainment of peak bone mass among peripubertal Finnish girls: a 3-y prospective study. *Am J Clin Nutr* 2002; 76: 1446-1453.

44. Cheng S, Tylavsky F, Kroger H, et al. Association of low 25-hydroxyvitamin D concentrations with elevated parathyroid hormone concentrations and low cortical bone density in early pubertal and prepubertal Finnish girls. *Am J Clin Nutr* 2003; 78: 485-492.

Correspondence to: Prof Kevin D. Cashman, Dept of Food and Nutritional Sciences, University College, Cork
Tel.: +353 21 4901317; Fax.: +353 21 4270244
E-mail: k.cashman@ucc.ie