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Vitamin D: determinants of status, indications for testing and knowledge in a convenience sample of Irish adults

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Abstract

Vitamin D deficiency is common in Irish adults, though there is limited research on its determinants, knowledge of vitamin D or indications for testing. We aimed to explore the determinants of vitamin D status in adults and examine knowledge and reasons for testing. The study population comprised adults who had serum 25-hydroxyvitamin D tested by general practitioners request at a Dublin Hospital in 2020. Questionnaires detailing dietary intake, sun exposure, ethnicity, biophysical factors and vitamin D knowledge were sent to a sample stratified by age, sex and vitamin D status. In total, there were 383 participants, mean age 56·0 (SD 16·6) years. Wintertime deficiency disproportionally affected non-white *v.* white (60 % *v.* 24 %, $P < 0{\cdot}001$). The greatest predictors of deficiency were low vitamin D intake (< 10 µg/d) ($P < 0{\cdot}001$) and non-white ethnicity ($P = 0{\cdot}006$), followed by sun avoidance ($P = 0{\cdot}022$). It was also more prevalent in those with lower body exposure when outdoors. The majority (86 %) identified vitamin D as important for bone health. However, 40 % were tested for non-clinical indications and half were not aware of the recommended daily allowance (RDA). Low vitamin D intake was the most important determinant of deficiency, but ethnicity and sun exposure habits were also significant predictors. The majority had no clear indication for testing and were not aware of the RDA. Public health policies to improve knowledge and vitamin D intake, especially for those of non-white ethnicity and with reduced sun exposure, should be considered.

Keywords: Vitamin D: Ireland: Determinants: Knowledge: Testing

Vitamin D is primarily derived (80–90 %) from the action of UVB sunlight on dehydrocholesterol in the skin and apart from supplement use only a small proportion is obtained from dietary sources(1). However, cutaneous synthesis is negligible between October and March in Ireland which results in a dependency on dietary vitamin D in winter months(2). Apart from season, UVB exposure also depends on latitude, cloud cover, air pollution, sunscreen use and clothing while biophysical factors such as skin type and ageing can affect cutaneous synthesis(3,4). However, the Irish diet is characteristically low in sources of vitamin D including cod liver oil and oily fish, with 87 % of men and 77 % of women not meeting the recommended intake (10 µg)(5,6). Furthermore, only 10–17 % of Irish adults consume a supplement, yet this is the most consistent way of achieving adequate intake(5,7).

To date, most research on the determinants of vitamin D status in the Irish population has focused on older adults(7–10). Overall, studies point to supplement use as the most important determinant(7,9,10). Several have identified a characteristic seasonal variation and found positive associations with proxy measures of sun exposure (sun enjoyment, sun holiday travel, geographical UVB irradiation and sunshine hours)(4,10,11). However, they did not specifically assess body skin exposure. Lower physical activity and frailty which may be indirectly linked to sun exposure have also been associated with lower vitamin D status(9,10). Only four studies have investigated vitamin D status in a non-European ethnic demographic, finding lower 25-hydroxyvitamin D (25(OH)D) and a high prevalence of deficiency (< 30 nmol/l) between 57 and 88 %(12–15). Few have examined the association with dietary or specific food intakes,

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Abbreviations: RDA, recommended daily allowance; 25(OH)D, 25-hydroxyvitamin D.; FFQ, Food Frequency Questionnaire; Ca, Calcium.

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though fortified milk, fish and egg consumption were found to be positive determinants in older adults and adolescents(4,10,16). Biophysical factors such as increased BMI and female sex were also associated with lower vitamin D status in children and older Irish adults(7,9,16–18) while smoking, living alone and lower socio-economic status have been found to be negative predictors(9,10,19).

Despite an increase in referrals for vitamin D testing in Ireland and evidence of up to a third being done inappropriately (too early, too frequently or in replete individuals), no studies have explored the indications for these 25(OH)D assessments(20–22). Furthermore, just one study investigated knowledge regarding vitamin D, but only in pregnant women where 70 % had little awareness of dietary sources(12). Given the lack of studies, we aimed to explore in detail the biophysical, lifestyle and dietary determinants of vitamin D status in a diverse population of adults. Furthermore, we aimed to explore for the first time in Ireland indications for vitamin D testing, as well as adult knowledge of vitamin D.

Methods

Data collection

Data were collected at St James's Hospital (SJH), Dublin, Republic of Ireland (53° Northern latitude) which receives referrals primarily from Dublin city and surrounds. A search was completed for vitamin D requests from primary care general practitioners in 2020 using the laboratory information system (iSOFT Telepath®) at SJH Biochemistry Department. A convenience sample was identified using the exclusion criteria: age < 18 years, incomplete or missing demographic data, non-community address (e.g. hospital, nursing home, convent) or location outside the Republic of Ireland.

Participant screening and selection

Of the 13 669 results collected, 1639 were excluded due to incomplete data (*n* 423), age < 18 (*n* 262), non-community address (*n* 239) and repeat samples (*n* 715) (Fig. 1). This left a sample size of 12 030 from which we randomly selected 1260 adults initially stratified by season (winter: *n* 630, summer: *n* 630). Within each season, we further stratified by age (above 50 years, *n* 315, below 50 years, *n* 315) and then by vitamin D status (< 30 nmol/l, *n* 100; 30–49 nmol/l, *n* 100; 50–124 nmol/l, *n* 100 nmol/l; > 125 nmol/l, *n* 15). In this way, we were left with a sample of 1260 adults with an equal distribution of age, vitamin D status and season of testing to which questionnaires were sent. Participants were contacted via postal address with an information sheet, consent form and questionnaire which could be completed online (via link to survey monkey) or sent back manually in hard copy form in a pre-stamped, self-addressed envelope.

Questionnaire

The questionnaire we designed included thirty-three questions detailing medical information (indications for testing and pre-existing conditions that might affect vitamin D), biophysical (ethnicity, BMI, body size(23), socio-economic status (education level; third level or below), vitamin D intake (supplement and dietary intake) as well as dietary Ca intake using a FFQ, lifestyle (smoking, alcohol intake) and sun exposure (time spent in peak sunshine, sunscreen use, body exposure, sun-seeking habits). Information also included data on participants vitamin D knowledge (familiarity, awareness of health benefits and recommended daily allowance (RDA)). Questionnaires were sent to individuals between March and June 2022 and answers to our survey related to the period in which they had serum 25(OH) D tested. Reasons for vitamin D testing were queried, with routine health checks, patient requests and fatigue considered inappropriate.

Ethnicity was dichotomised into white and non-white (Black, Asian-Chinese, Asian-other and mixed). BMI category was determined based on self-identification using a 10 image scale of body sizes representing underweight, normal weight, overweight and obese as validated by Harris *et al.*(23). We asked if participants had any of the following conditions that could affect vitamin D status (gastrointestinal conditions, e.g., Crohn's, coeliac disease, bowel/stomach surgery, inflammatory bowel disease), cystic fibrosis, liver/renal conditions, pancreatic disease and eating disorders.

Sun-seeking was categorised as no (avoid the sun) or yes (spend some time/seek the sun). Time spent outdoors was calculated based on the daily period spent outside between the hours of 13.00 and 17.00 during March to September. Body exposure was categorised as high, if more than face and hands exposed on a sunny day and otherwise as being low. Vitamin D familiarity was categorised as yes (extremely, very familiar) *v.* no (somewhat, not so, not at all familiar).

Vitamin D/Ca intake

Dietary vitamin D (μg) from food sources (unfortified and fortified) and Ca intake (mg) was calculated using a FFQ adapted from The Irish LongituDinal Study on Ageing questionnaire(9). For each food consumed, an average vitamin D/Ca content per portion was estimated using food manufacturer's information and Nutritics software version 5.78 (online Supplementary Table 1). Where an approximate size of a food portion was not specified in the FFQ, an average portion size was assumed (e.g. yogurt = 125 g pot). In order to estimate daily dietary Ca and vitamin D intake, we initially calculated total weekly intake as follows: once per week ($1 \times$ unit food), 2–4 times per week ($3 \times$ unit food), 5–6 times per week ($5{\cdot}5 \times$ unit food), once per day ($7 \times$ unit food), 2–3 times per day ($2{\cdot}5 \times \text{unit} \times 7$) and 4–5 times per day ($4{\cdot}5 \times \text{unit} \times 7$). The weekly total was then divided by 7 to give the total daily intake for vitamin D and Ca. We also dichotomised daily vitamin D intake from unfortified or fortified sources. The daily vitamin D intake from supplements (cod-liver oil, vitamin D only supplement, multivitamin containing vitamin D) was also calculated. Total daily vitamin D intake was then estimated by combining supplemental and dietary intake, and those who met the RDA were identified (10 μg/d as per advised by the Food Safety Authority of Ireland (FSAI) at the time of vitamin D sampling). We also identified those who exceeded the tolerable upper intake level for

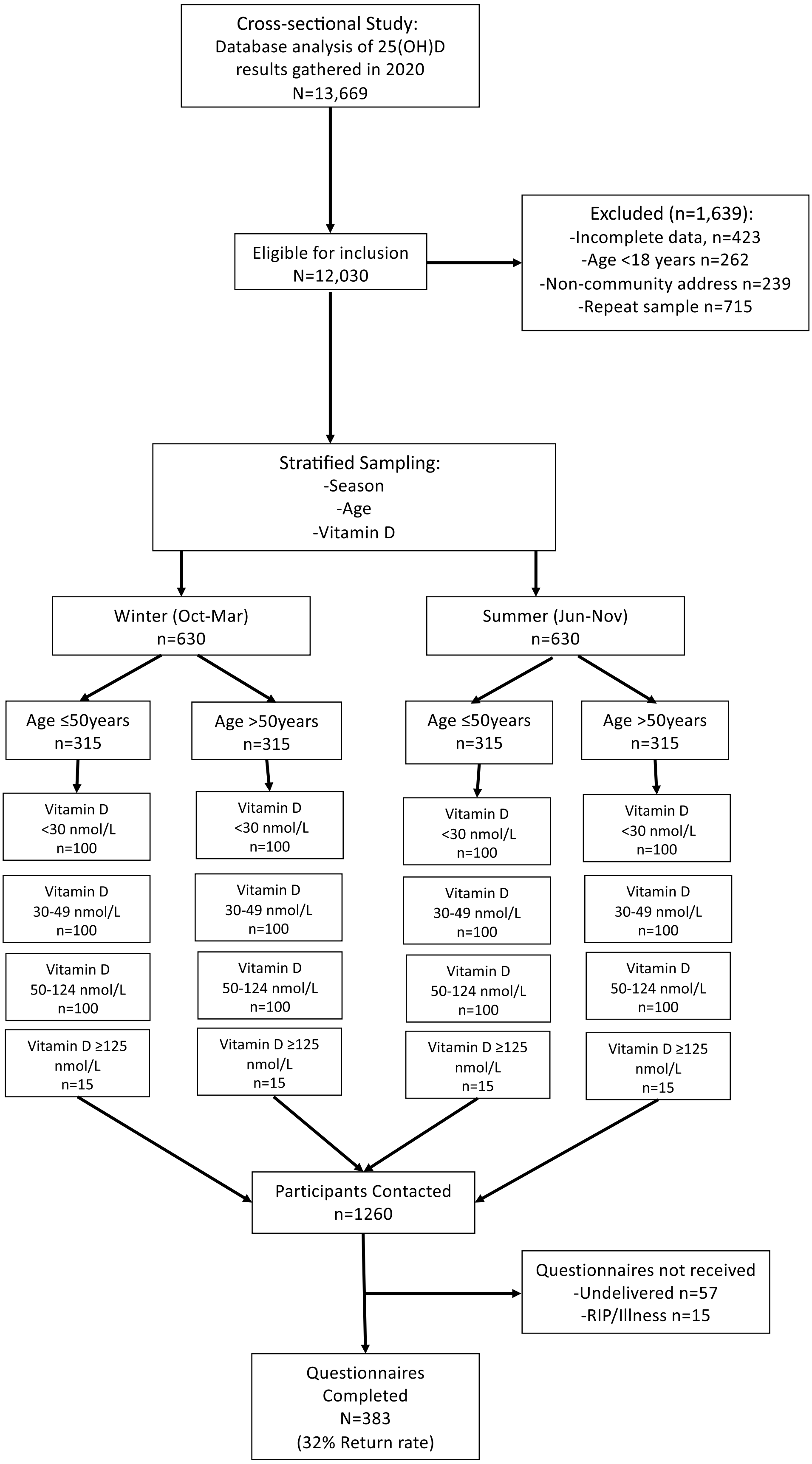

Fig. 1. Flow diagram.

vitamin D of 100 μg (4000 μg) per day[24] and who met the dietary Ca RDA (1000 mg/d in those aged 18–24 and 950 mg/d when aged > 25 years)[24].

Ethics

Ethical approval for this study was granted by the St James's Hospital/Tallaght University Hospital (SJH/TUH) joint ethics committee (Ref: 5658). This study was conducted according to the Declaration of Helsinki.

Serum 25-hydroxyvitamin D and biochemical markers

Liquid chromatography tandem mass spectrometry (API 400; AB SCIEX) was utilised to measure vitamin D (total 25(OH)D2 and 25(OH)D3) at the Biochemistry Department of SJH. A validated method of analysis was employed (Chromsystems Instruments and Chemicals GmbH; MassChrom 25-OH-Vitamin D3/D2) accredited to ISO 15189:2012 standards. Participation in the vitamin D External Quality Assessment Scheme and assay of internal and third-party quality controls ensured assay quality. National Institute of Standards and Technology 972 25(OH)D standard reference material (SRM 972) was used to determine accuracy. The inter- and intra-assay coefficients of variation are 5·7 and 4·5 %, respectively. Vitamin D cut-offs were defined according to the Institute of Medicine as deficiency: < 30 nmol/l, insufficiency: 30·0–49·9 nmol/l and sufficiency: ≥ 50 nmol/l[22,25]. Serum 25(OH)D ≥ 125 nmol/l was also identified as this level may constitute vitamin D excess and has been associated with some adverse health outcomes[25,26].

Statistics

Data were checked for normality by the Kolmogorov–Smirnov test. Geometric mean with standard deviation was reported in tables. Median and interquartile range were used to report dietary intakes. Categorical variables were tested using Chi-squared, with independent sample t-tests, Mann–Whitney and Kruskal–Wallis test for continuous variables. Independent factors associated with vitamin D deficiency (< 30 nmol/l) were explored in binary logistic regression models using the following variables and reference categories: age (≥ 50 years), sex (male), BMI category (normal weight), season of sampling (summer), ethnicity (white), smoking (non-smoker), alcohol (alcohol consumer), sun habits (sun seeker), education (third level) and adherence to vitamin D RDA (yes/no). Body exposure and hours spent in peak sunshine were co-correlated with sun-seeking behaviour and were therefore not included in the model. Statistical analysis was carried out using SPSS (Version 26, IBM Corp). Statistical significance was accepted when $P < 0·05$.

Results

Demographics

Questionnaires were completed by 383 (32 %) of the contacted participants. In fifty-seven cases (4·5 %), they were not received by the participant due to a change of address, and in fifteen (1·1 %), they were not completed due to death or illness (Fig. 1). Characteristics of the sample are shown in Table 1. The average age was 56·0 (SD 16·6) years, 60 % were female and 90 % were of white ethnicity. Two-thirds (67 %) had third level education and one-fifth (21 %) identified as having a condition that could predispose to lower vitamin D. The majority of the population were overweight or obese (58 %), with 36 % normal and 7 % underweight. Most participants were sun seekers (74 %), had a high UV body exposure (81 %) and used sunscreen (71 %) and were not familiar with vitamin D (70 %). About 50 % (192/383) were taking a vitamin D supplement with precise data on vitamin D content and dosing frequency available in 79 % (151/191). For this reason, the sample size (n 338) on which there was estimation of total vitamin D intake and analysis of RDA was smaller (Table 3). There was a near equal split between

Table 1. Population demographics
(Numbers and percentages)

		n	%
Sex	Female	230	60
	Male	153	40
Age (years)	<50	145	38
	≥50	238	62
Age categories (years)	18–39	72	19
	40–49	69	18
	50–59	66	17
	60–69	87	23
	70–79	60	16
	>80	29	8
Season	Winter	219	57
	Summer	164	43
Condition affecting vit D*	Yes	79	21
	No	304	79
Ethnicity	White	344	90
	Non-white	39	10
BMI (n 380) (kg/m^2)	Underweight	26	7
	Normal weight	135	36
	Overweight/obese	219	58
Third level education (n 379)	Yes	256	68
	No	123	32
Smoking (n 379)	Yes	41	11
	No	338	89
Alcohol consumer	Yes	311	81
	No	72	19
Supplement user	Yes	192	50
	No	191	50
Sunscreen user (n 380)	Yes	271	71
	No	109	29
Sun seeker (n 380)	Yes	282	74
	No	98	26
Body exposure (n 380)	Low	73	19
	High	307	81
Time spent in peak sunshine (min)	0	74	19
	<30	64	17
	>30	245	64
Vitamin D familiarity	Yes	115	30
	No	268	70

Season: winter, Oct–Mar; summer, Apr–Nov. Conditions affecting vitamin D included gut/gastrointestinal diagnoses (e.g. Crohn's disease, coeliac disease, bowel/stomach surgery, inflammatory bowel disease), cystic fibrosis, liver/renal conditions, pancreatic disease and eating disorders. BMI was determined based on response to a 10-point image scale[23] on body size categorised as underweight, normal weight, overweight and obese. Sun-seeking was categorised as no (avoid the sun) or yes (spend some time/seek the sun). Body exposure was categorised as low if only face and hands or higher if additional body parts exposed on a sunny day. Time spent outdoors calculated based on the daily period spent outside between the hours of 13.00 and 17.00 during March to September. Vitamin D familiarity was defined as yes (extremely, very) *v.* no (somewhat, not so, not at all familiar).
*$P < 0·05$.

Table 2. Vitamin D categories by season
(Numbers; mean values and standard deviations)

			GM		Winter							Summer							
		n	Mean	SD	*P*	*n*	<30 %	*P*	30–49 %	*P*	≥50 %	*P*	*n*	<30 %	*P*	30–49 %	*P*	≥50 %	*P*
Sex	Female	230	48·2	36·0	0·853	135	27	0·908	24	0·073	49	0·083	95	21	0·559	33	0·336	46	0·197
	Male	153	47·5	32·2		84	27		36		37		69	17		26		57	
Age	<50 years	145	48·5	38·3	0·704	81	30	0·492	26	0·477	44	0·974	64	20	0·836	22	0·703	58	0·140
	≥50 years	238	47·6	31·9		138	25		30		44		100	19		35		46	
Age category (years)	18–39	72	43·3	39·1	0·380	40	40	0·129	25	0·335	35	0·113	32	22 %	0·979	25 %	0·372	53 %	0·528
	40–49	69	54·0	37·1		37	22		24		54		32	19		19		63	
	50–59	66	47·3	31·4		43	26		42		33		23	17		26		57	
	60–69	87	50·9	32·9		51	16		27		57		36	19		36		44	
	70–79	60	44·0	34·2		34	35		21		44		26	23		35		42	
	>80	29	47·9	27·2		14	29		36		36		15	13		47		40	
Condition affecting vit D	Yes	79	47·1	35·1	0·774	37	38	0·101	22	0·292	41	0·614	42	19	0·930	36	0·338	45	0·419
	No	304	48·2	34·4		182	25		30		45		122	20		28		52	
Ethnicity	White	344	50·8	34·3	<0·001	199	24	<0·001	30	0·364	47	0·022	145	16	0·001	29	0·461	55	0·001
	Non-white	39	28·7	26·2		20	60		20		20		19	47		37		16	
BMI (*n* 380)	Underweight	26	61·2	35·8	0·014	12	25	0·963	8	0·094	67	0·152	14	14	0·581	21	0·705	64	0·319
	Normal Weight	135	51·2	41·5		83	28		24		48		52	15		29		56	
	Overweight/Obese	219	45·2	28·2		122	26		34		40		97	22		32		46	
Third level education (*n* 379)	Yes	256	51·3	34·9	0·018	150	23	0·071	32	0·15	45	0·779	106	15	0·072	24	0·02	61	<0·001
	No	123	42·6	33·1		67	34		22		43		56	27		41		32	
Smoking (*n* 379)	Yes	41	40·0	33·8	0·065	23	43	0·047	35	0·521	22	0·019	18	33	0·104	17	0·201	50	0·912
	No	338	49·5	34·5		194	24		28		47		144	17		31		51	
Alcohol consumer	Yes	311	51·3	34·2	<0·001	185	23	0·001	30	0·252	47	0·057	126	14	0·002	27	0·14	59	<0·001
	No	72	35·8	33·0		34	50		21		29		38	37		39		24	
Supplement user	Yes	192	60·0	37·0	<0·001	107	15	<0·001	21	0·009	64	<0·001	85	8	<0·001	28	0·634	64	0·001
	No	191	38·3	27·0		112	38		37		25		79	32		32		36	
Sunscreen user (*n* 380)	Yes	271	52·5	36·0	<0·001	157	22	0·013	34	0·005	44	0·719	114	13	0·004	27	0·223	60	0·001
	No	109	39·4	27·7		60	38		15		47		49	33		37		31	
Sun seeker (*n* 380)	Yes	282	50·6	35·1	0·041	172	23	0·019	31	0·134	46	0·476	110	15	0·095	29	0·697	55	0·095
	No	98	42·3	32·1		45	40		20		40		53	26		32		42	
Body exposure (*n* 380)	Low	73	42·4	32·9	0·044	34	32	0·38	35	0·381	32	0·115	39	31	0·032	33	0·609	36	0·031
	High	307	49·8	34·7		183	25		28		47		124	15		29		56	
Time spent in peak sunshine (min)	0	74	44·8	34·3	0·531	41	37	0·225	20	0·131	44	0·840	33	24	0·745	36	0·186	39	0·118
	<30	64	47·3	37·3		37	30		22		49		27	19		41		41	
	>30	245	49·1	33·9		141	23		33		43		104	18		25		57	
	Total	383	47·9	34·5		219	27		29		44		164	20		30		51	

GM mean, geometric mean; Vit D, vitamin D.
Vitamin D categories reported as % < 30 nmol/l, %30–49 nmol/l and % ≥ 50 nmol/l. Winter was defined as October–March, Summer: April–Sept. *P*-values were determined by Mann–Whitney or Kruskal–Wallis test for continuous variables, and Chi-squared was used for categorical, significant at $P < 0.05$.

Table 3. Predictors of vitamin D deficiency (< 30 nmol/l) in regression (Odds ratios)

Non-deficient (> 30 nmol/l) v. deficient (< 30 nmol/l)	*n*	B	OR	Lower, upper	*P*
Intercept		−3·099	0·045		
Age < 50	123	−0·284	0·753	0·379, 1·494	0·416
Female	204	0·173	1·189	0·661, 2·137	0·564
BMI – Underweight	22	−0·521	0·594	0·153, 2·308	0·452
BMI – Overweight/obese	194	0·045	1·046	0·571, 1·917	0·884
Ethnicity – Non-white	31	1·361	3·899	1·464, 10·379	0·006*
Smoking – Yes	36	0·655	1·924	0·817, 4·530	0·134
Alcohol – No	65	0·616	1·851	0·894, 3·831	0·097
Third level education – No	109	0·191	1·210	0·644, 2·275	0·553
Sun seeker – No	89	0·731	2·077	1·113, 3·876	0·022*
Meeting vitamin D RDA – No	189	1·267	0·282	0·15, 0·528	<0·001**

Logistic regression adjusts for all of the above variables and season. Reference category for each variable: meeting vitamin D RDA: yes; sun-seek: yes; third level education: yes; alcohol consumer: yes; smoking: no; ethnicity: white; BMI: normal weight; sex: male: age: ≥ 50 years.
* $P<0{\cdot}05$.
** $P<0{\cdot}001$

seasons, with 57 % of results in winter and 43 % in summer. In total, 24 % of this stratified convenience sample were vitamin D deficient (< 30 nmol/l), 29 % insufficient (30–50 nmol/l) and 5 % had levels > 125 nmol/l. The associations between vitamin D status and factors are discussed below and outlined in Tables 2 and 3.

Biophysical

There was no significant difference in 25(OH)D by sex or age (Table 2). However, those of white ethnicity had significantly higher mean 25(OH)D levels than non-white (50·8 *v.* 28·7 nmol/l, $P<0{\cdot}001$). They also had a substantially lower prevalence of deficiency (24 % *v.* 60 %, $P=0{\cdot}001$) and higher rate of sufficiency (47 % *v.* 20 %, $P=0{\cdot}022$) in winter. In summer, results for white *v.* non-white were also similar for deficiency (16 % *v.* 47 %, $P=0{\cdot}001$) and sufficiency (55 % *v.* 16 %, $P=0{\cdot}001$). Compared with the white population, the non-white cohort had a higher proportion < 50 years (77 % *v.* 33 %, $P<0{\cdot}001$) and of non-alcohol consumers (64 % *v.* 14 % $P<0{\cdot}001$), but there was no difference in supplement use, season of sample, smoking, education, body exposure or proportion meeting vitamin D RDA. Furthermore, being non-white was an independent predictor of deficiency (OR 3·90, 95 % CI 1·46, 10·38, $P=0{\cdot}006$) (Table 3). Vitamin D levels were also lower in those who were overweight or obese *v.* normal weight (45·2 *v.* 51·2 nmol/l, $P=0{\cdot}014$) but this was not found to be an independent predictor of deficiency. No significant difference in 25(OH)D was identified between those with or without a condition affecting vitamin D (47·1 *v.* 48·2 nmol/l, $P=0{\cdot}774$).

Lifestyle/social factors

There was a trend for a lower overall mean 25(OH)D concentrations in smokers *v.* non-smokers (40·0 *v.* 49·5 nmol/l, $P=0{\cdot}065$) though only in winter did they have a higher prevalence of deficiency (43 % *v.* 23 %, $P=0{\cdot}047$). Furthermore, smoking was not found to predict deficiency when adjusting for other factors. Alcohol users had higher 25(OH)D than non-users (51·3 *v.* 35·8 nmol/l, $P<0{\cdot}001$) and were also less likely to be deficient in winter (23 % *v.* 50 %, $P=0{\cdot}001$) and summer (14 % *v.* 37 %, $P=0{\cdot}002$). However, they were also more likely to be sun seekers (78 % *v.* 58 %, $P<0{\cdot}001$) and it was not identified as an independent predictor of deficiency (Table 3). Finally, those with third level education had higher 25(OH)D (51·3 *v.* 42·6 nmol/l, $P=0{\cdot}018$) and were more likely to have sufficient status in the summer (61 % *v.* 32 %, $P<0{\cdot}001$), but no relationship was found with deficiency in multivariable analysis.

Sun exposure

Sun seekers were more likely to have higher 25(OH)D (50·6 *v.* 42·3 nmol/l, $P=0{\cdot}041$) and lower prevalence of deficiency in winter (23 % *v.* 40 %, $P=0{\cdot}019$). Overall, those who avoided the sun were about twice as likely to be deficient (OR 2·08, 95 % CI 1·11, 3·88, $P=0{\cdot}022$) (Table 3). High body exposure was also associated with greater mean 25(OH)D (49·8 *v.* 42·4 nmol/l, $P=0{\cdot}044$) and less deficiency in summer (15 % *v.* 31 %, $P=0{\cdot}032$). There was no difference in mean 25(OH)D comparing those who spent more or less than 30 min in peak sunshine. Finally, sunscreen users had better 25(OH)D (52·5 *v.* 39·4 nmol/l, $P<0{\cdot}001$) and were less likely to be deficient in winter (22 % *v.* 38 %, $P=0{\cdot}013$) and summer (13 % *v.* 33 %, $P=0{\cdot}004$).

Dietary intakes

The overall contribution of diet to vitamin D intake was low with half of all participants consuming less than 4·5 μg (180 μg) per day. There was a trend for better vitamin D status with higher levels of vitamin D intake from either unfortified or fortified sources (Table 4). However, total dietary vitamin D intake (combining unfortified and fortified foods) was significantly lower in those who were deficient *v.* sufficient (4·0 *v.* 5·2 μg/d, $P=0{\cdot}044$). We also identified that those who were over 50 had higher dietary intakes (median 5·4 *v.* 3·7 μg/d, $P<0{\cdot}001$) and were more likely to consume oily fish on a weekly basis (60 % *v.* 30 %, $P<0{\cdot}001$). However, there was no difference in dietary intake by sex. We also found that the median dietary Ca intake was 658 mg/d and was significantly different by vitamin D status ($P=0{\cdot}004$): lowest in those with deficiency (527 mg/d) and highest with sufficiency (768 mg/d).

Table 4. Vitamin D and Ca intake
(Medians and interquartile ranges)

		Total		< 30 nmol/l		30–49 nmol/l		≥50 nmol/l		
	n	Median	IQR	Median	IQR	Median	IQR	Median	IQR	*P*
Unfortified food	338	1·9	2·8	1·6	2·8	2·0	2·6	2·1	2·9	0·118
Fortified food	338	1·9	4·4	1·1	3·6	2·0	4·6	2·3	5·1	0·21
Unfortified and fortified	338	4·5	5·0	4·0	4·5	4·5	4·4	5·2	5·0	0·044
Supplement intake*	151	10·0	11·4	9·3	11·4	8·6	11·4	12·9	16·4	0·032
Total vitamin D intake	338	8·8	15·9	4·9	8·5	7·0	10·4	14·4	20·8	<0·001
Ca Intake	338	658·3	615·8	527·1	636·7	595·6	677·3	767·9	540·2	0·004

*Supplement intake dose (total cod-liver oil, vitamin D and multivitamin containing vitamin D) available for n 151. P-value determined by Kruskal–Wallis test, significant at $P<0·05$. Values reported as median intake (interquartile range) in micrograms for vitamin D and milligrams for Ca.

Supplement intake

The median intake due to supplements was 10·0 µg (400 µg) per day. Higher supplement intake was identified in those who were sufficient *v.* deficient (median 12·9 *v.* 9·3 µg/d, $P=0032$). Overall, those who took supplements had higher mean 25(OH)D (60·0 *v.* 38·3 nmol/l, $P<0·001$) and were much less likely to be deficient in both summer (8 % *v.* 32 %, $P<0·001$) and winter (15 % *v.* 38 %, $P<0·001$). They were also more likely to be sufficient (64 % *v.* 30 %, $P<0·001$). There was no difference in mean daily vitamin D daily intake from food in supplement users *v.* non-supplement users (6·9 *v.* 5·7 µg/d, $P=0·251$). Supplement use was also not predicted by age, sex, season ethnicity or education when explored in binary logistic regression.

Total vitamin D intake and RDA

About half of participants had a total vitamin D intake (diet and supplements) of less than 8·8 µg (352 µg) per day, but fewer than 50 % of our study sample consumed a supplement. Median total intake was highest in those who were sufficient (14·4 µg/d) and lowest in deficiency (4·9 µg/d). In fact, total intake was twice as high in non-deficient *v.* deficient (11·1 *v.* 4·9 µg/d, $P<0·001$), and nearly three times higher comparing sufficiency *v.* non-sufficiency (14·4 *v.* 5·8 µg/d, $P<0·001$). Less than half the population (43 %) met the vitamin D RDA (online Supplementary Fig. 1). However, this was much more likely in supplement *v.* non-supplement users (81 % *v.* 13 %, $P<0·001$). Furthermore, there was a substantially lower prevalence of deficiency (12 % *v.* 32 %, $P<0·001$) and higher sufficiency (64 % *v.* 33 %, $P<0·001$) in those meeting this RDA. Overall, those not achieving the RDA were 72 % more likely to be deficient (OR 0·28, 95 % CI 0·15, 0·53, $P<0·001$) (Table 3). We identified that 30 % achieved the RDA for dietary Ca intake.

Vitamin D excess

Serum 25(OH)D levels ≥ 125 nmol/l were identified in nineteen respondents and were more likely in those aged <50 years ($P=0·020$) and in supplement users ($P=0·001$). The median total vitamin D intake in those with a level ≥ 125 nmol/l was 27·5 µg (1100 µg)/d) with the highest intake of 145 µg/d (5800 µg) in a patient with a serum concentration of 131 nmol/l. Overall, 1·5 % (n 5) had an intake above the tolerable upper intake level of 100 µg (4000 µg) per day(2) and the highest 25(OH)HD level identified in this group was 193 nmol/l.

Vitamin D knowledge and testing indications

The primary reason, in more than a third (34 %) of patients for testing, was for a routine health check. Appropriate reasons for testing included unexplained aches and pains (21 %), brittle bones (10 %) and limited sun exposure (9 %), though 19 % reported 'other' which included requests due to patient request (n 13), fatigue (n 7) and immunity/COVID (n 6) (online Supplementary Fig. 2). There was a lack of awareness of current vitamin D guidelines, with nearly half (46 %) not knowing, one-third (32 %) believing the RDA was more than 20 µg (1000 µg)/d and just 12 % correctly identifying 10–15 µg (400–600 µg)/d (online Supplementary Fig. 3). The vast majority (86 %) of respondents cited vitamin D as being important for bone health with 66 % citing immunity/COVID, 47 % heart health and 40 % mental health (online Supplementary Table 4). There was no difference in vitamin D status in those who were familiar *v.* not familiar with vitamin D (61·9 *v.* 55·5 nmol/l, $P=0·097$). Vitamin D familiarity was predicted by education in binary logistic regression, with no effect found for age, sex, season or ethnicity. A total of 40 % (n 152) of referrals were inappropriate, including for routine health checks (n 132), patient request (n 13) and fatigue (n 7).

Discussion

This is the first study to investigate in detail the determinants of vitamin D status in Irish adults and to explore indications for testing as well as knowledge of vitamin D's role in health and its RDA. The strongest predicators for deficiency were low vitamin D intake (< 10 µg/d) and non-white ethnicity, and it was also twice as likely in sun avoiders. The contribution of dietary sources to overall intake was small, but it was still positively associated with better vitamin D status. However, the vast majority who met the RDA were taking supplements. More than a third had vitamin D testing for inappropriate reasons and less than 12 % could correctly identify the recommended dietary intake.

Vitamin D intake

The overall contribution of diet to vitamin D intake was low with half of all participants consuming less than 4·5 µg (180 µg) per day. The median intake due to supplements was 10·0 µg (400 µg) per day, and those taking supplements were about three times less likely to be deficient in summer. The mean difference in serum 25(OH)D in users *v.* non-users of supplements was 21·7 nmol/l, which is similar to that found previously in older Irish adults and pregnant women(10,14,27). Older adults had both higher dietary and total vitamin D intakes. These findings are in keeping with other dietary surveys in Ireland that found intakes between 3·0 and 6·9 μg/d, though being lower in younger (18–35 years) *v.* older adults (> 65 years)(6,28). We found similar rates of supplement use by age in this study which contrasts to findings elsewhere(2,5). However, oily fish consumption was more frequent in those > 50 in our survey which may partly explain their higher intake.

Nearly half (43 %) of adults did not meet the RDA for vitamin D while in those taking supplements this was lower at 19 %. However, some supplements, especially those over the counter, contain relatively small amounts of vitamin D and/or Ca. Importantly, those achieving the vitamin D RDA were 72 % less likely to be deficient though this still occurred in 12 % of our population. Previous meta-analysis studies estimated that 12–13 μg/d per day is required for the general population living ≥40°N to maintain wintertime vitamin D status ≥ 30 nmol/l(29,30). However, previous dietary surveys in Ireland have found that just 10 % of adults meet the 10 μg/d level, indicating that fortification may be required to achieve adequate vitamin D intakes in the population(5,29). In addition, 10 % of our survey participants were of non-white ethnicity, for whom studies suggest higher vitamin D intakes to optimise status(31). Furthermore, the RDA (10 μg/d) on which we based our analysis was the recommendation at the time participants had their serum 25(OH)D tested. However, the FSAI more recently advised on a higher daily intake (15 μg/d) for older adults (aged >65) which constitute 32 % of our sample(32). We found that 1·5 % of participants exceeded the tolerable upper intake level of 100 μg (4000 μg) per day, but the highest 25(OH)D level identified was below that which predisposes to acute vitamin D toxicity.

Ethnicity

Non-white ethnicity was associated with a very high prevalence of winter deficiency of 60 % *v.* only 24 % in white participants. Furthermore, 80 % of non-white ethnicity had levels <50 nmol/l in wintertime. The proportion in our survey who were non-white is also similar to that found in a recent census of the Dublin urban area(33). There is very limited research on vitamin D status in ethnic populations in Ireland with only four studies published(12–15). In South-East Asian adults (*n* 186) living in Dublin, 67 % had 25(OH)D < 30 nmol/l(13). A high prevalence of deficiency (<30 nmol/l) was also identified in eighty-one pregnant women of Middle Eastern and African (88 %), Sub-Saharan (68 %) and Asian origin (59 %) *v.* Thirty-one indigenous Irish (36 %) living in Ireland(12). A larger study of pregnant woman in Ireland found that those of non-white ethnicity had a mean 25(OH)D that was 19·3 nmol/l lower(14). African ethnicity was also a significant determinant of vitamin D status in a small sample (*n* 7) of Irish children(15). We found no difference in vitamin D intake, supplement use, education or body exposure between white and non-white participants suggesting that ethnic difference in skin pigmentation is having a dramatic effect on vitamin D status. However, we did not look at sun holiday travel which could explain some of the variation and has been associated with better vitamin D status in older Irish adults(10,34). Similar to our study, non-white ethnicity has been found to predict lower rates of deficiency in England(34) and better vitamin D status in European populations at a similar latitude(35).

In Ireland, overall, about 5 % of the population are non-white and this demographic has increased in recent years(36). Routine vitamin D supplementation for this section of the population is advisable as it has been found to be more effective than sunlight exposure for treating deficiency(37) and is currently recommended by the European Calcified Tissue Society(38). Importantly, the vitamin D requirements for non-whites have been estimated to be much higher than the standard RDA advised in Ireland and by most international agencies. For example, maintaining a winter serum 25(OH)D ≥ 30 nmol/l in 97·5 % of individuals who are of South Asian and Black ethnicity would require an estimated respective daily vitamin D intake of 27·3 μg (1092 μg) and 33·2 μg (1328 μg)(31). Public health information promoting dietary and supplement advice targeting this ethnic population in Ireland may be needed to address this deficiency.

Sun exposure

We found those who avoided sun exposure were up to twice as likely to be deficient while conversely greater body exposure when outside was associated with higher 25(OH)D concentrations and less deficiency in summer. This is in keeping with other Irish research which found that sun enjoyment was predictive of vitamin D status in older adults(4,10) and in patients with lupus(39). Sun-seeking behaviours have also been identified as influencing vitamin D status in Irish and European women and children(40,41). Our study indicates that summertime deficiency was halved in those with high *v.* low body exposure. Body exposure (days with sun exposed upper body) has been positively correlated with 25(OH)D at a similar latitude(42). While there are concerns about skin cancer risk, moderate sun exposure has been shown to make up for deficiency in those who consume relatively low vitamin D(43). Furthermore, for white-skinned people in the UK and similar latitudes, spending 9 min outdoors at lunchtime from March to September was estimated to be sufficient to maintain 25 nmol/l throughout winter(44). Consistent with this, we found no difference in vitamin D status in those who spent more than 30 min in peak sunshine in the same period. We also identified that sunscreen users had better vitamin D status which can be considered a proxy for sun exposure with similar findings also reported in the Irish population(15,45,46) and at similar European latitudes(47,48). While our study only explored vitamin D status in Dublin, other Irish studies have detected variations in deficiency by geographical location(7) that could be explained by differences in UVB availability due to latitude(4).

Vitamin D knowledge and indications for testing

Despite a surge for vitamin D testing and increasing costs, there remains little evidence on the indications for assessing 25(OH)D status. In a recent Irish study, a high proportion (a third) of vitamin D retests were found to be inappropriate, resulting in considerable unnecessary expenditure; however, no information was available on testing indications(21). In this study, routine health checks accounted for a third of the reasons for testing, though this is not recommended and is considered inappropriate(49). Additionally, 19 % reported other reasons including fatigue which are also not recognised as a valid clinical indication. Our results are similar to the UK and the Netherlands where 70–77 % of testing was considered inappropriate(50,51). Patient reassurance has also been found to be a key driver of testing by general practitioners which is consistent with our finding that 'patient requests' were the most frequently declared other reason for testing(51).

We found that half (46 %) had no knowledge of any RDA recommendations, though a third (32 %) felt it was higher (≥ 20 µg/d) and 4 % lower (≤ 5 µg/d). Better vitamin D knowledge has been associated with increased likelihood of taking supplements(52), though supplement use has been found to be relatively low (10–17 %) in Ireland(5,7) suggesting a low level of concern for deficiency. However, during the COVID pandemic there is some evidence to suggest increased supplement use in Irish adults and possible improvement in vitamin D status(53). Indeed, a publicised report by Irish researchers in April 2020 recommended a higher daily vitamin D intake of 20–25 µg (800–1000 µg) during COVID for adults aged > 70(54) so some knowledge of higher RDA's than advised by the FSAI might be expected. The majority (86 %) of respondents cited vitamin D as being important for bone health, similar to other studies(52,55). Perhaps surprisingly, the second most common health association (66 %) was for immunity/COVID. This likely reflects media coverage during the pandemic of research on vitamin D's possible beneficial effects on COVID infection(56). Indeed, trend analysis indicates there was a peak in Google searches for vitamin D coinciding with the first COVID wave in Ireland (March 2020) and during a subsequent wave (January 2021)(57). The only other research was based on a small sample (n 112) of pregnant women attending a maternity hospital and found that 71 % had insufficient knowledge, with just 10 % recognising supplements as a source(12). While there was good awareness of the benefits for bone and immune health, there is poor knowledge of the vitamin D RDA and little understanding of the indications for testing. This suggests that better awareness may help to improve vitamin D intake and status.

Strengths and limitations

This is the first study of its kind to explore multiple determinants of serum vitamin D in Irish adults including dietary intake, ethnicity and measures of sun exposure. It also adds to the limited research on adult knowledge and perceptions of vitamin D in Ireland and is the first to investigate indications for testing. However, as the study participants were selected from a sample of patients who had their vitamin D tested by their general practitioner, it may not be representative of the wider population. In particular, there may have been information bias as participants may have been aware of their vitamin D test results. Additionally, there may be also exclusion bias given that a significant proportion of adults did not return our questionnaire, though our response rate is in keeping with other studies using a similar methodology(58). Finally, there may be recall bias as regards the recollection of food and supplement intakes when completing the FFQ.

Conclusion

We found, in a convenience sample of Irish adults, the biggest predictors of deficiency were low vitamin D intake (< 10 µg/d) ($P < 0{\cdot}001$) and non-white ethnicity ($P = 0{\cdot}006$), while it was twice as likely in those who were sun avoiders ($P = 0{\cdot}022$). In particular, deficiency in winter was twice as likely in those who of non-white ethnicity and was also more prevalent in those with lower body exposure when outside. Dietary sources of intake were small but still associated with better vitamin D status. However, the vast majority (81 %) who met the RDA were taking supplements. More than a third of vitamin D testing was for non-clinical indications, and the majority were not aware of the current RDA. Public health policy should be considered to improve vitamin D intake, especially in those of non-white ethnicity and with reduced sun exposure.

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Supplementary material

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References

1. Macdonald HM, Mavroeidi A, Fraser WD, *et al.* (2011) Sunlight and dietary contributions to the seasonal vitamin D status of cohorts of healthy postmenopausal women living at northerly latitudes: a major cause for concern? *Osteoporos Int* **22**, 2461–2472.
2. Scientific Advisory Committee on Nutrition (2016) SACN Vitamin D and Health Report. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/537616/SACN_Vitamin_D_and_Health_report.pdf (accessed January 2023).
3. Holick MF (2007) Vitamin D deficiency. *N Engl J Med* **357**, 266–281.
4. O'Sullivan F, Laird E, Kelly D, *et al.* (2017) Ambient UVB dose and sun enjoyment are important predictors of vitamin D status in an older population. *J Nutr* **147**, 858–868.

5. Cashman KD, Muldowney S, McNulty B, *et al.* (2013) Vitamin D status of Irish adults: findings from the National Adult Nutrition Survey. *Br J Nutr* **109**, 1248–1256.
6. Irish Universities Nutrition Alliance (IUNA) (2011) *National Adult Nutrition Survey: Summary Report*. March 2011. IUNA: Cork, Ireland.
7. Laird E, Rhodes J & Kenny RA (2020) Vitamin D and inflammation: potential implications for severity of COVID-19. *Ir Med J* **113**, P81.
8. Hill TR, O'Brien MM, Lamberg-Allardt C, *et al.* (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.
9. Laird E, O'Halloran AM, Carey D, *et al.* (2018) The prevalence of vitamin D deficiency and the determinants of 25 (OH) D concentration in older Irish adults: data from The Irish Longitudinal Study on Ageing (TILDA). *J Gerontol A-Biol* **73**, 519–525.
10. McCarroll K, Beirne A, Casey M, *et al.* (2015) Determinants of 25-hydroxyvitamin D in older Irish adults. *Age Ageing* **44**, 847–853.
11. Griffin TP, Wall D, Blake L, *et al.* (2020) Higher risk of vitamin D insufficiency/deficiency for rural than urban dwellers. *J Steroid Biochem Mol Biol* **197**, 105547.
12. Toher C, Lindsay K, McKenna M, *et al.* (2014) Relationship between vitamin D knowledge and 25-hydroxyvitamin D levels amongst pregnant women. *J Hum Nutr* **27**, 261–269.
13. Laird E, Walsh JB, Lanham-New S, *et al.* (2020) A high prevalence of vitamin D deficiency observed in an Irish South East Asian Population: a cross-sectional observation study. *Nutrients* **12**, 3674.
14. Kiely ME, Zhang JY, Kinsella M, *et al.* (2016) Vitamin D status is associated with uteroplacental dysfunction indicated by pre-eclampsia and small-for-gestational-age birth in a large prospective pregnancy cohort in Ireland with low vitamin D status. *Am J Clin Nutr* **104**, 354–361.
15. Carroll A, Onwuneme C, McKenna MJ, *et al.* (2014) Vitamin D status in Irish children and adolescents: value of fortification and supplementation. *Clin Pediatr* **53**, 1345–1351.
16. 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.
17. Scully H, Laird E, Healy M, *et al.* (2022) Low socioeconomic status predicts vitamin D status in a cross-section of Irish children. *J Nutr Sci* **11**, e61.
18. Forsythe LK, Livingstone MBE, Barnes MS, *et al.* (2012) Effect of adiposity on vitamin D status and the 25-hydroxycholecalciferol response to supplementation in healthy young and older Irish adults. *Br J Nutr* **107**, 126–134.
19. Sutherland JP, Zhou A, Leach MJ, *et al.* (2021) Differences and determinants of vitamin D deficiency among UK biobank participants: a cross-ethnic and socioeconomic study. *Clin Nutr* **40**, 3436–3447.
20. McKenna MJ, Murray B, Crowley RK, *et al.* (2015) Laboratory trend in vitamin D status in Ireland: dual concerns about low and high 25OHD. *J Steroid Biochem Mol Biol* **186**, 105–109.
21. Scully H, Laird E, Healy M, *et al.* (2021) Vitamin D retesting by general practitioners: a factor and cost analysis. *Clin Chem Lab* **59**, 1790–1799.
22. Scully H, Laird E, Healy M, *et al.* (2020) Geomapping vitamin D status in a large city and surrounding population—exploring the impact of location and demographics. *Nutrients* **12**, 2663.
23. Harris C, Bradlyn A, Coffman J, *et al.* (2008) BMI-based body size guides for women and men: development and validation of a novel pictorial method to assess weight-related concepts. *Int J Obes* **32**, 336–342.
24. EFSA Panel on Dietetic Products N & Allergies (2015) Scientific Opinion on dietary reference values for calcium. *EFSA Journal* **13**, 4101.
25. Institute of Medicine (IOM) (2011) *Dietary Reference Intakes for Calcium and Vitamin D*. Washington, DC: The National Academies Press.
26. Ross AC, Manson JE, Abrams SA, *et al.* (2011) The 2011 report on dietary reference intakes for calcium and vitamin d from the institute of medicine: what clinicians need to know. *J Clin Endocrinol Metab* **96**, 53–58.
27. Romero-Ortuno R, Cogan L, Browne J, *et al.* (2011) Seasonal variation of serum vitamin D and the effect of vitamin D supplementation in Irish community-dwelling older people. *Age Ageing* **40**, 168–174.
28. O'Brien M, Kiely M, Harrington K, *et al.* (2001) The North/South Ireland food consumption survey: vitamin intakes in 18–64-year-old adults. *Public Health Nutr* **4**, 1069–1079.
29. Cashman KD, Kiely ME, Andersen R, *et al.* (2021) Individual participant data (IPD)-level meta-analysis of randomised controlled trials with vitamin D-fortified foods to estimate Dietary Reference Values for vitamin D. *Eur J Nutr* **60**, 939–959.
30. Cashman KD, Ritz C, Kiely M, *et al.* (2017) Improved dietary guidelines for vitamin D: application of individual participant data (IPD)-level meta-regression analyses. *Nutrients* **9**, 469.
31. Cashman KD, Kiely ME, Andersen R, *et al.* (2022) Individual participant data (IPD)-level meta-analysis of randomised controlled trials to estimate the vitamin D dietary requirements in dark-skinned individuals resident at high latitude. *Eur J Nutr* **61**, 1015–1034.
32. Food Safety Authority of Ireland (FSAI) (2020) Vitamin D Scientific Recommendations for Food-Based Dietary Guidelines for Older Adults in Ireland. https://www.fsai.ie/DietaryGuidelines_OlderAdults_Ireland/ (accessed January 2023).
33. Fahey E, Russell H, McGinnity F, *et al.* (2019) *Diverse Neighbourhoods: An Analysis of the Residential Distribution of Immigrants in Ireland*. Dublin, Ireland: Economic and Social Research Institute; Department of Justice and Equality.
34. Aspell N, Laird E, Healy M, *et al.* (2019) The prevalence and determinants of vitamin D status in community-dwelling older adults: results from the English Longitudinal Study of Ageing (ELSA). *Nutrients* **11**, 1253.
35. van der Meer IM, Middelkoop BJC, Boeke AJP, *et al.* (2011) Prevalence of vitamin D deficiency among Turkish, Moroccan, Indian and sub-Sahara African populations in Europe and their countries of origin: an overview. *Osteoporos Int* **22**, 1009–1021.
36. Central Statistics Office (2016) Profile 8 – Irish Travellers, Ethnicity and Religion, Population Usually Resident and Present in the State 2011–2016. https://www.cso.ie/en/csolatestnews/presspages/2017/census2016profile8-irishtravellersethnicityandreligion/ (accessed January 2023).
37. Wicherts I, Boeke A, Van Der Meer I, *et al.* (2011) Sunlight exposure or vitamin D supplementation for vitamin D-deficient non-western immigrants: a randomized clinical trial. *Osteoporos Int* **22**, 873–882.
38. Lips P, Cashman KD, Lamberg-Allardt C, *et al.* (2019) Current vitamin D status in European and Middle East countries and strategies to prevent vitamin D deficiency: a position statement of the European Calcified Tissue Society. *Eur J Endocrinol* **180**, P23–P54.
39. Cusack C, Danby C, Fallon JC, *et al.* (2008) Photoprotective behaviour and sunscreen use: impact on vitamin D levels in cutaneous lupus erythematosus. *Photodermatol Photoimmunol Photomed* **24**, 260–267.

40. Andersen R, Mølgaard 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.
41. Mortensen C, Mølgaard C, Hauger H, *et al.* (2018) Sun behaviour and physical activity associated with autumn vitamin D status in 4–8-year-old Danish children. *Public Health Nutr* **21**, 3158–3167.
42. Thieden E, Philipsen PA, Heydenreich J, *et al.* (2009) Vitamin D Level in summer and winter related to measured UVR exposure and behavior. *Photochem Photobiol* **85**, 1480–1484.
43. Kift R, Rhodes LE, Farrar MD, *et al.* (2018) Is sunlight exposure enough to avoid wintertime vitamin D deficiency in United Kingdom population groups? *Int J Environ Res* **15**, 1624.
44. Webb AR, Kazantzidis A, Kift RC, *et al.* (2018) Colour counts: sunlight and skin type as drivers of vitamin D deficiency at UK latitudes. *Nutrients* **10**, 457.
45. McVey MK, Geraghty AA, O'Brien EC, *et al.* (2019) An exploratory analysis of associations of diet, sun exposure, and body composition with 25OHD at five years of age: findings from the ROLO Kids Study. *J Steroid Biochem Mol Biol* **188**, 111–116.
46. Lucey AJ, Muldowney S, Walsh E, *et al.* (2012) Determinants of serum 25-hydroxyvitamin D concentrations in a nationally representative sample of Irish adults. *Proc Nutr Soc* **71**, E99.
47. Brembeck P, Winkvist A & Olausson H (2013) Determinants of vitamin D status in pregnant fair-skinned women in Sweden. *Br J Nutr* **110**, 856–864.
48. Hansen L, Tjønneland A, Køster B, *et al.* (2016) Sun exposure guidelines and serum vitamin D status in Denmark: the StatusD study. *Nutrients* **8**, 266.
49. McChesney C, Singer A, Duquette DA, *et al.* (2022) Do not routinely test for vitamin D. *BMJ* **378**, e070270.
50. Woodford HJ, Barrett S & Pattman S (2018) Vitamin D: too much testing and treating? *Clin Med* **18**, 196.
51. Hofstede H, Van Der Burg H, Mulder B, *et al.* (2019) Reducing unnecessary vitamin testing in general practice: barriers and facilitators according to general practitioners and patients. *BMJ open* **9**, e029760.
52. O'Connor C, Glatt D, White L, *et al.* (2018) Knowledge, attitudes and perceptions towards vitamin D in a UK adult population: a cross-sectional study. *Int J Environ Res* **15**, 2387.
53. McKenna MJ, Lyons OC, Flynn MA, *et al.* (2022) COVID-19 pandemic and vitamin D: rising trends in status and in daily amounts of vitamin D provided by supplements. *BMJ Open* **12**, e059477.
54. Laird E & Kenny RA (2019) Vitamin D deficiency in Ireland–implications for COVID-19. Results from the Irish Longitudinal Study on Ageing (TILDA). https://www.doi.org/10.38018/TildaRe.2020-05 (accessed January 2023).
55. Clark B, Hill T & Hubbard C (2019) Consumers' perception of vitamin D and fortified foods. *Br Food J* **121**, 2205–2218.
56. Sattar N, Welsh P, Panarelli M, *et al.* (2012) Increasing requests for vitamin D measurement: costly, confusing, and without credibility. *Lancet* **379**, 95.
57. Trends G Google (2022) Trends for vitamin D - Ireland, 01/01/2019–01/01/2022. https://trends.google.com/trends/explore/TIMESERIES/1663343400?hl=en-GB&tz=-60&date=2019–01–01+2022–01–01&geo=IE&q=vitamin+d&sni=3 (accessed September 2022).
58. Dickson-Spillmann M, Siegrist M & Keller C (2011) Development and validation of a short, consumer-oriented nutrition knowledge questionnaire. *Appetite* **56**, 617–620.