

Commonly recommended daily intake of vitamin D is not sufficient if sunlight exposure is limited

H. GLERUP¹, K. MIKKELSEN², L. POULSEN², E. HASS², S. OVERBECK², J. THOMSEN¹, P. CHARLES¹ & E. F. ERIKSEN¹

From the ¹Department of Endocrinology and Metabolism C, Aarhus Amtssygehus, University Hospital of Aarhus, Aarhus, and the ²Primary Health Care Centre, City Vest, Aarhus, Denmark

Abstract. Glerup H, Mikkelsen K, Poulsen L, Hass E, Overbeck S, Thomsen J, Charles P, Eriksen EF (University Hospital of Aarhus, and Primary Health Care Centre, City Vest, Aarhus, Denmark). Commonly recommended daily intake of vitamin D is not sufficient if sunlight exposure is limited. *J Intern Med* 2000; **247**: 260–268.

Objectives. Sunlight exposure of the skin is known to be the most important source of vitamin D. The aims of this study were: (i) to estimate vitamin D status amongst sunlight-deprived individuals (veiled Arab women, veiled ethnic Danish Moslem women and Danish controls); and (ii) through food intake analysis to estimate the oral intake of vitamin D necessary to keep a normal vitamin D status in sunlight-deprived individuals.

Design. Cross-sectional study amongst randomly selected Moslem women of Arab origin living in Denmark. Age-matched Danish women were included as controls. To control for racial differences, a group of veiled ethnic Danish Moslem women (all Caucasians) was included.

Setting. Primary Health Care Centre, City Vest and Department of Endocrinology and Metabolism C, University Hospital of Aarhus, Aarhus Amtssygehus, Aarhus, Denmark.

Subjects. Sixty-nine Arab women (60 veiled, nine non-veiled) and 44 age-matched Danish controls were randomly selected amongst patients contacting the primary health care centre for reasons other than vitamin D deficiency. Ten ethnic Danish Moslem women were included through a direct contact with their community.

Main outcome measures. Serum levels of 25-hydroxyvitamin D were used as estimates of vitamin D status. Intact parathyroid hormone (PTH) was used to control for secondary hyperparathyroidism. Alka-

line phosphatase and bone-specific alkaline phosphatase were used as markers for osteomalacic bone involvement. Oral intake of vitamin D and calcium were estimated through a historical food intake interview performed by a trained clinical dietician.

Results. Veiled Arab women displayed extremely low values of 25-hydroxyvitamin D: 7.1 ± 1.1 nmol L⁻¹, compared with 17.5 ± 2.3 ($P < 0.002$) in ethnic Danish Moslems and 47.1 ± 4.6 ($P < 10^{-17}$) in Danish controls. PTH was increased amongst veiled Arab women: 15.6 ± 1.8 pmol L⁻¹, compared with 5.7 ± 1.4 in ethnic Danish Moslems and 2.7 ± 0.3 ($P < 10^{-6}$) in Danish controls. The vitamin D intake (including food supplementation) was very low amongst Arab women: $1.04 \mu\text{g day}^{-1}$, compared with 13.53 amongst ethnic Danish Moslems and 7.49 amongst Danish controls ($P < 0.0005$).

Conclusions. Severe vitamin D deficiency is prevalent amongst sunlight-deprived individuals living in Denmark. In veiled Arab women, vitamin D deficiency is the result of a combination of limitations in sunlight exposure and a low oral intake of vitamin D. The oral intake of vitamin D amongst veiled ethnic Danish Moslems was, however, very high, at 13.53 μg (approximately 600 IU), but they were still vitamin D-deficient. Our results suggest that the daily oral intake of vitamin D in sunlight-deprived individuals should exceed 600 IU; most probably it should be 1000 IU day⁻¹ to secure a normal level of 25-hydroxyvitamin D. This finding is in contrast with the commonly used RDA (recommended daily allowance) for adults in Europe: 200 IU day⁻¹.

Keywords: 25-hydroxyvitamin D, food intake, hyperparathyroidism, sunlight exposure, UV-B.

Introduction

Sunlight exposure is by far the most important source of vitamin D. The human skin has a large capacity for vitamin D production [1–3]. Under normal conditions the skin is able to supply the body with 80–100% of vitamin D requirements. The fact that the body can produce vitamin D by itself has changed our understanding of this substance. It is no longer believed to be a true vitamin, but rather a steroid hormone. However, the direct exposure of the skin to sunlight is critical, and any limitation in sunlight exposure may result in vitamin D deficiency.

Vitamin D₃ is synthesized in the skin from 7-dehydrocholesterol under the influence of UV-B (wavelength 290–315 nm) radiation and temperature [4–6]. UV-B radiation depends on many factors. First of all, the clothing style is very important [7]. Black clothes exclude 100% UV-B. Glass and plastic also exclude 100% UV-B [8]. The use of sunscreen factor 8 excludes 95% [9, 10]. In studies performed in Boston (42°N) Holick and coworkers [1, 2, 8] demonstrated the importance of latitude, season and time of the day of sunlight exposure. The maximal production of vitamin D₃ was seen around noon in July, with decreasing production in spring and autumn and no production between 1 November and 15 March. In countries around the equator, the production is constant throughout the year.

It is obvious that moving people from sun-rich countries to countries with more northern or southern latitudes without changing their habit of avoiding direct sunlight exposure may cause vitamin D deficiency. In agreement with this, 'Asian osteomalacia' has been reported, especially in the UK, during the last three to four decades [11–21], and recently also in the Netherlands [22], Norway [23, 24] and Denmark [25].

Individuals exposed to very limited amounts of sunlight become dependent on an oral intake of vitamin D, as if it were a true vitamin. We do not know, however, what doses of vitamin D should be given to individuals deprived of sunlight to secure a normal serum level of 25-hydroxyvitamin D (25-OHD, the storage form of vitamin D). Recently, the recommendations for vitamin D intake have been increased [26–29], especially for elderly individuals, who also display reduced capacity for cutaneous vitamin D production [30, 31]. In a study where

submariners were sunlight-deprived for 3 months, Holick [8] found that a daily dose of 600 IU (15 µg) vitamin D was not enough to keep a normal serum level of 25-OHD.

The aim of this study was to determine the degree of vitamin D deficiency amongst sunlight-deprived veiled Moslems living in Denmark. Additionally our aim was, through food intake analysis, to get an impression of what doses of oral vitamin D intake were needed to maintain normal 25-OHD levels.

Patients and methods

Patients

The participants were recruited through a primary health care centre in a suburban area with a high percentage of Arab inhabitants. As controls, we included age-matched Danish women living in the same suburban area coming to the same primary health care centre. Four doctors were employed in the health care centre and the method of inclusion was as follows: every day, each doctor randomly chose one Arab woman or one age-matched Danish woman attending for reasons other than vitamin D deficiency. The cases and the controls were not pairwise matched. The only exclusion criterion was age below 18 years.

Sixty-nine Arab women and 44 Danish controls were included in the study during the period December 1996–June 1997. Additionally, 10 veiled ethnic Danish Moslem women (Danish Caucasians, who have converted to Islam) were included through a direct contact with their community. Finally, 29 Arab women were included during the months August–September 1997 in order to control for seasonal variations in 25-OHD.

A subgroup of non-veiled Arab women ($n = 9$) could be identified. These women still had the habit of wearing long sleeves when outside.

There were no significant differences amongst the groups in age and weight (see Table 1), but the Danish women were taller than the Arab women (170.2 ± 0.9 vs. 160.5 ± 0.7 cm) and the body mass index (BMI) of the Arab women was slightly ($P < 0.01$) higher than that of the Danish women (27.8 ± 0.7 vs. 24.4 ± 0.7 kg m⁻²).

The group of Arab women consisted of Palestinians originating from Lebanon (except one, who came from Iraq). They had been living in Denmark

Table 1 Screening data in age-matched Danish women, ethnic Danish Moslem women and Arab women (mean \pm SEM). Values in brackets are normals

	Danish women (n = 44)	P-value (unpaired t-test)	Danish Moslem women (n = 10)	P-value (unpaired t-test)	Arab women (veiled, n = 60)	P-value (ANOVA)
Age	36.1 \pm 1.6	NS	37.1 \pm 3.4	NS	32.2 \pm 1.4	NS
Weight (kg)	70.7 \pm 1.9	NS	70.7 \pm 4.2	NS	71.3 \pm 0.9	NS
Height (cm)	170.2 \pm 0.9	< 0.002	163.0 \pm 1.6	NS	160.5 \pm 0.7	< 10 ⁻¹¹
BMI (kg m ⁻²)	24.4 \pm 0.7	NS	26.7 \pm 1.7	NS	27.8 \pm 0.7	< 0.01
Ca (corr.) (mmol L ⁻¹) (2.20–2.52)	2.40 \pm 0.02	NS	2.38 \pm 0.02	NS	2.31 \pm 0.02	< 0.01
BAP (U L ⁻¹) (0–140)	56.2 \pm 3.5	< 0.001	84.1 \pm 7.3	NS	127.2 \pm 18.0	< 0.01
PTH (pmol L ⁻¹) (1.3–7.6)	2.7 \pm 0.3	< 0.002	5.7 \pm 1.4	NS	15.6 \pm 1.8	< 10 ⁻⁶
TAP (U L ⁻¹) (80–270)	146.9 \pm 6.0	< 0.002	186.0 \pm 10.1	NS	247.6 \pm 19.4	< 0.0002
25-OHD (nmol L ⁻¹) (> 20)	47.1 \pm 4.6	< 0.002	17.5 \pm 2.3	< 0.002	7.1 \pm 1.1	< 10 ⁻¹⁷
1,25-(OH) ₂ D (pmol L ⁻¹) (40–60)	99.9 \pm 8.0	NS	102.6 \pm 15.1	NS	98.3 \pm 4.0	NS
dU-Ca ²⁺ (mmol 24 h ⁻¹)	3.6 \pm 0.3	NS	2.4 \pm 0.4	NS	2.7 \pm 0.2	NS
dU-hydroxyproline	165.2 \pm 10.3	NS	168.0 \pm 25.5	NS	247.8 \pm 26.8	NS

BMI, body mass index; BAP, bone-specific alkaline phosphatase; PTH, parathyroid hormone; TAP, total alkaline phosphatase.

for 8.5 \pm 0.5 years (mean \pm SEM). The Danish Moslems had been veiled for 7.2 \pm 1.1 years.

The study was approved by the local ethical committee, and was performed in accordance with the Helsinki Declaration II.

Laboratory evaluations

After inclusion in the study, participants provided a blood sample for analysis of serum levels of 25-OHD, 1,25-(OH)₂D, PTH, Ca²⁺ (albumin-corrected), phosphate, magnesium, total alkaline phosphatase (TAP) and bone-specific alkaline phosphatase (BAP). Twenty-four hour urinary excretion of calcium and hydroxyproline (U-OHP) was also assessed.

Serum 25-OHD (S-25-OHD) was measured by a radioimmunoassay with ¹²⁵I-labelled tracer [32]. The intra-assay and interassay coefficients of variation (CVs) were 6 and 15%, respectively. S-1,25-(OH)₂D was measured by radioreceptor assay with single cartridge extraction and purification [33]. Intra- and interassay CVs were both 10%.

S-BAP was lectin-precipitated and the supernatant was analysed spectrophotometrically [34]. The intra-assay and interassay CVs were 8 and 25%, respectively.

S-PTH(1-84) was measured by a radioimmunoassay (Immulite intact PTH; DPC Diagnostic Products Corporation, Los Angeles, CA, USA). The intra-assay and interassay CVs were 6 and 6–12%, respectively [35].

Calcium, phosphate, creatinine and alkaline phosphatase were determined according to standard methods. U-OHP was estimated on 24-h urine collections. To avoid contribution of dietary items, participants kept to a gelatine-free diet during the urine collection. U-OHP was measured spectrophotometrically with p-dimethylamino-benzaldehyd (Organon Tecnica, BV Boxtel, Holland). Intra-assay and interassay CVs were 10 and 12%, respectively.

A historical food intake interview was performed amongst 12 Arab women, 10 ethnic Danish Moslem and 21 Danish controls. All meals during a period of 14 days were described separately. The sizes of meals were estimated by comparing the meals with photographs and models of meal items. The participants were interviewed about their intake of snacks, fruits, cakes, soft drinks, beers, wine and alcohol during a period of 1 month and about seasonal variations in food intake during the previous year. Finally, an estimate of the usual intake of food supplementation (vitamin and calcium tablets) was made. All records were made by a trained dietician. The software package Dankost was used for calculation of the average daily intake of vitamin D, calcium, etc. The software package is designed for this kind of estimation and contains information on the content of vitamin D, calcium, etc. in all known Danish food items. In addition, all food items in traditional Arabic food are included in the software package. The CVs for vitamin D and calcium estimates performed by the same dietician

have previously been calculated in the Danish Osteoporosis Prevention Study (28 and 15%, respectively).

Clinical symptoms were evaluated by a simple questionnaire. The symptoms evaluated were: (i) change in gait; (ii) muscle pain; (iii) difficulties in ascending a staircase/rising from a chair; (iv) paraesthesiae of hands and feet; and (v) muscle cramps.

Data analysis

Statistical analysis was carried out using Microsoft Excel 7.0 and SPSS 6.1.3. *P*-values < 0.05 were considered significant. ANOVA was used for the comparison of parametric data.

Results

Vitamin D metabolites

Amongst the veiled Arab women, S-25-OHD was found to be low: 7.1 ± 1.1 nmol L⁻¹, compared with 17.5 ± 2.3 amongst ethnic Danish Moslems and 47.1 ± 4.6 amongst Danish controls (ANOVA: $P < 10^{-17}$) (see Table 1). S-25-OHD amongst non-veiled Arab women (12.6 ± 2.6 nmol L⁻¹) was slightly (NS) higher than that in veiled Arab women (see Table 2).

Ninety-six per cent of the veiled Arab women exhibited levels of 25-OHD < 20 nmol L⁻¹ and 85% were below 10 nmol L⁻¹. In the Danish control group, none had 25-OHD < 10 nmol L⁻¹ and only 9% were below 20 nmol L⁻¹. Amongst the non-veiled Arab women, 89% had 25-OHD < 20 nmol L⁻¹ and 40% < 10 nmol L⁻¹. In the group of

ethnic Danish Moslems, the frequencies were 60% < 20 nmol L⁻¹ and 20% < 10 nmol L⁻¹.

The S-1,25-(OH)₂D values showed no differences between the groups (see Tables 1 and 2).

Serum parathyroid hormone

Veiled Arab women revealed significantly higher values of PTH (15.6 ± 1.8 pmol L⁻¹) than ethnic Danish Moslem women (5.7 ± 1.4) and Danish controls (2.7 ± 0.3 ; ANOVA: $P < 10^{-6}$). PTH was elevated above the normal range (1.3–7.6 pmol L⁻¹) in 57% of veiled Arab women, 55% of non-veiled Arab women, 20% of ethnic Danish Moslems and 2% of Danish controls.

Alkaline phosphatases

In veiled Arab women, BAP and TAP were elevated above normal levels in 17 and 22%, respectively. None of the participants from the other groups exhibited alkaline phosphatase values above normal level.

The mean values of BAP (127.2 ± 18.0 U L⁻¹) and TAP (247.6 ± 19.4 U L⁻¹) in veiled Arab women were significantly higher than all other groups (Danish control: BAP, 56.2 ± 3.5 U L⁻¹ [ANOVA: $P < 0.01$]; TAP, 146.9 ± 6.0 U L⁻¹ [ANOVA: $P < 0.0002$]).

Serum values of calcium, phosphate, magnesium and creatinine

Serum calcium was found to be below normal (2.20 – 2.52 mmol L⁻¹) in 6% of the veiled Arab women but none of the other participants. There was a small but significant difference in serum calcium in the veiled Arab women (2.31 ± 0.02 mmol L⁻¹) compared with ethnic Danish Moslems (2.38 ± 0.02) and Danish controls (2.40 ± 0.02) (ANOVA: $P < 0.01$). Serum levels of phosphate, magnesium and creatinine were within normal levels, and there were no differences between the groups.

Urine calcium and hydroxyproline

There was no significant difference between the groups in 24-h urine excretion of calcium. The hydroxyproline excretion was slightly higher (NS)

Table 2 Blood tests amongst Arab women: veiled and non-veiled (mean \pm SEM)

	Veiled women (<i>n</i> = 60)	Non-veiled women (<i>n</i> = 9)	<i>P</i> -value (unpaired <i>t</i> -test)
BAP	127.2 ± 18.0	77.0 ± 10.9	< 0.03
TAP	247.6 ± 19.4	181.4 ± 11.7	< 0.01
PTH	15.6 ± 1.8	11.8 ± 1.5	NS
25-OHD	7.1 ± 1.1	12.6 ± 2.6	NS
1,25-OH ₂ D	98.3 ± 4.0	79.5 ± 8.3	NS

BAP, bone-specific alkaline phosphatase; TAP, total alkaline phosphatase; PTH, parathyroid hormone.

Table 3 Seasonal variation amongst Arab women in Denmark (mean \pm SEM)

	Arab women December 1996–June 1997 (<i>n</i> = 60)	Arab women August–September 1997 (<i>n</i> = 29)	<i>P</i> -value (unpaired <i>t</i> -test)
25-OHD	7.1 \pm 1.1	12.2 \pm 1.3	< 0.05
PTH	15.6 \pm 1.8	8.5 \pm 1.4	< 0.03
BAP	127.2 \pm 18.0	81.1 \pm 9.1	NS
TAP	247.6 \pm 19.4	200.3 \pm 23.5	NS

PTH, parathyroid hormone; BAP, bone-specific alkaline phosphatase; TAP, total alkaline phosphatase.

amongst the veiled Arab women than amongst ethnic Danish Moslems and Danish controls.

Seasonal variations in 25-OHD, PTH, BAP and TAP

When comparing the values of veiled Arab women included in the period December 1996–June 1997 with those included in the period August–September 1997 (see Table 3), a small but significant increase in S-25-OHD (7.1 \pm 1.1 vs. 12.2 \pm 1.3 nmol L⁻¹; *P* < 0.05) and a small decrease in S-PTH (15.6 \pm 1.8 vs. 8.5 pmol L⁻¹; *P* < 0.03) were demonstrated. Smaller but insignificant decreases in BAP and TAP were also seen. In the group included in August–September 1997, 92% still had 25-OHD levels below 20 nmol L⁻¹ and 34% had levels below 10 nmol L⁻¹; PTH was raised in 38% and BAP and TAP were elevated in 12 and 10%, respectively.

Food intake analysis

Food intake analysis showed that the Arab women had a very low intake of vitamin D: 1.04 \pm 0.91 μ g day⁻¹ (mean \pm SD), compared with 2.28 \pm 2.51 in the ethnic Danish Moslems and 2.25 \pm 1.40 in Danish controls (ANOVA:

P < 0.05) (see Table 4). The Arab women did not take any vitamin D supplementation, whereas the ethnic Danish Moslems and the Danish controls did. The total vitamin D intakes for the three groups were 1.04 \pm 0.91, 13.53 \pm 5.60 and 7.49 \pm 4.73 μ g, respectively (ANOVA: *P* < 10⁻⁶).

The daily calcium intake was almost identical in ethnic Danish Moslems (1016 mg) and Danish controls (1032 mg), whereas the intake of the Arab women (549 mg) was significantly lower (ANOVA: *P* < 0.002).

Clinical findings

Twenty-six per cent of veiled Arab women reported a change in gait compared with 9% of Danish controls (χ^2 -test, *P* < 0.03). Muscle pain was felt by 88% of Arab women compared with 32% of Danish controls (*P* < 0.001). Difficulties in rising from a chair/ascending a staircase were experienced by 32% of Arab women compared with 14% of Danish women (*P* < 0.04). Paraesthesiae of the hands and feet were seen in 59% of Arab women compared with 0% in Danish controls (*P* < 0.001). Muscle cramps were seen in 72% of Arab women compared with 0% in Danish controls (*P* < 0.001).

Table 4 Results of food intake analysis (mean \pm SD)

	Arab women (<i>n</i> = 12)	Danish Moslem (<i>n</i> = 10)	Danish controls (<i>n</i> = 21)	<i>P</i> -value (ANOVA)
Vitamin D (μ g)	1.04 \pm 0.91	2.28 \pm 2.51	2.25 \pm 1.40	< 0.05
Vitamin D (vitamin pills, μ g)	0 \pm 0	11.25 \pm 4.43	5.24 \pm 4.60	< 10 ⁻⁶
Vitamin D (total, μ g)	1.04 \pm 0.91	13.53 \pm 5.60	7.49 \pm 4.73	< 10 ⁻⁶
Calcium (mg)	549 \pm 370	816 \pm 255	1004 \pm 330	< 0.002
Calcium (incl. supplement)	549 \pm 370	1016 \pm 415	1032 \pm 341	< 0.002

Discussion

We have demonstrated severe vitamin D deficiency (levels $< 10 \text{ nmol L}^{-1}$) amongst 85% of our study group of veiled Arab women living in Denmark. 25-OHD $< 20 \text{ nmol L}^{-1}$ was seen in 96%. PTH has previously been shown to be the best single marker of osteomalacic bone disease [21]; 57% of the Arab women displayed PTH values above normal level, indicating a high frequency of secondary hyperparathyroidism. Alkaline phosphatase, another widely used marker of osteomalacic bone disease, was only increased above normal in 17–22%, so the true frequency of osteomalacic bone disease is in the region of between 22 and 57%. It can be argued that the results of our study are a product of selection bias, as only Arab women who came to see the doctor for reasons other than vitamin D deficiency were included. Those who came to see the doctor could have been more ill than the average member of the Arabic society. However, none of the participants had diseases known to influence vitamin D status. Furthermore, the controls were included according to the same criteria.

The finding of non-significant differences in 1,25-OH₂D, dU-Ca and dU-hydroxyproline indicated that these parameters were of no value in identifying patients with severe vitamin D deficiency.

Finch *et al.* [14] reported a mean level of 25-OHD of 9.8 nmol L^{-1} amongst vegetarian Asians in the UK; amongst non-vegetarians, they found a mean 25-OHD of 18.9 nmol L^{-1} . In our study, Arab women living in Denmark had an even lower level of 25-OHD, although only very few were vegetarians. In Norway [23, 24], low values of 25-OHD have been reported amongst pregnant Pakistani women (mean $15.1\text{--}19 \text{ nmol L}^{-1}$). Again, the Arab women in our study displayed an even more pronounced vitamin D deficiency.

Our results demonstrated a seasonal variation in 25-OHD and PTH (Table 3). The variations were, however, very limited. Finch *et al.* [14] reported seasonal variations for 25-OHD in vegetarian Asians (winter, 9.8 nmol L^{-1} , with a 180% summer increase) and non-vegetarian Asians (winter, 18.9 nmol L^{-1} , 138% summer increase). In our study we found the following seasonal variation: winter, 7.1 nmol L^{-1} , with a 72% summer increase. The seasonal variations amongst our study group of Arab women living in Denmark are clearly blunted,

and it seems very likely that the group with the lowest 25-OHD ($< 10 \text{ nmol L}^{-1}$) does not have any seasonal variation. To prove this concept, however, we would have to follow the group throughout the year without starting any treatment, and this was not considered ethically correct.

The non-veiled Arab women displayed significantly less abnormal blood tests than those who were veiled, but they still exhibited raised PTH and low 25-OHD levels (Table 2). This finding underlines the importance of sunlight exposure in maintaining a normal vitamin D status. In agreement with our results El-Sonbaty and Abdul Ghaffar [36] reported a difference in 25-OHD between veiled (14.4 nmol L^{-1}) and non-veiled (30.2 nmol L^{-1}) women in Kuwait.

The most likely explanation for these findings is that all Arabs (women: veiled, non-veiled) avoid direct exposure to sunshine and wear long sleeves when outside. To support this view, several researchers [36–42] have reported vitamin D deficiency in Arabic countries. Woodhouse and Norton [38] reported a mean 25-OHD level of 9 nmol L^{-1} amongst randomly chosen Saudi Arabian people compared with 42.8 nmol L^{-1} amongst Westerners living in Saudi Arabia. Al-Arabi *et al.* [40] reported more pronounced vitamin D deficiency amongst Arabs living in modern air-conditioned flats compared with traditional Arab houses. The most likely explanation is that the traditional Arab houses usually have a central courtyard where the women do not need to be veiled, giving them an opportunity of direct sunlight exposure. Modern urban Arab women always cover face, arms and legs with clothing when going outside. Arab women living in Denmark also live in modern flats and cover their skin when outside. Thus, even in the sun-rich Arabic countries, vitamin D deficiency seems to be common. The problem seems primarily to be avoidance of direct exposure to sunlight.

In an attempt to test for racial differences, we decided to include a group of ethnic Danish Moslem women, who were using the same clothing style as the Arab Moslem women. Despite a high oral intake of vitamin D ($13.53 \mu\text{g day}^{-1}$) (see Table 4), the ethnic Danish Moslems displayed low values of 25-OHD (17.5 nmol L^{-1}). This finding further supports the notion that any limitation in exposure to sunlight is more important than racial differences. Furthermore, Sedrani *et al.* [41] experimentally

exposed normal Saudi Arabians to direct sunlight, which resulted in a 2.5-fold increase in 25-OHD, showing that the capacity of vitamin D production of the skin is normal in Arabs and that racial difference as an explanation of the differences between Arabs and Westerners is unlikely.

Another possible difference between the races could be related to intestinal uptake of vitamin D, but the low values of 25-OHD are most probably explained by a combination of limited exposure to sunlight and low oral intake of vitamin D. Previous studies [19, 20, 38] do not support racial differences in intestinal absorption of vitamin D, as oral supplements of vitamin D to vitamin D-deficient Asians and Arab women were found to normalize S-25-OHD easily.

The food intake analysis (see Table 4) showed that the ethnic Danish Moslems have a food intake very much like Danish controls; they drank milk and took multivitamin tablets as supplements. The Arab women did not take any vitamin D supplements and had a very limited consumption of dairy products.

The Arab women had a very low intake of vitamin D ($1.04 \mu\text{g day}^{-1}$). This means that the high frequency of vitamin D deficiency amongst Arab women is caused by a combination of limited exposure to sunlight and low food intake of vitamin D. A confounder of results could be that only Arab women who were able to speak Danish or English could participate in the food intake analysis. This could have biased our results. If they were biased, however, one would expect those Arab women who spoke Danish or English to be more integrated into Danish society than those who only spoke Arabic. If so, their food would be more likely to be of a Western orientation than that of the Arabic-speaking Arab women. However, our results are very much in agreement with the findings of Woodhouse and Norton [38] and Fonseca *et al.* [39], who reported a daily vitamin D intake of 1–1.75 μg amongst Arab women in Saudi Arabia. This suggests that the Arab women living in Denmark have not changed their food intake very much since emigrating from their original country. In addition, the control group could have been biased, as only 21 of the 44 people who performed a blood test agreed to participate. However, no differences in blood test could be detected between control persons who participated in the food intake analysis and those who did not.

Despite a high intake of vitamin D

($13.53 \mu\text{g day}^{-1}$; nearly three times the RDA of $5 \mu\text{g day}^{-1}$ or 200 IU), the Danish Moslems were unable to maintain a normal level of S-25-OHD (17.5 nmol L^{-1}). This shows that the daily intake of vitamin D for individuals with limited exposure to sunlight should be above $13.5 \mu\text{g}$. The control group of Danish women, on the other hand, could, with normal sunlight exposure, easily maintain normal S-25-OHD levels on a daily intake of $7.5 \mu\text{g}$.

Underreporting has been shown to be a problem in food intake analysis [42, 43]. The degree of underreporting can be estimated from the calculated energy intake (EI) and the basal metabolic rate (BMR), which can be calculated from sex, weight, height and age:

$$BMR_{\text{women}}(\text{kJ}) = 4.166 \times (655 + 9.5 \times \text{weight}[\text{kg}] + 1.8 \times \text{height}[\text{cm}] - 4.7 \times \text{age} [\text{years}])$$

If the ratio EI:BMR is below 1.35, underreporting is suspected. The EI:BMR ratios in our study were estimated as follows: Danish controls, 1.16; Danish Moslems, 1.21; and Arabs, 1.12. These ratios suggest some degree of underreporting in all groups. The result of underreporting can be underestimation of vitamin D and calcium intake. If the true intake of vitamin D were slightly higher, the relative importance of solar exposure in maintaining a normal vitamin D status must be even higher, and the oral intake requirements of vitamin D in patients with limited sunlight exposure are higher than our calculations have shown.

We believe that our observations allow us to propose that the RDA for vitamin D intake for adults with limited sunlight exposure should be raised to above $13.5 \mu\text{g}$, and most probably should be $20\text{--}25 \mu\text{g day}^{-1}$ (800–1000 IU). For adults with normal exposure, the RDA could be $7.5 \mu\text{g day}^{-1}$ (300 IU).

Conclusions

Severe vitamin D deficiency is extremely prevalent amongst sunlight-deprived individuals living in Denmark. In veiled Arab women, vitamin D deficiency is a result of a combination of limitations in sunlight exposure and a low oral intake of vitamin D. Veiled ethnic Danish Moslems were vitamin D-deficient despite an oral vitamin D intake three times the RDA. Our results suggest that the daily oral intake of vitamin D in sunlight-deprived

individuals should exceed 600 IU; in fact, the RDA for sunlight-deprived individuals should probably be raised to 800–1000 IU day⁻¹ (20–25 µg) to secure a normal level of 25-hydroxyvitamin D.

Vitamin D deficiency results in impaired bone mineralization, muscle weakness and, through a decreased intestinal calcium absorption, probably also osteoporosis. We therefore believe that it is very important to diagnose vitamin D deficiency correctly and to treat the disease with sufficient doses of vitamin D.

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Correspondence: Henning Glerup MD PhD, Department of Endocrinology and Metabolism C, Aarhus Amtssygehus, University Hospital of Aarhus, Tage Hansensgade 2, DK-8000 Aarhus C, Denmark (fax: 45-89497684; e-mail: h.glerup@dadlnet.dk).