

Sun beds and cod liver oil as vitamin D sources

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Abstract

The objective of this study was to (1) to determine the contribution of moderate sun bed exposure to serum 25(OH)D₃ levels; (2) to estimate the decay time of a high 25(OH)D₃ level obtained by sun bed exposure; and (3) to evaluate if the recommended ingestion of vitamin D is sufficient to maintain the 25(OH)D₃ concentration obtained by sun bed exposure.

Ten volunteers (20–35 y.o.), skin type I and II, living in Oslo, Norway were whole body exposed twice per week to the radiation of a commercial and approved sun bed (Life Sun S 100 W, Wolff System), starting with 0.5 MED (minimal erythema dose) and escalating to up to 1 MED per exposure for 4 weeks. After that, half of the volunteers were given a daily supplement of 200 IU vitamin D in the form of cod liver oil capsules, while the other half of the persons received no supplements.

Erythema did not occur at any time and a slight pigmentation was seen in most of the volunteers after the sun bed exposures. Serum level of 25(OH)D₃ increased by about 40% on the average. The initial serum 25(OH)D₃ level was different among the volunteers (40–100 nmol/L). Within eight weeks after the last exposure the 25(OH)D₃ level decreased to the initial value in all volunteers irrespective of vitamin D supplementation or not.

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1. Introduction

Recently, the health effects of an adequate vitamin D status have been strongly emphasized [1–3]. According to a number of reports, prognosis is improved, adverse symptoms are alleviated and incidence rates are reduced for several forms of common cancers (breast, colon, lung, lymphomas, ovarian, prostate, etc.) [4–8], for multiple sclerosis [9], diabetes type 1 and 2 [10,11], rheumatoid arthritis and several other autoimmune diseases [12], as well as car-

diovascular diseases [13] and influenza [14]. Furthermore, rickets and osteomalacia, both resulting from too low vitamin D levels, are reappearing in certain population groups [15,16].

The vitamin D status is usually estimated by measuring the serum concentration of 25(OH)D₃. Optimal levels associated with reduction of disease risk may be disease-specific [17]. Most researchers agree that levels below 50 nmol/L are inadequate, while much higher levels are probably needed for optimal health [3,18,19].

Exposure of skin to solar radiation is by many researchers regarded as the main human source for vitamin D [20]. Consumption of fat fish (herring, mackerel, salmon),

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cod liver oil and supplements are good alternatives [21]. During winter months (October–March) at latitudes above 40° N vitamin D formation in the skin is insufficient due to the low UVB fluences [22,23]. This is supported by practically all published investigations on seasonality of vitamin D status (for a review, see [24]). Typically, average summer values are about 70–80 nmol/L, while average winter values are 40–50 nmol/L [24–32]. We, and others, have found that cancer prognosis is significantly better for summer diagnosis than for winter diagnosis [7,33–39], and we have suggested that this is related to seasonal variations of the levels of 25(OH)D₃. In view of this observation, it seems important to maintain summer levels of 25(OH)D₃ during the winter as well. This can be achieved either by exposure to sunbeds or by ingestion of sufficient amounts of food and supplements containing vitamin D.

Three goals were addressed in this study in healthy volunteers: (1) to determine if non-erythemogenic sun bed doses can induce summer levels of 25(OH)D₃, (2) to determine how fast these summer levels decrease after termination of the sun bed exposure and (3) to see if the recommended intake of 200 IU/day [74] of vitamin D is adequate to maintain a “summer” level of 25(OH)D₃.

2. Materials and methods

2.1. Volunteers

Ten healthy volunteers were included in the study, three men and seven women, aged 23–35 years, living in Oslo (59° N). All of them are Caucasians with similar skin types. None of them were using supplements including vitamin D or were exposed to sun or artificial UV sources for at least one month prior to the study start. To exclude any contribution of solar radiation, we conducted the study between the months of October and February; a time of the year when no vitamin D is synthesized from the sun at our latitudes [22,23]. Since we were interested in within-subject changes, we asked the participants to stick to their normal diet, even if this would contain small amounts of vitamin D from fish, milk or margarine.

The Regional Ethical Committee approved the study and each participant gave informed consent. All followed the entire study. Giving placebos was deemed unnecessary. A pilot study had indicated that the low number of participants was adequate to give reliable trends.

2.2. Protocol

The study extended over 12 weeks and consisted of two periods. During the first 4 weeks we simulated a Norwegian summer by giving moderate sun bed exposures two times per week. The individual minimum erythema doses (MEDs) were determined to avoid any sunburning. The first exposure was 0.5 MED and then increased by approximately 0.1 MED per exposure to reach 1 MED. Exposures were continued to 1 MED and totaled 10 sessions. After

the period of sun bed exposure was terminated, the experimental group was divided in two: one subgroup got a daily supplement of 200 IU of vitamin D₃ (the standard recommended dose for adults) in the form of cod liver oil capsules (Møllers dobbel produced by Peter Møller AS, Norway, the amount of vitamin D per capsule being given by the producer) (Group A), while the other subgroup received no supplement (Group B). The main endpoint was to determine the change in the serum concentration of 25(OH)D₃.

2.3. Ultraviolet exposure

The source of UV radiation was a commercially available and approved sun bed, equipped with Life Sun S 100 W tubes (Wolff System, Basel, Switzerland). The spectrum given by the producer is given in Fig. 1. The fluence rate was measured using an UV-meter (Solar Light Company Inc., USA) and were: 12 mW/cm² in UVA and 0.48 mW/cm² in UVB.

Individual minimal erythema doses (MED) were measured before the commencement of the study by exposing three skin areas on the anterior forearm to three doses of UV (12–15–22 min) from the sun bed. Erythema was evaluated clinically 24 h after the end of the irradiation.

UV radiation was administered to the whole body in incremental doses starting from 0.5 MED and increasing to 1 MED.

2.4. Blood sampling and methods of analyses

Blood was sampled at the start of the experiment and weekly thereafter. Serum was separated from cells by centrifugation, frozen down to –20 °C and the samples were shipped on dry ice in one batch to the Haukeland University Hospital, Bergen, for analysis. The 25(OH)D₃ assay was performed according to a modified version of the method described [40]. Briefly, 100 µl serum samples were spiked with 26,27-dexadeuterium-25-hydroxy Vitamin D₃ (Synthetica AS, Oslo, Norway) as internal standard and

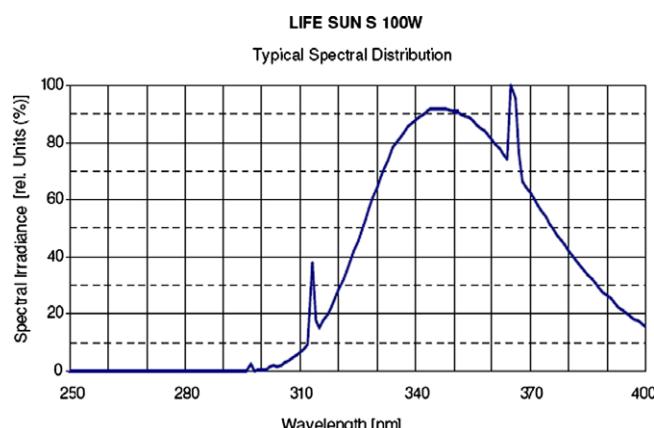


Fig. 1. Spectral characteristics of the sun bed lamps used in this study.

extracted with methanol and *n*-hexane. The *n*-hexane phase was collected, evaporated to dryness and ejected into a reverse-phase high-performance liquid chromatography system. Elution of 25(OH)D₃ was performed with methanol/water (88:12, v/v, with 0.1% formic acid) and the eluate was monitored by a LC/MS-detector (LC/MSD SL, Agilent Technology INC, CA 95051, USA) equipped with a multimode ion-source. 25(OH)D₃ and internal standard were monitored at 395.0 and 407.3 m/z, respectively, in the APCI positive mode. The mean recovery of 25(OH)D₃ was 77.2% (SD 3.9%) and the inter-assay variation was 4.9%, with a detection limit < 4 nmol/l.

3. Results

Moderate and non-erythemogenic UV exposures in a commercial sun bed (Fig. 1) twice per week increased the serum 25(OH)D₃ level significantly (Fig. 2). After seven exposures (three weeks) a plateau level was reached. On the average the level was raised from 65 nmol/L to 92 nmol/L, i.e., by 40%, which is similar to what is found for the winter-to-summer increase in other Nordic investigations [22]. The initial level of 25(OH)D₃ of the volunteers was in the range 40–100 nmol/L, and the sun bed-induced increase was not dependent on the initial level (Fig. 3A). Thus, even though all persons were of similar age and had similar skin types (individual MED varied from 20 to 22 min), their abilities to generate vitamin D from exposure to a sun bed were different. Men seemed to show the highest ability to generate vitamin D, although too few persons were included in the study to permit any firm conclusion (data not shown). Body mass index (BMI) might influence the serum levels of generated 25(OH)D₃ [17,41], since vitamin D and its precursors all are fat soluble [20]. The range of BMIs in our study was moderate (22–30), and we observed no correlation between BMI within this rather narrow range and increase in 25(OH)D₃ level (Fig. 3B).

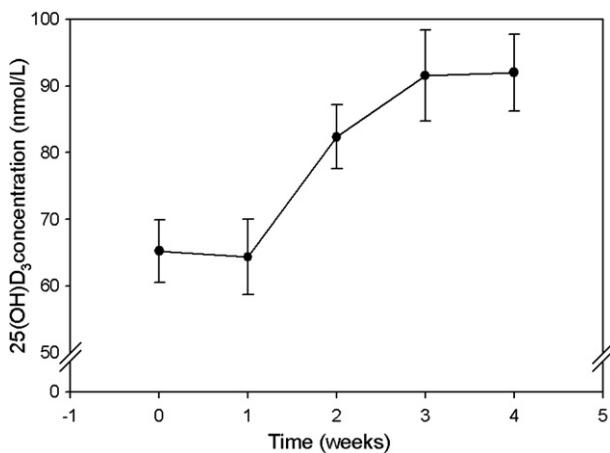


Fig. 2. Level of 25(OH)D₃ (nmol/L) at baseline and increase after ten sun sessions. Data represent averages (SE) for ten volunteers.

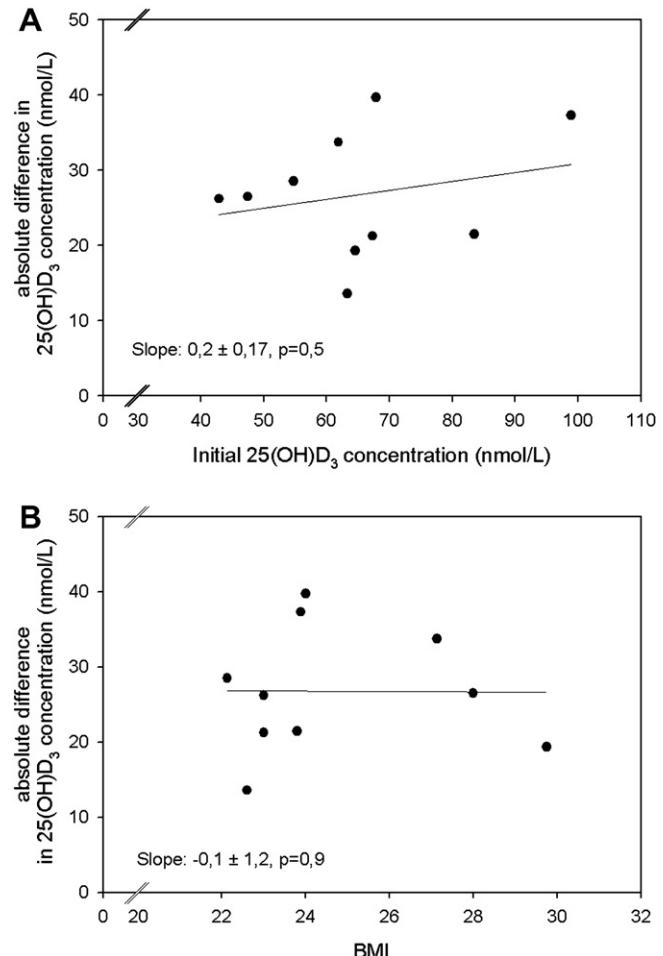


Fig. 3. Association between the absolute increase in 25(OH)D₃ (nmol / L) and baseline 25(OH)D₃ levels (A) and body mass index, BMI (B).

After termination of the sun bed session, 25(OH)D₃ levels were measured weekly (Fig. 4). Data were normalized to the initial value. The function $y = 1 + at^2 \exp(-ct)$ was fit

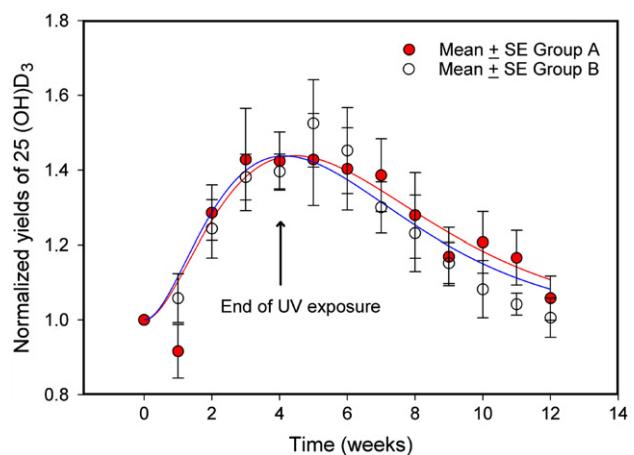


Fig. 4. Evolution of 25(OH)D₃ levels in the two study groups. After the sun bed exposures, half of the volunteers were given a daily supplement of 200 IU vitamin D in the form of cod liver oil tablets (Group A), while the other half of the persons received no supplements (Group B). Data are normalized to the initial value.

to the experimental data to analyze the buildup and decay of $25(\text{OH})\text{D}_3$. The term at^2 describes the buildup phase and $\exp(-ct)$ the decay phase. The average values of the two groups and their regression lines are shown in Fig. 4. The individual values of the parameters vary over a large range independently of which group they belong to. The mean values ($\pm \text{SE}$) of the buildup parameter and decay parameter are 0.16 ± 0.03 and 0.44 ± 0.03 for Group A and 0.018 ± 0.03 and 0.48 ± 0.03 for Group B. The difference between groups was analyzed using a *T*-test and the results are statistically non significant: $p = 0.6$ for the buildup parameter and $p = 0.5$ for the decay parameter.

4. Discussion

The main sources of vitamin D in humans are ultraviolet (UV) exposure to the sun and ingestion of fish products (fat fish, cod liver oil) and vitamin D supplements. In the present study we have investigated the efficiency of a commercially available sun bed in increasing serum $25(\text{OH})\text{D}_3$ levels in healthy, young persons. Our study has one main limitation in the population size which was too small to allow us to draw reliable conclusions on the relationship between BMI and $25(\text{OH})\text{D}_3$ increase.

The exposure pattern chosen by us did not give erythema at any time, but still raised the serum level of $25(\text{OH})\text{D}_3$ by about 40% on the average (26 nmol/L on the average). Our results are in agreement with a number of previous publications performed in healthy volunteers exposed to artificial UV sources [42–48]. After the ten sun bed sessions the concentration of $25(\text{OH})\text{D}_3$ was increased to levels found during a typical Nordic summer. The increase was not dependent on the initial $25(\text{OH})\text{D}_3$ level, which was widely different (40–100 nmol/L) among the volunteers. This result is in agreement with other publications [45,46] but contradicts the results of Mawer [44] and Snell [43] who found the increase in $25(\text{OH})\text{D}_3$ to be dependent on the initial level.

Furthermore, we observed no correlation between BMI and increase in $25(\text{OH})\text{D}_3$ level. Wortsman et al [41] reported a significant inverse relationship between these two variables in obese individuals ($\text{BMI} > 30$) exposed to whole body UV. We can draw no similar conclusion from our data since the population was small and only three, out of 10 volunteers were overweight ($\text{BMI} = 25.0\text{--}29.9$). A high body mass is likely to induce a decrease in the bioavailability of vitamin D formed in the skin or ingested [41].

There was a lag time of one to two weeks from the first exposure to the start of the increase in the $25(\text{OH})\text{D}_3$ level. This is as expected, since $25(\text{OH})\text{D}_3$ is formed in several steps after UV exposure: first previtamin D is formed, then transformed in a thermal process to vitamin D, which, in turn, has to diffuse to the blood vessels and bind to D-binding proteins to be transported to the liver. Vitamin D enters liver cells, and, finally, is hydroxylated to $25(\text{OH})\text{D}_3$, bound to D-binding protein and enters the blood stream [20].

A main conclusion of our work is that moderate exposures to a commercial sun bed give improvements of the vitamin D status. This is in agreement with our earlier, preliminary investigation [24], as well as with the results of others [42–49]. Regular use of sun beds, with more than one exposure per week for six months or more resulted in 90% higher $25(\text{OH})\text{D}_3$ serums values and in higher bone mineral densities, (0.97 ± 0.03 vs. $0.92 \pm 0.01 \text{ g/cm}^2$) [49]. Sun beds are manufactured so as to follow the legislation in different countries. This means that the biologically weighted fluence rates have to be below a certain limit, often comparable with that of the Mediterranean, midsummer and midday level [50]. Furthermore, based on the belief that UVB is more carcinogenic than UVA (ultraviolet A, 320–400 nm) according to the action spectrum of squamous cell carcinoma in mice [51], sun beds are made to emit about two orders of magnitude more UVA than UVB. However, we and others have shown that even in such sun beds it is mainly the small UVB fraction that gives the biological effect [52,53]. Since the absorption spectrum of 7-dehydrocholesterol (presumably similar to the action spectrum of pre-vitamin D formation in solution) [54] is similar to the DNA absorption spectrum [55], to the melanogenesis action spectrum and to the erythema action spectrum [56] in the range 290–315 nm, we can assume that whenever a sun bed generates significant amounts of vitamin D, it also gives DNA damage.

The risk of cutaneous malignant melanoma (CMM) associated with sun bed use has been the topic of a number of investigations, as summarized in several reviews [57–59]. Some investigations show a CMM-generating effect of sun bed use [60–62], while other investigations show no effect or even protective effects [63,64]. It has been stated that the discrepancies may be related to methodological short-comings [63,64]. However, in a reanalysis of the data in a recent IARC report [65] it was pointed out that several studies were included from the UK where people with Scottish ancestry have a genetically related increased risk of getting CMM [66], but that some of the UK studies did not adjust for skin phenotype or genetic risk [67,68]. Melanogenesis may be protective against CMM [69], and chronic UV exposure in some investigations is associated with reduced risk of CMM [5,70]. Thus, the issue of the CMM-generating effect of sunbeds is being discussed. When constructing future sun beds, and when designing proper legislation it should be kept in mind that UVA, may be more CMM-generating than previously believed [71].

In view of the documented health effects of an adequate level of vitamin D, the vitamin D-generating effect of sun beds should be weighted against the carcinogenic risk. We have earlier [22] estimated that by moving 10° southwards, as from Tromsø to Oslo in Norway, the annual vitamin D-generating solar exposure would increase by 40–50%. This would, under otherwise similar conditions, give a 10% improved vitamin D status, averaged over a year. Such an increase might have a significant impact on death rates from several cancers [5,72,73].

After the sun bed exposures, half of the volunteers were given a daily supplement of 200 IU vitamin D in the form of cod liver oil capsules, while the other half of the persons received no supplements. Within eight weeks the serum level of 25(OH)D₃ decreased to the initial value in all volunteers, irrespective of vitamin D supplementation or not. Thus, our results seem to indicate that the recommended intake of 200 IU vitamin D per day [74] is not adequate to maintain a summer vitamin D status. The half life of 25(OH)D₃ in serum is reported to be 1–2 months [75–77]. In our case the decay seems faster, with 25(OH)D₃ reaching 50% of the peak level within 1 month. The decay seems to be faster in the control group (Group B) but the difference between groups is not significant ($p = 0.5$).

Raising winter levels to summer levels (50–80 nmol/L in the Nordic countries, [22]) would lead to an average annual 25(OH)D₃ level of 22 nmol/L higher than at present. This might be achieved by moderate sun bed exposures during the winter or by increasing the daily intake of vitamin D up to 1500 IU [78], corresponding to 20 ml cod liver oil. According to the estimations of Giovannucci and coworkers [72] this would reduce the total number of cancer deaths by 29% in the US, corresponding to a reduction of the annual number of cancer deaths in Norway by 3000 from the present level of 11,000. This is more than 10 times the number of CMM deaths in Norway per year (about 250) [79].

Taking into account that moderate and regular sun bed exposure in the winter might not necessarily lead to any large increase in the number of CMM deaths, one should reconsider the restrictive attitude towards sun bed use. A daily increase of vitamin D intake corresponding to 20 ml cod liver oil may be harder to achieve, but should still be considered in view of the possible carcinogenic effect of sun bed exposure. It should be noted that vitamin D supplements should probably be in the form of cholecalciferol (vitamin D₃) rather than of ergocalciferol (vitamin D₂) since the former is more efficient [80].

Conflict of interests

The sun bed used in the present study was borrowed from The Norwegian Tanning Association.

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References

- [1] M.F. Holick, High prevalence of vitamin D inadequacy and implications for health, Mayo Clin. Proc. 81 (2006) 353–373.
- [2] R. Vieth, H. Bischoff-Ferrari, B.J. Boucher, B. wson-Hughes, C.F. Garland, R.P. Heaney, M.F. Holick, B.W. Hollis, C. Lamberg-Allardt, J.J. McGrath, A.W. Norman, R. Scragg, S.J. Whiting, W.C. Willett, A. Zittermann, The urgent need to recommend an intake of vitamin D that is effective, Am. J. Clin. Nutr. 85 (2007) 649–650.
- [3] A. Zittermann, Vitamin D in preventive medicine: are we ignoring the evidence? Br. J. Nutr. 89 (2003) 552–572.
- [4] W.B. Grant, C.F. Garland, The association of solar ultraviolet B (UVB) with reducing risk of cancer: multifactorial ecologic analysis of geographic variation in age-adjusted cancer mortality rates, Anticancer Res. 26 (2006) 2687–2699.
- [5] W.B. Grant, An ecologic study of cancer mortality rates in Spain with respect to indices of solar UVB irradiance and smoking, Int. J. Cancer 120 (2007) 1123–1128.
- [6] W.B. Grant, C.F. Garland, E.D. Gorham, An estimate of cancer mortality rate reductions in Europe and the US with 1,000 IU of oral vitamin D per day, Recent Res. Cancer Res. 174 (2007) 225–234.
- [7] M.F. Holick, Vitamin D: its role in cancer prevention and treatment, Prog. Biophys. Mol. Biol. 92 (2006) 49–59.
- [8] G.G. Schwartz, H.G. Skinner, Vitamin D status and cancer: new insights, Curr. Opin. Clin. Nutr. Metab. Care 10 (2007) 6–11.
- [9] K.L. Munger, L.I. Levin, B.W. Hollis, N.S. Howard, A. Ascherio, Serum 25-hydroxyvitamin D levels and risk of multiple sclerosis, JAMA 296 (2006) 2832–2838.
- [10] B. Littorin, P. Blom, A. Scholin, H.J. Arnqvist, G. Blohme, J. Bolinder, A. Ekbom-Schnell, J.W. Eriksson, S. Gudbjornsdottir, L. Nystrom, J. Ostman, G. Sundkvist, Lower levels of plasma 25-hydroxyvitamin D among young adults at diagnosis of autoimmune type 1 diabetes compared with control subjects: results from the nationwide Diabetes Incidence Study in Sweden (DISS), Diabetologia 49 (2006) 2847–2852.
- [11] A. Suzuki, M. Kotake, Y. Ono, T. Kato, N. Oda, N. Hayakawa, S. Hashimoto, M. Itoh, Hypovitaminosis D in type 2 diabetes mellitus: association with microvascular complications and type of treatment, Endocr. J. 53 (2006) 503–510.
- [12] L. Adorini, Intervention in autoimmunity: the potential of vitamin D receptor agonists, Cell Immunol. 233 (2005) 115–124.
- [13] A. Zittermann, Vitamin D and disease prevention with special reference to cardiovascular disease, Prog. Biophys. Mol. Biol. 92 (2006) 39–48.
- [14] J.J. Cannell, R. Vieth, J.C. Umhau, M.F. Holick, W.B. Grant, S. Madronich, C.F. Garland, E. Giovannucci, Epidemic influenza and vitamin D, Epidemiol. Infect. 134 (2006) 1129–1140.
- [15] K. Alver, H.E. Meyer, J.A. Falch, A.J. Sogaard, Bone mineral density in ethnic Norwegians and Pakistani immigrants living in Oslo – The Oslo Health Study, Osteoporos. Int. 16 (2005) 623–630.
- [16] M.F. Holick, Resurrection of vitamin D deficiency and rickets, J. Clin. Invest. 116 (2006) 2062–2072.
- [17] M.G. Bischof, G. Heinze, H. Vierhapper, Vitamin D status and its relation to age and body mass index, Horm. Res. 66 (2006) 211–215.
- [18] C.F. Garland, E.D. Gorham, S.B. Mohr, W.B. Grant, E.L. Giovannucci, M. Lipkin, H. Newmark, M.F. Holick, F.C. Garland, Vitamin D and prevention of breast cancer: pooled analysis, J. Steroid Biochem. Mol. Biol. 103 (2007) 708–711.
- [19] E.D. Gorham, C.F. Garland, F.C. Garland, W.B. Grant, S.B. Mohr, M. Lipkin, H.L. Newmark, E. Giovannucci, M. Wei, M.F. Holick, Optimal vitamin d status for colorectal cancer prevention a quantitative meta analysis, Am. J. Prev. Med. 32 (2007) 210–216.
- [20] M.F. Holick, Vitamin D: photobiology metabolism and clinical application, in: I.M. Arias, J.L. Boyer, N. Fausto, W.B. Jakoby, D. Schachter, D.A. Shafritz (Eds.), *The Liver: Biology and Photobiology*, Raven Press, New York, 1994, pp. 543–562.
- [21] Z. Lu, T.C. Chen, A. Zhang, K.S. Persons, N. Kohn, R. Berkowitz, S. Martinello, M.F. Holick, An evaluation of the vitamin D(3) content in fish: is the vitamin D content adequate to satisfy the dietary requirement for vitamin D? J. Steroid Biochem. Mol. Biol. (2007).
- [22] J. Moan, A.C. Porojnicu, T.E. Robsahm, A. Dahlback, A. Juzeniene, S. Tretli, W. Grant, Solar radiation, vitamin D and survival rate of

- colon cancer in Norway, *J. Photochem. Photobiol. B* 78 (2005) 189–193.
- [23] A.R. Webb, L. Kline, M.F. Holick, Influence of season and latitude on the cutaneous synthesis of vitamin D3: exposure to winter sunlight in Boston and Edmonton will not promote vitamin D3 synthesis in human skin, *J. Clin. Endocrinol. Metab.* 67 (1988) 373–378.
- [24] J. Moan, Z. Lagunova, A.C. Porojnicu (Eds.), *Vitamin D, Photobiology and Relevance for Cancer: Sunlight Robbery*, 2006, pp. 33–40. Available from: <<http://www.healthresearchforum.org.uk/oliver.html>>
- [25] V. Carnevale, S. Modoni, M. Pileri, G.A. Di, I. Chiodini, S. Minisola, R. Vieth, A. Scillitani, Longitudinal evaluation of vitamin D status in healthy subjects from southern Italy: seasonal and gender differences, *Osteoporos. Int.* 12 (2001) 1026–1030.
- [26] S.S. Harris, B. wson-Hughes, Seasonal changes in plasma 25-hydroxyvitamin D concentrations of young American black and white women, *Am. J. Clin. Nutr.* 67 (1998) 1232–1236.
- [27] T.J. Hine, N.B. Roberts, Seasonal variation in serum 25-hydroxy vitamin D3 does not affect 1,25-dihydroxy vitamin D, *Ann. Clin. Biochem.* 31 (1994) 31–34.
- [28] D. Lapatsanis, A. Moulas, V. Cholevas, P. Soukakos, Z.L. Papadopoulou, A. Challa, Vitamin D: a necessity for children and adolescents in Greece, *Calcif. Tissue Int.* 77 (2005) 348–355.
- [29] K. Overgaard, L. Nilas, J.S. Johansen, C. Christiansen, Lack of seasonal variation in bone mass and biochemical estimates of bone turnover, *Bone* 9 (1988) 285–288.
- [30] V. Tangpricha, E.N. Pearce, T.C. Chen, M.F. Holick, Vitamin D insufficiency among free-living healthy young adults, *Am. J. Med.* 112 (2002) 659–662.
- [31] L. Tjellesen, C. Christiansen, Vitamin D metabolites in normal subjects during one year. A longitudinal study, *Scand. J. Clin. Lab. Invest.* 43 (1983) 85–89.
- [32] A. Zittermann, K. Scheld, P. Stehle, Seasonal variations in vitamin D status and calcium absorption do not influence bone turnover in young women, *Eur. J. Clin. Nutr.* 52 (1998) 501–506.
- [33] R. Bouillon, G. Eelen, L. Verlinden, C. Mathieu, G. Carmeliet, A. Verstuyf, Vitamin D and cancer, *J. Steroid Biochem. Mol. Biol.* 102 (2006) 156–162.
- [34] S. Christakos, P. Dhawan, Q. Shen, X. Peng, B. Benn, Y. Zhong, New insights into the mechanisms involved in the pleiotropic actions of 1,25-dihydroxyvitamin D3, *Ann. NY Acad. Sci.* 1068 (2006) 194–203.
- [35] Z. Lagunova, A.C. Porojnicu, A. Dahlback, J.P. Berg, T.M. Beer, J. Moan, Prostate cancer survival is dependent on season of diagnosis, *Prostate* 67 (2007) 1362–1370.
- [36] A.C. Porojnicu, T.E. Robsahm, A. Hansen Ree, J. Moan, Season of diagnosis is a prognostic factor in Hodgkin lymphoma. A possible role of sun-induced vitamin D, *Br. J. Cancer* 93 (2005) 571–574.
- [37] A.C. Porojnicu, T.E. Robsahm, A. Dahlback, J.P. Berg, D.C. Christiani, O.S. Bruland, J. Moan, Seasonal and geographical variations in lung cancer prognosis in Norway. Does vitamin D from the sun play a role? *Lung Cancer* 55 (2007) 263–270.
- [38] A.C. Porojnicu, Z. Lagunova, T.E. Robsahm, J.P. Berg, A. Dahlback, J. Moan, Changes in risk of death from breast cancer with season and latitude: Sun exposure and breast cancer survival in Norway, *Breast Cancer Res. Treat.* 102 (2007) 323–328.
- [39] T.E. Robsahm, S. Tretli, A. Dahlback, J. Moan, Vitamin D3 from sunlight may improve the prognosis of breast-colon and prostate cancer (Norway), *Cancer Causes Control* 15 (2004) 149–158.
- [40] L. Aksnes, Simultaneous determination of retinol, alpha-tocopherol, and 25-hydroxyvitamin D in human serum by high-performance liquid chromatography, *J. Pediatr. Gastroenterol. Nutr.* 18 (1994) 339–343.
- [41] J. Wortsman, L.Y. Matsuoka, T.C. Chen, Z. Lu, M.F. Holick, Decreased bioavailability of vitamin D in obesity, *Am. J. Clin. Nutr.* 72 (2000) 690–693.
- [42] T.C. Stamp, J.G. Haddad, C.A. Twigg, Comparison of oral 25-hydroxycholecalciferol vitamin D and ultraviolet light as determinants of circulating 25-hydroxyvitamin D, *Lancet* 1 (1977) 1341–1343.
- [43] A.P. Snell, W.J. MacLennan, J.C. Hamilton, Ultra-violet irradiation and 25-hydroxy-vitamin D levels in sick old people, *Age Ageing* 7 (1978) 225–228.
- [44] E.B. Mawer, J.L. Berry, E. Sommer-Tsilenis, W. Beykirch, A. Kuhlwein, B.T. Rohde, Ultraviolet irradiation increases serum 1,25-dihydroxyvitamin D in vitamin-D-replete adults, *Miner. Electrolyte Metab.* 10 (1984) 117–121.
- [45] L.Y. Matsuoka, J. Wortsman, B.W. Hollis, Suntanning and cutaneous synthesis of vitamin D3, *J. Lab. Clin. Med.* 116 (1990) 87–90.
- [46] A. Falkenbach, U. Unkelbach, B.O. Boehm, A. Regeniter, J. Stein, U. Seiffert, T. Wendt, Bone metabolism before and after irradiation with ultraviolet light, *Eur. J. Appl. Physiol. Occup. Physiol.* 66 (1993) 55–59.
- [47] M.W. Davie, D.E. Lawson, C. Emberson, J.L. Barnes, G.E. Roberts, N.D. Barnes, Vitamin D from skin: contribution to vitamin D status compared with oral vitamin D in normal and anticonvulsant-treated subjects, *Clin. Sci. (Lond)* 63 (1982) 461–472.
- [48] M. Varghese, J.S. Rodman, J.J. Williams, A. Brown, D.M. Carter, J.E. Zerwekh, C.Y. Pak, The effect of ultraviolet B radiation treatments on calcium excretion and vitamin D metabolites in kidney stone formers, *Clin. Nephrol.* 31 (1989) 225–231.
- [49] V. Tangpricha, A. Turner, C. Spina, S. Decastro, T.C. Chen, M.F. Holick, Tanning is associated with optimal vitamin D status (serum 25-hydroxyvitamin D concentration) and higher bone mineral density, *Am. J. Clin. Nutr.* 80 (2004) 1645–1649.
- [50] Safety of tanning devices for cosmetic purposes, 2007.
- [51] F.R. de Gruyl, H.J. Sterenborg, P.D. Forbes, R.E. Davies, C. Cole, G. Kelfkens, H. van Weelden, H. Slaper, J.C. van der Leun, Wavelength dependence of skin cancer induction by ultraviolet irradiation of albino hairless mice, *Cancer Res.* 53 (1993) 53–60.
- [52] J. Moan, B. Johnsen, What kind of radiation is efficient in solaria, UVA or UVB? *J. Photochem. Photobiol. B* 22 (1994) 77–79.
- [53] A. Woollons, C. Kipp, A.R. Young, C. Petit-Frere, C.F. Arlett, M.H. Green, P.H. Clingen, The 0.8% ultraviolet B content of an ultraviolet A sunlamp induces 75% of cyclobutane pyrimidine dimers in human keratinocytes in vitro, *Br. J. Dermatol.* 140 (1999) 1023–1030.
- [54] O.N. Galkin, I.P. Terenetskaya, ‘Vitamin D’ biodosimeter: basic characteristics and potential applications, *J. Photochem. Photobiol. B* 53 (1999) 12–19.
- [55] R.B. Setlow, E. Grist, K. Thompson, A.D. Woodhead, Wavelengths effective in induction of malignant melanoma, *Proc. Natl. Acad. Sci. USA* 90 (1993) 6666–6670.
- [56] J.A. Parrish, K.F. Jaenicke, R.R. Anderson, Erythema and melanogenesis action spectra of normal human skin, *Photochem. Photobiol.* 36 (1982) 187–191.
- [57] P. Autier, Perspectives in melanoma prevention: the case of sunbeds, *Eur. J. Cancer* 40 (2004) 2367–2376.
- [58] V. Bataille, M. Boniol, V.E. De, G. Severi, Y. Brandberg, P. Sasieni, J. Cuzick, A. Eggermont, U. Ringborg, A.R. Grivegnée, J.W. Coebergh, M.C. Chignol, J.F. Dore, P. Autier, A multicentre epidemiological study on sunbed use and cutaneous melanoma in Europe, *Eur. J. Cancer* 41 (2005) 2141–2149.
- [59] R.P. Gallagher, J.J. Spinelli, T.K. Lee, Tanning beds, sunlamps, and risk of cutaneous malignant melanoma, *Cancer Epidemiol. Biomar. Prev.* 14 (2005) 562–566.
- [60] T.R. Fears, C.C. Bird, D. Guerry, R.W. Sagebiel, M.H. Gail, D.E. Elder, A. Halpern, E.A. Holly, P. Hartge, M.A. Tucker, Average midrange ultraviolet radiation flux and time outdoors predict melanoma risk, *Cancer Res.* 62 (2002) 3992–3996.
- [61] M.B. Veierod, E. Weiderpass, M. Thorn, J. Hansson, E. Lund, B. Armstrong, H.O. Adami, A prospective study of pigmentation, sun exposure, and risk of cutaneous malignant melanoma in women, *J. Natl. Cancer Inst.* 95 (2003) 1530–1538.
- [62] B. Diffey, Sunbeds beauty and melanoma, *Br. J. Dermatol.* 157 (2007) 215–216.
- [63] V. Bataille, A. Winnett, P. Sasieni, J.A. Newton Bishop, J. Cuzick, Exposure to the sun and sunbeds and the risk of cutaneous melanoma in the UK: a case-control study, *Eur. J. Cancer* 40 (2004) 429–435.

- [64] H.J. van der Rhee, V.E. De, J.W. Coebergh, Does sunlight prevent cancer? A systematic review, *Eur. J. Cancer* 42 (2006) 2222–2232.
- [65] The international agency for research on cancer working group on artificial ultraviolet (UV) light and skin cancer, The association of use of sunbeds with cutaneous malignant melanoma and other skin cancers: A systematic review, *Int. J. Cancer* 120 (2007) 1116–1122.
- [66] J. Lang, N. Hayward, D. Goldgar, H. Tsao, D. Hogg, J. Palmer, M. Stark, E.S. Tobias, R. MacKie, The M53I mutation in CDKN2A is a founder mutation that predominates in melanoma patients with Scottish ancestry, *Gene Chromosome Cancer* 46 (2007) 277–287.
- [67] S.A. Adam, J.K. Sheaves, N.H. Wright, G. Mosser, R.W. Harris, M.P. Vessey, A case-control study of the possible association between oral contraceptives and malignant melanoma, *Br. J. Cancer* 44 (1981) 45–50.
- [68] A.J. Swerdlow, J.S. English, R.M. MacKie, C.J. O'Doherty, J.A. Hunter, J. Clark, D.J. Hole, Fluorescent lights, ultraviolet lamps, and risk of cutaneous melanoma, *BMJ* 297 (1988) 647–650.
- [69] N. Agar, A.R. Young, Melanogenesis: a photoprotective response to DNA damage? *Mutat. Res.* 571 (2005) 121–132.
- [70] M. Berwick, B.K. Armstrong, L. Ben Porat, J. Fine, A. Kricker, C. Eberle, R. Barnhill, Sun exposure and mortality from melanoma, *J. Natl. Cancer Inst.* 97 (2005) 195–199.
- [71] J. Moan, A. Dahlback, R.B. Setlow, Epidemiological support for an hypothesis for melanoma induction indicating a role for UVA radiation, *Photochem. Photobiol.* 70 (1999) 243–247.
- [72] E. Giovannucci, Y. Liu, E.B. Rimm, B.W. Hollis, C.S. Fuchs, M.J. Stampfer, W.C. Willett, Prospective study of predictors of vitamin D status and cancer incidence and mortality in men, *J. Natl. Cancer Inst.* 98 (2006) 451–459.
- [73] G.G. Schwartz, W.J. Blot, Vitamin D status and cancer incidence and mortality: something new under the sun, *J. Natl. Cancer Inst.* 98 (2006) 428–430.
- [74] European Commission, Opinion of the scientific committee on food on the tolerable upper intake level of vitamin D, 2002.
- [75] M.R. Clements, M. Davies, M.E. Hayes, C.D. Hickey, G.A. Lumb, E.B. Mawer, P.H. Adams, The role of 1,25-dihydroxyvitamin D in the mechanism of acquired vitamin D deficiency, *Clin. Endocrinol. (Oxf)* 37 (1992) 17–27.
- [76] D.J. Dlugos, P.L. Perrotta, W.G. Horn, Effects of the submarine environment on renal-stone risk factors and vitamin D metabolism, *Undersea Hyperb. Med.* 22 (1995) 145–152.
- [77] M.A. Preece, S. Tomlinson, C.A. Ribot, J. Pietrek, H.T. Korn, D.M. Davies, J.A. Ford, M.G. Dunnigan, J.L. O'Riordan, Studies of vitamin D deficiency in man, *Q. J. Med.* 44 (1975) 575–589.
- [78] R.P. Heaney, K.M. Davies, T.C. Chen, M.F. Holick, M.J. Barger-Lux, Human serum 25-hydroxycholecalciferol response to extended oral dosing with cholecalciferol, *Am. J. Clin. Nutr.* 77 (2003) 204–210.
- [79] Cancer in Norway 2005, in: F. Bray (Ed.), 2006. Available from: <www.kreftregisteret.no>.
- [80] L.A. Houghton, R. Vieth, The case against ergocalciferol (vitamin D₂) as a vitamin supplement, *Am. J. Clin. Nutr.* 84 (2006) 694–697.