Burning daylight: balancing vitamin D requirements with sensible sun exposure

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ABSTRACT

Objective: To examine the feasibility of balancing sunlight exposure to meet vitamin D requirements with sun protection guidelines.

Design and setting: We used standard erythemal dose and Ultraviolet Index (UVI) data for 1 June 1996 to 30 December 2005 for seven Australian cities to estimate duration of sun exposure required for fair-skinned individuals to synthesise 1000 IU (25 µg) of vitamin D, with 11% and 17% body exposure, for each season and hour of the day. Periods were classified according to whether the UVI was < 3 or ⩾ 3 (when sun protection measures are recommended), and whether required duration of exposure was ⩽ 30 min, 31–60 min, or > 60 min.

Main outcome measure: Duration of sunlight exposure required to achieve 1000 IU of vitamin D synthesis.

Results: Duration of sunlight exposure required to synthesise 1000 IU of vitamin D varied by time of day, season and city. Although peak UVI periods are typically promoted as between 10 am and 3 pm, UVI was often ⩾ 3 before 10 am or after 3 pm. When the UVI was < 3, there were few opportunities to synthesise 1000 IU of vitamin D within 30 min, with either 11% or 17% body exposure.

Conclusion: There is a delicate line between balancing the beneficial effects of sunlight exposure while avoiding its damaging effects. Physiological and geographical factors may reduce vitamin D synthesis, and supplementation may be necessary to achieve adequate vitamin D status for individuals at risk of deficiency.

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Vitamin D_3 (cholecalciferol) is a provitamin obtained through exposure of the skin to sunlight and from dietary sources. Vitamin D is essential for calcium homeostasis and bone health, and deficiency has been associated with several chronic diseases.[1] Vitamin D requires metabolism in the liver to 25-hydroxyvitamin D (25[OH]D),[2] the major circulating form and indicator of vitamin D status.[3]

There is debate about what serum level of 25(OH)D constitutes deficiency or sufficiency. While deficiency can be regarded as a 25(OH)D level below 50 nmol/L (< 20 ng/mL),[4] a recent Institute of Medicine report suggested a level of 50 nmol/L represents adequacy,[5] and that further randomised trials are needed before a higher level can be recommended. However, it has elsewhere been suggested that a level of 75 nmol/L (30 ng/mL) should represent sufficiency.[6] To maintain a 25(OH)D level of 75 nmol/L, a daily intake or synthesis of at least 1000 IU (25 µg) of vitamin D is required.[6]

Exposure of skin to ultraviolet B (UVB) radiation in sunlight is the body's principal vitamin D source.[7] UVB penetrates outer layers of skin, causing temporary redness (erythema). UVA radiation penetrates deeper layers of the skin, causing photoageing[8] and increased risk of cutaneous malignant melanoma.[9] Although UVB is lower early and late in the day, UVA may be relatively high at these times.[10] The Ultraviolet Index (UVI) measures ultraviolet radiation (UVR) intensity, and ranges from 1 to about 14 in Australia (higher towards lower latitudes in the north, and decreasing towards higher latitudes in the south).

Melanoma incidence is associated with higher UVI, lower latitude[11] and history of sunburn.[12] Australian skin cancer prevention campaigns advise sun protection (shade, protective clothing, broad-brimmed hats, sunglasses, sunscreen) during "peak UVI periods", typically promoted as between 10 am and 3 pm, or when the UVI reaches 3.[4,13,14] Conversely, bone health experts recommend short periods of unprotected exposure of the face, arms and hands to sunlight three to six times per week to prevent vitamin D deficiency.[15,16] Adherence to protective guidelines without compensatory vitamin D intake increases the risk of deficiency, as clothing,[17] shade[18] and sunscreen[19] reduce vitamin D synthesis. Although evidence is limited, high rates of vitamin D deficiency have been reported in Australians.[20,21] Vitamin D deficiency is more prevalent in winter, and insufficiency is common in summer and autumn, suggesting that regular sunlight exposure or intake is required year-round.

A practical tool enabling individuals to maintain adequate vitamin D status that also considers the deleterious effects of UVR is warranted. Here, we aim to identify sunlight exposure duration required for fair-skinned individuals in Australian cities to generate 1000 IU of vitamin D throughout the year, and to determine the feasibility of achieving this within 30 min at times when sun protection is not required.

METHODS

The cumulative or standard erythemal dose (SED) of UVR determines the magnitude of vitamin D synthesis. Minimal erythemal dose (MED) is the measure of cumulative UVR exposure that causes erythema, and is equal to about 2 SED. Whole-body exposure to 1 MED is equivalent to an oral dose of about 20 000 IU of vitamin D in fair-skinned individuals.[22]

Data on hourly UVI and SED between 1 June 1996 and 30 December 2005 were obtained from the Australian Radiation Protection and Nuclear Safety Agency[23] for seven cities with data loggers — Darwin (12.4°S), Townsville (19.3°S), Brisbane (27.5°S), Perth (31.9°S), Sydney (34.0°S), Adelaide (34.9°S) and Melbourne (37.7°S). Data from Tasmania were unavailable for the study period. When SED was below 0.005, a value of zero was given. Missing values, indicating data monitor failure, were excluded from calculations.

The Lund–Browder burn diagram[24] was used to estimate skin surface exposure percentages (Box 1). The face was not included, as sun protection of the eyes and face is always recommended.[14] Estimated body surface areas for children and adolescents did not differ greatly from adults.

Current guidelines suggest exposure of 15% of the body to one-third of an MED to produce 1000 IU of vitamin D, four to five

1 Estimated percentage of skin exposure on one side of the body, and vitamin D synthesis from exposure to 0.294 or 0.455 MED*

Body parts exposed to sun	% of one side of body	Vitamin D synthesis (IU) 0.294 MED	0.455 MED
Full body (eg, wearing bikini)	100%	5882	9091
Neck, hands, full arms, full legs	28%	1647	2545
Neck, hands, full arms, lower legs	17%	1000	1545
Neck, hands, full arms	11%	647	1000
Neck, hands, lower arms	7%	412	636

MED = minimal erythemal dose. * Extrapolated from Lund–Browder burn diagram[24] and Holick.[22] ◆

2 Duration (min) required to achieve synthesis of 1000 IU of vitamin D with one side of the hands, arms and neck (11% of the body) exposed to the sun (0.455 MED), by city, season and time of day*

City†	Season	6	7	8	9	10	11	12	13	14	15	16	17
Darwin (12.4° S)	Summer	4149	218	44	17	10	7	6	7	8	12	22	63
	Autumn	180 684	359	52	18	10	7	6	7	8	13	30	120
	Winter	452 732	744	83	25	12	9	8	8	10	16	36	148
	Spring	1699	124	31	14	8	7	6	6	7	12	28	110
Townsville (19.3° S)	Summer	394	63	21	11	8	6	6	7	8	13	29	101
	Autumn	1923	149	37	17	10	9	9	10	15	28	84	633
	Winter	5517	339	65	25	15	11	11	13	18	36	117	998
	Spring	286	54	20	10	7	6	6	7	10	19	55	334
Brisbane (27.5° S)	Summer	116	33	15	10	7	7	7	7	10	17	41	169
	Autumn	810	100	31	16	12	11	12	15	24	55	237	4042
	Winter	5436	342	75	31	19	16	17	23	41	110	618	25 337
	Spring	145	39	18	12	9	8	9	11	18	38	136	1190
Perth (31.9° S)	Summer	467	73	24	12	8	6	6	6	8	12	24	74
	Autumn	22 825	676	122	45	26	20	19	23	36	80	321	3802
	Winter	14 496	562	109	41	23	18	17	20	29	57	180	1348
	Spring	150	41	18	11	8	7	7	8	11	18	39	139
Sydney (34.0° S)	Summer	147	43	19	12	8	7	7	8	11	19	41	136
	Autumn	1924	196	54	25	16	14	14	18	28	65	262	3191
	Winter	25 134	331	58	22	12	9	9	12	21	55	300	12 312
	Spring	217	58	25	15	11	10	11	13	20	42	130	817
Adelaide (34.9° S)	Summer	210	51	21	11	8	6	6	6	8	12	24	65
	Autumn	10 349	559	117	46	27	21	20	23	34	67	217	1773
	Winter	na	2402	304	94	46	33	32	37	57	130	546	7673
	Spring	353	79	31	17	12	10	10	12	17	31	82	384
Melbourne (37.7° S)	Summer	225	60	25	14	9	8	7	8	9	14	24	58
	Autumn	16 494	567	109	42	24	18	17	19	27	51	154	1055
	Winter	na	5259	499	139	66	46	43	49	75	162	665	10 395
	Spring	456	101	39	22	16	13	13	15	20	35	84	330

Time of day (24-hour time)

MED = minimal erythemal dose. na = not applicable. * Red areas represent periods when Ultraviolet Index (UVI) is ⩾ 3 (when sun exposure is discouraged by sun protection guidelines); green areas represent periods when UVI is < 3 and required duration of exposure is ⩽ 30 min; blue areas represent periods when UVI is < 3 and required duration of exposure is 31–60 min; and grey areas represent periods when UVI is < 3 and required duration of exposure is > 60 min. Individuals should check real-time UVI data (http://www.arpansa.gov.au/uvindex/realtime), as the actual level may vary from the long-term average. † Cities are listed from most northern (lowest latitude) to southern (highest latitude). ◆

times a week.[13,16] Excluding the face equates to 11% body exposure, which would reportedly produce 733 IU of vitamin D.[22] We calculated that when hands, arms and neck on one side of the body (11% of the body) are exposed to the sun, a dose of 0.455 MED is required for fair-skinned individuals to achieve 1000 IU of vitamin D, whereas including one side of the lower legs (17% of the body) decreases the required dose to 0.294 MED (Box 1). We then determined the duration of sun exposure required to achieve each of these MEDs for each hour of daylight between 6 am and 5 pm, by season and city.

Average monthly SEDs for each hour of daylight during January, April, July and October were used to represent summer, autumn, winter and spring, respectively. Periods when the average UVI (UVI_{av}) was < 3 were recorded in tabular format as green if synthesis of 1000 IU could be achieved in ⩽ 30 min, and blue if it could be achieved in 31–60 min. Periods when the UVI_{av} was ⩾ 3 were coded red to reflect sun protection guidelines. Periods when it was impossible to achieve 1000 IU of vitamin D synthesis within 1 hour were recorded as grey.

RESULTS

Our data showed it was possible for fair-skinned individuals to obtain 1000 IU of vitamin D within 30 min of exposure of 11% (Box 2) or 17% (Box 3) of the skin to the sun, but there were few occasions when this could be achieved at times not excluded by sun protection guidelines. More opportunities to achieve synthesis of 1000 IU in ⩽ 30 min occurred, and required duration was shorter, when 17% of the body was exposed to the sun, relative to 11%, as seen by the greater number of green cells in Box 3 relative to Box 2.

UVI_{av} often reached 3 outside the publicised peak UVI period of 10 am–3 pm (Box 2, Box 3). In summer, the UVI_{av} was ⩾ 3 between 8 am and 5 pm in all cities except Townsville and Sydney (8 am–4 pm) and Darwin (9 am–5 pm). In winter in Darwin, Townsville, and Brisbane, the UVI_{av} was ⩾ 3 from 10 am until 4 pm, 3 pm and 2 pm, respectively. In contrast, in winter in Sydney, Adelaide, and Melbourne, the UVI_{av} remained < 3 throughout the day, allowing exposure without protection during the warmer parts of the day.

UVI_{av} and duration of sun exposure required to achieve 1000 IU of vitamin D synthesis varied according to time of day, season and city (Box 2, Box 3). Opportunities when this could be achieved within 30 min when the UVI was < 3 were limited.

With 11% body exposure, there were no opportunities in summer and autumn to achieve 1000 IU of vitamin D synthesis in $\leqslant$ 30 min except Townsville in summer, whereas during winter and spring there were some opportunities in most cities (Box 2).

When lower legs were included in exposure, 1000 IU synthesis could be achieved within 30 min on at least one occasion each day for almost all seasons (with the exceptions of Adelaide, Perth and Melbourne in summer; Townsville in spring; and Darwin and Sydney in autumn) (Box 3). As the UVI was < 3 during the middle part of the day in winter in Perth (except at midday), Sydney, Adelaide and Melbourne, sun exposure of $\leqslant$ 30 min during the middle of the day could achieve 1000 IU of vitamin D synthesis.

DISCUSSION

We found that duration of sunlight exposure required for fair-skinned individuals to achieve 1000 IU of vitamin D synthesis varies according to time of day, season and city.

Overall, when 11% of the body is exposed to the sun, there are few opportunities to synthesise 1000 IU of vitamin D within 30 min at times of the day when sun exposure without protection is not discouraged. In nearly all cities during summer and autumn, there are no opportunities to achieve this, whereas there are more opportunities during winter and spring, particularly in southern cities such as Sydney and Melbourne. For exposure durations of 31–60 min, most cities have at least one opportunity each day to synthesise 1000 IU; however, as these periods mostly occur early and late in the day, we advise caution due to the potentially damaging effects of UVA light at these times.[10] It may be preferable to instead increase the amount of skin exposed to the sun to reduce the required duration.

We consider 30 min as the maximum duration that individuals could feasibly spend in the sun each day on a regular basis. Formation of pre-vitamin D plateaus in fair-skinned individuals within 15–45 min of exposure to UVR, after which further exposure causes the breakdown of pre-vitamin D into biologically inactive lumisterol and tachysterol.[2]

Our findings extend previous guidelines,[1,16] which suggest that the majority of fair-skinned individuals in Australia can achieve vitamin D requirements at 10 am or 3 pm, and individuals with no other risk factors for skin cancer can achieve their requirements at 12 noon. However, our findings suggest that UVI_{av} is often $\geqslant 3$ at these times, and the risk of overexposure is therefore higher. We found that UVI_{av} often reached 3 outside commonly promoted peak UVI periods, indicating sun protection behaviour should extend beyond these times.

Our UVI data cover a period of 10 years, and therefore are likely to be robust and based on "typical" cloud cover, although

3 Duration (min) required to achieve synthesis of 1000 IU of vitamin D with one side of the hands, arms, neck and lower legs (17% of the body) exposed to the sun (0.294 MED), by city, season and time of day*

City†		Time of day (24-hour time) 6	7	8	9	10	11	12	13	14	15	16	17
Darwin (12.4° S)	Summer	2684	141	29	11	7	5	4	4	5	8	14	41
	Autumn	116 912	232	34	12	6	5	4	4	5	9	19	78
	Winter	292 941	481	54	16	8	6	5	5	6	10	23	96
	Spring	1100	80	20	9	5	4	4	4	5	8	18	71
Townsville (19.3° S)	Summer	255	41	14	7	5	4	4	4	5	8	18	66
	Autumn	1244	96	24	11	7	6	6	7	10	18	54	409
	Winter	3570	219	42	16	9	7	7	8	12	23	76	646
	Spring	185	35	13	7	5	4	4	5	6	12	35	216
Brisbane (27.5° S)	Summer	75	21	10	6	5	4	4	5	7	11	26	109
	Autumn	524	65	20	11	8	7	8	10	15	35	153	2615
	Winter	3518	221	49	20	13	11	11	15	26	71	400	16 395
	Spring	94	25	12	7	6	5	6	7	11	25	88	770
Perth (31.9° S)	Summer	302	47	15	8	5	4	4	4	5	8	15	48
	Autumn	14 769	437	79	29	17	13	12	15	23	52	208	2460
	Winter	9 380	364	71	27	15	12	11	13	19	37	117	872
	Spring	97	27	12	7	5	5	5	5	7	11	25	90
Sydney (34.0° S)	Summer	95	28	13	8	5	5	4	5	7	12	27	88
	Autumn	1 245	127	35	16	11	9	9	12	18	42	169	2065
	Winter	16 263	214	38	14	8	6	6	8	14	36	194	7966
	Spring	140	37	16	10	7	6	7	9	13	27	84	529
Adelaide (34.9° S)	Summer	136	33	13	7	5	4	4	4	5	8	15	42
	Autumn	6696	362	75	30	18	14	13	15	22	44	141	1147
	Winter	na	1554	197	61	30	22	20	24	37	84	353	4965
	Spring	229	51	20	11	8	7	7	8	11	20	53	249
Melbourne (37.7° S)	Summer	145	39	16	9	6	5	5	5	6	9	15	37
	Autumn	10 672	367	71	27	16	12	11	13	17	33	99	683
	Winter	na	3403	323	90	43	30	28	32	48	105	430	6726
	Spring	295	65	25	14	10	8	9	10	13	23	54	213

MED = minimal erythemal dose. na = not applicable. * Red areas represent periods when Ultraviolet Index (UVI) is $\geqslant 3$ (when sun exposure is discouraged by sun protection guidelines); green areas represent periods when UVI is < 3 and required duration of exposure is $\leqslant$ 30 min; blue areas represent periods when UVI is < 3 and required duration of exposure is 31–60 min; and grey areas represent periods when UVI is < 3 and required duration of exposure is $>$ 60 min. Individuals should check real-time UVI data (http://www.arpansa.gov.au/uvindex/realtime), as the actual level may vary from the long-term average. † Cities are listed from most northern (lowest latitude) to southern (highest latitude). ◆

daily variation in cloud cover and pollution levels will alter the required exposure durations. As reported previously,[25] we found that the UVI_{av} remains below 3 throughout the day in Sydney, Adelaide and Melbourne during winter, suggesting that there may be a wider safety margin to allow sufficient sunlight exposure to achieve adequate vitamin D synthesis in winter in these cities.

Our recommendations take into account Australian guidelines that suggest sun protection is not required when the UVI is below 3.[4] Our suggested doses of 0.455 and 0.294 MED are unlikely to cause sunburn, as 1 MED produces only a faint pinkness in fair-skinned individuals.[26] We recommend individuals check real-time UVI data,[27] as the actual level may vary from the long-term average.

A limitation of our study is our inability to take into account physiological factors that contribute to vitamin D deficiency, such as increased age,[28] increased skin pigmentation,[29] fat malabsorption,[30] and obesity,[31] and as such our recommendations are likely to be an underestimate for individuals affected by these factors.

It could be argued that the recommendation of avoiding sunlight exposure when the UVI is ⩾ 3 could be more nuanced, as skin is damaged relative to the total exposure, which is dependent on both UVR intensity and duration of exposure. Although brief exposure when the UVI is ⩾ 3 could be identical to longer exposure during periods of low UVI in terms of both vitamin D synthesis and skin damage, exposure during high UVI periods requires careful timing to avoid overexposure. Additionally, the achievements made in educating the public about the dangers of high UVI could be lost if alternative recommendations were to be made.

Australians should be aware of methods to obtain sufficient vitamin D while minimising skin damage. Given the difficulty of achieving adequate vitamin D synthesis in some individuals, increasing oral intake with daily supplementation or consuming food naturally containing or fortified with vitamin D may be required.

COMPETING INTERESTS

None identified.

AUTHOR DETAILS

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