Vitamin D status and sun exposure in India

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Background: Little if any cutaneous production of vitamin D3 occurs at latitudes above and below 35° N and 35° S during the winter months. It was postulated that those residing in tropics synthesize enough vitamin D3 year round. Several studies have documented the effect of latitude, season and time of the day on the cutaneous production of vitamin D3 in an ampoule model. Studies from India have shown high prevalence of vitamin D deficiency despite abundant sunshine.

Results: The percent conversion of 7-DHC to previtamin D3 and its photoproducts and formation of vitamin D3 and vitamin D3 was maximal between 11 a.m. to 2 p.m. of the day during the entire year (median 11.5% and 10.2% respectively at 12.30 p.m.).

Methods: We studied the influence of season and time of the day on synthesis of previtamin D3 in an ampoule model in Tirupati, (latitude 13.40° N and longitude 77.2° E) south India, between May 2007 to August 2008. Sealed borosilicate glass ampoules containing 50 µg of 7-DHC in 1 ml of methanol were exposed to sunlight hourly from 8 a.m. until 4 p.m. The percent conversion of 7-DHC to previtamin D3 and its photoproducts and the percent of previtamin D3 and vitamin D3 formed was estimated and related to solar zenith angle.

Conclusions: Therefore at this latitude exposure to sunlight between the hours of 11 a.m. and 2 p.m. will promote vitamin D production in the skin year round.

Introduction

Casual exposure to solar radiation wavelengths 290–315 nm results in the cutaneous production of previtamin D3.1 During sun exposure the UVB photons (290–315 nm) that enter the epidermis cause a photochemical transformation of 7-dehydrocholesterol (7-DHC) (provitamin D3) to previtamin D3. Previtamin D3 exists in two conformeric forms cis,cis (CZC) and cis,trans (CZT). The S-cis,S-cis-previtamin D3 (CZC) rapidly undergoes conformational change to the thermodynamically more stable S-trans,S-cis-previtamin D3 (CZT).2 However the thermodynamically less stable CZC conformer is the only form of previtamin D3 that can convert to vitamin D3. The 7-DHC is incorporated into lipid bilayer. During exposure to solar UV radiation (wavelengths 290–315 nm) 7-DHC in the triglyceride portion of the plasma membrane is converted only to czc-previtamin D3, which then rapidly converts into vitamin D3 at body temperature. Once formed the more stable vitamin D3 is sterically altered and is ejected from plasma membrane into extracellular space. At body temperature it takes 12 h for ~99% of previtamin D3 to be converted to vitamin D3. The previtamin D3 formed is also photolabile and excessive sunlight exposure results in its photoisomerization to at least two biologically inert products, lumisterol and tachysterol.2

The ability to synthesize previtamin D3 is affected by latitude, rotation of earth about the sun (season) and its own axis (day and night)—time of day. Atmospheric pollution attenuates solar radiation. Dress code, skin pigmentation, and application of sun protection factor (SPF) of 15 reduces the UVB penetration into epidermis by > 95%, thereby limiting the production of previtamin D3 by the skin. With age the cutaneous 7-DHC levels decline, reducing the skin’s capacity to produce vitamin D3. With the increase in solar zenith angle in winter (sun angle becomes more oblique), more UVB photons are absorbed by the stratospheric zone, and therefore very few of the UVB photons can penetrate to earth’s surface to produce cutaneous previtamin D3. Thus the amount of UVB radiation reaching earth’s surface is a function of solar zenith angle, time of day, season of the year, amount of ozone, cloud, aerosols, and latitude and altitude, which all influence the cutaneous production of vitamin D3.3 Chen et al.4 reported little if any cutaneous production of previtamin D3 at latitudes above and below 35° N and 35° S during the winter months. For latitude above 51° (north and south of equator) UV index is less than 0.5 in winter months. Any casual exposure to sunlight will not result in any appreciable vitamin D3 synthesis during these periods and is called “vitamin D winter.”5 Several studies have documented the effect of latitude, season time of the day and altitude on the cutaneous production of vitamin D3.5 It has been assumed that those residing in tropics can produce enough vitamin D3 in the skin throughout the year.6 Recent studies from India have shown high prevalence of vitamin D deficiency both in rural and urban

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populations, in north and south India. It has been shown in population surveys from south India (Tirupati latitude 13.4° N and longitude 77.2° E) that rural populations, who are agricultural laborers exposed to sunlight for more than 4 h with at least 35% of their body surface area exposed to sunlight, also have vitamin D deficiency. There is no study that has determined the effect of time of day and season in India on previtamin D₃ synthesis. Hence we evaluated the influence of season and time of the day on synthesis of previtamin D₃ in an ampoule model in Tirupati, south India.

**Results**

The relationship between solar zenith angle, the percent conversion of 7-DHC to previtamin D₃ and its photoproducts, lumisterol and tachysterol and the percentage of previtamin D₃ and vitamin D₃ formed, along with the correlation coefficient r and the p values of significance are given against each day studied, is shown in Figure 1A–D. The maximum and minimum temperatures on the day of the study are depicted against each day. There was a strong negative correlation between zenith angle and percent conversion of 7-DHC to previtamin D₃ and vitamin D₃ for the whole duration of the study.

The hourly data obtained in a time dependent fashion from morning to evening for the whole duration of the study were analyzed together. The mean ± SD of hourly data and percent conversion of 7-DHC to previtamin D₃ and its photoproducts, and the percentage of previtamin D₃ and vitamin D₃ formed from May 2007 to August 2008. The correlations between them are shown individually for each day. The maximum (max) and minimum (min) temperature (Temp) on the day of the study is given above each day studied. August 2007 is not depicted. r, correlation coefficient; P, significance.

![Figure 1](image-url)

**Figure 1.** Influence of time of day and season on synthesis of previtamin D₃ at Tirupati located at 13.4° N and 79.2° E. Figure shows the relation between zenith angles (ZA), percent conversion of 7-Dehydrocholesterol (7-DHC) to previtamin D₃ and photoproducts, and the percentage of previtamin D₃ and vitamin D₃ (%Pre D₃+D₃) formed from May 2007 to August 2008. The correlations between them are shown individually for each day. The maximum (max) and minimum (min) temperature (Temp) on the day of the study is given above each day studied. August 2007 is not depicted. r, correlation coefficient; P, significance.
Previtamin D$_3$ and vitamin D$_3$ formed (Y) = 20.466 - 0.285*Zenith angle (X).

Keeping other parameters constant, a decrease in the angle by one degree, led to an increase in the product of 0.285 units. This model was also found to be significant; the p-value was almost zero in the ANOVA (p < 0.0001). In the above model the correlation between the percent of previtamin D$_3$ and vitamin D$_3$ formed and solar zenith angle was 0.813 and the R-square value was 0.66 and p < 0.0001, which denotes that about 67% of variation in previtamin D$_3$ and vitamin D$_3$ formed can be attributed to the zenith angle. The regression coefficient was also significant (p < 0.0001). It can also be observed from Figure 3 that the percent of previtamin D$_3$ and vitamin D$_3$ formed is maximum when the zenith angle is minimum. Since the zenith angle derived, also incorporates the year, month and time of the day, the model is integrated with these parameters. We substituted the known zenith angles and derived the percent of previtamin D$_3$ and vitamin D$_3$ formed using the above equation. The results were not different with a p = 0.76 (NS).

The percent conversion of 7-DHC to previtamin D$_3$ and its photoproducts and percent of previtamin D$_3$ and vitamin D$_3$ formed was maximal between 11 a.m. to 2 p.m. when the zenith angle was at its minimum (Fig. 3). The minimum zenith angle observed was on the April 18, 2008 at 1 p.m. with an angle of 5°. At this time 28.9% of 7-DHC was converted to previtamin D$_3$ and vitamin D$_3$ and an additional 19.7% was converted to lumisterol and tachysterol. At a maximum zenith angle of 67° on the January 18, 2008 at 9 a.m. only 1.3% of 7-DHC was converted to previtamin D$_3$. At 1 p.m. on the same day (January 18, 2008) the Zenith angle was 34° with 18% 7-DHC conversion and 13% being previtamin D$_3$ and vitamin D$_3$ formed. The median percent conversion of 7-DHC to previtamin D$_3$ and its photoproducts was 11.5% with 10.2% being previtamin D$_3$ and vitamin D$_3$ formed at a zenith angle of 37° at 12.30 p.m. The maximum temperature on the day of study during the whole period is depicted along with zenith angle, percent conversion of 7-DHC to previtamin D$_3$ and its photoproducts and percent of previtamin D$_3$ and vitamin D$_3$ formed in the three-dimensional Figure 4.

During the study time of September 2007 and March 2008 when there were thick overcast clouds the zenith angle was less than 25°. The percent conversion of 7-DHC to previtamin D$_3$ and its photoproducts and previtamin D$_3$ was significantly reduced (Figs. 4 and 5). The maximum percent conversion of 7-DHC to previtamin D$_3$ and its photoproducts and previtamin D$_3$ formed at a zenith angle of 37° at 12.30 p.m. The maximum temperature on the day of study during the whole period is depicted along with zenith angle, percent conversion of 7-DHC to previtamin D$_3$ and its photoproducts and percent of previtamin D$_3$ and vitamin D$_3$ formed in the three-dimensional Figure 4.

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**Discussion**

The synthesis of vitamin D in the skin occurs in a two-stage process. As soon as the skin is exposed to solar UVB radiation
previtamin D$_3$ and vitamin D$_3$ between 11 a.m. to 2 p.m. (Fig. 2).

Indian meteorologists classify seasons as follows: Winter is January to February; pre-monsoon is March to May; south east monsoon is June to September and winter monsoon or north east monsoon is October to December. It was observed by three dimensional aerosol assimilation models during Indian Ocean Experiment (INDOEX) a layer of air pollution covers north Indian Ocean, India, Pakistan and parts of south Asia, south East Asia and China. The vertical extent of this cloud extends to 3 km above sea level over Asia (Cloud Aerosol Lidar and Infrared pathfinder satellite–CALISPO data). Termed as “Asian Brown Cloud,” it occurs every year and extends over a period from November to April and possibly longer. The Asian Brown Cloud is the result of biomass burning (rural) and fossil fuel consumption (urban). The fossil fuel consumption and biomass burning contribute to particulate (aerosol) pollution, while biomass burning plays a major role in gaseous pollution (as carbon monoxide). The most direct effect of Asian Brown Cloud documented in INDOEX is the 10% reduction of average radiative heat of the ocean and 50–100% increase in solar heating of lower atmosphere. In the present study (from September 2007 to March 2008) the percent conversion of previtamin D$_3$ and its photo products were significantly reduced (Figs. 2 and 3), indicating the Asian Brown Cloud effect.

The results obtained in the in vitro study using ampoule model represent the maximal conversion of 7-DHC to previtamin D$_3$ and vitamin D$_3$. There are studies that correlated the synthesis of previtamin D$_3$ and vitamin D$_3$ in the ampoule model to human

7-DHC is photolyzed to previtamin D$_3$. After this initial photolysis the previtamin D$_3$ undergoes a temperature and membrane dependent isomerization in the skin to vitamin D$_3$. Latitude, altitude, season, time of the day, ozone amount, cloud amount, aerosol and reflectivity of the earth’s surface (albedo) are the factors that control the number of UVB photons that reach the earth’s surface. In Tirupati (latitude 13.40° N), the average duration of cloud-free sunshine is 8–10 h/day throughout the year. The UV index at this latitude during the study period is 7–9.

Among the factors that control the ambient UVB radiation is the cyclical and predictable solar zenith angle. With increasing solar zenith angle the UVB radiation traverses a long path through the ozone in the atmosphere resulting in the decreasing number of UVB photons reaching the earth’s surface. When the sun is low in the sky, there is attenuation of UVB photons reaching the earth’s surface. Motion of Earth rotating around the sun and about its own axis combined with season, time of the day and latitude all affects the solar zenith angle and thus cutaneous production of previtamin D$_3$. This was observed in this study (Figs. 1–4). In our study location with the UV index of 7–9 the percent conversion of 7-DHC to previtamin D$_3$ and its photo-products and formation of previtamin D$_3$ and vitamin D$_3$ was between 12 to 18% throughout the year with maximum production between 11 a.m. to 2 p.m. (Figs. 1–3). The amount of UVB radiation capable of producing previtamin D$_3$ in the skin is 70 times more effective at 25° than at 75° due to the influence of the zenith angle of the sun. The present study demonstrated that the percent conversion of 7-DHC to previtamin D$_3$ is maximum at solar zenith angle of 15° or lower with maximum formation of

![Figure 3. Figure depicting the percent conversion of 7-Dehydrocholesterol (7-DHC) to previtamin D$_3$ and photoproducts, and the percentage of previtamin D$_3$ and vitamin D$_3$ formed from May 2007 to August 2008 along with zenith angles of various time of the day during the whole study period.](image-url)
Aerosols in the BL destabilize the atmosphere. Aerosol particles indirectly impact atmospheric stability and radiation by affecting cloud microphysics. Extensive studies have been conducted on the impact of aerosols on earth’s radiative balance and on climate (aerosol radiative force). The geophysical parameters like normal zenith angle (θ), total ozone amount, surface albedo (the fraction of light reflected from earth’s surface), absorption and scattering by gas particles affect vitamin D₃ production in the human body. Ozone is the only important absorbing gas near UV spectrum. The present study was conducted on a flat surface of a terrace of the hospital. With natural surface and vegetation in the region of study the reflectivity was estimated to be approximately 5–10%. Even in clean and clear atmosphere a major attenuation process is Rayleigh scattering of air molecules a process that is inversely proportional to the fourth power of wavelength, λ (i.e., scattering α λ⁻⁴). The short UVB wavelengths are scattered by this process. There is a report of high incidence of vitamin D deficiency rickets in toddlers living in areas of high atmospheric pollution in Delhi, India (28.35° N). There are other interfering factors of solar zenith angle like air pollutants and reflectivity of the surface. Most pollutants are emitted into the lowest kilometer or so of the atmosphere called the planetary boundary layer (BL). Aerosols emitted in this layer exert cooling and drying effects on the surface temperatures. Scattering aerosols tend to cool the BL and absorbing aerosols in the BL destabilize the atmosphere. Caucasian skin with skin type III (which sometimes burns and always tans) and skin type V (which never burns or tans) demonstrated that 0.8% of 7-DHC converted to previtamin D₃ in the ampoules before any previtamin D₃ appeared in the skin samples in type III skin and 1.8% of 7-DHC converted to previtamin D₃ in the ampoules before any previtamin D₃ appeared in the skin samples in type V skin. Subjects residing in the northern India have lighter skin pigmentation as an adaption to UV radiation compared with the subjects in southern India who have darker skin pigmentation and exposed to higher UV radiation. The 25 (OH) D levels in South Indian subjects are relatively higher compared with the subjects from North India from the various studies published in literature. There is a strong inverse correlation between the 25 (OH) D levels and latitude (r = -0.48; p < 0.0001) from various studies conducted in the country (Fig. 7A; Table 1). The 25 (OH) D levels of various studies from India along with latitude and location are shown in Figure 7B.

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The turning of the Earth, the weather or the state of atmosphere is a variable that controls the UV rays reaching the sun. The height, thickness and spatial distribution of the clouds attenuate the UVB radiation reaching the earth’s surface. Fair weather cumulus clouds called as “cotton wool clouds” that do not cover...
D3 and its photoproducts and previtamin D3 formation from September 2007 to March 2008 (Fig. 3).

The estimated UV exposure for sufficient vitamin D status for North America is derived from total ozone mapping spectrophotometer (TOMS) satellite instrument ozone and cloud reflectivity measurements.19 The time required to obtain the recommended UV dose for adequate vitamin D synthesis in human skin is “1 Standard vitamin D Dose” (SDD).24 While UV index is instantaneous value, SDD is a time accumulated dose. One SDD is calculated for skin type II on assumption that ¼ MED (minimal erythema dose) on ¼ skin area (hands, face and arms) to produce UV equivalents of oral dose of 1000 IU of vitamin D at 42° N in March.25 The website ftp://es-ee.tor.ec.gc.ca/pub/vitaminD/ gives 1 SDD for all six skin types at different latitudes. For a skin type V (Indian) 1 Med is 600 (Jm-2 erythemal).25 The minimum recommended exposure to achieve 1SDD (111.4 Jm-2 effective) is 50 min at 42.5° N (at solar noon). At lower latitudes lesser time is required. At 11.5° N for skin type V it is 10–15 min throughout the year (at solar noon), at 29° N for skin type V it is 10–45 min throughout the year (at solar noon) with longer duration in winter.25 India is located 8.4 and 37.6° N. Cloudy skies or pigmented skin will increase the times, low ozone or high altitude and highly reflective environment will decrease times.25

The sun have little effect on the UV radiation reaching the surface. Indeed they may enhance the UV for a brief period due to reflection from cloud sides.15,16 On the other hand a thick layer of stratus cloud covering the sky also called as “heavy overcast clouds” strongly attenuates the UV radiation reaching the surface of earth.21-23 Also, clouds are very unpredictable in mid-high latitudes interspersed with regions of low and high pressure system. In the present study we tried to inter-relate the weather satellite picture of the country on the day of study and the data acquired (Figs. 5 and 6). The median percent conversion of 7-DHC to previtamin D3 and its photoproducts and percent of previtamin D3 and vitamin D3 formed was 11.5% and 10.2% respectively at a solar zenith angle of 36.8° and at 12:30 p.m. Since the study period overlapped for three similar months in the years 2007 and 2008 we tried to compare the percent conversion of 7-DHC to previtamin D3 and its photoproducts and previtamin D3 formation for the months of May, June and July in 2007 and 2008 (Fig. 6) and correlated with weather changes in the atmosphere. In all three months in both years the solar zenith angle was less than 10° and the percent conversion was more than 20% of 7-DHC into previtamin D3, and its photoproducts and the formation of previtamin D3 was above 15%. Asian Brown Cloud had a significant reduction in the percent conversion of 7-DHC to previtamin D3 and its photoproducts and previtamin D3 formation from September 2007 to March 2008 (Fig. 3).

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Figure 5. Satellite picture of the country on the day of study at 11.30 h. First picture on the left upper panel (row 1) shows the location of study site (TIRUPATI—latitude 13.40° N and longitude 77.2° E). The date and maximum and minimum temperature on the day of study is shown in each picture. The satellite picture is downloaded from www.hinduonnet.com under section miscellaneous—weather chart.
The equation derived from the study gives a near approximate percentage of conversion of 7-DHC to previtamin D3 and its photoproducts (FastRT web page gives the duration of exposure to sunlight required for 1 SDD). Attenuating factors like the clothing, duration of exposure to sunlight, type of skin, sunscreen usage and age of individual need to be taken into consideration for extrapolation to humans. Studies from the Indian subcontinent have shown wide prevalence of vitamin D deficiency despite more accurate computation can be done using FastRT web page which takes into consideration, the latitude, dietary consumption of vitamin D, duration and time of exposure, etc. Clouds aerosols, thick ozone events, can reduce the vitamin D synthesis and force a "vitamin D winter" even near the equator.

This study reports on the efficiency of sunlight at tropical latitude to photolyze 7-DHC to previtamin D3 and its photoproducts and previtamin D3 formation in a clean and clear atmosphere. The equation derived from the study gives a near approximate percentage of conversion of 7-DHC to previtamin D3 and its photoproducts (FastRT web page gives the duration of exposure to sunlight required for 1 SDD). Attenuating factors like the clothing, duration of exposure to sunlight, type of skin, sunscreen usage and age of individual need to be taken into consideration for extrapolation to humans. Studies from the Indian subcontinent have shown wide prevalence of vitamin D deficiency despite

Figure 6. Percent conversion of 7-DHC to previtamin D3 and photoproducts and formation of previtamin D3 and vitamin D3 for three similar months in consecutive years—May, June and July in 2007 and 2008.
plentiful sunlight (Table 1).28-52 The studies from south India as well as from north India have shown that there is high prevalence of vitamin D deficiency [25(OH)D < 20 ng/ml] (Table 1). Studies from Pune (18.31° N) have shown that toddlers exposed to sunlight (playing outside) for more than 30 min exposing more than 40% of their body surface area have a normal vitamin D status compared with the toddlers who were indoors for most part of the day (in a crèche).46 In the Middle East vitamin D status is very low in summer [97% have 25 (OH) D levels less than 30 ng/ml] [11.6% had vitamin D insufficiency (between 20 to 30 ng/ml) and 85.2% had vitamin D deficiency (< 20 ng/ml)]. This was attributed to conservative clothing and very hot weather in summer causing and the people to stay indoors.25 In India also the summers are very hot and arid and many people stay indoors. This may be one of the contributing factors for low vitamin D status in the Indian population apart from other factors discussed above. The present study also demonstrates that previtamin D₃ production is highly variable depending upon the time of day, season, latitude, cloud cover, etc. The photo conversion of 7-DHC to previtamin D₃ and its photoproducts is maximal between 11 a.m. to 2 p.m. throughout the year. Therefore we as human can get vitamin D from abundant sunshine. Exposure of an adult in a bathing suit to an amount of sunlight that causes a slight pinkness to the skin (1 MED, known as a minimal erythemal dose) is equivalent to ingesting approximately 20,000 IU of vitamin D.54 Thus exposure of arms (18% body surface) to sunlight between 11 a.m. and 2 p.m. for an amount of time to cause an MED would be equivalent to ingesting about 3600 IU vitamin D. Since the vitamin D produced in the skin lasts two times longer in the body, casual exposure to an amount of sunlight that is equivalent to 0.5 MED of arms and legs, three times a week can provide adequate amount of vitamin D. The amount of time it takes to get 0.5 MED between 10 a.m. to 3 p.m. depends on skin pigmentation, latitude, etc., described above. In populations where there is limited exposure to sunlight, vitamin D supplementation may also be required.

Materials and Methods

The study was conducted in Tirupati latitude 13.40° N and longitude 77.2° E from May 2007 to August 2008. Sealed borosilicate glass ampoules containing 50 μg of 7-DHC in 1 ml of methanol were exposed to sunlight hourly beginning from 8 a.m. until 4 p.m. The ampoules were placed in a Petri dish (precoated with black paint) which was placed on ice to maintain a temperature of 4°C to prevent temperature dependent changes. The ampoules were placed on an open terrace of the hospital exposed to sunlight on a cloudless day when possible with no interference from buildings or vegetation. An ampoule was placed outside each hour so that the photolysis of 7-DHC could be studied in a time dependent fashion for the whole day. From 12 p.m. to 1 p.m. a control ampoule was placed together with ampoule for study. The control ampoule was wrapped in a silver foil so that no UVB irradiation could enter it. At the end of the day of the study the hourly solar zenith angle of the study period was obtained from the website http://solardat.uoregon.edu/SolarPositionCalculator.html. The satellite picture of the country on the day of study at 11:30 a.m. was downloaded from the website www.hinduon-net.com under section miscellaneous—weather report from the archives of the newspaper. From the weather report published in

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**Figure 7.** (A) Graph showing the inverse correlation between the 25 (OH) D levels and latitude (r = -0.48; p < 0.0001) from various studies conducted in the country (Table 1). (B) The 25 (OH) D levels of various studies from India along with latitude and location from various studies conducted in the country (Table 1).
### Table 1. Vitamin D status of India summarized based on latitude and longitude

| LAT      | LONG    | Location                  | n   | STUDY POPULATION            | AGE (Yrs) | 25 OH D | UNIT      | Ref No  |
|----------|---------|---------------------------|-----|----------------------------|-----------|---------|-----------|---------|
| 34.6°N   | 74.48°E | Kashmir Valley            | 64  | Men                        | 28.8 ± 4.9| 37.7 ± 30| nmol/l    | Zargar et al.²⁸ |
|          |         |                           | 28  | Women                      | 26.8 ± 4.8| 13.8 ± 11| nmol/l    |         |
| 30.3°N   | 76.47°E | Chandigarh                | 329 | Males and females (summer) | 19.4 ± 1.48| 52.9 ± 33.7| nmol/l   | Santosh et al.²⁹ |
|          |         |                           | 237 | Males and females (winter) | 19.4 ± 1.43| 31.8 ± 21.1| nmol/l   |         |
| 28.35°N  | 77.12°E | Delhi                     | 12  | Controls (Resident Doctors) | 25–35     | 8.3 ± 2.5| μg/ml     | Harinarayan et al.³⁰ |
|          |         |                           | 29  | Pregnant women (summer)     | 23 ± 3    | 21.9 ± 10.73| nmol/l | Goswami et al.³¹ |
|          |         |                           | 29  | Newborn (summer)            | newborn   | 16.72 ± 4.99| nmol/l |         |
|          |         |                           | 31  | Soldiers males (winter)      | 21.2 ± 2  | 41.17 ± 11.73| nmol/l |         |
|          |         |                           | 19  | Phys. and nurse (summer)     | 23 ± 5    | 7.89 ± 3.49| nmol/l  |         |
|          |         |                           | 19  | Phys. and nurse (winter)     | 24 ± 4    | 17.97 ± 7.98| nmol/l  |         |
|          |         |                           | 15  | Depigmented persons (winter)| 43 ± 16   | 18.2 ± 11.23| nmol/l  |         |
|          |         |                           | 26  | Toddlers (Mori gate)        | 16 ± 4 mo | 12.4 ± 7  | ng/ml    | Agarwal et al.²⁰ |
|          |         |                           | 1   | Infants (Gurgaon)           | 16 ± 4 mo | 28 ± 7    | ng/ml    |         |
| Delhi Slums |       | Sunder Nagar Jan 2001     | 47  | 9–30 mo                    | 96 ± 25.7 | 12.8 ± 7 | nmol/l   | Tiwari et al.³² |
|          |         | Rajiv colony Feb 2001     | 49  | 9–30 mo                    | 23.8 ± 27 | 17.8 ± 22.4| nmol/l  |         |
|          |         | Rajiv Colony Aug 2001     | 48  | 9–30 mo                    | 17.8 ± 22.4| 19 ± 20   | nmol/l  |         |
|          |         | Gurgaon Colony Aug 2001   | 52  | 9–30 mo                    | 19 ± 20   |           |          |         |
| Delhi    |         | LSES School girls         | 193 | 12.4 ± 3.2                 | 34.6 ± 17.43| 29.4 ± 12.7| nmol/l  | Puri et al.³³ |
|          |         | USES School girls         | 211 | 12.3 ± 3                   | 29.4 ± 12.7|           |          |         |
| Delhi    |         | LSES School boys          | 42  | 10–12                      | 12.4 ± 5.5 | 11.3 ± 5.8| ng/ml    | Marwaha et al.³⁴ |
|          |         |                           | 85  | 13–15                      | 11.3 ± 5.3 |           |          |         |
|          |         |                           | 40  | 16–18                      | 11.3 ± 5.3 |           |          |         |
|          |         |                           | 33  | USES School boys           | 10–12     | 19.3 ± 8.8| ng/ml    |         |
|          |         |                           | 70  | 13–15                      | 13.1 ± 7  |           |          |         |
|          |         |                           | 55  | 16–18                      | 13.5 ± 7  |           |          |         |
|          |         |                           | 78  | LSES School girls          | 10–12     | 11 ± 6.5  | ng/ml    |         |
|          |         |                           | 123 | 13–15                      | 10 ± 6.2  |           |          |         |
|          |         |                           | 62  | 16–18                      | 11 ± 5.7  |           |          |         |
|          |         |                           | 47  | USES School girls          | 10–12     | 12.5 ± 8.9| ng/ml    |         |
|          |         |                           | 62  | 13–15                      | 10.2 ± 5.7|           |          |         |
|          |         |                           | 63  | 16–18                      | 12.9 ± 10.5|           |          |         |
| Delhi    |         | Indian Paramilitary forces men | 40  | 20–30                      | 18.4 ± 5.3| 25.3 ± 7.4| ng/ml    | Tandon N et al.³⁵ |
|          |         | Indian Paramilitary forces women | 50  | 20–30                      | 25.3 ± 7.4|           |          |         |
| Delhi    |         | Rural males               | 32  | 42.8 ± 16.6                | 44.2 ± 24.4|           |          | Goswami et al.³⁶ |
|          |         | Rural females             |     | 43.4 ± 12.6                | 26.9 ± 15.9|           |          |         |

*Mean ± SEM; **Values are median and inter-quartile range; For conversion from nmol to ng—multiply by 0.4; Age Adj, Age Adjusted; LAT, Latitude; LONG, Longitude.
Table 1. Vitamin D status of India summarized based on latitude and longitude

| Location       | Group                  | Sample Size | Age Adjusted Mean ± SEM | Age Adjusted Median and IQR | Reference |
|----------------|------------------------|-------------|-------------------------|----------------------------|-----------|
| Delhi          | Mothers 1st Trimester (summer) | 97          | 24.4 ± 2.67            | 23.4 ± 11.3 ng/ml           | Marwah et al. | 38 |
|                | Mothers 1st Trimester (winter) | 59          | 19.6 ± 9.2             | nmol/l                      |           |
|                | Mothers 2nd Trimester (summer) | 125         | 25 ± 2.94              | 25.7 ± 15.1 nmol/l          |           |
|                | Mothers 2nd Trimester (winter) | 93          | 20.2 ± 10.6            | nmol/l                      |           |
|                | Mothers 3rd Trimester (summer) | 77          | 24.26 ± 2.82           | 27.7 ± 9.2 nmol/l           |           |
|                | Mothers 3rd Trimester (winter) | 90          | 21.1 ± 12.4            | nmol/l                      |           |
|                | Mothers 6 wks postpartum   |             | 19.6 ± 8.3             | nmol/l                      |           |
| Delhi          | Infants                |             | 22.3 ± 10.5            | nmol/l                      |           |
| Delhi          | Women                  | 703         | 50 ± 9.5               | 9.78 ± 8.3 nmol/l           | Marwah et al. | 39 |
|                | Males                  | 643         | 50 ± 9.5               | 9.81 ± 6.79 nmol/l          |           |
| Lucknow        | Pregnant women (urban)  | 140         | 24 ± 4.1               | 14 ± 9.5 ng/ml              | Sachan et al. | 40 |
|                | Pregnant women (rural)  | 67          | 24.7 ± 5.1             | 14 ± 9 ng/ml                |           |
|                | Cord Blood (OSM)       | 29          | -                      | 12 ± 8 ng/ml                |           |
|                | Cord Blood (no OSM)    | 178         | -                      | 14.3 ± 9.5 ng/ml            |           |
| Lucknow        | Pregnant women (summer) | 139         | 55.5 ± 19.8            | nmol/l                      | Sahu et al. | 41 |
|                | Pregnant women (winter) | 139         | 27.3 ± 12.3            | nmol/l                      |           |
|                | Girls (winter)         | 28          | 31.3 ± 1.5             | nmol/l                      |           |
|                | Boys (winter)          | 34          | 67.5 ± 29              | nmol/l                      |           |
| Lucknow        | Controls               | 53          | 61 ± 36                | nmol/l                      | Balasubramanian et al. | 42 |
|                | Rickets/OSM            | 40          | 49 ± 38                | nmol/l                      |           |
| Lucknow        | Healthy volunteers     | 92          | 34.2 ± 6.7             | 12.3 ± 11 ng/ml             | Arya et al. | 43 |
| Mumbai         | Mothers Suppl Ca 250–500 additinal | 42       | 20 to 35               | 23 ± 11 ng/ml              | Bhalala et al. | 44 |
|                | Cord Blood             | 42          | -                      | 19.5 ± 9.6 ng/ml            |           |
|                | Infants                | 35          | 3 mo                   | 18.2 ± 9.8 ng/ml            |           |
| Mumbai         | Males                  | 558         | 30.11 ± 3.53           | 18.9 ± 8.9 ng/ml            | Shivane et al. | 45 |
|                | Females                | 579         | 30.52 ± 3.57           | 15.8 ± 9.1 ng/ml            |           |
| Pune           | Male toddlers (outdoor) | 25          | 2.26 ± 0.8             | 95.86 (91.6) nmol/l         | Ekbote et al. | 46 |
|                | Female toddlers (outdoor) | 25          | 2.53 ± 0.8             | 130.2 (67.7) nmol/l         |           |
|                | Male toddlers (indoor) | 31          | 2.94 ± 0.6             | 14.0 (32.0) nmol/l          |           |
|                | Female toddlers (indoor) | 29          | 2.70 ± 0.6             | 5.2 (21.1) nmol/l           |           |
| Tirupati       | Tirupati rural*        | 191         | 44 ± 1.03              | 21 ± 0.46 ng/ml             | Harinarayan et al. | 57 |

*Mean ± SEM; **Values are median and inter-quartile range; For conversion from nmol to ng—multiply by 0.4; Age Adju, Age Adjusted; LAT, Latitude; LONG, Longitude.
the newspaper the maximum temperature recorded in the place of study was also recorded. The study was repeated around the same day every month in the same location for the whole period of the study. The analysis of the ampoules for 7-DHC, previtamin D \(_3\), and photoproducts including lumisterol and tachysterol was summarized based on latitude and longitude.

### Statistical analysis

Descriptive results are presented as mean ± SD. Pearson’s coefficient was calculated for the correlation. \( p \) values < 0.05 were considered significant. Analysis of variance was used to estimate the main effects. Analysis was performed with the use of SPSS (version 11.5; SPSS Inc.).

### Disclosure of Potential Conflicts of Interest

No conflicts of interest were disclosed.

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