ANTICANCER RESEARCH *42*: 5101-5106 (2022)
doi:10.21873/anticanres.16020

Ultra-low Ultraviolet Radiation in Office Lighting Can Moderate Seasonal Vitamin D Cycle: A Pilot Study

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Abstract. *Background/Aim: Ultraviolet-B (UV-B) radiation initiates vitamin D synthesis in the skin, making sun exposure a major source of vitamin D. We aimed to determine whether office lighting containing ultra-low levels of UV-B radiation could modify the winter decline in vitamin D status in the UK, while being safe and well tolerated. Patients and Methods: Twenty commercial office desk lamps were modified with the addition of UV-B LEDs. Ten hospital office administrative staff received UV-modified lamps with UV-on, and 10 staff received identical placebo lamps with UV switched off, in a double-blind, cross-over pilot study during the winter of 2021/22. Circulating 25-hydroxyvitamin D [25(OH)D] was measured every 4 weeks for 20 weeks: at baseline and during an 8-week trial period, 4-week washout, and a cross-over 8-week trial period. Results: The linear regression combining the complete datasets for phase 1 and 2 of the trial showed that an 8-week UV light intervention significantly increased 25OHD by 7.13 nmol/l with a p-Value=0.02, compared to the placebo group. Similar results were confirmed by cross-over analyses using the datasets of those completing both phases of the trial both with and without using the inverse probability weighing method to handle dropouts. Conclusion: The UV-B-modified lighting was well-tolerated and safe with weekly doses of UV-B of 0.5 – 0.9 Standard Erythema Dose [SED=100 Jm^{-2} erythema weighted UV radiation] measured at chest level. This ultra-low dosing was effective in reducing the winter decline in vitamin D status.*

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Key Words: Ultraviolet Radiation, vitamin D, 25(OH)D, winter, cross-over trial, office lighting.

The main source of vitamin D for most people is through cutaneous synthesis following skin exposure to the UV-B radiation in sunlight. Modern diets contain only small amounts of vitamin D, while food fortification and advice on supplementation depend on national policies and personal choice. At mid-high latitudes winter with low solar elevations, short daylight hours and cold temperatures result in negligible cutaneous synthesis of vitamin D and vitamin D status declines to a nadir at the end of winter/early spring. Vitamin D is well known for its importance to the musculoskeletal system, but its active form 1,25 dihydroxyvitamin D [1,25$(OH)_2$D] has anti-proliferative effects, and it has been shown that vitamin D can protect against and improve prognosis across a range of cancers (1). It also plays a part in protecting against autoimmune diseases such as multiple sclerosis and asthma, as well as acute respiratory tract infections including covid-19 (2). Therefore, avoiding low or deficient vitamin D status, variously defined in the literature as between 25(OH)D < 25 nmol/l and 25(OH)D < 50 nmol/l (3-5), is widely promoted.

Although vitamin D is a major benefit of exposing skin to solar UV-B radiation during daily activities, excess UV-B can also cause skin damage manifested as sunburn and an increased risk of skin cancer. This can lead to confusion and requires care when delivering public health information. It further leads to concern about artificial sources of UV radiation in the workplace, home, or recreation. The UV-B exposure regime for vitamin D sufficiency (small, sub-erythemal doses on a regular basis) should not contribute to skin damage (6, 7), but this knowledge is of little benefit when there is a lack of solar UV radiation (winter months) or when infirmity, or social/cultural conditions, prevent or

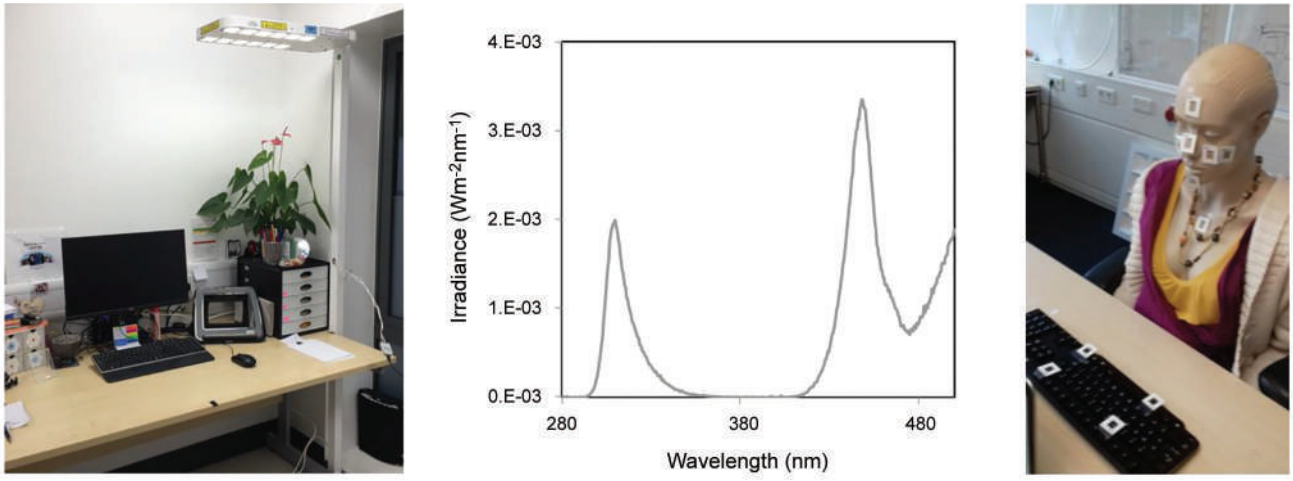

Figure 1. *Desk lamp installed in an office (left), UV-blue spectrum of lamp showing the 309 nm LED peak (center) and mannequin tests with dosimeter badges (right).*

severely limit sun exposure. Furthermore, vitamin D intake is not a solution for all due to issues of malabsorption from the gut, poor appetite or diet, and cost and compliance of taking supplements. When sunlight is not available, an alternative is to provide UV-B radiation from artificial sources in a manner that is safe and easy for the recipient and does not provide an unwanted UV dose to others. Here we present a pilot study of such a solution, provided as office desk lighting to healthy administrative staff during the winter months.

Table I. *Cumulative dose over 8 weeks (sum of 8 polysulphone film dosimeters), measured at the chest of volunteers.*

Cumulative dose (SED), Mean (standard deviation)		
	Active	Placebo
Phases combined	5.2 (3.3)	0.8 (0.41)
Phase 1	4.2 (1.9)	0.76 (0.49)
Phase 2	7.3 (3.3)	0.79 (0.34)

Patients and Methods

A double-blind cross-over trial was conducted between mid-October 2021 and March 2022 at the Sunderland and South Tyneside NHS Trust hospitals, Northeast England. Twenty healthy office administrative staff were recruited by open advertisement, with exclusion criteria being: pregnancy, malignant skin conditions, a first degree relative who has suffered from malignant skin conditions, photosensitive medical conditions or use of photosensitising drugs, unstable chronic medical conditions including inflammatory and malignant diseases, planned use of sun beds or sunny foreign trips during study periods, currently taking oral vitamin D supplements, and severe vitamin D deficiency. Participants were split into two groups of 10, matched by age and baseline 25(OH)D status. UV-modified desk lamps were installed over the desks of one group, while the other group received placebo lamps. The first phase of the trial took 8 weeks from mid-October to mid-December 2021. This was followed by a 4-week break over the Christmas holiday period, and a further 8-weeks of desk lighting use with placebo and active UV lighting groups crossed-over in early 2022. Venous blood samples were drawn every 4 weeks throughout the 20-week trial and analysed for 25(OH)D by Roche Total II competitive electrochemiluminescence protein binding assay (Roche Diagnostics International AG, Rotcreuz, Switzerland). Within-run and total variation was shown to be 5.6% and 8.2%, respectively, at 62.8 nmol/l, while long-term inter-assay variation was 6.7% at 69 nmol/l (8).

The desk lighting was provided by commercially available floor-standing desk lamps (Philips SmartBalance Free Floor Standing FS484F LED125S/840 PSD-T MLO ACL WH, Philips, Eindhoven, the Netherlands). All units were modified. The modifications included a replacement of the light exit window with a UV-B transparent window and the addition of UV-B LEDs with narrow-band output centred at 309 nm. Depending on the group allocation of the participants, the units were programmed to either turn on UVB and visible light or only the visible light. All units were programmed to come on at 08:50 and go off at 17:10 from Monday to Friday; they could not be controlled by the participants and supplemented the normal room lighting that was available. Visually all desk lamps were identical, and all provided the same level of visible radiation.

The UV-modified lamps were tested independently at the University of Manchester prior to approval of the trial, and again immediately before installation in the offices at the start of the trial. Measurements of spectral irradiance were made at a comprehensive series of locations beneath the emitting surface of the lamp with a double monochromator Bentham DTM300 spectroradiometer

Table II. *Data summary for the 18 participants who completed Phase 1.*

Group	Number of participants	Age (y)		Skin type: Number of II/III	Difference in 25(OH)D (nmol/l)	
					Week 8 *vs*. Baseline	
		Mean	Range		Mean	Range
Active	9	45.44	[28, 59]	5/4	–11.01	(–32.4, 0)
Placebo	9	45.78	[28, 55]	4/5	–16.12	(–32.7, –9.2)

(Bentham Instruments Ltd, Reading, UK), calibrated to NIST standards of spectral irradiance. Further evaluation was made with polysulphone film badges attached to a mannequin sitting at a desk (Figure 1).

The lamp output was also monitored at the start of each phase and at the end of the trial by Signify. Throughout the trial all volunteers wore a UV dosimeter [polysulphone film badge (9)], using one dosimeter a week worn at chest level (on the hospital ID lanyard). A second weekly dosimeter was placed on the desk next to the lamp support as a measure of the full-time exposure available, recognising volunteers were mobile and could leave their desks. Polysulphone film is usually calibrated to measure erythema-effective UV radiation from the sun. The spectrum of the LED source is very different to that of the sun and an alternative calibration specific to the UV LEDs used was generated by the University of Manchester, still in units of erythema-effective UV.

The UV-modified desk lamps received MHRA approval (CI/2020/0033) and ethical approval was provided by the Office for Research and Ethics Committees of Northern Ireland (RECB). The trial was registered with the ISRCTN registry, trial ID: ISRCTN56526926.

Results were analysed using R version 4.0.3. Various analyses were carried out based on multiple linear regression. Missing covariates were assumed to be missing at random and imputed by the multiple imputation method (10) using the mice package (Multivariate Imputation *via* Chained Equations) version 3.14.0 in R 4.1.3. Late measured outcomes were validated or modified by multiple imputation. Dropouts were handled by the inverse probability weighting method (11).

Results

Characteristics of UV-modified desk lamps. The UV-modified desk lamps were designed and tested to meet the European Working Directive 2006/25/EC that addresses health and safety requirements of workers exposed to physical agents – in this case artificial optical radiation (12). The Directive limits exposure to 30 Jm^{-2} of actinic hazard weighted UV radiation over a period of 30,000 seconds (8 h and 20 min). As a more precise measure of skin damage, the limit for erythema weighted UV radiation over the same period was set at 1 SED (where 1 SED=100 Jm^{-2} erythema weighted UV).

The UV-modified desk lamps were placed such that the active emitting surface was over the desk and area where the keyboard would be, not directly over the chair where a worker would sit (see Figure 1). The minimum distance from the emitting surface at which the EU Directive is met is 800 mm, and the units were labelled with a warning label to this effect. For reference, the distance from the emitting surface to the desktop was approximately 1,200 mm. The irradiance field on the desk beneath the emitting head was homogenous at the 10% level and then decreased moving laterally away from this area. At a distance of 1.4 m from the centre of the emitting head, the irradiance was 10% of the central maximum. This was taken as an indication of the impact of the lighting on other people in the office and was deemed negligible.

Trial participants. All participants were female, aged 28-59 (mean 45) years, and all of skin types II and III. Twenty volunteers were initially recruited, with a further 4 recruited for phase 2. Full details are given with the vitamin D results. One volunteer withdrew complaining of headaches but had a long history of migraines which was not considered to be associated with the trial. The other dropouts were due to job rotation, and one was withdrawn due to vitamin D deficiency at week 4. In addition, the individual start dates in Phase 2 varied due to holiday or sick leave. Phase 2 ended on 6th March 2022 for most volunteers. The very last blood sampling took place on 1st April 2022.

UV stability, tolerance, and dosing. The lighting units provided a stable output throughout the 20-week trial, with the UV output varying by no more than 5%. All units (active and placebo) performed exactly as programmed, turning on and off at the correct times of day

The UV-modified desk lamps were well tolerated, and no adverse effects were recorded. Feedback from qualitative interviews following the end of the study period was very positive with the majority of participants not having any problems with the lamps. A common feeling was that as they were "just there" and automatically switched on, using the lamp would be something participants would prefer to taking oral vitamin D supplements as it means they wouldn't forget to take them.

Table III. *Data summary for the 15 participants who completed Phase 2.*

Group	Number of participants	Age (y)		Skin type: Number of II/III	Difference in 25(OH)D (nmol/l)	
					Week 20 *vs*. 12	
		Mean	Range		Mean	Range
Active	8	46	[24, 59]	4/4	3.86	(–5.2, 17.7)
Placebo	7	46.43	[28, 55]	2/5	–5.22	(–18.1, 5.3)

Table IV. *Data summary for the 12 participants who completed both phases.*

Number of Participants	Age (y)		Skin type: Number of II/III	Difference in 25(OH)D (nmol/L)					
				Group	Week 8 *vs*. Baseline		Group	Week 20 *vs*. 12	
	Mean	Range			Mean	Range		Mean	Range
4	50.25	[45, 59]	1/3	Active	–14.05	[–2.4, –32.4]	Placebo	–4.48	(–18.4, 5.3)
8	46	[28, 55]	4/4	Placebo	–16.45	[–9.2, –32.7]	Active	3.86	(–5.2, 17.7)

Table V. *Results of multiple linear regressions under different analyses and datasets. The response variable is the 8-week change in 25(OH)D. The coefficients are in units of nmol/l representing the increase/decrease in the response variable with respect to the variation in the predictor variables. The corresponding p-Values are in parentheses.*

Predictors	Combined analysis of those completing a single phase (n=18 and n=15)	Cross-over Analysis for those completing both phases (n=12)	Cross-over Analysis with inverse probability weighting, both phases (n=12)
8-week intervention *vs*. placebo	7.13 (**0.02**)	7.55 (**0.03**)	7.12 (0.05)
Baseline 25(OH)D Phase 1	–0.23 (**0.01**)	–0.99 (**0.001**)	–0.50 (**0.002**)
Baseline 25(OH)D Phase 2	0.00 (0.98)	0.58 (**0.03**)	0.30 (**0.04**)

Significant *p*-Values are shown in bold.

The erythema effective doses measured at the participants' chest level are shown in Table I. Over an 8-week period the intervention (UV) group received 4-7 SED at the chest level dosimeter. This equates to 0.5-0.9 SED/working week, which is close to the mannequin tests that delivered 0.6 SED/working week at the mannequin chest. The mannequin test provided for 1.45 SED/working week on the hands at keyboard level, so we might reasonably expect that the hands of the volunteers received a similar dose, and this would also be consistent with the control dosimeter badges placed on the desks.

Vitamin D results. Not all participants completed the full trial. Two dropouts in phase 1 resulted in eighteen complete data sets for phase 1. The data are summarized in Table II. Six dropouts after phase 1 were replaced by 4 new participants and there was one further dropout during phase 2, resulting in fifteen complete datasets for this phase. The phase 2 data are summarized in Table III. Twelve participants completed the entire trial: these data are summarized in Table IV. The results of statistical analyses of the 25(OH)D outcomes for the different datasets are summarized in Table V.

Table V shows that all the three analyses gave similar estimates for the effect of UV light intervention. The multiple linear regression for the combined data of the 18 and 15 participants who completed Phase 1 and 2 respectively, shows the average impact of low-level UV intervention over an 8-week period is an increase in circulating 25(OH)D of 7.13 nmol/l (p=0.02), compared to the placebo group, after adjusting for age, skin type and baseline 25(OH)Ds at the start of the two phases. As shown in Table II, Table III, and Table IV, in phase 1 this was seen

as less of a drop in 25(OH)D from the end-summer maximum vitamin D status, while in phase 2 a small increase in circulating 25(OH)D was seen, compared to a continuing drop in the placebo group.

The cross-over analysis for the 12 participants completing both phases indicated an impact of UV intervention of 7.55 nmol/l (p=0.03). The pattern of dropouts was analysed using logistic regression and weak evidence of association was found between dropout and the last observation of 25(OH)D before dropout (p=0.08), and with the group (p=0.09). The inverse probability weighting method (10) was used with cross-over analysis and resulted in a similar estimate of 7.12 nmol/l (p=0.05). There was no significant carry-over or period effect found, and no significant effect of age or skin type was identified, as one might expect from this fairly homogenous set of volunteers.

Discussion

This trial of ultra-low UV-B lighting, assessed on healthy office workers, has shown the lighting units to be stable, reliable, safe, and well tolerated. The UV-B doses as measured at the desk level (for hands and arms: ~0.3 SED/day) and at the chest of participants (~0.2 SED) were well below the 1 SED/working day limit defined by the EU Directive. No adverse effects of the lighting were reported; on the contrary participants welcomed the additional lighting and even mentioned to prefer lighting above supplements.

Even these very low doses of UV-B, equivalent to being outside for less than 5 minutes on a sunny summer day at lunchtime in Sunderland, produced a statistically significant effect on circulating 25(OH)D of 7.13 nmol/l when delivered 5 days a week for a period of 8 weeks. While this is a modest result, if it was maintained for the full 20-week winter part of the year (mid-October to mid-March) this would be a difference of ~18 nmol/l, enough to reduce the amplitude of the seasonal cycle in 25(OH)D, and in many cases prevent vitamin D deficiency in the later winter months.

The study had certain limitations. There was a small number of participants, originally 10 in each group and these were subject to attrition during the study. Despite these small numbers, the majority of results are statistically significant. The participants were also all females. This was not deliberate but rather representative of the hospital employees in these administrative roles.

The wavelength of UV-B radiation employed, at 309 nm, is towards the edge of the action spectrum for pre-vitamin D synthesis (13) and moving to a somewhat shorter wavelength could increase the effectiveness of radiation, provided care is also taken to maintain the very low erythema-effective doses. Such a wavelength shift could be even more relevant if the CIE action spectrum should be shifted to shorter wavelengths, as has been suggested (14).

Conclusion

The results show that ultra-low doses of UV radiation provided in the workplace can reduce the winter-time decline in vitamin D status that is common at middle-high latitude locations. Such a method of low-dose UV-B radiation, delivered on a daily basis through a UV-modified desk lamp that can be employed in an office or home, offers an alternative method of increasing vitamin D status. It is of particular benefit to those who find it difficult to gain vitamin D from the gut and have very limited access to sun exposure. As an alternative to supplementation in for example sheltered accommodation or care homes it could offer a cost-effective alternative to vitamin D supplementation over many years, although the practicalities of dose delivery in a private setting to >65-year-olds remains to be examined.

Conflicts of Interest

Signify financially sponsored the study and provided the lighting intervention. The Authors declare no other conflicts of interest.

Authors' Contributions

All Authors contributed to protocol development and to the manuscript preparation, which was written by ARW. BvdZ, ARW, RK were responsible for installation of the lighting, safety and UV-B stability assessment and characterization of the UV from the ultra-low dose intervention. ARW and RK provided dosimetry. HO'N recruited and managed the participants in the trial. NL provided independent statistical design and analysis. DW provided access to South Tyneside and Sunderland Foundation NHS Trust for all aspects of the trial.

Acknowledgements

South Tyneside and Sunderland Foundation NHS Trust are gratefully acknowledged in supporting the study. All volunteers who kindly participated in the study are thanked as well as Stephen Wardropper and Cameron Patterson (Engineering Department, Sunderland), and Annemieke Wondergem and Rémy Broersma (Signify).

References

1 Carlberg C and Velleuer E: Vitamin D and the risk for cancer: A molecular analysis. Biochem Pharmacol *196*: 114735, 2022. PMID: 34411566. DOI: 10.1016/j.bcp.2021.114735

2 L Bishop E, Ismailova A, Dimeloe S, Hewison M and White JH: Vitamin D and Immune Regulation: Antibacterial, Antiviral, Anti-Inflammatory. JBMR Plus *5(1)*: e10405, 2020. PMID: 32904944. DOI: 10.1002/jbm4.10405

3 The Scientific Advisory Committee on Nutrition (SACN): Recommendations on Vitamin D. Public Health England, 2016. Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/537616/SACN_Vitamin_D_and_Health_report.pdf [Last accessed on May 24, 2022]

4 Institute of Medicine (US): Dietary Reference Intakes for Calcium and Vitamin D. Washington, DC, The National Academies Press, 2011. PMID: 21796828. DOI: 10.17226/13050

5 European Food Safety Authority (EFSA): Dietary reference values for vitamin D. EFSA J *14(10)*: e04547, 2016. DOI: 10.2903/j.efsa.2016.4547

6 Webb AR, Kazantzidis A, Kift RC, Farrar MD, Wilkinson J and Rhodes LE: Meeting vitamin D requirements in white Caucasians at UK latitudes: providing a choice. Nutrients *10(4)*: 497, 2018. PMID: 29673142. DOI: 10.3390/nu10040497

7 Felton SJ, Shin BB, Watson REB, Kift R, Webb AR and Rhodes LE: Photoprotection conferred by low level summer sunlight exposures against pro-inflammatory UVR insult. Photochem Photobiol Sci *19(6)*: 810-818, 2020. PMID: 33856672. DOI: 10.1039/c9pp00452a

8 Batista MC, Menegat FD, Ferreira CES, Faulhaber ACL, Campos DALS and Mangueira CLP: Analytical and clinical validation of the new Roche Elecsys Vitamin D Total II assay. Clin Chem Lab Med *56(12)*: e298-e301, 2018. PMID: 29886453. DOI: 10.1515/cclm-2018-0406

9 Davis A, Deane GH and Diffey BL: Possible dosimeter for ultraviolet radiation. Nature *261(5556)*: 169-170, 1976. PMID: 1272391. DOI: 10.1038/261169a0

10 Robins J, Rotnitzky A and Zhao L: Analysis of semiparametric regression models for repeated outcomes in the presence of missing data. Journal of the American Statistical Association *90(429)*: 106-121, 2019. DOI: 10.1080/01621459.1995.10476493

11 Van Buuren S: Flexible imputation of missing data, Second Edition. 2018. DOI: 10.1201/9780429492259

12 Directive 2006/25/EC of the European Parliament and of the Council: on the minimum health and safety requirements regarding the exposure of workers to risks arising from physical agents (artificial optical radiation) (19th individual Directive within the meaning of Article 16(1) of Directive 89/391/EEC). OJEU, L114: 38, 2006. Available at: https://eur-lex.europa.eu/eli/dir/2006/25/2014-01-01 [Last accessed on July 11, 2022]

13 CIE 174:20. Action Spectrum for the Production of Previtamin D3 in Human Skin. Vienna, Austria, CIE, 2006. Available at: https://cie.co.at/publications/action-spectrum-production-previtamin-d3-human-skin [Last accessed on July 11, 2022]

14 Webb AR, Terenetskaya IP, Holick MF, van Dijk A, McKenzie RL, Lucas RM, Young AR, Philipsen PA and de Gruijl FR: Previtamin D action spectrum: challenging CIE towards a standard. Light Res Technol, in press, 2022.

Received June 1, 2022
Revised July 9, 2022
Accepted July 11, 2022