Novel Phototherapy Kiosk Shows Promise as a Treatment Option for Low Vitamin D

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ABSTRACT

Introduction:
The purpose of this study was to demonstrate the feasibility of a phototherapy kiosk (PK) to engage community adults in health promotion and to stimulate production of circulating 25-hydroxyvitamin (OH)D as effectively as a vitamin D3 oral supplement (OS). Although optimal production of vitamin D comes from sun exposure, ultraviolet B radiation with a wavelength of 290 to 320 nm penetrates exposed skin and may produce vitamin D_3 using a PK.

Materials and Methods:
A prospective study was conducted with adults randomized to either six PK treatments or D_3 OS for 10 weeks. Serum 25(OH)D was drawn at baseline, 10 weeks, and 14 weeks. Primary outcome was serum 25(OH)D level. Mann–Whitney test was used to assess continuous data and Chi squared test for pairwise comparisons of categorical data. Significance was set at $P < .05$.

Results:
With 18% attrition, final sample size was 88; OS, $n = 45$, PK, $n = 43$. Sample was mostly female (60%), median age 35 years, with no differences observed between groups for age, race/ethnicity, marital status, military affiliation, or season of enrollment. Median daily intake of calcium and vitamin D was well below the recommended daily allowance for each nutrient, and group. Baseline median serum 25(OH)D levels were similar. By 10 weeks, PK median level was 30 ng/mL (interquartile range [IQR] 25.8-37.0) and OS was 26 ng/mL (IQR 21.5-30.5), $P = .02$. The difference in 25(OH)D levels persisted at 14 weeks; the PK group returned to baseline, 27 ng/mL (IQR 22.0-32.5), and OS group declined to 21 ng/mL (IQR 17.0-30.0), $P = .02$.

Conclusion:
Programmed ultraviolet B phototherapy appears to be an efficacious alternative to oral vitamin D supplementation with consistent use.

INTRODUCTION

Despite the proliferation of research over the past decade aimed at advancing our understanding of vitamin D, to include its complex metabolism, relationship to noncommunicable diseases, impact on gene expression and simply, the amount necessary to consume for optimal health of the population, essentially no new recommendations have been published.[1–5] This overall conclusion was confirmed by a recent report on vitamin D and calcium from the Agency for Healthcare Research and Quality, which reviewed data from nearly 250 new studies published between 2009 and 2013.[6] The report concluded that there remains insufficient evidence to specify a relationship between vitamin D and health outcomes other than bone health. Clearly, the community of nutrition research scientists should be more active in the search for solutions to the widespread problem of vitamin D insufficiency (less than 30 ng/mL) and deficiency (less than 20 ng/mL).[7] The latest figure, published in 2017, for hypovitaminosis D (less than 20 ng/mL) in the adult civilian population over 20 years of age in 2011 to 2012 was 39.9%; data were extracted from the National Health and Nutrition Examination Surveys, which continuously assess a large representative sample of all ages for various health indicators.[5] In a Letter to the Editor, DiNicola et al. pointed out the need for routine screening of young service members because of the high rate of insufficiency and deficiency observed in their research involving young adults aged 11 to 18 years with rates of 48% and 32%, respectively, and females were more affected than males.[8] Prevalence of low vitamin D in military populations is somewhat variable yet consistently higher than in the civilian population.[9,10] Previous research conducted by these co-authors (M.S.M., E.B.E., B.M.S.) revealed a high

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prevalence of vitamin D insufficiency and deficiency in Active Duty (AD) service members in the Pacific Northwest.[9,10] In 1 study, 435 overweight service members were randomized to 4 arms involving various combinations of weight management tools; 83% to 87% was insufficient or deficient upon enrollment, and 68% to 78% remained so after 12 weeks of nutrition counseling in a structured program. In a subsequent study involving vitamin D oral supplementation in 152 AD service members, again, 67% were found to have low serum 25-hydroxyvitamin (OH)D levels upon enrollment.[10] Most reports suggest that the low vitamin D levels in military populations are the result of a lack of sun exposure from wearing uniform sleeves down, avoidance of heat injuries by shade-seeking behaviors, use of sunscreen, limited intake of fortified foods, especially if consuming Meals Ready to Eat, and nighttime operational requirements.[8] As a consequence of the low vitamin D levels, service members may experience higher rates of musculoskeletal and overuse injuries, along with a greater susceptibility to immune system dysfunction, hypertension, diabetes, and post-traumatic stress and mental health disorders.[8,11–13]

Sunlight exposure provides 80% to 100% of the body's vitamin D requirements. Factors that influence ultraviolet B (UVB) exposure and vitamin D synthesis include season, time of day, length of day, cloud cover, smog, skin melanin content, and sunscreen.[14] The only alternative to sunlight has been vitamin D supplementation, yet there is a paucity of evidence for how often, how much, and how long one should consume supplements. Unlike endogenous vitamin D, research shows that supplements do not bind completely to vitamin D binding protein and are not regulated in the body to prevent overdose.[15,16] Fat malabsorption conditions (cystic fibrosis, Crohn's disease, celiac, etc.) can reduce the ability to absorb fat soluble vitamin D supplements however, endogenous vitamin D production from UVB light is uninhibited.[17,18] The phototherapy kiosk (PK) was developed as an Internet-enabled technology that stimulates endogenous vitamin D production via narrowband UVB at 293 to 303 nm during 2 treatments each lasting 1 to 10 minutes per month.[19–21]

The current standard of care for supplementation is 600 International Units (IU) oral vitamin D_3 daily, which is the recommended daily allowance (RDA) established by the National Academy of Medicine (formerly Institute of Medicine) who identified clinically significant levels of circulating 25(OH)D to be less than 20 ng/mL.[22] The RDA for vitamin D represents a daily intake sufficient to maintain bone health and normal calcium metabolism in 97.5% of the population. Although debate surrounds a sufficient range for 25(OH)D, there does seem to be a general acceptance that the optimum range is between 30 and 60 ng/mL.[1,11]

The primary purpose of this study was to demonstrate the capability of a PK to stimulate the production of 25(OH)D with twice-a-month treatment effectively as an oral vitamin D_3 supplement. The specific aims included:

(1) Demonstrate that narrow spectrum UVB delivered by the PK is not inferior to 600 IU of D_3 to raise or maintain serum 25(OH)D levels over 10 weeks, with sustainment at 14 weeks;
(2) Determine acceptability and feasibility of the PK designed for AD, retired service members, beneficiaries, and Department of Army civilians;
(3) Examine the relationship of demographic variables, including gender, age, body mass index, ethnicity, and sun exposure to serum 25(OH)D levels in both treatment groups.

METHODS

Study Design and Participants

This was a two-group prospective randomized controlled trial designed to assess noninferiority of a PK. The study received funding support from BeneSol, Inc. (Bainbridge Island, WA) and approval as a minimal risk human use protocol from the Regional Health Command-Pacific Institutional Review Board. The study was performed in compliance with FDA 21 CFR 812. This trial is registered on ClinicalTrials.gov (NCT04556136).

To qualify for the study, volunteers had to be over 18 years of age, fluent in English, not relocating or deploying for the next 4 months, and subjectively in good health. We excluded pregnant or currently breastfeeding females, anyone with a chronic health problem (e.g., kidney disease, intestinal malabsorption), any volunteer currently taking vitamin D or medications such as levothyroxine or oral hypoglycemic agents for an endocrine disorder. The research pharmacist and the medical consultant advised against enrolling volunteers taking medications having a high potential for interaction with vitamin D including anti-seizure medications, cyclosporine, and indinavir, or those diagnosed with light allergies (e.g., Actinic prurigo, Polymorphous light eruption, Solar urticaria) or light sensitivities (e.g., Protoporphyria, Photodermatitis, Xeroderma pigmentosum, Lupus erythematosus, Actinic dermatitis, UV-sensitive syndrome), or Sarcoidosis.

Procedures

The study team recruited volunteers from May through December 2018 on a large joint base in the Pacific Northwest, where over 25,000 soldiers and airmen train every day and regional beneficiaries total 98,000. Recruiting efforts were designed to capture a convenience sample representative of the population including both genders, diverse ethnicities, and a range of age and body mass index (BMI), in adults with no contraindication for UVB exposure or oral vitamin D supplementation. Approved flyers, poster boards, and social media postings were used as marketing tools. Interested volunteers contacted the study team via email or phone and arranged an in-person appointment for the research staff to provide an overview of the study to describe its purpose, the voluntary

nature of participation, and methods used to ensure confidentiality and anonymity. Each participant provided written informed consent. Following the consent process, the subject was directed to the outpatient laboratory and the research pharmacist was notified. Using a random numbers generator and concealed allocation, the research pharmacist randomized subjects to 1 of 2 groups for the 14-week study period. It was not possible to blind either the research team or the subjects for this study.

Active Control Group—oral supplement (OS): Pharmacist dispensed a 1-time 70-day supply of vitamin D_3 600 IU capsules to subjects assigned to this group. Subjects received email reminders to continue taking one capsule each day with a meal until the bottle was empty at 70 days. The subjects then returned to the research office with their pill bottle, and the number of pills remaining was counted.

Treatment Group—PK: Spectrum isolation modules in the kiosk delivered the UVB dose under supervised conditions over a 1- to 10-minute interval based on the Fitzpatrick skin type category with the subject wearing minimal or no clothing, preferably no more than a bathing suit, and protective eye wear. The participant stood in place for the UVB treatment for a total of 6 visits over 10 weeks. Subjects were informed that treatments would take place about every other week and the next appointment was made during the treatment session based on subject availability. Subjects received email reminders and phone calls to return for the next scheduled treatment.

A demographic survey was completed at baseline to capture relevant personal and family history as well as age, gender, ethnicity, military occupational specialty if applicable, alcohol and tobacco use, bone health history, sun exposure, travel, physical activity, and dietary data. Active duty participants also reported the number of days on profile for the previous 3 months at baseline and 10 weeks.

Serum levels of 25(OH)D, calcium, and parathyroid hormone were drawn at baseline, immediately following the last treatment at 10 weeks, and 25(OH)D at 14 weeks to document sustainment of the treatment effect. The Elecsys Vitamin D Total II assay intended for the quantitative determination of total 25-(OH)D in human serum and plasma was used on the cobas e immunoassay analyzer. Remuneration in the form of $20 Amazon gift cards was provided to all volunteers after the baseline and final scheduled blood draw.

Anthropometric measurements were obtained upon enrollment and again at 10 weeks. Vertical height (inches) was measured using a stadiometer (Seca 213, Portable Stadiometer Height Rod, China, CA) and body weight (pounds), lean and fat mass, and % body fat using the InBody 230 bioelectrical impedance analyzer (Biospace America, Los Angeles, California). The bioelectrical impedance analyzer has been shown to be comparable to the gold standard, dual energy X-ray absorptiometry, for measuring lean and fat mass.[23] The protocol required that subjects empty their bladder before the measurement and remove shoes, belts, and items in their pockets. Interrater reliability checks were performed by two study team members who periodically took separate measurements and compared results; intrarater reliability was established by taking 2 readings and recording the average. The device was maintained in the research office suite where maintenance and calibration occur regularly.

The PK (BeneSol, Inc., Bainbridge Island, WA) was designed with a patented light path strategy incorporating several filters and lenses to deliver uniform narrow spectrum exposure to the full body. Proprietary algorithms are used to calculate a safe and effective dosage of UVB. Treatment time was expected to be 1 to 10 minutes on average twice a month. According to the onsite radiation protection official, the amount of harmful rays for one treatment was similar to standing in the sun at noon for 13 seconds. Minimal erythema dose is the dose of radiation that is needed to produce slight pinkness in the skin 24 hours after exposure.[24] An important tool to determine treatment dose and evaluate response was the Fitzpatrick skin type classification scale[25] used in conjunction with an erythema index to detect adverse events.[24] Adverse events for UVB exposure were defined by a grade of E3 or higher on a well-established erythema index where E3 represents a skin color change lasting more than 3 days with skin discomfort or pain. Erythema rated as E1 where skin color change did not last more than 3 days, or erythema rated as E2 where skin color change may have lasted more than 3 days but with no discomfort were reported as side effects. To help prevent unintended erythema, the previously mentioned algorithms calculated treatment dose for each subject after he/she responded to the online erythema questionnaire at each follow-up visit once inside the kiosk.

We assessed feasibility by the ability to meet enrollment projections, study attrition, and compliance with supplement prescription and return for kiosk treatments. We evaluated acceptance with the Device Usability Scale. This tool was a 12-item Likert-type scale adapted from the original 10-item System Usability Scale.[26] This scale assessed cleanliness, ease of use, and comfort of the kiosk with anchors of 1 = Strongly disagree to 5 = Strongly agree. The overall score was calculated by summing all scores and multiplying by 2.5; results ranged from 0 to 100. A system or product that receives a score of 68 and above is considered to have good usability. Subjects in the PK group completed the Device Usability Scale at the final visit.

Statistical Analysis

Exploratory data analyses were conducted on the serum 25(OH)D levels of subjects assigned to either the OS or PK group. The analysis was restricted to subjects with valid baseline serum 25(OH)D data and at least one follow-up blood draw. The Shapiro–Wilk test was used to assess the normality of the data distribution. Measures of central tendency and dispersion were performed for continuous data as medians with associated interquartile ranges (IQRs). We examined

summary statistics for categorical variables and have included the number of subjects as well as the prevalence within each group. To examine differences in continuous data between the two groups, the Mann–Whitney test was used. Effect sizes for significant differences are provided as eta squared (η2) values.[27] Within groups repeated measures analysis was accomplished using the Wilcoxon signed ranks test. The chi squared test was used for pairwise comparisons of categorical data. Multiple comparisons were accomplished using the Kruskal–Wallis test. Logistic regression models were created to assess the effects of ordinal or continuous data such as sunlight exposure and age on categorical variables. Spearman's rank-order correlation assessed relationships between continuous data. For participants with valid baseline vitamin D data but missing follow-up sera, the assumption that the data were missing completely at random (MCAR) was assessed using Little's MCAR test.[28] Compliance among the supplement group was determined by the percentage of vitamin D supplement pills used (pills remaining/pills issued *100). Primary analyses utilized a one-sided test, and all others utilized two-sided tests. Statistical significance for all tests was declared at $P < .05$. Analyses were conducted using SPSS version 25 (IBM, Chicago, IL).

RESULTS

A total of 106 volunteers were enrolled in the study; 18 (18%) either dropped out or were removed after enrollment. One participant (1.1%) did not complete the 3-month follow-up, and 8 participants (9.1%) did not complete their four-month follow-up. Reasons provided for the remaining 9 participants include recent diagnosis of suspicious skin lesion (2), lack of time for study treatments (2), relocation (4), and referral to primary care physician for severe vitamin D deficiency (1). Missing data were found to be MCAR, $P = .21$.

The final sample included 45 participants in group OS and 43 in group PK. The median age of the sample was 35 years (IQR 28-46). Although group OS was nearly balanced between men ($n = 25$, 55.6%) and women ($n = 20$, 44.4%), group PK in comparison had significantly more females ($n = 32$, 74.4%) than males ($n = 10$, 25.6%), $P < .01$. Despite this within-group difference, no between-group difference was noted based on gender distribution, $P = .06$. Similarly, no differences were observed between the groups with respect to race/ethnicity, marital status, or military affiliation, all $P > .05$. Table I shows the demographic characteristics of participants.

Although no between-group differences were noted at baseline in terms of overall fat mass, BMI, or percent fat (all $P > .05$), the groups did differ with respect to lean mass and basal metabolic rate (both $P = .02$). Neither group experienced a change in either metric of more than 1%.

Table II details the skin type classification, a history of vitamin D deficiency, bone disorders, and sunscreen use of the two groups. No between-groups difference was observed in Fitzpatrick skin type or any other medical history. Despite the low rate of deficiency in the sample, the majority of subjects ($n = 70$, 79.5%) endorsed prior use of vitamin D supplementation.

TABLE I. Demographic Characteristics

	Total		Supplement		Kiosk		
	n	%	*n*	%	*n*	%	*P*[a]
Age, years							
18-29	26	29.5	16	35.6	10	23.3	.53
30-39	28	31.8	14	31.1	14	32.6	
40-49	16	18.2	8	17.8	8	18.6	
50 +	18	20.5	7	15.6	11	25.6	
Gender							
Male	31	35.2	20	44.4	11	25.6	.06
Female	57	64.8	25	55.6	32	74.4	
Race/Ethnicity							
Non-Hispanic white	47	53.4	20	44.4	27	62.8	.27
Non-Hispanic black	12	13.6	7	15.6	5	11.6	
Hispanic	15	17.0	8	17.8	7	16.3	
Non-Hispanic other	14	15.9	10	22.2	4	9.3	
Marital Status							
Single	20	22.7	12	26.7	8	18.6	.37
Married	68	77.3	33	73.3	43	81.4	
Military Affiliation							
Active duty	50	56.8	28	62.2	22	51.2	.65
Prior service or retired military	19	21.6	8	17.8	11	25.6	
Dependent	14	15.9	6	13.3	8	18.6	
None	5	5.7	3	6.7	2	4.7	

[a]Significance based on Kruskal–Wallis test.

TABLE II. Skin Type Classification

	Total		Supplement		Kiosk		
	n	%	*n*	%	*n*	%	*P*[a]
Fitzpatrick skin type							
1	8	9.1	3	6.7	5	11.6	.17
2	28	31.8	13	28.9	15	34.9	
3	29	33.0	15	33.3	14	32.6	
4	13	14.8	7	15.6	6	14.0	
5	6	6.8	4	8.9	2	4.7	
6	4	4.5	3	6.7	1	2.3	
Ever diagnosed with Vitamin D deficiency[b]							
Yes	32	38.6	15	36.6	17	40.5	.72
Any form of Vitamin D in the past							
Yes	70	79.5	35	77.8	35	81.4	.68
Family history of bone disorder							
Yes	14	15.9	7	15.6	7	16.3	.93
Ever had a stress/overuse fracture							
Yes	13	14.8	6	13.3	7	16.3	.70
Use Sunscreen							
Yes	74	84.1	36	80.0	38	88.4	.29

[a]Significance based on Kruskal–Wallis test.
[b]Question sample size, $n = 83$.

Examining the daily calcium (mg) and vitamin D (IU) intake among subjects revealed greater dietary intake of calcium in group OS (median 760.6, IQR 458.0-1027.8) as compared to group PK (median 596.4, IQR 410.3-762.4), $P = .03$. No difference was found with regard to dietary vitamin D intake between group OS (median 180.4, IQR 112.8-296.4) and PK (median 160.6, IQR 105.6-228.2), $P = .27$. No difference in PTH concentration was observed between the groups, $P = .35$.

The two groups did not differ at baseline with respect to the total number of hours per week of sun exposure, $P = .80$. At baseline, group OS reported a median of 10 hours (IQR 4-15) of sun exposure per week and group PK reported a median of 9 hours (IQR 4-18). By the 10-week follow-up, the two groups still did not differ in self-reported total hours of sun exposure per week ($P = .76$); however, both significantly decreased sun exposure compared with baseline (both $P < .05$).

With a median of 92.9% (IQR 83.6-99.3) compliance, supplement use during the study in group OS was determined to be acceptable. Group PK had a median of 100% compliance. Of the 43 participants, 42 were 100% compliant (6/6 exposures), and 1 participant was 83% compliant (5/6 exposures) but only because of failure by the kiosk to deliver a full dose.

Vitamin D levels by time are shown in Table III.

No outlier values were identified requiring exclusion from the analysis. Groups OS and PK did not differ in serum 25(OH)D levels at baseline, $P = .25$. By Week 10 group PK showed significantly higher levels of vitamin D compared with group OS, $P = .02$. By Week 14 follow-up, the 2 groups again showed a slight difference in serum 25(OH)D levels with group PK demonstrating higher levels of 25(OH)D, $P = .02$.

TABLE III. Group Level Vitamin D Concentration by Time, ng/mL

		Supplement	Kiosk	
Time	*n*	Median (IRQ)	Median (IRQ)	*P*[a]
Baseline	88	25.0 (21.0-32.0)	28.0 (22.0-35.0)	.25
Week 10	87	26.0 (21.0-30.5)	30.0 (25.8-37.0)	.02
Week 14	80	21.0 (17.0-30.0)	27.0 (22.0-32.5)	.02

[a]Mann–Whitney U statistic.

No subject experienced any adverse event from supplement or UVB exposure in this study. During the study, there were a total of 257 UVB exposures for the PK group. Of these, 25 (9.7%) exposures were categorized as side effects with a minimal E1 ($n = 13$) or moderate E2 ($n = 12$) erythemal index. Overall, 20 subjects experienced E1 to E2 erythema on 1 visit and 3 subjects reported E1 erythema, with skin color change that did not last more than 3 days, on 2 to 3 follow-up visits.

We administered the Device Usability Scale to the PK group upon completion of the study to assess user acceptability of the new device. The average raw score was 92.3 out of a total score of 100; all participants scored the kiosk at or above 80.

DISCUSSION

The narrow spectrum ultraviolet UVB delivered by the PK was not inferior to 600 IU of D3 to raise or maintain serum 25(OH)D levels over 10 weeks. At the end of all treatments, phototherapy-treated subjects demonstrated significantly higher levels of 25(OH)D compared with those consuming supplements. Although few studies exist comparing phototherapy to oral vitamin D supplementation, phototherapy used primarily for dermatological conditions

has been studied for its ability to impact 25(OH)D levels. In the study by Edstrom et al., whole-body phototherapy (ultraviolet A, UVB, Psoralen plus ultraviolet A) 2 to 3 times a week administered to subjects standing in a light box resulted in significantly higher 25(OH)D levels and a greater sense of well-being than subjects receiving placebo light at 6 weeks.[29] Also contrary to our findings, a study by Biersack et al. administered three full-body suberythemal ultraviolet radiation doses to 20 young healthy women in 1 week and achieved 25(OH)D levels significantly above baseline for up to 6 weeks after the last ultraviolet radiation exposure.[30]

It is possible that our conservative UVB treatment doses (0.6 minimal erythema dose) or the twice-a-month regimen were insufficient to achieve optimal 25(OH)D levels or to sustain levels for 4 weeks. PK subjects demonstrated a significant increase in serum 25(OH)D after 6 treatments; however, this incremental increase was only by 2 ng/mL, and 4 weeks later, the 25(OH)D level had returned to baseline. Median 25(OH)D levels were at or below 30 ng/mL, which do not meet the recommendation of greater than 30 ng/mL by the Endocrine Society Clinical Practice Guidelines.[7] Unfortunately, original estimates that a single treatment in the PK was expected to produce 9 times more vitamin D than 19 minutes of midday summer sunlight, with the total amount of ultraviolet radiation administered equivalent to only 13 seconds in the sun, did not come to fruition.[20] Possible strategies to enhance the results of the well-received PK include more frequent treatments or longer treatments with appropriate safeguards. However, our aim was to evaluate whether the PK could stimulate production of circulating 25(OH)D as effectively as a vitamin D3 OS and the PK did in fact outperform the supplement.

Subjects found the kiosk novel and appealing, which could explain the 100% compliance with return visits. Although there are numerous published accounts of poor compliance with pill regimens,[31] in this study, compliance was a respectable 83%, with only 3 of 45 subjects taking fewer than 50% of the pills.

Regarding device acceptability, the mean score of 92.3 out of 100 indicated a high degree of acceptance by the 43 subjects in group PK. We had concerns about limiting recruitment to an AD population since treatment visits may not have been feasible given the work demands and lack of flexibility for many service members. For this reason, we extended recruitment to the broader community with access to the military base. We met our enrollment goal in 8 months, with over 50% being AD military, experienced a low rate of attrition overall at 18%, and had excellent compliance with 100% of subjects returning for kiosk treatments, suggesting that a PK is feasible in the military setting.

The final aim was to examine the relationship of demographic variables, including gender, age, BMI, ethnicity, and sun exposure to serum 25(OH)D levels in both treatment groups; this revealed a lack of significance for any variable and serum vitamin D level. Several studies have been published attempting to uncover relationships between BMI and vitamin D, or season and levels of vitamin D, yet results are inconsistent and inconclusive.[7,9,32] More research is needed to examine ways to safely promote vitamin D production with critical consideration of the influences of gender, ethnicity, body mass index, and season.

Limitations included the small sample size, the lack of heterogeneity in the sample, the single center recruitment, and the relatively short intervention period with no long-term follow-up on serum 25(OH)D levels.

CONCLUSION

Limited potential to optimize serum 25(OH)D continues to pose a threat to physical and mental health, disease prevention, and resilience so critical to individual wellness and readiness. Educating the public, and young Warfighters in particular, about the potential for acute musculoskeletal injuries, slow healing overuse injuries, immune dysfunction, and chronic disease risk with low levels of vitamin D is imperative by all healthcare professionals.[2,11,33] Given the challenges of safe sun exposure and a limited list of vitamin D containing foods, a phototherapy device intended to stimulate production of vitamin D to maintain 25(OH)D levels may have a significant role in readiness and quality of life for both the Warfighter and the beneficiary.

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REFERENCES

1. Grant WB, Boucher BJ: Requirements for vitamin D across the life span. Biol Res Nurs 2011; 13(2): 120-33.
2. Al-Daghri NM, Al-Attas OS, Alkharfy KM, et al: Association of the VDR-gene variants with factors related to the metabolic syndrome, type 2 diabetes, and vitamin D deficiency. Gene 2014; 542(2): 129-33.
3. Berlanga-Taylor AJ, Knight JC: An integrated approach to defining genetic and environmental determinants for major clinical outcomes involving vitamin D. Mol Diagn Ther 2014; 18(3): 261-72.
4. Garland CF, Gorham ED, Mohr SB, Garland FC: Vitamin D for cancer prevention: global perspective. Ann Epidemiol 2009; 19(7): 468-83.
5. Parva NR, Tadepalli S, Singh P, et al: Prevalence of vitamin D deficiency and associated risk factors in the U.S. population (2011-2012). Cureus 2018; 10(6): e2741.
6. Newberry SJ, Chung M, Shekelle PG, et al: Vitamin D and Calcium: A Systematic Review of Health Outcomes (Update). Rockville, Maryland, Agency for Healthcare Research and Quality (US); 2014: Report No.: 14-E004-EF. Available at https://www.ncbi.nlm.nih.gov/books/NBK253540/
7. Holick MF, Binkley NC, Bischoff-Ferrari HA, et al: Evaluation, treatment, and prevention of vitamin D deficiency: an endocrine society clinical practice guideline. J Clin Endocrinol Metab 2011; 96(7): 1911-30.
8. DiNicola AF, DiNicola PJ, Sanchez L: Need for routine vitamin D screening in military personnel. J Mil Med 2016; 181(9): 1163.
9. McCarthy MS, Elshaw E, Szekely BM, Hobbs C: A randomized controlled trial of nurse coaching vs. herbal supplementation for weight reduction in soldiers. J Mil Med 2017; 182(3/4 Suppl): 274-80.
10. McCarthy MS, Elshaw EB, Szekely BM, Raju D: A prospective cohort study of vitamin D supplementation in AD soldiers: preliminary findings. J Mil Med 2019; 184(Suppl 1): 498-505.

11. He CS, Yong XHA, Walsh NP, Gleeson M: Is there an optimal vitamin D status for immunity in athletes and military personnel? Exer Immunol Rev 2016; 22: 42-64.
12. Barringer ND, Kotwal RS, Lewis MD, et al: Fatty acid blood levels, vitamin D status, physical performance, activity, and resiliency: a novel potential screening tool for depressed mood in active duty soldiers. J Mil Med 2016; 181(9): 1114-20.
13. Hauret KG, Jones BH, Bullock SH, Canham-Chervak M, Canada S: Musculoskeletal injuries description of an under-recognized injury problem among military personnel. Am J Prev Med 2010; 38 (Suppl 1): S61-70.
14. LeBlanc E, Chou R, Zakher B, Daeges M, Pappas M: Screening for Vitamin D Deficiency: Systematic Review for the U.S. Preventive Services Task Force Recommendation. Rockville, Maryland, Agency for Healthcare Research and Quality; 2014: Available at https://www.ncbi.nlm.nih.gov/pubmed/25521000
15. Holick MF: The cutaneous photosynthesis of previtamin D3: a unique photoendocrine system. J Invest Dermatol 1981; 771: 51-8.
16. Haddad JG, Matsuoka LY, Hollis BW, Hu YZ, Wortsman J: Human plasma transport of vitamin D after its endogenous synthesis. J Clin Invest 1993; 91(6): 2552-5.
17. Chandra P, Wolfenden LL, Ziegler TR, et al: Treatment of vitamin D deficiency with UV light in patients with malabsorption syndromes: a case series. Photodermatol Photoimmunol Photomed 2007; 23(5): 179-85.
18. Gronowitz E, Larkö O, Gilljam M, et al: Ultraviolet B radiation improves serum levels of vitamin D in patients with cystic fibrosis. Acta Paediatr 2005; 94(5): 547-52.
19. Bouillon R, Eisman J, Garabedian M, et al: Action spectrum for production of previtamin D3 in human skin. *CIE Technical Report 174, Commission Internationale de l'Eclairage (CIE)*, Vienna, Austria; 2006.
20. Solius Knowledge Base: Available at https://support.solius.com/hc/en-us/categories/360001483453-Treatment-Use; accessed January 15, 2020.
21. Bogh MK, Schmedes AV, Philipsen PA, Thieden E, Wulf HC: A small suberythemal ultraviolet B dose every second week is sufficient to maintain summer vitamin D levels. Br J Dermatol 2012; 166(2): 430-3.
22. Ross AC, Taylor CL, Yaktine AL, Del Vallee HB, editors: Dietary Reference Intakes for Calcium and Vitamin D. Washington, DC, National Academies Press; 2011.
23. Malavolti M, Mussi C, Poli M, et al: Cross calibration of eight-polar bioelectrical impedance analysis versus dual energy X-ray absorptiometry for the assessment of total and appendicular body composition in healthy subjects ages 21-82 years. Ann Hum Biol 2003; 30(4): 380-91.
24. Amblard P, Beani J, Gautron R, et al: Statistical study of individual variations in sunburn sensitivity in 303 volunteers without photodermatosis. Arch Dermatol Res 1982; 274(3-4): 195-206.
25. Fitzpatrick TB: The validity and practicality of sun reactive skin types I through VI. Arch Dermatol 1988; 124(6): 869-71.
26. Brooke J: SUS-A quick and dirty usability scale. Usability Eval Ind 1996; 189(194): 4-7.
27. Fritz CO, Morris PE, Richler JJ: Effect size estimates: current use, calculations, and interpretation. J Expl Psychol Gen 2012; 141(1): 2-18.
28. Little RJ: A test of missing completely at random for multivariate data with missing values. J Am Stat Assoc 1988; 83(404): 1198-202.
29. Edstrom DW, Linder J, Wennersten G, Brismar K, Ros A-M: Phototherapy with ultraviolet radiation: a study of hormone parameters and psychological effects. J Eur Acad Dermatol Venereology 2010; 24(4): 403-9.
30. Biersack MG, Hajdukiewicz M, Uebelhack R, et al: Sustained increase of 25-hydroxyvitamin D levels in healthy young women during wintertime after three suberythemal UV irradiations – the MUVY pilot study. PLoS ONE 2016; 117: e0159040.
31. Conn VS, Ruppar TM: Medication adherence outcomes of 771 intervention trials: systematic review and meta-analysis. Prev Med 2017; 99: 269-76.
32. Karppinen T, Ala-Houhala M, Ylianttila L, et al: Narrowband ultraviolet B exposures maintain vitamin D levels during winter: A randomized controlled trial. Acta Derm Venereol 2016; 96(4): 490-3.
33. Andersen NE, Karl JP, Cable SJ, et al: Vitamin D status in female military personnel during combat training. J Int Soc Sports Nutr 2010; 7: 38-42.