Evaluation of fall Sun Exposure Score in predicting vitamin D status in young Canadian adults, and the influence of ancestry

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1. Introduction
Vitamin D insufficiency is associated with increased risk of and poorer outcomes in autoimmune, cardiovascular and malignant disease. Although vitamin D can be obtained through diet or supplements, our main source is solar ultraviolet (UV)-B mediated cutaneous synthesis.

In Canada, seasonal fluctuations in solar UVB and, thus, resultant production of vitamin D limit the utility of serum 25-hydroxyvitamin D [25(OH)D] tests [1]. A brief questionnaire to screen sun exposure could provide a cost and time-effective strategy to guide individual vitamin D supplementation practices.

In a previous study of healthy Italian adults, a 7-day sun exposure questionnaire predicted serum 25(OH)D concentrations in the summer [2]. However, the utility of this questionnaire in estimating vitamin D status in other settings is unknown. We therefore sought to evaluate the value of the Sun Exposure Score in predicting fall 25(OH)D concentrations in ancestrally diverse young Canadian adults, and to ascertain the strongest predictors of 25(OH)D concentrations, including sun exposure, self-reported ancestry, skin pigmentation and vitamin D intake.

2. Materials and methods

2.1. Study population and recruitment
Recruitment, study eligibility and most aspects of data collection have been previously described [1]. Participants between the ages of 18 and 35 years were recruited at the University of Toronto Mississauga campus (Toronto, Ontario, Canada; 43°N) in fall 2007 and 2008. Exclusion criteria included...
kidney or liver disease, a diagnosis potentially affecting vitamin D metabolism or absorption, such as osteomalacia, osteopenia, or Crohn’s disease, use of medications affecting vitamin D metabolism such as steroids or anticonvulsants, and recent exposure to unreasonably high UVB (e.g. tanning salons or travel to sunny destinations in the preceding three months). This study was approved by the University of Toronto Health Sciences Research Ethics Board, and all participants provided written informed consent.

2.2. Data collection

Participants completed a visit during September–October of 2007 or 2008. Information on age, sex, weight, height, ancestry, and sun exposure (summer and fall) was collected, as described below. A blood sample was drawn for determination of 25(OH)D concentrations. Constitutive skin pigmentation (melanin) was derived from the mean of three measures taken using a narrowband reflectometer (DermaSpectrometer, Cortex Technology) at the upper inner arm (previously validated as a method of objective determination of melanin levels in human skin [3]).

2.2.1. Sun Exposure Score

Participants completed a sun exposure questionnaire based on Time Exposed to Sun (0 = <5 min., 1 = 5–30 min., and 2 = >30 min.) and Skin Exposed to Sun (1 = face and hands uncovered, 2 = arms uncovered, 3 = legs uncovered, 4 = “bathing suit”) for each day in the previous week (Fig. 1). This questionnaire was previously validated in a population of middle-aged healthy Italian adults during the summer [2]. A daily Sun Exposure Score was calculated based on the product of the Time Exposed to Sun and Skin Exposed to Sun scores (min = 0, max = 8), and a weekly Sun Exposure Score was calculated by the sum of each day’s exposure scores, as previously described [2]. A minimum score of 0 corresponded to <5 min outdoors in the sun for 7 days a week, and a maximum score of 56 corresponded to >30 min in bathing suit outdoors in the sun for 7 days a week.

2.2.2. Biochemical analyses

Serum 25(OH)D concentration was measured using liquid chromatography tandem mass spectrometry as described previously [1].

2.2.3. Ancestry

A questionnaire was administered, in which participants provided their country of birth, ethnic background, native language (and other languages), and family history (country of birth, native language and ethnic background of their parents and grandparents). Participant ancestry was defined by familial geographic origins: African, East Asian, European, Middle Eastern, South Asian, and Other” (‘family members from multiple geographic origins).

Only those of East Asian, European and South Asian ancestries were included in the present study due to low enrollment of other ancestral groups.

2.2.4. Vitamin D Intake

A food frequency questionnaire (FFQ) was used to estimate daily vitamin D intake over the previous month [1,4].

2.2.5. Recent summer sun exposure

Participants estimated the amount of time spent outdoors daily during the most recent summer between 9 a.m. and 5 p.m. (<5 min, 5–30 min, <1 h, 1–2 h, and > 2 h).

2.3. Statistical analyses

Serum 25(OH)D concentration was evaluated as both a continuous and categorical variable. Vitamin D sufficiency was defined as 25(OH)D concentrations ≥75 nmol/L according to consensus definitions [5]. Vitamin D deficiency was defined as 25(OH)D concentrations <30 nmol/L according to the Institute of Medicine definition [6]. Pearson correlation and simple linear regression were used to assess the unadjusted associations. Multiple linear regression was applied to (i) estimate the unconfounded association between Sun Exposure Score and 25(OH)D concentrations and (ii) to assess the ability of Sun Exposure Score, ancestry, skin pigmentation, vitamin D intake, summer sun exposure, year of study, age, sex and BMI, to predict 25(OH)D concentrations. For objective 1, associations between covariate, and both the exposure and the outcome were assessed to evaluate confounding. A backward deletion change in estimate approach (≥10% change) was used to build our final unconfounded model [7]. For objective 2, we began with a full model and both p-values (<0.05) and model fit criteria (Akaike Information Criterion (AIC) and Bayesian Information Criterion (BIC)) were used to select the final predictive model. Logistic regression assessed the association between the predictors and the 25(OH)D cut-offs for deficiency (≥30 nmol/L) and for sufficiency (≥75 nmol/L). Diagnostics of the final regression models were performed. Post-hoc analyses were conducted to explore the role of ancestry in more depth. Analyses were performed using SPSS version 20 and STATA 11.

3. Results

3.1. Participant characteristics

A total of 310 participants from the three main ancestral groups completed a sun exposure questionnaire and were included in subsequent analyses. Participant characteristics are displayed in Table 1.
3.2. Sun Exposure Score and 25(OH)D concentrations

The unadjusted correlation between Sun Exposure Score and 25(OH)D concentration was weak although statistically significant (Pearson’s correlation = 0.19, p = 0.01; Fig. 2). Using multiple linear regression analyses, several variables were identified as potential confounders of the association between fall Sun Exposure Score and 25(OH)D concentrations: age, ancestry, melanin, year of study visit, sex, summer sun exposure, and vitamin D intake. In the final adjusted model, Sun Exposure Score was not associated with 25(OH)D concentrations (β = 0.06 nmol/L; 95% CIs: −0.21 to 0.33).

3.3. Variables predicting 25(OH)D concentrations

Ancestry, recent summer and fall sun exposure, vitamin D intake, melanin and age were each independently associated with 25(OH)D concentrations. We also included sex, year of study and BMI in multivariable analyses to ensure we ascertained all potential conditional predictors of 25(OH)D concentrations. In a multivariable predictive model, ancestry, recent summer sun exposure, vitamin D intake, and year of study were significant predictors of 25(OH)D concentrations (Table 2) while age, sex, fall sun exposure and BMI were not. Although melanin was no longer significantly associated with 25(OH)D when accounting for the other predictors in the multivariable predictive model (p = 0.12), it was retained in the final model as including melanin did not meaningfully impact the model fit.

In the final model presented in Table 2, those of East and South Asian ancestries had lower predicted 25(OH)D concentrations than those of European ancestry. In fact, ancestry had the largest impact on the model fit: the adjusted R² for the model that included only ancestry was 43%. The adjusted R² increased to 50% with the addition of the other significant predictors.

As expected from the linear model, ancestry had the greatest impact on model fit in the logistic models evaluating vitamin D sufficiency/insufficiency. Interestingly, very few participants of South Asian (3%) or East Asian (9%) ancestry were vitamin D sufficient; thus, the precision of the estimates was very low and resulted in very large confidence intervals (data not shown). In addition to ancestry, vitamin D intake and recent summer sun exposure were significant predictors of vitamin D sufficiency/insufficiency in multivariable logistic regression. No participants of European ancestry were vitamin D deficient; this precluded use of logistic regression for vitamin D deficiency, as the model could not converge.

3.4. Post-hoc analyses of ancestry and 25(OH)D concentrations

The percent of vitamin D insufficient participants in the European, East Asian, and South Asian groups were 55%, 91% and 97%, respectively. We wanted to explore whether there were interactions between ancestry and the other determinants of 25(OH)D concentrations, and thus, may partly explain why ancestry was the variable most strongly related to fall 25(OH)D concentrations. In the final model presented in Table 2, those of East and South Asian ancestries had lower predicted 25(OH)D concentrations than those of European ancestry. In fact, ancestry had the greatest impact on model fit. As expected from the linear model, ancestry had the greatest impact on model fit in the logistic models evaluating vitamin D sufficiency/insufficiency. Interestingly, very few participants of South Asian (3%) or East Asian (9%) ancestry were vitamin D sufficient; thus, the precision of the estimates was very low and resulted in very large confidence intervals (data not shown). In addition to ancestry, vitamin D intake and recent summer sun exposure were significant predictors of vitamin D sufficiency/insufficiency in multivariable logistic regression. No participants of European ancestry were vitamin D deficient; this precluded use of logistic regression for vitamin D deficiency, as the model could not converge.

![Fig. 2. Fall serum 25(OH)D concentration and fall Sun Exposure Score. Simple linear regression line with r^2 value is also displayed. Unadjusted Pearson's correlation was weak although statistically significant (r = 0.19, p = 0.01).](image-url)

Table 1

Participant characteristics.

<table>
<thead>
<tr>
<th>Predictor</th>
<th>Mean (SD) or Number (%)</th>
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<tbody>
<tr>
<td>Number of participants (females, males)</td>
<td>310 (208, 102)</td>
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<tr>
<td>Mean age, y (SD)</td>
<td>21.1 (3.0)</td>
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<tr>
<td>Mean BMI, kg/m² (SD)</td>
<td>23.1 (4.2)</td>
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<tr>
<td>Sex (female, male)</td>
<td>208 (68%, 32%)</td>
</tr>
<tr>
<td>Ancestry (n, %)</td>
<td>European 111 (35.8%), East Asian 104 (33.6%), South Asian 95 (30.7%)</td>
</tr>
<tr>
<td>Median 25(OH)D concentrations, nmol/L (IQR)</td>
<td>49.7 (36.7–70.3)</td>
</tr>
<tr>
<td>Vitamin D deficient (&lt;30 nmol/L; n (%))</td>
<td>European 0 (0%), East Asian 12 (12%), South Asian 92 (97%)</td>
</tr>
<tr>
<td>Mean Sun Exposure Score (SD)</td>
<td>15.2 (8.5)</td>
</tr>
<tr>
<td>Mean Time in Sun Score (SD)</td>
<td>9.0 (3.4)</td>
</tr>
<tr>
<td>Mean Skin Exposed Score (SD)</td>
<td>11.3 (3.9)</td>
</tr>
<tr>
<td>Mean skin pigmentation, units of melanin (SD)</td>
<td>33.7 (5.5)</td>
</tr>
<tr>
<td>Mean daily vitamin D intake, IU/d (IQR)</td>
<td>199 (126–341)</td>
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</tbody>
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BMI, body mass index; d, day; IQR, inter-quartile range; IU, international units; n, number; nmol/L, nanomoles per litre; SD, standard deviation; y, years.

Table 2

Significant predictors of Serum 25(OH)D concentrations (nmol/L).

<table>
<thead>
<tr>
<th>Predictors of 25(OH)D concentrations</th>
<th>Coefficient ± Standard error</th>
<th>[95% Confidence interval]</th>
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<tr>
<td>South Asian ancestry</td>
<td>−41.8 ± 3.3</td>
<td>(−48.4 to −35.2)</td>
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<tr>
<td>East Asian ancestry</td>
<td>−26.4 ± 2.5</td>
<td>(−31.3 to −21.4)</td>
</tr>
<tr>
<td>Year of study</td>
<td>−6.8 ± 2.2</td>
<td>(−11.1 to −2.4)</td>
</tr>
<tr>
<td>Summer Sun Exposure</td>
<td>1.9 ± 0.9</td>
<td>0.2 ± 1.7</td>
</tr>
<tr>
<td>Melanin</td>
<td>0.4 ± 0.3</td>
<td>−0.1 to 0.9</td>
</tr>
<tr>
<td>Vitamin D intake</td>
<td>0.02 ± 0.005</td>
<td>0.01 ± 0.03</td>
</tr>
<tr>
<td>Intercept</td>
<td>63.2 ± 8.8</td>
<td>45.8 ± 80.5</td>
</tr>
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</table>

* Ancestry: reference group is European ancestry; year of study: 2007 compared to 2008; summer Sun Exposure: 4 level ordinal variable, with higher values representing more summer sun exposure; melanin & vitamin D intake (IU/d): continuous variables (per one-unit increase).
4. Discussion

Fall Sun Exposure Scores were not correlated with serum 25(OH)D concentrations after adjustment for confounders, demonstrating that in this population, using the Sun Exposure Score in the fall is of limited use in predicting vitamin D status. Another study using the same Sun Exposure Score [2] demonstrated a stronger correlation between Sun Exposure Score and 25(OH)D concentrations during summer in an ancestrally homogeneous Italian population. The weaker correlation in the present study is likely due to several factors, with the lower vitamin D-weighted climatological UV in Toronto during the fall [9] vs. San Giovanni Rotondo in the summer likely being the most important difference. Sun Exposure Score and 25(OH)D concentrations would likely have had a stronger correlation in this population if measured in summer.

Other significant predictors of 25(OH)D concentrations were ancestry, recent summer sun exposure, sex, skin pigmentation, vitamin D intake, and year of study, with ancestry alone explaining most of the variance in 25(OH)D concentrations in this study population.

In the multiple regression model, ancestry was the strongest predictor of 25(OH)D concentrations even after accounting for skin pigmentation and vitamin D intake. This finding agrees with a study in California that observed significant association between ancestry and vitamin D status [8]. However, other studies evaluating the association between sun exposure and 25(OH)D concentrations in diverse ancestries have found other variables other than ancestry to be stronger predictors, such as forehead skin reflectance [8], self-reported skin colour [10], and consumption of fatty fish [11].

“Ancestry” is related to many measured factors e.g. skin pigmentation and vitamin D intake, as well as factors not queried herein, e.g. cultural habits, customary clothing, foods not captured in the FFQ, and genetic differences in vitamin D metabolism, among others. Future studies focusing on these factors, may help to elucidate the observed association between ancestry and fall 25(OH)D concentrations.

Limitations of this study include accuracy of recall associated with the Sun Exposure Score, and generalizability, as our population represented only a certain age range, relatively few ancestries, and was recruited from a single university campus during early fall. Assessment of sun exposure over the previous week may not be long enough to represent overall sun exposure habits, and durations of much greater than 30 min outside may not be adequately quantified. As well, this study may not adequately represent participants who have darker skin and slower rate of production of vitamin D [12]. Future directions involve longitudinal evaluations of sun behaviours, validating the Sun Exposure Score with UV dosimetry in different seasons and locations, querying sunscreen use and face or head coverings, and including more diverse populations.

5. Conclusions

Fall Sun Exposure Score was not associated with 25(OH)D concentrations. Ancestry was a relatively strong predictor of 25(OH)D concentrations and vitamin D sufficiency status, with the vast majority of individuals of East and South Asian ancestry being vitamin D insufficient (91% and 97%), as compared to just over half of those of European ancestry (55%). Thus, query of ancestry could be used as a possible screen to identify those at risk of vitamin D insufficiency, as it is a better predictor of vitamin D status during the fall than recent sun exposure, skin pigmentation or vitamin D intake, and it is simple to perform. Use of such a simple screen could result in reduced health care costs related to laboratory measurements of circulating 25(OH)D concentrations, and potentially, reduced prevalence of vitamin D insufficiency if individuals were counseled about their risk of vitamin D insufficiency and need for vitamin D supplementation.

Acknowledgements

This work was supported by an endMS Summer Research Studentship (L.S.), a Multiple Sclerosis Society of Canada Doctoral Studentship (S.M.), an Early Research Award from the Government of Ontario and the Natural Sciences and Engineering Research Council of Canada (E.J.P.), and a Hospital for Sick Children Restracomp Fellowship (H.E.H.).

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