Predictive Factors for Vitamin D Concentrations in Swiss Athletes: A Cross-sectional Study

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ABSTRACT

Vitamin D concentrations corresponding to 75 nmol/L 25(OH) D have been associated with maintained muscle function, growth and regeneration, optimal bone health and immunology in athletes. The objective of this study was to investigate the prevalence and predictors of insufficient 25(OH)D concentrations in athletes. Six hundred three Swiss athletes were assessed. 25(OH)D was analysed by high-performance liquid chromatography (HPLC). A standardized questionnaire was used to gather information about potential predictors for 25(OH)D concentrations; 50.5 % showed insufficient 25(OH)D concentrations. Differences in predicted probability of insufficient 25(OH)D were found for those vitamin D supplemented (42 %) versus not supplemented (52 %), in those performing indoor (58 %) versus outdoor sports (43 %), and during the sun-deprived seasons of fall (49 %), winter (70 %) and spring (57 %) compared with summer (17 %). Higher BMI z-scores and age were associated with higher 25(OH)D concentrations. In conclusion, insufficient 25(OH)D concentrations were common among athletes especially at a younger age, among those not supplemented, in athletes who trained indoors, and during the sun-deprived seasons. Because the prevalence of insufficient 25(OH)D concentrations in this study was high, regular supplementation in athletes may be indicated, except perhaps during the summer season. Further research is needed to determine which 25(OH)D concentrations lead to optimal health and performance in athletes.

Main Points

- Desirable vitamin D concentrations corresponding to 75 nmol/L of 25(OH)D or more have been associated with improved muscle function, regeneration and performance, optimal bone health and immune function in athletes.
- The prevalence of insufficient vitamin D concentrations was high with one in two athletes presenting insufficient concentrations of 25(OH)D (< 75 nmol/L).
- Younger age, type of sport with mainly indoor training, the lack of vitamin D supplementation, lower BMI, and the sun-deprived seasons (fall, winter and spring) were found to be potential risk factors for low 25(OH)D concentrations.
- Vitamin D supplementation in athletes should be considered, especially during sun-deprived seasons.

Introduction

Higher vitamin D concentrations [25(OH)D] are associated with multiple health benefits such as higher bone mass and acquisition, and protective effects against cardiovascular diseases, cancer and other chronic diseases [4, 26]. Nevertheless, there is still controversy about the clinical relevance of 25(OH)D [55]. In general, 25(OH)D is increased by sun radiation (sun angle > 30 °) on non-covered skin, nutrition, and vitamin D supplementation, and decreased by various diseases (e. g. obesity, liver failure) [26]. Further studies suggest that higher age [30], higher BMI or fat mass [24, 49], darker skin colour [8, 9], sunscreen use [27, 36], and indoor compared to outdoor sports activities [14, 35, 44] are associated with lower 25(OH)D concentrations as an expression of inadequate intake or production by the skin or altered metabolic pathways. The influence of sex is controversial [30, 37].

On a population level, most international authorities classify 25(OH)D of > 50 nmol/L as sufficient and ≥ 75 nmol/L as desirable [11, 12, 27, 41, 47]. The higher 75 nmol/L target is supported by studies that show multiple beneficial effects such as increased peak bone mass and mineral density, muscle strength, a maximal suppression of parathyroid hormone, optimized intestinal calcium resorption and immunological benefits [4, 11, 20, 23, 26, 27].

In athletes, circulating 25(OH)D has been associated with maintained muscle function including improvements in muscle contractions, enhanced growth and regeneration following muscle damage, and optimal bone health [7, 17, 43, 48, 56]. Athletes with desirable 25(OH)D concentrations show an improved immune function including, but not limited to, lower incidence of upper respiratory tract infections [20, 28]. Yet, inadequate concentrations of 25(OH)D are highly prevalent in athletes especially during the winter months [3, 14].

Several predictors of vitamin D insufficiency have been reported in the past that allow detecting populations at risk that may deserve more preventive attention. Because we are dealing with an athlete population that may differ from the general population, predictors from the general population (e. g. age, sex, BMI, skin colour and protection, vitamin D substitution, season, latitude) may differ [8, 9, 27, 30, 36, 37, 49], and selective factors in athletes such as training hours or location of sports activity as a proxy for sun exposure may play a role [14].

Previous studies that investigated the prevalence and predictors of insufficient 25(OH)D in athletes lacked external validity, limiting their generalisability for central Europe (e. g. Switzerland) due to different reasons: studies used different analytical approaches for 25(OH)D concentrations (e. g. RIA, CLIA) which affects comparability of results [2, 14, 18, 34, 50], included non-comparable populations (e. g. Northern countries like the UK, other races as in Qatar, Middle East) [10, 14, 18], used small sample sizes of < 30 [14, 16, 63, 64], or focussed on only one specific season or selective predictors without controlling for others [14].

To address the study limitations mentioned, the objective of this study was to assess the prevalence and predictors of insufficient 25(OH)D concentrations by conducting a cross-sectional study on a large diverse (e. g. age, type of sport) sample of competitive athletes in Switzerland over the period of one year. We hypothesised a high prevalence of vitamin D insufficiency and variables like sex, age, BMI, vitamin D substitution, skin colour, sunscreen use, hours of training (proxy variable for sun exposure), location of sport activities (indoor vs. outdoor sports), and season to be associated with 25(OH)D concentrations.

Materials and Methods

Participants

This is a cross-sectional study that was conducted on a convenience sample of 603 Swiss Olympic athletes corresponding to 3.4 % of a total of 17,927 active Swiss Olympic card holders [54]. All athletes with a National Olympic Committee (Swiss Olympic) card reflecting a regional, national or international competitive sport level were eligible to participate. No other eligibility criteria were applied. All participants were healthy (e. g. no diagnosis of renal insufficiency). A total of 24 (out of 39) National Olympic Committee-accredited sports medical centres participated in the study and recruited study participants during the pre-participation evaluation (PPE) over a period of 13 months (5/2014–6/2015). Participation was voluntary for centres. The PPE by the physician included a medical examination, routine blood sample examination and the completion of a questionnaire. Blood samples were processed and analysed at a single certified central laboratory (Canton hospital Aarau AG, Aarau, Switzerland) after being sent by express mail within 12 h. Participation was voluntary and written informed consent was obtained for all participants. Data protection was ensured through pseudonymisation. According to Swiss regulations no ethical approval from national authorities had to be obtained for this type of study, which met the ethical standards in sport and exercise science research [19].

Vitamin D

Vitamin D (cholecalciferol/25-hydroxyvitamin D3) was analysed using a kit for the quantification of vitamin D2 and vitamin D3 (PerkinElmer, Turku, Finland). The kit employed isotope dilution and HPLC coupled with mass spectrometry (ID-LC-APCI-MS/MS) and was installed on an Ultimate 3000 HPLC (Thermo Fisher, Waltham, MA, USA) and a QTRAP 5500 mass spectrometer (Sciex, Framingham, MA, USA) [50, 57]. The detection limit (detection of lowest concentration) was 5 nmol/L. According to the manufacturer, intra-assay variability is between 4.45 and 5.0 % and inter-assay variability lies between 4.3 % and 5.6 %. For the main analysis, 25(OH)D was dichotomized, with concentrations < 75 nmol/L defining insufficient and concentrations ≥ 75 nmol/L defining desirable levels.

Predictors

Information about sociodemographic factors, sports and training, clinical information, clinical symptoms and further variables potentially related to 25(OH)D was gathered via a questionnaire. Age was included in years. Body mass index (BMI, kg/m2) and BMI-for-age z-scores were calculated according to the World Health Organization references (athletes above 19 years were set to 19 years) [65]. Season was categorized based on the four astronomic seasons that take solar radiation into account; spring (March 21 to June 20), summer (June 21 to September 20), fall (September 21 to December 20) and winter (21 December to 20 March). The main sport activities were divided into indoor sports (e. g. hockey, gymnastics, swimming) and outdoor sports (e. g. football, snow sports, marathon). Training hours were assessed as average hours per week over the last three months. Skin colour was assessed at five levels and subsequently dichotomized into fair skin (pale/fair skin, fair skin = northern European and Scandinavian type) and dark skin (brown, dark skin and black = southern European, Indian, and African type) due to low case numbers in some categories [15]. Sunscreen use was rated on a 5-point Likert scale from regular to never use (in 100 %, 75 %, 50 %, 25 %, or 0 % of time). The first three answers were categorized as "regular" use and the latter two as "seldom/never". Information about vitamin D (cholecalciferol) supplementation was collected by asking for intake frequency, dosage and the trade name. All reported supplements were checked for cholecalciferol/ergocalciferol content, but exact dosage IU could not be determined due to partially imprecise product information from participants. A binary variable (yes/no) was coded indicating cholecalciferol/ergocalciferol supplementary intake. If no trade name was stated for multivitamins, vitamin D supplementation was assumed and coded as "yes".

Statistical analysis

Sample characteristics are presented as means ± standard deviations (SD) for continuous variables and as counts and frequencies for categorical variables. The two sample proportion (z-test) or chi-squared test was used to detect differences in 25(OH)D (insufficient versus desirable) fractions for each level of all independent categorical variables. Mean differences of continuous variables (across the binary outcome variable) were tested by independent t-test with unequal variances (Welch's t-test).

A binary logistic regression (main model) was calculated to detect potential risk factors of 25(OH)D concentrations < 75 nmol/L. Coefficients are reported as odds ratio including 95 % confidence interval. To obtain additional information on the extent of influence of the predictors, a multiple linear regression was calculated reporting beta coefficients and 95 % confidence interval. To minimize potential bias, loss of precision and power due to item non-response (missing values of single athlete on one or more variables), we imputed the data (m = 40) using a chained equation approach (MI) [51, 52, 62]. All variables used in the analytical models were also used in the imputation models including the outcome [38, 51]. Additionally, a complete case analysis (CCA) was performed in order to compare the results with the multiple imputation-based analysis (differences between complete case and imputed analysis are reported). Predicted probabilities of all independent variables (predictive margins) including a 95 % confidence interval (holding other variables constant at their mean values) were calculated to graphically display the effects of the predictors in the logistic regression model. Data analysis was performed using Stata for Windows version 13.1 (StataCorp LP, College Station, TX, USA).

Results

The characteristics of the total sample of athletes and athletes stratified by 25(OH)D categories (desirable ≥ 75 nmol/L or insufficient < 75 nmol/L) are shown in ▶ **Table 1**. Athletes (63 % male) ranged from 9 to 46 years of age and showed a mean (SD) weight of 63.4 (15.1). Missing values were present for BMI, training hours, skin colour, sunscreen use, and outdoor/indoor sports ranging from 0.3 to 15.6 %.

Insufficient 25(OH)D concentrations < 75 nmol/L were present in 50.5 % of athletes while a deficiency < 50 nmol/L was present in 14 %. Insufficient concentrations of 25(OH)D were significantly more prevalent in females, in athletes without vitamin D supplementation, and in fall, winter and spring compared with summer. Age, BMI (unstandardised and standardised), and training hours per week were significantly lower in athletes with insufficient 25(OH)D concentrations compared with the desirable group. Mean (SD) and median (interquartile range) 25(OH)D concentrations were 75.9 (23.4) and 74.8 (31.3) nmol/L, respectively. Further sample characteristics (type of sport) are given in Appendix **Table 1S**).

Tested predictors of insufficient 25(OH)D concentrations investigated by logistic and linear regression are shown in ▶ **Table 2**. By logistic regression, younger age, lower BMI z-scores, the lack of vitamin D supplementation, indoor versus outdoor sport activities and the seasons of fall, winter, and spring as compared with summer significantly increased the probability of insufficient 25(OH)D. ▶ **Fig. 1–3** summarize the mean-adjusted predicted probabilities of insufficient 25(OH)D concentrations for all categorical predictors, age and BMI z-scores. Differences in probability of insufficient 25(OH)D were found for indoor (58.5 %) versus outdoor sports (42.5 %), the lack of vitamin D supplementation (52.4 %) versus supplementation (42.0 %) and during the sun-deprived seasons of fall (49.5 %), winter (70.3 %) and spring (57.3 %) as compared with summer (17.0 %). Higher predicted probabilities of insufficient 25(OH) D were also found for younger as compared with older age and for lower compared with higher BMI z-scores (see ▶ **Fig. 2**, **3**). Similar results were obtained from multiple linear regressions (adjusted for all other variables). A one-unit increase in age (year) and BMI z-score was associated with an increase of 0.85 nmol/L and 3.04 mmol/L 25(OH)D, respectively. Likewise, 25(OH)D concentrations were significantly lower in the group without than with vitamin D supplementation (−5.1 nmol/L), in indoor than outdoor sports (−5.4 nmol/L) and during fall (−16.9 nmol/L), winter (−28.6 nmol/L), spring (19.7 nmol/L) compared to summer. Minor differences in results based on the multiple imputation as compared to the complete case analysis occurred but did not change the conclusion.

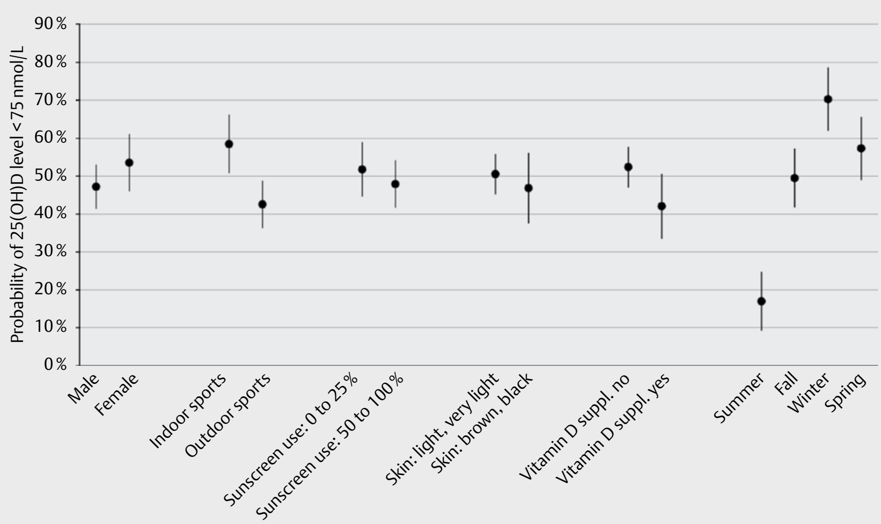
▶ **Table 1** Sample characteristics by 25(OH)D category (desirable ≥75 nmol/l and insufficient < 75 nmol/l) and in the total sample (n = 603) including missing values.

	Desirable level (n = 297)		Insufficient level (n = 303)		Total sample (n = 603)		Mean differences	
	n (%)	Mean (SD)	n (%)	Mean (SD)	n (%)	Mean (SD)	Diff.	(95 % CI)
Outcome								
25(OH)D	297 (49.5)		303 (50.5)		600 (99.5)	75.9 (23.4)		
25(OH)D unknown, missing					3 (0.5)			
Predictors								
Sex [a]								
Female	91 (40.4)		134 (59.6)		225 (37.3)		14.5 * *	(22.6; 6.3)
Male	206 (54.9)		169 (45.1)		378 (62.7)			
Age (years) [b]	297	20.4 (5.7)	303	17.2 (5.3)	603	18.8 (5.8)	3.2 * *	(2.3; 4.1)
BMI & BMI z-score								
BMI [b]	271	22.1 (2.9)	235	20.4 (2.9)	509 (84.4)	21.3 (3.0)	1.8 * *	(1.3; 2.3)
BMI unknown, missing					94 (15.6)			
BMI z-score [b]		0.22 (0.80)		− 0.10 (0.84)		0.07 (0.8)	0.31 * *	(0.16; 0.45)
Vitamin D supplementation [a]								
Yes	93 (57.1)		70 (42.9)		164 (27.2)			
No	204 (46.7)		233 (53.3)		439 (72.8)		10.4 *	(1.5; 19.3)
Skin colour [a]								
Pale, fair	205 (48.8)		215 (51.2)		421 (69.8)		5.6	(−3.8; 15.0)
Brown, dark	80 (54.4)		67 (45.6)		149 (24.7)			
Sun protection unknown, missing					33 (5.5)			
Sunscreen use [a]								
0 % to 25 %	109 (46.0)		128 (54.0)		238 (39.5)		7.4	(− 1.0; 15.8)
50 % to 100 %	173 (53.4)		151 (46.6)		326 (54.1)			
Sun protection unknown, missing					39 (6.5)			
Training hours / week [b]	285	13.3 (5.7)	282	12.3 (6.9)	570 (94.5)	12.8 (6.3)	1.0 *	(0.0; 2.1)
Training hours / week unknown, missing				33 (5.5)				
Location of sport [a]								
Outdoor	177 (52.7)		159 (47.3)		337 (55.9)		7.3	(−1.0; 15.0)
Indoor	119 (45.4)		143 (54.6)		264 (43.8)			
Outdoor sports unknown, missing					2 (0.3)			
Season [c]								
Summer	90 (83.3)		18 (16.7)		108 (17.9)		0.00 * *	
Fall	98 (50.0)		98 (50.0)		197 (32.7)			
Winter	43 (32.1)		91 (67.9)		135 (22.4)			
Spring	66 (40.7)		96 (59.3)		163 (27.0)			

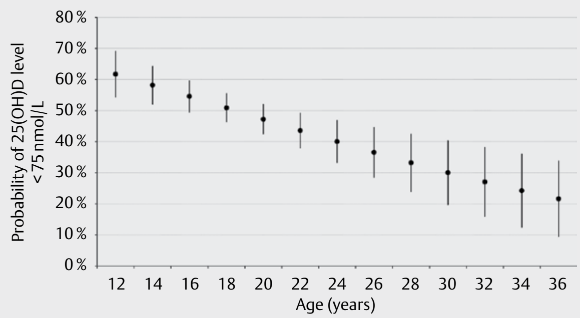
* Sig ($p < 0.05$)/ * * highly sig ($p < 0.01$) based on two-sided tests; [a] Difference (%) based on two sample proportion z-test (e. g. proportion (female insufficient) - proportion (male insufficient)); [b] Two-sample t-test with unequal variances (Welch approximation) ; [c] Chi-squared test

▶ **Table 2** Predictors of 25(OH)D concentrations (<75 nmol/l) by logistic regression (insufficient<75 nmol/l 25(OH)D vs. desirable ≥75 nmol/l 25(OH)D) and linear regression (n=603).

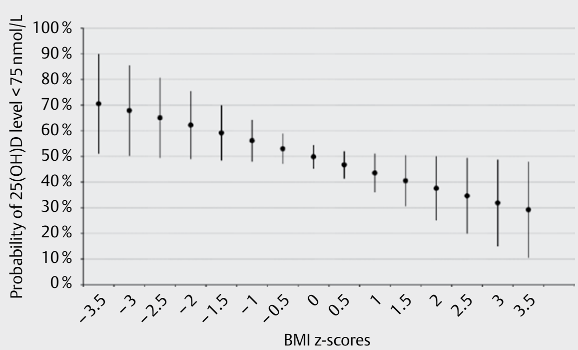
	Logistic regression (insufficient vs. desirable)			Linear regression (prediction of continuous levels of 25(OH)D)		
	OR	(95% CI)	p-value	Beta coef.	(95% CI)	p-value
Sex						
Male	Reference			Reference		
Female	1.29	(0.88 to 1.90)	0.20	0.41	(−3.09 to 3.92)	0.82
Age (years)	0.93	(0.89 to 0.97)	<0.001	0.85	(0.52 to 1.18)	<0.001
BMI z-scores WHO	0.77	(0.60 to 1.00)	0.046	3.04	(0.83 to 5.24)	0.007
Vitamin D supplementation						
No	Reference			Reference		
Yes	0.66	(0.43 to 0.99)	0.045	5.12	(1.39 to 8.85)	0.007
Skin color						
Light, very light	Reference			Reference		
Brown, black	0.85	(0.55 to 1.32)	0.48	−0.80	(−4.63 to 3.04)	0.68
Sunscreen use						
0% to 25%	Reference			Reference		
50% to 100%	0.85	(0.58 to 1.25)	0.41	1.04	(−2.42 to 4.50)	0.55
Training hours (week)	1.01	(0.97 to 1.04)	0.68	0.15	(−0.15 to 0.44)	0.33
Location of sport						
Indoor sports	Reference			Reference		
Outdoor sports	0.53	(0.34 to 0.82)	0.004	5.38	(1.55 to 9.20)	0.006
Season						
Summer	Reference			Reference		
Fall	4.78	(2.49 to 9.19)	<0.001	−16.91	(−22.20 to −11.61)	<0.001
Winter	11.49	(5.68 to 23.23)	<0.001	−28.58	(−34.28 to −22.89)	<0.001
Spring	6.59	(3.45 to 12.57)	<0.001	−19.71	(−24.91 to −14.52)	<0.001



▶ **Fig. 1** Mean-adjusted predicted probabilities of 25(OH)D concentrations<75 nmol/L (95% confidence interval) for categorical variables derived from the logistic regression model (n=603). Predictions are mean-adjusted for all other variables listed in ▶ **Table 2**. Significantly higher probabilities of 25(OH)D insufficiency were present for indoor vs. outdoor sports, not supplemented vs. supplemented athletes, and in fall, winter and spring compared to summer.



▶**Fig. 2** Mean-adjusted predicted probabilities of 25(OH)D concentrations < 75 nmol/L (95 % confidence interval) for different age groups derived from the logistic regression model (n = 603). Predictions are mean-adjusted for all other variables listed in ▶**Table 2**. Higher age was significantly related to lower probability of 25(OH)D insufficiency.



▶**Fig. 3** Mean-adjusted predicted probabilities of 25(OH)D concentrations < 75 nmol/L (95 % confidence interval) for different BMI z-scores derived from the logistic regression model (n = 603). Predictions are mean-adjusted for all other variables listed in ▶**Table 2**. Higher BMI z-scores were significantly related to lower probability of 25(OH)D insufficiency.

Discussion

This cross-sectional study in a large cohort of Swiss athletes demonstrated that one in two Swiss athletes showed insufficient 25(OH)D below 75 nmol/L, potentially compromising health and athletic performance. Lower age, lower BMI and the seasons fall, winter and spring showed to be risk factors for insufficient 25(OH)D concentrations, whereas vitamin D supplementation and outdoor sports were positively related to 25(OH)D concentrations. Sex, skin colour, sun cream use and training hours did not significantly predict 25(OH)D levels.

Prevalence insufficient 25(OH)D concentrations

The prevalence of insufficient 25(OH)D of approximately 51 % shown in this study was comparable to previous research in athletes (56 %) and somewhat lower than in the general population (64–70 %) [6, 14, 37]. This is not surprising because 25(OH)D levels can be influenced by many factors. These include age, BMI, ethnicity, different skin types, sun protection approaches (e. g. sunscreen use, clothing), latitude of residence, and seasonal variation determining the extent of sun exposure, as well as dietary intake and supplementation [14, 26, 31]. Irrespective of personal and environmental factors, 25(OH)D measurement approaches are subject to high variability which may result in different prevalence estimates of insufficient 25(OH)D concentrations ranging from 8 to 42 % [50].

Season

In this study, season was the strongest predictor of 25(OH)D concentrations with the sun-deprived seasons of fall, winter and spring as compared to summer as the strongest risk factors for insufficient 25(OH)D concentrations. This finding is consistent among studies [14, 35] as during these seasons, the zenith angle to the earth is too shallow (< 45 °) to induce any vitamin D production in the skin [32]. Moreover, colder temperatures during these sun-deprived seasons requires proper clothing that covers the skin completely and prevents any natural production of vitamin D.

Age and sex

Higher age was associated with lower odds of insufficiency and therefore higher 25(OH)D concentrations. This was not expected based on epidemiological data [30] because 25(OH)D production in the skin becomes less efficient with increasing age due to a lower 7-dehydrocholesterol content in the epidermal layer of the skin [33]. We doubt that this mechanism played a relevant role in our rather young population, because the decrease in vitamin D production efficiency seems to be especially prominent at an older age [13, 33]. Yet, the rising awareness of the carcinogenic effect of UV radiation over the last several decades may have led to preventive strategies with the avoidance of sun exposure and the unconditional use of sun cream [40]. The younger athletes might have been more aware of this, potentially due to the influence of their health-conscious parents.

The influence of sex on 25(OH)D concentrations is controversial. Some authors found lower 25(OH)D concentrations in females, whereas others found the opposite pattern [30, 37, 39, 61]. In this study, a higher prevalence of insufficient 25(OH)D concentrations was found in females (compared to males), which is likely explained by other factors such as different body mass, fat percentage or time spent in the sun. It is not surprising, however, that the gender difference disappeared after adjusting for all other variables in the models.

BMI, skin colour & sunscreen use

Several studies suggest an inverse relation between BMI, fat mass and vitamin D concentrations [24, 49] because body fat serves as 25(OH)D storage and reduces its release [46]. We found weak evidence for the opposite scenario with a small but consistent positive association between BMI (z-scores) and 25(OH)D concentrations. In athletes, a higher BMI is generally not a marker of higher body fat, but rather of increased muscle mass. It is known that 25(OH)D plays an important role in muscle function such as induction of myogenic transcription, cell proliferation and differentiation, and suppression of myostatin. Therefore, higher muscle mass, expressed in our study as a higher BMI, possibly goes along with higher 25(OH)D [1, 29]. Another explanation for this positive relation in athletes could be the lower intake of dietary vitamin D in athletes with a lower BMI. A low dietary and therefore 25(OH)D intake and even eating disorders are common among sports athletes where low body weight might be an advantage such as in aesthetic or endurance sports [53]. But, whether and how much deficient dietary intakes play a role is still controversial. For instance, an investigation of a large cohort identified that less than 2 % of individuals studied met dietary intake requirements (RDA) for vitamin D, which questions the relevance of nutrition in the prevention of vitamin D deficiency [25].

Darker skin colour (more melanin) and frequent sunscreen use are relevant barriers of 25(OH)D production and therefore associated with a lower production of pre-vitamin D in the skin and consequently lower circulating 25(OH)D concentrations [8, 9, 27, 36]. Surprisingly, both factors were not found to be significant predictors of insufficient 25(OH)D concentrations in our statistical models, which may be partly explained by the lack of measurement precision (questionnaire data).

Vitamin D supplementation

Levy, McKinnon, Barker, et al. [31] found that vitamin D supplementation in a general population was the strongest positive predictor of circulating 25(OH)D concentrations. Although vitamin D supplementation was associated with a 5 nmol/L higher 25(OH)D concentration compared to the not supplemented group, this difference is surprisingly small. This can be explained partly by the variation in supplemental dose of vitamin D. The majority of athletes in our study reported taking supplemental vitamin D, mostly in the form of a multivitamin supplements. Due to the imprecise recall of the exact name of the supplements by the athletes, the supplementation dosage could not be specified exactly, although most multi-vitamin supplements contain 400 IU of vitamin D [26] and may not be sufficient to reach the recommended daily allowance (RDA) levels of 600–800 IU/day [12, 27, 47]. Heaney [21] found that, depending on the baseline 25(OH)D, an increase between 6 nmol/L (2.4 ng/ml) and 10 nmol/L (4 ng/ml) is expected with supplementation of 400 IU/day, which is close to our estimate. In addition, poor compliance in taking supplements or even medications (approximately 50 % in other populations) may have contributed to the apparently low vitamin D concentrations despite supplementation [5, 66].

Indoor sports and training hours

Several studies have shown that athletes performing indoor sports rather than outdoor sports are more susceptible to 25(OH)D insufficiency, suggesting a difference in sun exposure [14, 35, 44]. In support of this belief, seasonal variations in 25(OH)D have been well described in the literature with consistently lower 25(OH)D concentrations in fall and winter than in summer [14, 27, 35, 42]. We included training hours per week as a possible correlate of 25(OH)D concentrations as a possible proxy variable for hours of sun exposure. We found higher training hours in the optimal 25(OH)D group in the descriptive analysis, but this effect disappeared after adjusting for other predictive variables. Therefore, training hours do not seem to be a good proxy for sun exposure, because it highly depends on time and location of training as well as skin protection provided by sunscreen and clothing.

Recommendation and supplementation

Based on the literature, target concentrations of 75 nmol/L 25(OH) D may be recommended for athletes to improve performance and regeneration [43] or to offer immunological benefits to prevent acute infection [20]. This target concentration is further supported by benefits to bone health which is an important value especially for younger athletes who may still be growing [4, 11, 23, 26, 27]. Because the prevalence of insufficient 25(OH)D concentrations in this study was high, supplementation in athletes may be indicated, except perhaps in the summer months [20]. The intake of at least 600 IU/day vitamin D3 for children and adults is recommended by different authorities (e. g. Endocrine Society, Institute of Medicine) [12, 27, 47]. However, to reach 25(OH)D levels of ≥ 75 nmol/L, higher dosages may be needed [12, 27, 47, 58]. Daily vitamin D3 supplementation at a dosage between 600 and 1000 IU is generally recommended and considered safe by different authorities [12, 22, 27, 47]. Under strict sunlight safety recommendations in summer (e. g. short regular exposure under strict avoidance of sunburn, application of sun cream after about 15 min of exposure) [59, 60], supplementation may be replaced by about 15 min of sun exposure (covered with a T-shirt and shorts) on most days. This allows obtaining desirable vitamin D concentrations of ≥ 75 nmol/L in a majority of supplemented populations [45, 60]. For those at high risk of sunburn, those who train mostly indoors or wear skin covering/clothing [18], and/or those who fear an increased risk of skin cancer, supplementation can safely be taken throughout the year [22].

Study strength and limitations

The major strength of this study is the inclusion of a large and variable sample of competitive athletes in Switzerland. 25(OH)D was uniformly assessed by one central and certified quality laboratory that used the gold standard assay of liquid chromatography–mass spectrometry to determine serum concentrations of 25(OH)D [50]. Multiple imputation was used to account for item non-response in the statistical analysis to increase precision and lower the probability of selection bias [52]. Limitations are related to the cross-sectional design precluding causality and the possibility of a selection bias that may have been induced by unit non-response. Moreover, we used questionnaire data to assess demographics and some risk factors prone to different types of bias. Unfortunately, the inclusion of objective measures such as body composition including fat, muscle and bone mass (e. g. by dual X-ray absorptiometry), aerobic endurance or muscle function, or immunological markers was not possible.

Conclusion

Insufficient 25(OH)D concentrations that potentially hinder health and sport performance are prevalent among athletes, especially during the sun-deprived seasons. Furthermore, those of younger age and with lower BMI, those who participate primarily in indoor sports and do not take vitamin D supplements were at a higher risk for 25(OH)D insufficiency. Vitamin D intake and sun exposure recommendations for athletes should be individually determined taking the aforementioned risk factors into account. Considering the uncertainty of compliance regarding vitamin D supplementation, further studies should evaluate whether commercial multi-vitamin supplements that normally contain 400 IU of vitamin D are sufficient to maintain desirable vitamin D levels. Further research is required to establish the range of 25(OH)D concentrations associated with optimal health and performance in athletes, whether the optimal range differs according to age, type and location of sport performed, and which supplementation doses are needed to reach these optimal 25(OH)D concentrations.

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Conflict of Interest

The authors declare that they have no conflict of interest

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