

Low Vitamin D Levels Are Associated With Increased Risk of Musculoskeletal Injuries in Collegiate Athletes

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Background: Vitamin (Vit.) D is an essential nutrient that is both synthesized by the body and supplemented via diet. Vit. D deficiency has been found to correlate with an increase in a variety of musculoskeletal injuries.

Hypothesis: Lower levels of serum Vit. D would be associated with an increased number of musculoskeletal injuries in collegiate athletes.

Study Design: Routinely collected data were reviewed for 284 student athletes at a Division I Big10 University.

Level of Evidence: Level 4.

Methods: Serum 25-hydroxyvitamin D (25[OH]D) levels were obtained on athletes via chart review and classified as normal (≥ 32 ng/ml), insufficient (20-31 ng/ml) and deficient (≤ 19 ng/ml). Vit. D was analyzed both as a continuous variable and based on the 3-level classification. The odds of injury were estimated with mixed effects logistic regression models.

Results: Results showed that 47.2% of athletes were Vit. D insufficient, with 17.6% being deficient. The odds of sustaining an injury at any point during the collection period were 13% higher for each 5 ng/ml decrease in the athlete's Vit. D level (odds ratio [OR], 1.13 (1.00-1.27); $P = 0.05$). There was no significant difference in injury time based upon Vit. D class. There was a significant negative correlation between Vit. D level and max jump height/max jump force (OR, -0.50 (-0.99, -0.02), $P = 0.04$; -0.20 (-0.37, -0.04), $P = 0.01$ respectively), which are clinically insignificant changes.

Conclusion: Many collegiate athletes had insufficient or deficient Vit. D levels. Our results showed for each 5 ng/ml decrease in an athlete's Vit. D level, there was a 13% increase in odds of injury. Finally, there was no significant association between Vit. D level and athletic performance or injury recovery length.

Clinical Relevance: Vit. D deficiency and insufficiency is highly prevalent in collegiate athletes.

Keywords: ankle; injury prevention; knee general; muscle injuries; shoulder general

Vitamin D (Vit. D) is a necessary nutrient that is synthesized by the body and supplemented via diet.⁸ The majority of the active form of Vit. D, Vit. D₃, is created by skin exposure to ultraviolet B irradiation and the minority is obtained from dietary intake (Figure 1).¹⁸ Vit. D deficiency is a global epidemic, with 41.6% of adults in the United States

meeting the criteria for deficiency.^{7,15} The highest rates in those affected are seen in people of African American descent (82.1%) followed by those of Hispanic descent (69.2%).⁷ Current evidence suggests that those with a Vit. D deficiency may be at a higher risk for myriad health complications, including poor calcium reabsorption, increased fracture risk and decreased

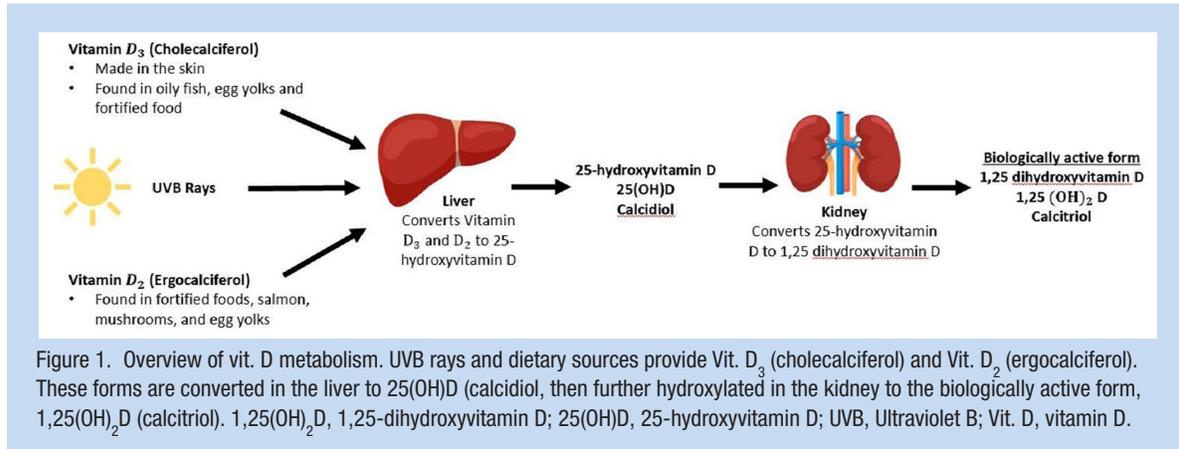
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muscular performance.⁴ Although traditionally thought of as a concern mostly for older populations, recent studies have found that a significant proportion of professional athletes have inadequate or deficient levels of Vit. D.^{6,12,17} A 2018 study on the National Football League found that 59% of the athletes studied had inadequate levels of Vit. D, with 10% of those athletes meeting criteria for Vit. D deficiency.¹⁷ This finding may prove to be significant for athletic performance, injury risk, and recovery.

Previous studies have shown a strong correlation between Vit. D levels and athletic performance. One study found that peak athletic performance occurred when Vit. D levels were at their highest.⁵ The inverse was also shown to be true, as another study found that a deficiency in Vit. D has been linked to atrophy of type II fast-twitch muscle fibers, which are crucial for physical exertion.¹⁶ Studies also show that there is a strong correlation between higher Vit. D levels and muscle protein synthesis, ATP concentration, jump height, jump power, and jump velocity.¹⁸

Recent evidence has shown that there may also be a correlation between Vit. D levels and injury susceptibility.¹ Vit. D has been shown to be helpful in reversing proximal skeletal muscle myopathy and increasing overall muscle strength and performance.^{4,5} It has also been shown to be an important factor in reducing inflammation by inhibiting pro-inflammatory cytokines, such as interleukin-6, which are increased after vigorous exercise.^{2,13,14} In National Football League players, researchers found that 50% of the players who had inadequate levels of Vit. D suffered a lower extremity muscle strain or core muscle injury, showing a possible link between inadequate Vit. D levels and increased musculoskeletal injuries.¹¹

Although current evidence suggests a correlation between musculoskeletal injuries and Vit. D inadequacy, this correlation has not yet been investigated thoroughly in the collegiate athlete population. The purpose of our study was to investigate the association of serum Vit. D levels in collegiate athletes and the risk of injuries sustained during 1 season of play. We

hypothesized that lower levels of serum Vit. D would be associated with an increased number of musculoskeletal injuries.

METHODS

This study analyzed routinely collected Vit. D testing results, measures of athletic performance, body composition, and sport-related injuries from student-athletes in the Badger Athletic Performance (BAP) database during the 2013-2014 academic year. The records review was approved by the University's Health Sciences Institutional Review Board.

Inclusion Criteria and Outcome Measures

All student-athletes whose serum 25(OH) Vit. D was obtained during their preseason physical examination or regular monitoring throughout the 2013-2014 academic year were included in the analysis. Given that our institution is located in the Midwest (Wisconsin) and there is large variation in sunlight duration depending on season, student-athletes underwent Vit. D testing multiple times throughout the 2013-2014 academic year and all test results were considered for analysis. Demographic information, athletic performance, body composition, and injury data for all student-athletes with available Vit. D levels were also extracted for analysis. Data on the demographic makeup of the athletes included is available in Table 1. Information regarding each individual athlete's personal medication history was not available. Information of athletes potential alcohol and personal supplementation use was not available. It is important to note that all student athletes at this institution were enrolled in a meal voucher program that provided a stipend to purchase nutritious foods and beverages, as well as access to "refueling stations" located in all training facilities.

Body Composition Data Collection

Body composition measures were obtained via dual-energy x-ray (Lunar iDXA, GE Healthcare). All scans were performed

Table 1. Demographics of student-athletes included in the sample by sport and ethnicity

	Total N	Male	Female
Sport			
Basketball	10	6	4
Cheer	11	3	8
Crew	1	-	1
Football	91	91	-
Golf	7	2	5
Hockey	34	14	20
Soccer	14	7	7
Softball	5	-	5
Swimming	34	15	19
Tennis	6	3	3
Track	61	24	37
Volleyball	4	-	4
Wrestling	7	7	-
Ethnicity			
White	241	135	106
African American	38	33	5
Asian	5	4	1
Hispanic	1	0	1
Total	285	172	113

by technicians trained by the International Society for Clinical Densitometry certified technologists following manufacturer recommendations. Scans were auto-analyzed by the software (enCORE Version 14.1, GE Healthcare) and adjusted manually when errors were identified.

Performance Data Collection

Performance testing occurred as part of a battery of seasonal performance assessments that took place regularly throughout the academic year. All athletes who completed performance testing were cleared for full athletic participation (e.g., were “healthy”) at the time of testing. The anterior reach direction of the Star Excursion Balance Test (SEBT) was collected using a previously described protocol.¹⁹ Briefly, while maintaining a unilateral stance and hands on hips, the athlete reached with the free limb as far as possible in the anterior direction. Reach distance was measured in centimeters and defined by the most

distal aspect of the big toe. Each athlete performed 4 practice and 3 recorded reaches (trials). This process was repeated while standing on the other limb, with the order of the starting limb randomized. Reach distances were normalized to the respective stance-limb length, measured from the anterior superior iliac spine to the inferior border of the lateral malleolus. The average normalized reach distance for each limb, respectively, was used for subsequent analysis.

Jump performance was assessed via a countermovement jump (CMJ) on the same day as SEBT testing. The CMJ was performed on a force platform with individual plates for each limb (Leonardo Mechanograph; Novotec Medical). Each athlete started from a standardized position with their feet shoulder-width apart, toes straight ahead, and hands on hips.⁹ All athletes were instructed to jump as high as possible and land back on the force plates for the trial to be considered successful. Forces were recorded (800 Hz) during a total of 3 successful trials, with

Table 2. Lowest Vit. D class for all 285 collegiate athletes across all Vit. D tests for an athlete

Vit. D level	N (%)
Normal serum Vit. D (≥ 32 ng/ml)	100 (35.2)
Vit. D insufficiency (21-31 ng/ml)	134 (47.2)
Vit. D deficiency (≤ 20 ng/ml)	50 (17.6)

Vit. D, vitamin D.

ample rest between trials to eliminate the impact of fatigue. The manufacturer's software was used to calculate the peak force (kN) and peak power (kW) for each jump before take off during each CMJ (Table 2). Jump height (cm) was also calculated using the impulse-momentum relationship.¹⁰ Total force and power, both normalized to body mass, and jump height were extracted from the jump with the greatest total power output and used for subsequent analysis.

Injury Monitoring

Injury data were also extracted from the BAP database and included all musculoskeletal injuries including the date of onset, return-to-play (if available), and the body part. Injuries used for the analysis included those occurring as a direct result of sport participation during the academic year, which were entered into the electronic medical record in real time. Other injuries that occurred outside of sport participation were not included due to inconsistent data availability for these injuries. Injuries were classified as such if they prevented the athlete from finishing practice or competition and required the athlete to be seen by an athletic trainer. For chronic injuries, the date of injury was defined as the date upon which the first mention of the injury was entered into the medical record. End of injury was defined as the date the athlete returned to play. Details on the specifics of each injury including a precise diagnosis and severity of the injury were not available. If an athlete suffered multiple injuries that met the above criteria, all were included in the study and the Vit. D level taken closest to the injury data was correlated to the injury.

Statistical Analysis

Student-athletes were classified as normal, insufficient, or deficient based on their Vit. D levels. A normal serum 25(OH) Vit. D level was defined as being ≥ 32 ng/ml, an insufficient level was defined as 25(OH) Vit. D of 21 ng/ml to 31 ng/ml and a deficient level was defined as 25(OH) Vit. D ≤ 20 ng/ml in concordance with previous studies to allow for direct comparison.^{6,17} Data were summarized via means and standard deviations, median (range), or N (%) as appropriate. Vit. D was analyzed both as a continuous variable and based on the 3-level classification of normal, insufficient, and deficient to capture

potential associations for discrete Vit. D values as well as broad classifications. The odds of any injury based on 5 unit changes in Vit. D were estimated via mixed effects logistic regression models. The odds of injury for those with insufficient or deficient Vit. D were compared with normal via mixed effects ordinal logistic regression. Linear relationships between Vit. D and performance data were estimated via mixed effects linear regression. All models used the subject as a random effect and season of the year in which Vit. D was collected as a covariate. Subanalysis of the relationship of days lost postinjury by Vit. D were analyzed by similar methods as described above, but only for those who had an injury. Only injuries that occurred within 90 days of a given Vit. D level were used in the analysis, as Vit. D levels should not change dramatically within this window.²⁰ All analyses were done in R for Statistical Computing Version 4.0. Significance was set a priori at $P \leq 0.05$.

RESULTS

A total of 285 athletes with Vit. D levels were studied, representing 13 different sports (Table 1). There were 461 Vit. D collections ranging from 1 to 4 collections per athlete with a median of 2 collections per athlete. The results of our study found that 50 athletes (17.5%) were Vit. D deficient at 1 point during the academic year, with an additional 134 athletes (47.0%) found to be insufficient (Table 2). Across all Vit. D tests, female athletes had normal values 64% of the time, while male athletes presented with normal Vit. D levels 37% of the time (Table 3).

A total of 148 injuries were observed during the study period, with football (N = 48) and track (N = 29) demonstrating the greatest number of total injuries. Athletes participating in soccer (50%), basketball (50%), cheer (45%), and football (44%) demonstrated the greatest number of injured athletes. The likelihood of an athlete sustaining an injury given his or her Vit. D level was evaluated via odds ratios (ORs) (Table 4). Statistical analysis showed that the mean Vit. D level for athletes who sustained ≥ 1 injury to be 30.8 ng/ml compared with 32.6 ng/ml for athletes who did not sustain any injury. The odds of having an injury increased by 13% for every 5 ng/ml decrease in Vit. D (Table 4). When examining the relationship between Vit. D class and incidence of injury, the results suggest athletes with insufficient Vit. D levels and deficient levels (Table 5) did not demonstrate increased odds of sustaining an injury compared with normal Vit. D athletes. This, coupled with our data when analyzing risk based upon Vit. D level and not class, seems to demonstrate that discrete cutoffs do not capture accurately the relationship between Vit. D and injury risk. Vit. D level and its relationship to the length of injury recovery time was also evaluated (Table 6) and no statistically significant associations were found ($P = 0.09$).

Finally, the association between Vit. D level and athletic performance was examined (Table 7). A significant negative linear relationship was seen between maximum jump height (cm) and Vit. D level with an expected decrease of -0.5 cm

Table 3. Vit. D classifications by sport across all included Vit. D tests for all athletes

	Male athlete Vit. D levels			Female athlete Vit. D levels		
	Normal	Insufficient	Deficient	Normal	Insufficient	Deficient
Basketball	4 (33.3%)	5 (41.7%)	3 (25.0%)	1 (14.3%)	5 (71.4%)	1 (14.3%)
Cheer	3 (60.0%)	2 (40.0%)	0 (0%)	6 (50.0%)	5 (41.7%)	1 (8.3%)
Crew	-	-	-	2 (100%)	0 (0%)	0 (0%)
Football	40 (29.6%)	63 (46.7%)	32 (23.7%)	-	-	-
Golf	2 (50.0%)	2 (50.0%)	0 (0%)	5 (62.5%)	3 (37.5%)	0 (0%)
Hockey	1 (4.2%)	15 (62.5%)	8 (33.3%)	10 (41.7%)	10 (41.7%)	4 (16.7%)
Soccer	7 (58.3%)	4 (33.3%)	1 (8.3%)	11 (78.6%)	3 (21.4%)	0 (0%)
Softball	-	-	-	5 (55.6%)	4 (44.4%)	0 (0%)
Swimming	13 (59.1%)	9 (40.9%)	0 (0%)	18 (72.0%)	7 (28.0%)	0 (0%)
Tennis	3 (60.0%)	1 (20.0%)	1 (20.0%)	2 (50.0%)	2 (50.0%)	0 (0%)
Track	23 (56.1%)	15 (36.6%)	3 (7.3%)	40 (71.4%)	12 (21.4%)	4 (7.1%)
Volleyball	-	-	-	7 (100%)	0 (0%)	0 (0%)
Wrestling	4 (33.3%)	6 (50.0%)	2 (16.7%)	-	-	-
Overall	100 (36.8%)	122 (44.9%)	50 (18.4%)	107 (63.7%)	51 (30.4%)	10 (6.0%)

Vit. D, vitamin D.

Table 4. Vit. D level and its relationship to the odds of injury

Injury status	Total Vit. D measurements (unique athletes)	Mean Vit. D level (95% CI)	OR (95% CI)	P value
No injury	303 (222)	32.6 (31.4-33.8)	Reference	0.05
Injury	148 (123)	30.8 (29.1-32.4)	1.13 (1.00-1.27)	

OR, odds ratio; Vit. D, vitamin D.

Table 5. Association between Vit. D class and the subsequent odds of sustaining an injury

Vitamin D class	Injured, %	OR (95% CI)	P value
Normal serum Vit. D (≥ 32 ng/ml)	28.3	Reference	
Vit. D insufficiency (21-31 ng/ml)	30.4	1.11 (0.68-1.81)	0.09
Vit. D deficiency (≤ 20 ng/ml)	41.7	1.82 (0.91-3.61)	0.68

OR, odds ratio; Vit. D, vitamin D.

Table 6. Vit. D level and its relationship to injury recovery length

Total days until return to play	N	OR (95% CI)	P value
0 days	26	30.4 (27.0-33.9)	0.09
<1 week	22	33.2 (29.4-37.0)	
1-4 weeks	38	27.2 (24.3-30.1)	
1-3 months	23	32.1 (28.6-35.6)	

OR, odds ratio; Vit. D, vitamin D.

(Table 7) of jump height for each 5 ng/ml decrease in Vit. D level. Similarly, there was a mean decrease in max force of -0.20 N/kg for each 5 ng/ml decrease in Vit. D (Table 5). There was no significant linear relationship between maximum power (watts/kg) and Vit. D (Table 5). Also, there was no association between right or left average reach distance and Vit. D level (Table 5).

DISCUSSION

The main findings of our study were that a majority of our collegiate athletes (64.8%) were either Vit. D deficient or insufficient. We also found that, in this collegiate athlete patient population, the odds of injury increased by 13% for every unit decrease in Vit. D. Recent studies have found that a significant proportion of the adult US population is Vit. D insufficient, and our study corroborated that finding with specific regard to collegiate athletes.

Previous studies have demonstrated that athletes who had inadequate levels of Vit. D had an increased risk of suffering a lower extremity muscle strain or core muscle injury, showing a possible link between inadequate Vit. D levels and increased musculoskeletal injuries.^{6,17} In our study, we aimed to verify this

relationship and further expand it to assess whether lower Vit. D levels were associated with an increased odds of any type of musculoskeletal injury. From our research, we found that the odds of sustaining an injury increased significantly as Vit. D levels decreased. Specifically, the odds of injury were 13% higher for each 5 ng/ml decrease in the athlete's Vit. D level (Table 3). We also evaluated whether the odds of injury varied by discrete Vit. D classes and found that the proportion of athletes who went on to sustain an injury did not vary significantly by Vit. D class alone (Table 4). This difference in results indicates a more gradual increase in injury odds over the range of Vit. D as opposed to prominent shifts in injury risk based on Vit. D milestones. This finding has large implications on the need to screen collegiate athletes for Vit. D deficiency. As reported earlier, a large proportion of athletes do suffer from Vit. D insufficiency or deficiency, suggesting that many athletes may be at an increased risk of sustaining a musculoskeletal injury; however, higher levels of evidence are necessary to further explore this relationship. Vit. D screening and supplementation is relatively inexpensive and nontoxic, meaning it could easily be incorporated into athletic departments screening and supplementation regimens for their athletes to potentially reduce their odds of injury. We believe our finding of a statistically significant relationship between Vit. D level and odds of injury has implications for all athletes across all age groups and warrants further investigation in professional athletics as well as youth sports.

With our finding of an increased odds of injury, we wanted to evaluate whether athletes' recovery time would also be connected to Vit. D level as was posited in previous literature. Our analysis found that the median days to return to play after injury did not vary significantly by Vit. D class (Table 6). However, this result was limited by a lack of data on the injury type and whether injuries were surgical or nonsurgical. In future studies, it would be helpful to track the severity of injuries and whether they required surgical management and try and correlate this to Vit. D level at the time of injury. We also believe that this statistical outcome was influenced by the fact that there was a high percentage of 0 days lost due to injury. Previous

Table 7. Vit. D level and its relationship to athletic performance

Performance measurement	Limb	Estimate (95% CI) ^a	P value
Jump height, cm	-	-0.50 (-0.99, -0.02)	0.04*
Peak total force, N/kg	-	-0.20 (-0.37, -0.04)	0.01*
Peak total power, W/kg	-	-0.33 (-0.83, 0.17)	0.18
Anterior reach distance, % limb length	Right	0.56 (-0.15, 1.26)	0.13
	Left	0.24 (-0.42, 0.90)	0.46

^aEstimate describes expected change in performance measure for a 5ng/ml increase in Vit. D. Vit. D, vitamin D.

*Significant ($P < 0.05$).

studies have shown there is a strong correlation between higher Vit. D levels and jump height, jump power, and jump velocity.¹⁸ While we observed a statistically significant difference in the maximum jump height and maximum jump force, these differences were of low magnitude (0.5 cm in jump height and 0.2 n/kg in force) and are unlikely to be clinically meaningful.

Our study had a number of limitations. First, since the data were collected as a standard of care and reviewed retrospectively, we were unable to obtain data at consistent timepoints across athletes. In addition, this study was limited by the necessity to supplement athletes found to have insufficient or deficient Vit. D levels during their season of play. For ideal outcome measurements, the athlete's Vit. D levels would not have been addressed throughout the season and allowed to follow their natural variation, but, ethically, it was essential that low Vit. D levels were addressed, once discovered, and treated with Vit. D supplementation. Before our findings, athletes were recommended routinely to use daily multivitamins; however, specific data on which athletes were compliant with supplementation and how much Vit. D was present in their chosen supplement were unavailable. In addition, many of the Vit. D tests were performed to evaluate whether supplementation was successful. In the future, it may be helpful to do an analysis where all athletes have Vit. D levels measured pre-, mid- and postseason regardless of supplementation status to help us capture a more accurate correlation between Vit. D and injury susceptibility. A study such as this would also be helpful to eliminate confounding factors such as sex/gender, athlete injury history, and athlete medical history. We were also limited by the lack of personal medical data for each athlete, and therefore were unable to exclude athletes who may have had a medical condition, or were on a medication that could affect Vit. D absorption. Given the small N for athletes in indoor-only sports, we were unable to conduct a separate analysis on the above parameters for indoor versus outdoor athletes. A future study looking at the variation between indoor and outdoor athletes and Vit. D levels is warranted.

In conclusion, we sought to further investigate the relationship between Vit. D level, musculoskeletal injuries, recovery length, and athletic performance. From our analysis, we found that a large percentage (64.8%) of collegiate athletes have insufficient or deficient levels of Vit. D. It was also found that, for each 5 ng/ml decrease in an athlete's Vit. D level, there was a 13% increased odds of injury. We were not able to support previous claims of Vit. D relating to athletic performance as we found no clinically significant association between Vit. D level and athletic performance. Finally, we did not find a statistically significant association between Vit. D level and duration of injury. Given the conclusions of our study, we recommend future research to evaluate the influence that Vit. D supplementation will have on injuries in collegiate athletes.

CLINICAL RELEVANCE

Vit. D deficiency and insufficiency is highly prevalent in collegiate athletes. Given the association between Vit. D levels and subsequent injury, it is reasonable for sports medicine physicians to screen their athletes for insufficiency or deficiency and consider supplementation when indicated, along with careful consideration of other athlete specific factors that may predispose injury.

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