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Vitamin D Practice Patterns in National Collegiate Athletic Association Division I Collegiate Athletics Programs

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Context: Vitamin D status has been associated with performance, health, and well-being in athletic populations. The measurement of vitamin D status via 25-hydroxyvitamin D [25(OH)D] testing has increased in the general population, as has vitamin D supplement use. It is unclear if similar patterns exist in collegiate athletics programs.

Objective: To describe the clinical care related to the prevention, evaluation, and treatment of vitamin D deficiency and insufficiency used by sports medicine providers with National Collegiate Athletic Association (NCAA) Division I programs.

Design: Cross-sectional study.

Setting: Population-based online survey.

Patients or Other Participants: All NCAA Division I head athletic trainers.

Main Outcome Measure(s): Information related to 25(OH)D testing, vitamin D supplementation, vitamin D–related protocols and procedures, and characteristics of athletic programs and participants.

Results: We received 249 responses (72% response rate). Use of 25(OH)D testing was described by 68% of participants, with the most common indicators being health status/history (78%) and injury status/history (74%). One-fifth of participants stated that vitamin D testing was conducted as screening (without a specific cause or indication). Target blood vitamin D concentrations were highly variable. A range of 8 to 1660 annual vitamin D blood tests was reported at a cost of <$50 (8%), $51 to $100 (51%), $101 to $150 (20%), and >$150 (10%). Forty-two percent of programs covered the cost of vitamin D supplements. More than half of the participants indicated that vitamin D blood testing and supplements were not a good use of program funds. In comparison with Football Championship Subdivision programs, Football Bowl Subdivision programs were more likely to conduct vitamin D testing and pay for vitamin D supplements, and their providers were more likely to believe that testing and supplements were a good use of program funds.

Conclusions: A great deal of variability was present in vitamin D–related clinical practices among NCAA Division I athletics programs, which reflects existing contradictions and uncertainty in research, recommendations, and guidelines. Knowledge of current practice patterns is important in evaluating and establishing best practices, policies, and procedures for sports medicine and sports nutrition professionals in the collegiate setting.

Key Words: 25-hydroxyvitamin D, supplement, sports nutrition

Key Points

- More than two thirds of National Collegiate Athletic Association Division I athletics programs conducted 25-hydroxyvitamin D [25(OH)D] testing and 42% purchased vitamin D supplements.
- Many aspects of clinical practice related to prevention, evaluation, and treatment of low vitamin D were highly variable among programs, including the 25(OH)D concentration considered adequate.
- More than half of head athletic trainers did not view 25(OH)D testing and vitamin D supplements as good uses of athletics program funds.

Vitamin D is a hormone primarily obtained by cutaneous synthesis upon exposure to sunlight and other sources of ultraviolet B (UVB) light. Some foods and dietary supplements also provide vitamin D. Vitamin D deficiency and insufficiency, or low vitamin D (LVD), are prevalent among athletes.[1] For example, 20% to 85% of National Collegiate Athletic Association (NCAA) athletes have LVD.[2–4]

Symptoms of LVD may include bone and muscle pain, weakness, and fatigue.[5] Evidence also suggests that LVD affects athletes' performance, health, and well-being. Observational studies[3,4,6–13] indicated that muscle function; exercise recovery and adaptation; and occurrence of stress fracture, soft tissue injury, and illness are higher in athletes with LVD. However, investigations to evaluate the effects of vitamin D supplementation on these measures have been limited in number and complicated by contradictory results.[6,14–23]

Presently, minimal consensus exists regarding the prevention, evaluation, and treatment of LVD for the general population[24] or athletes.[25] One example is the very definition of LVD. The Endocrine Society defined vitamin

D deficiency as a serum 25-hydroxyvitamin D [25(OH)D] <20 ng/mL and insufficiency as 25(OH)D of 20 to 30 ng/mL.[26] In contrast, the National Academy of Medicine (formerly known as the Institute of Medicine) described a 25(OH)D of 12 to 20 ng/mL as meeting the needs of 97.5% of adults in the United States.[27] Recommendations for optimal 25(OH)D for athletes vary broadly, but targets as high as 40 to 100 ng/mL exist.[28]

In light of the high prevalence of LVD and the potential health and performance consequences of LVD, vitamin D has become a popular topic for athletic populations. Anecdotal evidence of substantial increases in 25(OH)D screening (testing without specific cause or indication) and testing in the collegiate athletics setting, similar to those observed in the general population,[24] exist. Use of vitamin D supplements for prevention and treatment of LVD has increased in the athletic setting as well.[29] Knowledge of existing clinical practice patterns in the collegiate athletics setting is important for evaluating and establishing programmatic best practices, policies, and procedures for sports medicine providers. The purpose of our study was to describe the clinical care provided by NCAA Division I sports medicine providers related to the evaluation, prevention, and treatment of LVD.

METHODS

Participants and Study Design

In spring 2018, head athletic trainers (ATs) from the 347 athletics programs that sponsor NCAA Division I intercollegiate sports were invited via e-mail to participate in an online survey about vitamin D–related clinical care within their athletics programs. Head ATs were selected because they are well situated to respond to questions about the health and welfare of student-athletes. If a program did not have an individual with the title of "head athletic trainer," the director of sports medicine, athletic director for sports medicine, or director of sports health was invited to participate. When more than 1 individual had the same title, a group e-mail invitation was sent to each person possessing the title, with a request for only 1 response per program. Invited participants will be referred to as *head ATs* throughout this article. In all, e-mail invitations were sent to 361 head ATs. This study was reviewed by the Institutional Review Board of Virginia Tech and considered exempt (IRB No. 17-1239).

Survey Development

The survey contained 20 questions (6 of these were 2-part questions) in the following domain areas:

1. Protocol for the evaluation, prevention, and treatment of LVD
2. Serum 25(OH)D tests: procedures
3. Serum 25(OH)D tests: indicators
4. Serum 25(OH)D tests: results
5. Serum 25(OH)D tests: costs
6. Vitamin D supplements
7. Characteristics of the athletics program
8. Demographic characteristics of the participant

A survey-development team of 1 AT and 2 registered dietitians with >12 years of experience in NCAA Division I athletics programs developed the survey that contained multiple-choice and open-ended questions (Table 1). Questions were either based on those used in previous studies or were created by the survey-development team. A complete copy of the survey may be obtained by contacting the corresponding author (M.R.).

Table 1. Synopsis of Vitamin D Practice Patterns Survey Questions

- Whether the athletics program had a policy or procedures dedicated to vitamin D testing (ie, serum 25(OH)D testing) and treatment
- Whether vitamin D tests (ie, serum 25(OH)D) were conducted on any student-athletes
- Which student-athletes had vitamin D tests (ie, serum 25(OH)D)
- Indications for vitamin D tests (ie, serum 25(OH)D)
- Whether follow-up vitamin D tests (ie, serum 25(OH)D) were conducted if abnormal results were obtained on an initial test
- Target vitamin D (ie, serum 25(OH)D) concentration
- Individuals responsible for ordering vitamin D tests (ie, serum 25(OH)D)
- Cost of each vitamin D test (ie, serum 25(OH)D)
- Whether the athletics program covered the cost of vitamin D supplements
- Participants' opinions about the appropriateness of the program's target vitamin D (ie, serum 25(OH)D) concentration and the value of vitamin D tests (ie, serum 25(OH)D)

Abbreviation: 25(OH)D, 25-hydroxyvitamin D.

Questions were transferred into the Qualtrics online survey tool (version XM; Provo, UT). A group of 27 ATs working in NCAA Division I athletics programs pilot tested the survey in an online format. Modifications to survey questions were made based on the pilot-study feedback. For example, none of the 27 pilot participants were able to provide details about the vitamin D supplements (dose, form, frequency, and duration of treatment) prescribed to athletes in their programs. Thus, we asked more general questions about vitamin D supplements and allowed free-response space for provision of more details. Pilot participants also commented that the survey was too long and that some questions felt intrusive. Ten pilot participants stated that they would be unlikely to respond to the survey as written because they felt their institution could be identified through the data requested. Therefore, we eliminated or modified questions and details not considered essential for the primary objective. The survey-development team tested and provided feedback on the revised survey.

A brief statement of the study purpose was sent to head ATs along with a link to the online survey. Participants were given 6 weeks to complete the survey. Reminder e-mails were sent to head ATs who had not responded by weeks 4 and 5. Survey responses were considered complete if at least 50% of the questions were answered.

Data Analysis

Data were downloaded from Qualtrics into a single spreadsheet and imported into PRISM (version 8; GraphPad, San Francisco, CA) for statistical analysis. Descriptive statistics (frequency, percentage, and mean ± standard deviation, if applicable) were conducted on survey responses. One-way analysis of variance (ANOVA) was used to assess differences in responses based on program and participant characteristics. Chi-square tests were used for categorical responses. Significance was set at $P < .05$.

Table 2. Characteristics of Athletics Programs Represented by Participants

Characteristic	No. of Responses (%)[a]
No. of sports sponsored by the athletics program, mean (range)	24.8 (13–28)
Sport considered the highest revenue generator by the participant[b]	Football: 165 (69) Men's basketball: 53 (22)
Athletics program sponsors football?	Yes: 179 (72) No: 69 (28)
Football subdivision (if applicable)	Football Bowl Subdivision: 115 (64)[c] Football Championship Subdivision: 64 (36)
Athletics program employs a full-time registered dietitian or nutritionist?	Yes: 107 (43) No: 139 (56) Unsure: 2 (1)

[a] Except where otherwise indicated.
[b] Also mentioned by 1 to 3 participants: baseball, women's basketball, men's ice hockey, men's lacrosse.
[c] National Collegiate Athletic Association Division I football programs are classified into 2 subdivisions: Football Bowl Subdivision (which was called Division I-A until 2006) and Football Championship Subdivision (formerly I-AA).

RESULTS

Survey responses were received from 249 head ATs, which reflected a 72% response rate. Participants were 65% male, 82% were >45 years old, and 77% had >16 years of experience as an AT. Characteristics of the athletics programs represented are shown in Table 2. One response was omitted because <50% of questions were answered.

Vitamin D Protocol or Policy

Fifty participants (20%) indicated that their athletics program had a formal protocol or policy related to the evaluation, prevention, or treatment (or a combination of these) of LVD, while 198 (80%) participants indicated that their program did not or they were unsure. No participants supplied details about their vitamin D protocol or policy in the space provided.

Serum 25(OH)D Testing

In response to the question about whether 25(OH)D tests were conducted on any student-athletes in their athletics program, 169 (68%) participants responded *yes*, 70 (29%) *no*, and 8 (3%) *unsure*. About one quarter of participants (59 [24%]) indicated that student-athletes from *all sports* underwent serum 25(OH)D testing and 37 (15%) indicated that student-athletes from *all female sports* did. Other sports mentioned specifically by more than 10% of participants were men's basketball, women's basketball, women's cross-country, women's gymnastics, football, men's track and field, and women's track and field. Team physicians (163 [66%]) were most likely to order 25(OH)D tests, followed by ATs (47 [19%]), registered dietitians or nutritionists (25 [10%]), and student health personnel (12 [5%]).

The majority of participants responded that the athlete's general health status or health history (193 [78%]) or injury status or injury history (183 [74%]) were indicators for vitamin D blood tests. Vitamin D blood screening (ie, testing student-athletes without specific cause or indication) was reported by 49 (20%) respondents, while 22 (9%) responded that 25(OH)D tests were conducted based on previous 25(OH)D test results. In a separate question, 85 (35%) respondents indicated that student-athletes who had a diagnosis of LVD were likely to be followed up or retested in the future, while 146 (59%) indicated that no follow-up or repeat 25(OH)D tests would be likely to occur in student-athletes who had an LVD diagnosis (6% were unsure).

Target or goal 25(OH)D concentrations reported by participants are shown in Table 3. When asked their opinion about the appropriateness of their athletics program's target blood vitamin D concentrations, 74 (30%) thought the target was appropriate, 57 (23%) thought it should be lower, 22 (9%) thought it should be higher, and 94 (38%) were unsure.

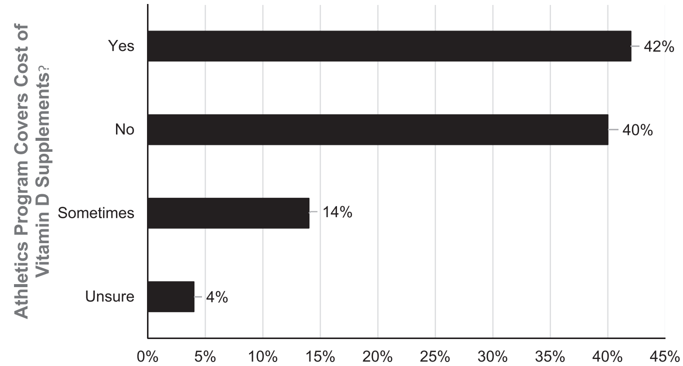

Figure 1. Athletics programs that cover the cost of vitamin D supplements.

Vitamin D Supplements

Responses related to whether the athletics program was responsible for the cost of vitamin D supplements are given in Figure 1. No correlation existed between whether an athletics program covered the cost of vitamin D supplements and whether vitamin D supplements were rated as a good use of athletics program funds. In response to the final survey question, which asked respondents to indicate "If there is any additional information you would like to share about clinical practice related to vitamin D within your athletics program," 43 (17%) of participants described blanket or routine vitamin D supplementation patterns in their athletics program. Participants' statements included the following:

- "We used to get a vitamin D test on every athlete at physicals, but it seems like they were all coming back low, so now we just give out vitamin D supplements after practice."
- "For all of our teams that are primarily indoors for training, we provide vitamin D [supplements] prophylactically."

Costs Related to 25(OH)D Testing and Vitamin D Supplements

Participants who reported 25(OH)D testing in their athletics programs noted that an average of 58.6 tests per year (range = 8–1660) were ordered. The costs to athletics programs per 25(OH)D test are shown in Figure 2. An estimated total cost of 25(OH)D tests was calculated by multiplying number of annual tests by the mid-range of the

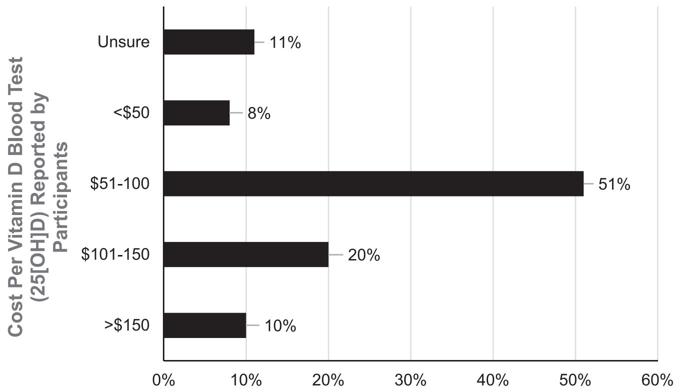

Figure 2. Cost per vitamin D blood test [25(OH)D] reported by participants.

costs summarized in Figure 2. According to this calculation, an average of $7250 was spent on 25(OH)D testing (range = $600 to $160 000). The cost of 25(OH)D tests and the number of tests ordered were not correlated. Of the participants, 143 (58%) stated that vitamin D blood testing and vitamin D supplements were not a good use of athletics program funds, while 77 (31%) responded that they were a good use of funds, 22 (9%) said they were sometimes a good use of funds, and 5 (2%) were unsure. No correlation existed between participants' perceptions of the use of athletics programs' funds and the likelihood of the program's conducting 25(OH)D testing or funding vitamin D supplements.

Athletics programs that employed a registered dietitian or nutritionist were more likely to have a vitamin D protocol in place ($P < .05$). The 115 respondents who reported that their athletics program was part of the Football Bowl Subdivision were more likely to conduct vitamin D testing, pay for vitamin D supplements, and believe that vitamin D testing and supplements were a good use of athletics program funds compared with programs that were part of the Football Championship Subdivision (all P values $< .05$). No other differences between responses based on characteristics of the athletics programs or head ATs were identified.

DISCUSSION

The purpose of our study was to describe clinical care related to the evaluation, prevention, and treatment of LVD by NCAA Division I collegiate athletics programs. The strong response rate from experienced ATs at diverse athletics programs led us to believe the responses were representative of NCAA Division I athletics programs throughout the United States. More than two-thirds of NCAA Division I athletics programs evaluated vitamin D status (via 25(OH)D testing). More than half of programs sometimes or always paid for vitamin D supplements for student-athletes. To our knowledge, this is the first study to describe vitamin D–related clinical care in the collegiate athletics setting.

Three primary reasons were given for ordering a blood test for a nutritional metabolite such as 25(OH)D: to evaluate deficiency, assess toxicity, or monitor treatment.[30] Screening for vitamin D deficiency and toxicity is typically not recommended in the general, healthy population due to insufficient evidence of its benefits and harms.[26,27,31] Some clinical practice guidelines[26,32] recommended testing 25(OH)D to monitor the response 8 to 12 weeks after initiating treatment. Different standards and specifications for biomarker testing in athletes are common, considering the desire to detect even minor physiological concerns or changes that may affect performance, recovery, and the risk of injury or illness.[33]

Table 3. Athletic Programs' Target Serum 25(OH)D Concentrations

Target or Goal Serum 25(OH)D, ng/mL	No. of Responses (%)
<20	0 (0)
20–30	7 (3)
30-40	15 (6)
40–50	67 (27)
>50	32 (13)
Unsure	126 (51)

Abbreviation: 25(OH)D, 25-hydroxyvitamin D.

In the absence of consistent athlete-specific 25(OH)D testing guidelines, observing the practices that have evolved in the athletic community can help us to evaluate current practices and move toward deliberate, evidence-informed care. One-fifth of NCAA Division I collegiate athletics programs reported 25(OH)D screening for all athletes without a particular cause. Future research or internal analyses should examine the utility and value of this testing. We found that fewer than half of the participants reported follow-up testing in athletes who were diagnosed with LVD based on a 25(OH)D test. To evaluate an athlete's response to treatment, determine the effectiveness of the treatment form or dose, and limit the risk of vitamin D toxicity, monitoring 25(OH)D throughout treatment is recommended, particularly once an athlete has received a diagnosis of LVD.[28]

The consequences of laboratory test overuse have been well documented in the general population.[34] Specifically, nonindicated laboratory testing has been associated with minimal patient benefit and increased harm.[35] As described, indicators for and expectations related to laboratory testing among some athletic populations differed from those of the general population. The American College of Sports Medicine and Academy of Nutrition and Dietetics joint position statement on nutrition and performance[36] advised that "athletes with a history of stress fracture, bone or joint injury, signs of overtraining, muscle pain or weakness, and a lifestyle involving low exposure to UVB" may require 25(OH)D assessment. Athletics programs may benefit from the development of strategic 25(OH)D testing and follow-up testing guidelines and protocols, particularly when budgetary resources are limited.

Few participants (20%) reported that their athletics program had a vitamin D–specific protocol in effect. A complicating factor in establishing vitamin D policies and procedures is disagreement over many aspects related to evaluating, preventing, and treating LVD. Conflicting recommendations for target 25(OH)D concentrations exist,[24] as evidenced by the large variability in target 25(OH)D concentrations reported among athletics programs in this study (Figure 1). It should be noted that many factors are known to influence 25(OH)D. For example, nonwhite individuals typically have lower 25(OH)D concentrations compared with individuals who have lighter skin pigmentation.[37] Although this may be explained in part by decreased endogenous synthesis when exposed to UVB rays based on differences in skin pigmentation, genetic variation likely also plays a role.[38] In addition, 25(OH)D concentrations may be lower in athletes with more body fat, illness, infection, or recent muscle damage.[39,40] Finally, variation within and between laboratories and assays that measure 25(OH)D is well documented,[41,42] so evaluating and comparing results is difficult. Variable guidelines for target dietary vitamin D intake and treatment strategies for LVD exist as well.[32] Furthermore, dosing strategies vary broadly in the form of vitamin D (D_2 versus D_3), mode of delivery (eg, tablet or capsule, spray, intramuscular injection), frequency of dosing (eg, daily, weekly, monthly), and amount of vitamin D (from 400 IU to 150 000 IU is available).[32] Although evidence suggested that vitamin D_3 was preferable to vitamin D_2 and daily or weekly dosing was preferable to larger monthly doses, an optimal dosing strategy has not been described.[43–45] In our study, athletics programs that employed a registered dietitian or nutritionist were more likely to have an established vitamin D protocol. Designating a specific member of the sports medicine staff to manage such a protocol and navigate the emerging and variable evidence may be valuable.

An alternative to 25(OH)D testing is blanket or routine supplementation (ie, providing vitamin D supplements broadly to athletes without individualization or knowledge of their 25(OH)D concentrations). This method has become more common among athletic populations, as noted by more than 15% of participants in this study. The ingestion of 1000 to 2000 IU of vitamin D_3 daily has been recommended for preventing LVD or maintaining the 25(OH)D concentration during the autumn and winter months, when UVB synthesis is low or nonexistent.[46] However, a limitation of this strategy is that individual factors influencing the 25(OH)D concentration are not considered and the choice of supplementation may be too low or excessive. Vitamin D toxicity is uncommon, but symptoms can include nausea and vomiting, other gastrointestinal symptoms, bone loss, and kidney stones.[26]

Based on our data, the option to conduct 25(OH)D testing may depend on the budget, as evidenced by Football Bowl Subdivision programs having a higher rate of 25(OH)D testing than Football Championship Subdivision programs. Interestingly, more than half of the participants responded that 25(OH)D testing and vitamin D supplements were not a good use of athletics program funds. It is impossible to determine the factors contributing to this response, yet continued education about the potential consequences of LVD on athletes' health and performance may be beneficial to ATs and other sports medicine providers.

Strengths of this study were the excellent response rate (72%), with nearly 250 head ATs from NCAA Division I collegiate athletics programs offering insight into their clinical practices related to vitamin D. Limitations of this study include not obtaining information about participants' geographic locations or the total number of student-athletes in each athletics program. Future research to learn more about specific vitamin D supplementation protocols used in athletics programs, in addition to the outcomes of 25(OH)D testing, is needed. Furthermore, clinical trials investigating the effects of vitamin D supplementation on athletic performance, health, and wellbeing would be beneficial in establishing best practices for sports medicine providers working with collegiate athletes.

CONCLUSIONS

Overall, vitamin D is an accessible, low-risk, and fairly low-cost intervention with the potential to improve performance and health in athletes. Emerging research, controversial guidelines, and a paucity of athlete-specific recommendations are reflected in the large variability of vitamin D–related clinical care demonstrated by NCAA Division I athletics programs. With 68% of athletics programs regularly testing 25(OH)D concentrations and 42% covering the costs of vitamin D supplements, developing policies and procedures informed by the best evidence available is important. Knowledge of clinical practice patterns in the collegiate setting is critical for evaluating and establishing best practices, policies, and procedures for sports medicine and sports nutrition professionals.

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REFERENCES

1. Farrokhyar F, Tabasinejad R, Dao D, et al. Prevalence of vitamin D inadequacy in athletes: a systematic-review and meta-analysis. *Sports Med*. 2015;45(3):365–378.
2. Villacis D, Yi A, Jahn R, et al. Prevalence of abnormal vitamin D levels among Division I NCAA athletes. *Sports Health*. 2014;6(4):340–347.
3. Hildebrand RA, Miller B, Warren A, Hildebrand D, Smith BJ. Compromised vitamin D status negatively affects muscular strength and power of collegiate athletes. *Int J Sport Nutr Exerc Metab*. 2016;26(6):558–564.
4. Halliday TM, Peterson NJ, Thomas JJ, Kleppinger K, Hollis BW, Larson-Meyer DE. Vitamin D status relative to diet, lifestyle, injury, and illness in college athletes. *Med Sci Sports Exerc*. 2011;43(2):335–343.
5. Holick MF. Vitamin D deficiency. *N Engl J Med*. 2007;357(3):266–281.
6. Carswell AT, Oliver SJ, Wentz LM, et al. Influence of vitamin D supplementation by sunlight or oral D3 on exercise performance. *Med Sci Sports Exerc*. 2018;50(12):2555–2564.
7. Geiker NRW, Hansen M, Jakobsen J, et al. Vitamin D status and muscle function among adolescent and young swimmers. *Int J Sport Nutr Exerc Metab*. 2017;27(5):399–407.
8. Home page. Choosing Wisely Web site. http://www.choosingwisely.org/. Accessed June 6, 2019.
9. Hamilton B, Whiteley R, Farooq A, Chalabi H. Vitamin D concentration in 342 professional football players and association with lower limb isokinetic function. *J Sci Med Sport*. 2014;17(1):139–143.
10. Koundourakis NE, Androulakis NE, Malliaraki N, Margioris AN. Vitamin D and exercise performance in professional soccer players. *PLoS One*. 2014;9(7):e101659.
11. Barker T, Henriksen VT, Martins TB, et al. Higher serum 25-hydroxyvitamin D concentrations associate with a faster recovery of skeletal muscle strength after muscular injury. *Nutrients*. 2013;5(4):1253–1275.
12. Rebolledo BJ, Bernard JA, Werner BC, et al. The association of vitamin D status in lower extremity muscle strains and core muscle

injuries at the National Football League Combine. *Arthroscopy*. 2018;34(4):1280–1285.
13. Ruohola JP, Laaksi I, Ylikomi T, et al. Association between serum 25(OH)D concentrations and bone stress fractures in Finnish young men. *J Bone Miner Res*. 2006;21(9):1483–1488.
14. Close GL, Leckey J, Patterson M, et al. The effects of vitamin D(3) supplementation on serum total 25[OH]D concentration and physical performance: a randomised dose-response study. *Br J Sports Med*. 2013;47(11):692–696.
15. Close GL, Russell J, Cobley JN, et al. Assessment of vitamin D concentration in non-supplemented professional athletes and healthy adults during the winter months in the UK: implications for skeletal muscle function. *J Sports Sci*. 2013;31(4):344–353.
16. Wyon MA, Wolman R, Nevill AM, et al. Acute effects of vitamin D3 supplementation on muscle strength in judoka athletes: a randomized placebo-controlled, double-blind trial. *Clin J Sport Med*. 2016;26(4):279–284.
17. Wyon MA, Koutedakis Y, Wolman R, Nevill AM, Allen N. The influence of winter vitamin D supplementation on muscle function and injury occurrence in elite ballet dancers: a controlled study. *J Sci Med Sport*. 2014;17(1):8–12.
18. Jung HC, Seo MW, Lee S, Jung SW, Song JK. Correcting vitamin D insufficiency improves some, but not all aspects of physical performance during winter training in taekwondo athletes. *Int J Sport Nutr Exerc Metab*. 2018;28(6):635–643.
19. Owens DJ, Sharples AP, Polydorou I, et al. A systems-based investigation into vitamin D and skeletal muscle repair, regeneration, and hypertrophy. *Am J Physiol Endocrinol Metab*. 2015;309(12):E1019–1031.
20. Mielgo-Ayuso J, Calleja-Gonzalez J, Urdampilleta A, et al. Effects of vitamin D supplementation on haematological values and muscle recovery in elite male traditional rowers. *Nutrients*. 2018;10(12). doi: 10.3390/nu10121968.
21. Lappe J, Cullen D, Haynatzki G, Recker R, Ahlf R, Thompson K. Calcium and vitamin d supplementation decreases incidence of stress fractures in female navy recruits. *J Bone Miner Res*. 2008;23(5):741–749.
22. Lewis RM, Redzic M, Thomas DT. The effects of season-long vitamin D supplementation on collegiate swimmers and divers. *Int J Sport Nutr Exerc Metab*. 2013;23(5):431–440.
23. He CS, Fraser WD, Tang J, et al. The effect of 14 weeks of vitamin D3 supplementation on antimicrobial peptides and proteins in athletes. *J Sports Sci*. 2016;34(1):67–74.
24. Rockwell M, Kraak V, Hulver M, Epling J. Clinical management of low vitamin D: a scoping review of physicians' practices. *Nutrients*. 2018;10(4):493.
25. Larson-Meyer DE. The importance of vitamin D for athletes. Gatorade Sports Science Institute Web site. https://www.gssiweb.org/sports-science-exchange/article/sse-148-the-importance-of-vitamin-d-for-athletes. Accessed June 6, 2019.
26. 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):1911–1930.
27. Ross AC, Manson JE, Abrams SA, et al. The 2011 report on dietary reference intakes for calcium and vitamin D from the Institute of Medicine: what clinicians need to know. *J Clin Endocrinol Metab*. 2011;96(1):53–58.
28. Larson-Meyer DE, Woolf K, Burke L. Assessment of nutrient status in athletes and the need for supplementation. *Int J Sport Nutr Exerc Metab*. 2018;28(2):139–158.
29. Owens DJ, Allison R, Close GL. Vitamin D and the athlete: current perspectives and new challenges. *Sports Med*. 2018;48(suppl 1):3–16.
30. Clinical utility of vitamin D testing: an evidence-based analysis. *Ont Health Technol Assess Ser*. 2010;10(2):1–93.
31. LeFevre ML; US Preventive Services Task Force. Screening for vitamin D deficiency in adults: U.S. Preventive Services Task Force recommendation statement. *Ann Intern Med*. 2015;162(2):133–140.
32. Pludowski P, Karczmarewicz E, Bayer M, et al. Practical guidelines for the supplementation of vitamin D and the treatment of deficits in Central Europe: recommended vitamin D intakes in the general population and groups at risk of vitamin D deficiency. *Endokrynol Pol*. 2013;64(4):319–327.
33. Lee EC, Fragala MS, Kavouras SA, Queen RM, Pryor JL, Casa DJ. Biomarkers in sports and exercise: tracking health, performance, and recovery in athletes. *J Strength Cond Res*. 2017;31(10):2920–2937.
34. Zhi M, Ding EL, Theisen-Toupal J, Whelan J, Arnaout R. The landscape of inappropriate laboratory testing: a 15-year meta-analysis. *PLoS One*. 2013;8(11):e78962.
35. Mafi JN, Parchman M. Low-value care: an intractable global problem with no quick fix. *BMJ Qual Saf*. 2018;27(5):333–336.
36. Thomas DT, Erdman KA, Burke LM. American College of Sports Medicine joint position statement. nutrition and athletic performance. *Med Sci Sports Exerc*. 2016;48(3):543–568.
37. Cannell JJ, Hollis BW, Zasloff M, Heaney RP. Diagnosis and treatment of vitamin D deficiency. *Exp Opin Pharmacother*. 2008;9(1):107–118.
38. Brown LL, Cohen B, Tabor D, Zappalà G, Maruvada P, Coates PM. The vitamin D paradox in Black Americans: a systems-based approach to investigating clinical practice, research, and public health. Expert panel meeting report. *BMC Proc*. 2018;12(suppl 6):6.
39. Waldron JL, Ashby HL, Cornes MP, et al. Vitamin D: a negative acute phase reactant. *J Clin Pathol*. 2013;66(7):620–622.
40. Heller JE, Thomas JJ, Hollis BW, Larson-Meyer DE. Relation between vitamin D status and body composition in collegiate athletes. *Int J Sport Nutr Exerc Metab*. 2015;25(2):128–135.
41. Lai JK, Lucas RM, Banks E, Ponsonby AL; Ausimmune Investigator Group. Variability in vitamin D assays impairs clinical assessment of vitamin D status. *Int Med J*. 2012;42(1):43–50.
42. Major JM, Graubard BI, Dodd KW, et al. Variability and reproducibility of circulating vitamin D in a nationwide U.S. population. *J Clinl Endocrinol Metab*. 2013;98(1):97–104.
43. Hirche F, Stangl GI, Lehmann U, Hinz K, Westphal S, Dierkes J. Bioavailability of vitamin D(2) and D(3) in healthy volunteers, a randomized placebo-controlled trial. *J Clin Endocrinol Metab*. 2013;98(11):4339–4345.
44. Tripkovic L, Lambert H, Hart K, et al. Comparison of vitamin D2 and vitamin D3 supplementation in raising serum 25-hydroxyvitamin D status: a systematic review and meta-analysis. *Am J Clin Nutr*. 2012;95(6):1357–1364.
45. Shieh A, Chun RF, Ma C, et al. Effects of high-dose vitamin D2 versus D3 on total and free 25-hydroxyvitamin d and markers of calcium balance. *J Clin Endocrinol Metab*. 2016;101(8):3070–3078.
46. Maughan RJ, Burke LM, Dvorak J, et al. IOC consensus statement: dietary supplements and the high-performance athlete. *Br J Sports Med*. 2018;52(7):439–455.

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