ORIGINAL

Effects of vitamin D on muscle mass and function in high school athletes

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Abstract:Nutrition and exercise have effects on the body. The aim of the present study was to assess vitamin D status (serum 25-hydroxyvitamin D [25(OH)D] levels) and investigate its associations with muscle mass and function, as well as the effects of vitamin D supplementation on muscle function in high school athletes. Twenty-one high-school athlete students (6 males and 15 females) participated in this study. The serum 25(OH)D levels of 15 athletes (71.4%) with vitamin D insufficiency (VDI)/vitamin D deficiency (VDD) were and those of six athletes (28.6%) with vitamin D sufficiency (VDS) were 24.2 (22.3–27.0) ng/mL and 35.8 (33.0–38.9) ng/mL, respectively. Serum 25(OH)D concentration was significantly associated with total power in the male, female, and total athlete groups. Daily 1,000 IU vitamin D supplementation for 6 months increased serum vitamin D levels from 27.0 (22.9–32.1) ng/mL to 37.9 (28.9–40.9) ng/mL and improved muscle function in the total athlete group. Our findings suggest that daily 1,000 IU vitamin D supplementation should be recommended to optimize maximal aerobic power in high school athletes. J. Med. Invest. 72 : 167-171, February, 2025

Keywords **:** *Vitamin D status, Muscle function, High school athlete*

INTRODUCTION

Optimal dietary intake and nutritional knowledge are key factors in improving the health and performance of athletes. Nutrition and exercise affect nearly every system in the body, and a holistic approach is essential for advancing scientific understanding (1). It is important to understand these interactions to optimize exercise performance and health promotion initiatives in athletes.

Vitamin D is an integral part of skeletal muscle physiology (2), because large numbers of vitamin D receptors are expressed in muscles (3). Vitamin D affects the transport of phosphate and calcium across muscle cell membranes, modulates phospholipid metabolism, and induces the expression of several myogenic transcription factors and myotubular sizes, which together affect contractile filaments (4-6).

In humans, vitamin D sufficiency (VDS), insufficiency (VDI), and deficiency (VDD) are classified based on serum 25-hydroxyvitamin D (25[OH]D) levels of > 30 ng/mL, 21–30 ng/mL, and < 20 ng/mL, respectively (1). The prevalence of VDI and VDD is high in Japan, affecting 50–70% of individuals across all age groups (7, 8). Vitamin D level potentially influences physical fitness;thus, VDD may impact performance, which has important ramifications for athletes. Previous studies reported that VDD results in impaired muscle action, leading to sarcopenia and decreased muscle strength (9-13). However, few studies have examined this phenomenon among youth athletes in Japan. The aim of our cross-sectional and interventional study of vitamin D was to evaluate the associations of 25(OH)D levels with muscle mass and function and to investigate the effects of daily 1,000 IU vitamin D supplementation for 6 months on skeletal muscle physical function in high school athlete students.

MATERIALS AND METHODS

Subjects

Twenty-one high-school athlete students (6 males and 15 females) participated in this study. The subjects included students that stayed at home and in the school dormitory. Athlete students trained at their self-selected pace. Most trained at a light to moderate intensity for 90–120 min, 5 days a week. The variables examined included anthropometric measurements (body mass and height), daily energy intake, water intake and output, vitamin D status (serum 25[OH]D levels), and performance on motor performance tests. Blood samples were collected from subjects following an overnight fast of more than 8 hours. The samples were immediately refrigerated, transported in cold storage to the SRL Laboratory in Tokyo, and analyzed within 24 hours. Serum 25(OH)D levels, as an indicator of vitamin D status, were measured by electrochemiluminescent immunoassay, as previously reported (14, 15). Players were divided into VDS and VDD/VDI groups according to 25(OH)D levels.

Nutritional analysis

Daily energy intake and water intake were calculated from food and water intake records over two consecutive days. In the water balance calculation, total water intake was compared to total water loss (the sum of non-renal water loss [NRWL] and 24 h urine volume). Each subject provided two 24 h urine samples at inclusion on two consecutive days. NRWL was determined by the following equation:NRWL (ml/day) = total water intake (ml/day) - 24 h urine volume (ml/day). Body composition parameters, such as appendicular skeletal muscle mass (ASMM), fat mass (FM), and water, were measured using direct segmental multi-frequency bioelectrical impedance analysis (BIA) (TANITA MC-780A, Tokyo, Japan). BIA measures body conductivity

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or resistance to a small electrical current through the body or across a limb. Resistance is strongly related to total body water content (BIA-water) and is used to assess BIA-ASMM and BIA-FM. BIA requires measurements under standardized conditions, including hydration status, recent food and beverage intake, skin temperature, and recent physical activity.

Motor performance tests

The Wingate anaerobic power test (WAPT) was used to estimate anaerobic capacity. As warm-up protocol, participants were instructed to cycle for 2–4 min at a resistance of 0.5 kilopond (kp), maintaining 60 RPM. Then, participants performed maximal cycling against a pre-determined resistance (0.075 kp/body weight) for 40 seconds on a cycle ergometer. Peak power and mean power were calculated using the following equation:{Power output (kpm × min−1) = (revs × resistance [kg] × distance [m] × 60 [sec])/time (sec), Watts = kpm × min−1/6.123, Watts/kg = Watts/body weight (kg)} (16). WAPT, maximal cycling, peak power, and mean power were assessed using Aerobike Powermax V3 (Konami Sports Co. Ltd., Tokyo, Japan).

For the countermovement jump test, participants started from a standing position with their hands placed on their hips. They performed a downward movement to approximately 90° knee flexion, followed by a maximum upward movement. The jumped height and the ground contact time were measured using the Jump Mat Measuring Instrument FMT series (4 Assist Co. Ltd., Tokyo, Japan). Participants performed three testing trials, and the best result was used.

Muscle strength was assessed as handgrip strength using a dynamometer (Smedley-type digital hand dynamometer T.K.K. 5401, Takei Device Kogyo Co. Ltd., Tokyo, Japan). Both hands were measured twice, and the maximum value of either hand was recorded.

Statistical analysis

Continuous data are presented as median (interquartile range [IQR]), and categorical data are presented as counts (%). Comparisons were conducted using Wilcoxon rank sum U test. Wilcoxon signed rank test was performed to assess changes in skeletal muscle function, muscle mass, and intestinal nutrition absorption rates after vitamin D supplementation, as well as the association between serum 25(OH)D levels and skeletal muscle mass and function. All p-values were two tailed, and p-values < 0.05 were considered significant. JMP version 13.1.0 (SAS Institute Inc., NC, USA) and R version 3.1.1 (R Foundation for Statistical Computing, Vienna, Austria) were used for statistical analysis.

RESULTS

Daily energy intake and water intake and output

We found no significant difference in daily energy and water intake (median [IQR]) between athletes with VDS and those with VDI/VDD for the total and female athlete groups (Table 1). The daily water output from urine and NRWL were 800 (480–940) ml/day and 1,989 (1,771–2,691) ml/day in total athletes with VDI/VDD, and 815 (533–1345) ml/day and 3,195 (1,439–4,208) ml/day in total athletes with VDS, respectively. The percentage of NRWL relative to total water output was 71.3 (68.9–77.1)% in the VDI/VDD athletes and 79.7 (63.6–83.8)% in the VDS athletes. The amount and percentage of NRWL was not significantly different between the athletes with altered vitamin D status, both for the total and female athlete groups.

Table 1. Effects of vitamin D status on various factors in high school athletes

	Total (n=21)		Male (n=6)		Female (n=15)	
	VDS (n=6)	VDI/VDD (n=15)	VDS (n=2)	VDI/VDD (n=4)	VDS (n=4)	VDI/VDD (n=11)
Age (Years)	16 (16-17)	16 (15-17)	16 (16-17)	17 (16-18)	16 (16-17)	16 (15-17)
Body weight (kg)	56.4 (52.9-68.1)	58.0 (53.1-61.8)	66.3 (54.9-77.6)	58.7 (56.7-60.4)	55.5 (51.2-62.7)	57.4 (52.5-62.1)
BMI (kg/m²)	22.1 (18.9-24.3)	22.0 (20.1-23.0)	23.3 (20.4-25.9)	20.0 (19.7-20.2)	22.1 (19.5-23.6)	22.3 (20.4-23.1)
Serum chemistry						
Albumin (g/dl)	4.7 (4.6-4.9)	4.6 (4.4-4.7)	4.6 (4.4-4.7)	4.5 (4.4-4.8)	4.8 (4.6-4.9)	4.6 (4.4-4.7)
25(OH)D (ng/ml)	35.8 (33.0-38.9)	24.2 (22.3-27.0)	36.2 (33.7-38.6)	23.6 (19.3-27.3)	35.8 (31.6-39.3)	24.2 (22.6-27.0)
Nutrition and water						
Energy intake (kcal/kg/day)	42.7 (25.9-59.8)	34.8 (24.4-43.2)	61.5 (58.2-64.7)	41.7 (24.4-54.7)	32.1 (23.0-45.6)	34.0 (23.7-40.4)
Total water intake (ml/kg/day)	71.9 (38.4-78.3)	50.0 (35.2-56.6)	78.6 (78.0-79.1)	64.3 (30.4-98.7)	55.5 (34.2-72.6)	50.0 (35.9-53.0)
Urine (ml/day)	815 (533-1345)	800 (480-940)	815 (750-880)	1322 (410-2760)	798 (528-1915)	800 (580-940)
NRWL (ml/day)	3195 (1439-4208)	1989 (1771-2691)	4717 (3699-5734)	2750 (1614-4334)	2268 (726-3423)	1989 (1771-2257)
Muscle mass and functions						
Skeletal muscle mass (kg)	22.5 (18.6-30.9)	20.4 (17.0-27.0)	29.1 (27.3-30.9)	23.2 (17-27.3)	19.3 (18.6-20.1)	19.4 (17.4-21.5)
Wingate anaerobic power (W)	586 (559-695)	552 (497-645)	776 (614-973)	675 (603-743)	582 (516-588)	541 (493-558)
Maximal cycling (/min)	134 (131-137)	127 (119-148)	135 (123-144)	146 (131-157)	134 (133-135)	122 (107-129)
Peak power (W)	440 (415-535)	393 (367-431)	549 (441-656)	447 (386-516)	431 (400-481)	386 (349-408)
Countermovement jump (cm)	35.0 (30.9-48.7)	32.4 (27.8-42.2)	49.8 (47.6-52.0)	43.2 (41.6-45.1)	32.7 (28.2-35.8)	30.6 (27.4-34.6)
Hand grip strength (kg)	30.5 (27.8-52.0)	30.0 (28.0-42.0)	39.2 (39.2)	36.8 (31.9-41.6)	28.0 (27.3-31.8)	30.0 (27.0-31.0)

BMI:Body mass index
25(OH)D:25-Hydroxy vitamin D
NRWL:Non-renal water loss

VDS:Vitamin D sufficient
VDI/VDD:Vitamin D insufficient/vitamin D deficient

Vitamin D status and its association with motor performance

Serum 25(OH)D levels of 15 athletes (71.4%) with VDI/VDD were 24.2 (22.3–27.0) ng/mL and those of six athletes (28.6%) with VDS were 35.8 (33.0–38.9) ng/mL (Table 1). Female and total athletes with VDS had a higher performance level (Peak power [W]) than athletes with VDI/VDD ($p = 0.078$ and $p = 0.056$, respectively). Furthermore, serum 25(OH)D concentration was significantly associated with total power (W:rs = 0.637, $p = 0.011$, W/kg:rs = 0.515, $p = 0.049$) in female athletes.

Effects of vitamin D supplementation in male, female, and total athletes (Table 2)

At baseline, serum 25(OH)D levels in six male, 15 female, and 21 total subjects were 27.3 (21.1–33.7), 26.6 (23.7–29.9), and 27.0 (22.9–32.1) ng/mL, respectively. After daily 1,000 IU vitamin D supplementation for 6 months, serum 25(OH)D levels significantly increased to 35.4 (27.3–39.7), 38.5 (29.3–43.3), and 37.9 (28.9–40.9) ng/mL in the male, female, and total subjects, respectively. Although skeletal muscle mass was unaffected by vitamin D supplementation in any of the groups, WAPT significantly improved in all groups.

DISCUSSION

In this study, there were no significant differences in energy intake, water intake, or water output among the male, female, and total athlete groups with VDI/VDD or VDS. However, the percentage of NRWL relative to total water output was 71.3 (68.9–77.1)% in VDI/VDD athletes and 79.7 (63.6–83.8)% in VDS athletes. In our previous study of high school students, the percentages of water output from urine and NRWL were 51.4 (30.5–66.5)% and 48.6 (33.5–69.5)% in male non-athletes, 19.5 (9.4–23.9)% and 80.5 (76.1–90.6)% in male athletes, 51.4 (38.6–62.9)%, 48.6 (37.1–61.4)% in female non-athletes, and 23.8 (10.8–26.1)% and 76.2 (73.9–89.2)% in female athletes, respectively (17). Thus, the daily total water output from NRWL in athletes was higher than that in non-athletes in both studies. These findings suggest that exercise increased respiratory water loss and sweat rate, which are major factors in the water loss of high school athletes. Sweat evaporation is important for the dissipation of metabolic heat production, which may increase 10- to 20-fold during exercise (18). The rate of sweat loss is directly related to exercise intensity (metabolic heat production) (19). Since evaporation of sweat is the primary avenue of heat loss during exercise, fluid losses and the risk of hypohydration in athletes can be large.

Inadequate levels of 25(OH)D have been reported among athletes worldwide (20). VDI/VDD were highly prevalent among high school athletes (71.4%) in this study. Our findings support previous studies that reported that the prevalence of VDI/VDD ranged from 59% to 94% among athletes such as football players and gymnasts (21-23). A meta-analysis that pooled data from 23 studies with 2,313 athletes reported that 56% of athletes had inadequate vitamin D levels (24). Athletes are more susceptible to being VDI/VDD compared with the general population, which is likely caused by their increased enzymatic activity following exercise (25). The problem is further heightened in youth athletes, as adolescents face an increased risk of malnutrition due to their higher energy and nutrient requirements for proper growth and development (26, 27). Athletes need higher levels of vitamin D because of the increased demands due to their strenuous daily training (28).

This cross-sectional study examined the relationship between serum 25(OH)D concentrations and maximal aerobic power in high school athletes. We found that female athletes with VDS displayed higher maximal aerobic power compared with female athletes with VDI/VDD. Several studies have suggested a positive correlation between vitamin D status and muscle function (29-33). Our results also support the hypothesis that vitamin D plays a determinant role in physical fitness tests with a clear physiological component. Thus, VDI/VDD may decrease skeletal muscle function and athletic performance (34, 35).

This study also found that vitamin D supplementation for 6 months increased serum vitamin D levels and improved muscle strength in female and total high school athletes. Our results are consistent with other studies that reported that vitamin D supplementation enhances athletic performance in vitamin D-deficient athletes (36-40). However, the existing data are mixed, with some studies reporting no effect (41, 42). Our findings suggest that the importance of vitamin D for health benefits should be emphasized, especially during growth periods. Moreover, serum 25(OH)D concentrations of ≥ 30 ng/mL should be maintained to ensure optimal physical performance in high school athletes.

A previous study analyzed 296 young Japanese women aged 21.2 ± 2.3 years old and found that they had a mean vitamin D intake of 12.4 ± 8.1 μg/day (496 ± 324 IU/day), and 82.4% had a higher intake of vitamin D than the adequate intake recommended in the Dietary Reference Intakes 2015 (43). The subjects had a mean serum 25(OH)D concentration of 18.4 ± 4.9 ng/mL, with approximately 64% having VDD (defined as < 20 ng/mL), and only 0.7% (n = 2) having VDS (44). This study suggests that it is challenging to intake sufficient vitamin D from Japanese food to maintain VDS.

Table 2. Effects of vitamin D supplementation on muscle mass and function

	Total		Male		Female	
	Before (n=21)	After (n=21)	Before (n=6)	After (n=6)	Before (n=15)	After (n=15)
25(OH)D (ng/ml)	27.0 (22.9-32.1)	37.9 (28.9-40.9)***	27.3 (21.1-33.7)	35.4 (27.4-39.7)*	26.6 (23.7-29.9)	38.5 (29.3-43.3)***
Skeletal muscle mass (kg)	25.7 (22.6-29.4)	25.1 (22.8-29.4)	30.6 (28.5-42.4)	32.1 (28.6-43.2)	23.0 (22.5-25.9)	23.4 (22.5-25.2)
Wingate anaerobic power (W)	580 (509-678)	598 (556-798)***	743 (645-969)	952 (721-979)	550 (485-582)	573 (532-598)**
Maximal cycling (/min)	127 (112-134)	133 (125-143)*	131 (123-149)	144 (135-158)	122 (105-131)	130 (119-133)
Peak power (W)	386 (301-425)	396 (367-472)*	441 (386-495)	480 (459-601)*	379 (346-392)	380 (357-413)
Countermovement jump (cm)	34.6 (27.7-43.9)	32.7 (29.8-44.1)	44.5 (42.2-48.1)	47.6 (41.2-54.5)	30.3 (27.1-34.0)	30.6 (26.1-32.7)
Hand grip strength (kg)	25.9 (24.0-46.0)	27.9 (25.4-45.6)	49.0 (45.7-54.1)	50.4 (44.4-61.2)	25.2 (23.8-26.1)	25.6 (25.3-28.0)

Before:Before vitamin D supplementation
After:After vitamin D supplementation

Significantly different from before vitamin D supplementation (*:p<0.05, **:p<0.01, ***:p<0.001)

Several limitations should be considered when evaluating the results of this analysis. These include the relatively small sample size (VDI/VDD, n = 15;VDS, n = 6), limited time points of measurement, and the specific population studied, which may affect the generalizability of our findings. Furthermore, this study relied on a single 24-hour recall method to assess nutrient intake, which may not accurately reflect the respondents' typical dietary habits or nutrient intake levels. The strengths of our study include its comparative design using high school athletes to explore the association between vitamin D status and athletic performance. Furthermore, daily supplementation of 1,000 IU of vitamin D was sufficient to maintain adequate serum 25(OH)D levels in athletes. Our findings suggest that 1,000 IU of vitamin D supplementation, in addition to regular food intake, should be recommended to optimize aerobic power in high school athletes.

CONFLICTS OF INTEREST AND ACKNOWLEDGEMENTS

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