

Vitamin D Supplementation and Body Composition Changes in Collegiate Basketball Players A 12-Week Randomized Control Trial

Tamara Hew-Butler (✉ tamara.hew-butler@wayne.edu)

Wayne State University <https://orcid.org/0000-0003-4954-9136>

Carrie Aprik

Oakland University

Brigid Byrd

Wayne State University

Jordan Sauborin

Wayne State University

Matthew VanSumeren

Wayne State University

Valerie Smith-Hale

Wayne State University

Andrew Blow

Precision Hydration

Research article

Keywords: 25-hydroxyvitamin D, basketball, body composition, sweat sodium

Posted Date: March 2nd, 2021

DOI: <https://doi.org/10.21203/rs.3.rs-254882/v1>

License:  This work is licensed under a Creative Commons Attribution 4.0 International License.

[Read Full License](#)

Version of Record: A version of this preprint was published at Journal of the International Society of Sports Nutrition on March 22nd, 2022. See the published version at <https://doi.org/10.1080/15502783.2022.2046444>.

Abstract

Background

Vitamin D promotes bone and muscle growth in non-athletes, suggesting supplementation may be ergogenic in athletes. Our primary aim was to determine if modest Vitamin D supplementation augments favorable body composition changes (increased bone and lean mass, decreased fat mass) and performance in collegiate basketball players following 12-weeks of standardized training.

Methods

Members of a men's and women's NCAA D1 Basketball team were recruited. Volunteers were randomized to receive either a weekly 4000IU Vitamin D3 supplement (D3) or placebo (P) over 12-weeks of standardized pre-season strength training. Pre- and Post-measurements included: 1) serum 25-hydroxy vitamin D (25-OH-D); 2) body composition variables (total body lean, fat and bone mass) using a dual energy x-ray absorptiometry (DXA) scan; and 3) vertical jump test to assess peak power output. Dietary intake was assessed using Food Frequency questionnaires. Main outcome measures included changes (Δ : post- minus pre-intervention) in serum 25-OH-vitamin, body composition, and performance.

Results

Eighteen of 23 players completed the trial (8 females/10 males). Eight received the placebo (20 ± 1 years; 3 females) while ten received Vitamin D3 (20 ± 2 years; 5 females). Weekly Vitamin D₃ supplementation induced non-significant increases (Δ) in serum 25-OH-vitamin D (2.6 ± 7.2 vs. -3.5 ± 5.3 ng/mL; $p=0.06$), total body bone mineral content (BMC) (73.1 ± 62.5 vs. 84.1 ± 46.5 g; $p=0.68$), and total body lean mass (2803.9 ± 1655.4 vs. 4474.5 ± 11389.8 g; $p=0.03$), plus a non-significant change in body fat (-0.5 ± 0.8 vs. $-1.1 \pm 1.2\%$; $p=0.19$) (Vitamin D₃ vs. placebo supplementation groups, respectively). Pre 25-OH-D correlated with both Δ total fat mass (g) ($r=0.65$; $p=0.003$) and Δ total body fat% ($r=0.56$; $p=0.02$). No differences noted in peak power output Δ between the D3 vs. P group

(-127.4 ± 335.4 vs. 50.9 ± 9 W; NS). Participants in the D3 group ingested significantly fewer total calories (-526.2 ± 583.9 vs. -10.0 ± 400 kcals; $p=0.02$) and sodium (-991.4 ± 986.1 vs. 174.1 ± 573.6 mg; $p=0.02$) than participants in the P group.

Conclusions

Modest (~517IU/day) vitamin D₃ supplementation did not enhance favorable changes in total body composition or performance, over 3-months of training, in collegiate basketball players. We alternatively exposed the potential role of sodium on bone metabolism. More practically speaking, weight training provides a robust training stimulus for bone and lean mass accrual, which likely predominates over isolated supplement use with adequate dietary intakes.

Introduction

Vitamin D supplementation is widely touted as an ergogenic aid [1]. The enhancement of performance appears to be most pronounced in athletes known to be Vitamin D deficient prior to supplementation [2]. While the performance enhancing benefits of Vitamin D are widely debated, the consequences of Vitamin D (routinely measured as serum 25-OH vitamin D) deficiency (<20ng/mL) and insufficiency (20-29ng/mL) are well-described in the general population [3].

Athletes with Vitamin D deficiency have smaller hearts [4], decreased lean mass [5], and are at greater risk for bone fractures [6] as well as frequent illness [7] when compared to peers with higher serum Vitamin D levels. Basketball players [8] and African-American athletes [1] appear to be at greatest risk for Vitamin D deficiency presumably due to differences in both diet and darkened skin complexion. However, a recent study suggests that African Americans have lower amounts of Vitamin D binding protein, so that a greater proportion of bioactive vitamin is available, despite lower serum 25-OH vitamin D levels [9].

Cross-sectional studies confirm that 94% of adolescent basketball players are Vitamin D insufficient [8] while 57% of Spanish professional basketball players are Vitamin D deficient [1]. An investigation performed on eleven National Collegiate Association Athletes (NCAA) Division 1 (D1) basketball players demonstrated a 6.1% decrease in total bone mineral content (BMC) from pre-season to late summer, which was reversed the following year when a robust calcium supplement (~2000mg/day), coupled with a standardized 400IU vitamin D supplement, was introduced to preserve bone mass [10]. Our prior data (unpublished) identified the men's basketball team as having serum 25-OH vitamin D concentrations which classified them as insufficient pre-season (21.8 ± 7.9 ng/L) and deficient post-season (14.5 ± 5.6 ng/mL). Collectively, with the (recommended) threshold for "peak performance" set at >50ng/mL [2] plus the University's exposure to long vitamin D winters (latitude 42°)[11], these basketball players appeared at greatest risk for bone injuries due to vitamin D deficiency.

The *primary* purpose of this pilot study was to investigate the effects of modest (4000IU/week, equivalent to 517IU/day) Vitamin D₃ supplementation on bone and body composition changes in collegiate basketball players during three months of organized summer strength training. A *secondary* purpose was to assess potential body composition differences between African American and Caucasian players. *Tertiary* purposes (from secondary analyses) investigated performance and other factors which potentially influence total body bone mass (i.e. dietary intakes, sweat sodium loss, lean, and/or fat mass).

Materials And Methods

After Institutional Review Board (IRB) approval was granted (IRB#922734), all members of a men and women's NCAA D1 basketball team were recruited to participate. All subjects gave informed consent before participating in the study, which was conducted in accordance with the Declaration of Helsinki. The study protocol was registered (retroactively) as identifier International Standard Randomized Controlled Trials Number (ISRCTN) #14155111.

After obtaining written informed consent, all participants underwent pre-intervention testing which was conducted in July (prior to summer strength training). Players were then randomized (single-blind, with participants blinded to the intervention) to receive either a Vitamin D (Vitamin D₃, 4000IU soft gels, Up&Up™, Greenville, SC) or placebo capsule (Gelatin 1300mg Spring Valley, Bentonville, AR) weekly. The randomization of subjects utilized an alternating (odd and even) number distribution, while ensuring that a racial balance between African American and Caucasian players existed between the two supplement groups, during the randomization process.

We chose to supplement weekly for logistical reasons (i.e. the IRB limited the daily dose to 4000IU and we were only allowed access the basketball players once per week), with the dosage based upon current recommendations (600 IU/day or 4,200mg/week with a daily tolerable upper limit of 4000 IU) for healthy young (19-50 years) individuals [3]. Weekly supplementation was administered by the research team over a 12-week period. Researchers brought the supplements in (labelled) plastic cups to the weight-training room and dispensed them after completion of Monday's workout. Participants ingested the supplements with milk *ad libitum* and completed a weekly questionnaire estimating how much time each player spent in the sun, between the hours of 10am-3pm. Post-intervention testing was conducted in October, just prior to the start of official basketball practice. The following tests were performed pre- and post-intervention:

For primary and secondary outcomes:

Blood Measures - Serum 25-OH vitamin D was assessed by a local hospital laboratory (Cobas E Immunoassay, Ascension-Crittenton Hospital, Rochester, Michigan) following venipuncture in a supine position.

Body composition – After a height and weight measurement was obtained on a weight beam scale, total body lean, fat and bone mass were assessed using a whole-body dual energy x-ray absorptiometry (DXA) scan (Horizon A, software version 13.6.0.5, Hologic®, Bedford, MA). All DXA scans were performed by a single technician following standardized protocols, based on the product user manual [12].

For tertiary outcomes:

Dietary Evaluation - Dietary intake was assessed using the Block 2005 3-month Food Frequency questionnaire (NutritionQuest, Berkeley, CA), completed under laboratory supervision at the time of testing. Dietary measures of specific interest included: total caloric, vitamin D, calcium, and sodium intake.

Sweat Testing - At pre-intervention testing only, sweat sodium concentration was assessed on the non-dominant forearm (volar surface, free of tattoos) via pilocarpine iontophoresis as described in detail elsewhere [13].

Performance - A standing vertical jump test was performed, using a vertec. The highest of three attempts was recorded and converted to Peak Power output using the following equation: $\text{peak power (watts)} = 60.7 \times (\text{jump height [cm]}) + 45.3 \times (\text{body mass [kg]}) - 2055$.

Statistics - A repeated-measures ANOVA was used to assess significant differences between Groups (vitamin D vs. placebo) over Time (pre-intervention vs. post-intervention). Unpaired t-tests were used to compare males vs. females, African American vs. Caucasian players, and between the change (Δ : post-intervention minus pre-intervention) variables. Simple (Pearson's r) regression correlations were used to assess relationships between variables, with statistical significance set at $p<0.05$. All data presented as mean \pm SD.

Results

Twenty-three collegiate basketball players signed written informed consent and participated in pre-intervention testing. Five players (two female) did not complete post-testing: one was injured, two were unable to donate blood, and two did not return (one left the team). Thus, eighteen players completed the trial with a full data set, including ten males and eight females (Figure 1).

No significant ($p>0.05$) differences were noted between males and females for body mass index (BMI), serum 25-OH vitamin D (pre, post or Δ), body composition Δ 's in fat, lean or bone mass nor dietary intake (pre, post or Δ) for vitamin D, calcium, sodium, or total calories. Therefore, male and female data were combined for analyses.

Primary outcomes: Ten players received the vitamin D₃ (five females) while eight received the placebo (three females) supplementation. Serum 25-OH vitamin D increased in the vitamin D supplement group (32.8ng/mL pre to 35.5ng/ml post) and decreased in the placebo group (35.0ng/mL pre to 31.5ng/mL post), but the pre- to post-intervention Δ was not statistically significant (2.6 vs. -3.5ng/mL; $p=0.06$, vitamin D₃ vs. placebo supplement groups, respectively). No significant differences were noted for any body composition variable (Figure 2). There were trends for participants in both supplement groups to increase total lean and bone mass, and decrease fat mass, over 12-weeks of standardized group strength training.

Demographic, peak power, and dietary intake variables are detailed in Table 1, with players in the vitamin D₃ supplement group ingesting fewer total calories and sodium than those players receiving the placebo supplementation, over the 12-week trial period.

Pre- and post-intervention total dietary vitamin D₃ intake (not including supplementation), obtained from the Food Frequency questionnaire, was linearly related to pre-intervention serum 25-OH vitamin D levels

(Figure 3a). Additionally, pre- and post-intervention serum 25-OH vitamin D levels were positively related to changes (post minus pre) in total fat mass (Figure 3b), whereas those athletes with the highest serum 25-OH vitamin D levels had the greatest pre-to post increases in fat mass.

Secondary outcomes: Ten players were African American (four female) while eight were Caucasian (four female). The African American players had lower baseline serum 25-OH vitamin D levels. The African American players lost more total body fat (%) and ingested more total calories (but less calcium and sodium) when compared with the changes (Δ) seen in Caucasian players (Table 2). A significant increase in the ratio of lean mass Δ over total mass Δ was seen in African American versus Caucasian players. More simply stated, African American players demonstrated increases in lean mass that were 141% greater than the increase in total mass because of concomitant fat mass losses. The Caucasian players gained both lean *and* fat mass so that on average, ~75% of the total mass gained was derived from lean mass (Table 2). Male African American players reported spending significantly less time in the sun vs. Caucasian players over the 12-week intervention period (7 ± 2 vs. 11 ± 4 hours/week; $p=0.03$, respectively). Female self-reported sun exposure was incomplete, so these data were not analyzed.

Tertiary outcomes: Total body BMC was significantly correlated with total body lean mass ($r=0.93$; $p<0.0001$) and sweat $[Na^+]$ at pre-intervention (baseline) testing ($r=0.67$; $p=0.003$). Total body BMD was also positively related with sweat $[Na^+]$ (Figure 4a), with non-significant linear trends for positive relationships between total dietary sodium (Figure 4b) and calcium (Figure 4c) intake vs. total body BMD and between dietary sodium intake vs. sweat $[Na^+]$ (Figure 4d); all measured pre-intervention. There were no significant differences in peak power (i.e. performance) between the Vitamin D₃ versus placebo supplement groups.

Discussion

Primary outcomes: Modest (~517IU/day) vitamin D₃ supplementation, approximating the daily dosage (400-600IU/day) recommended for 19-50 year-olds [3], did not enhance favorable body composition changes (i.e. increased bone and lean mass, with decreased fat mass) in basketball players following three months of strength training compared with placebo supplementation. One possible confounding variable in the present study, with regards to the lack of enhanced bone and lean mass gains, was the unexpected (pre to post) decrease in total caloric and sodium intakes seen in the vitamin D₃ supplement versus the placebo group (Table 1). The decrease in calories (to meet caloric deficits from heavy training) and mineral ions (sodium ions osmotically attract water into tissues) may have attenuated bone and muscle tissue gains in the vitamin D₃ supplement group, over the placebo group. Unfortunately, we were not able to control dietary intake (which was assessed using subjective recall) which may have further limited our ability to detect meaningful changes in body composition in our small randomized cohort.

With specific emphasis on bone mass, the present study mirrored the (non-significant) results obtained in a 6-month randomized-control trial performed on 32 collegiate swimmers and divers [14]. One of the stated limitations of the prior supplementation trial was that most of those participants were white (91%)

and none were vitamin D deficient [14]. We thereby performed the present randomized-control supplement trial on an athletic population known to be vitamin D deficient from past experience and prior studies [1]-[8]. At baseline (pre-intervention), half (n=9) of our cohort was either Vitamin D insufficient (<30ng/mL; n=7) or deficient (<20ng/mL; n=2) whereas in the swimmer study, the average 25-OH-vitamin D level across the 6-month testing period remained above 50ng/mL [14].

In addition, a large cross-sectional study performed on 604 racially diverse male athletes identified 58.6% of participants as vitamin D deficient (<20ng/mL). Similarly, no positive correlation was noted between serum 25-OH vitamin D levels versus BMD in that study [15]. After adjusting for age and ethnicity, however, calculated bioavailable vitamin D was positively associated with hip, femoral neck, and lumbar spine BMD [15]. These authors concluded that bioavailable vitamin D (which requires measurement of vitamin D binding protein) was a more accurate predictor of bone mass than serum 25-OH vitamin D levels [15]. Thus, the lack of relationship (between bone mass vs. 25-OH vitamin D) seen in our study may also reflect a limitation in measurement, as vitamin D binding protein was not quantified in the present study.

It could also be argued that a lack of concomitant calcium supplementation may have contributed to negligible differences in bone mass between our vitamin D₃ versus placebo supplement groups. A prior, prospective, study performed on 11 NCAA D1 basketball players demonstrated an increase in total BMC with individualized dosing of calcium (plus a standard 400IU/day vitamin D supplement) based upon BMC and estimated dermal (sweat) calcium losses [10]. We argue, however, that the average dietary intake of calcium in our participants hovered around ~1000mg/day (Table 1), in addition to the milk they drank *ad libitum* with each weekly supplement. This average dietary calcium intake was well-within the range of 800-1000mg/day, as recommended by the Institute of Medicine (IOM) [16]. Thus, we do not believe that the absence of additional calcium supplementation confounded our results. We interpret our overall favorable bone mass changes (seen in both the vitamin D and placebo supplement groups) more reflective of the robust training stimulus [17] that predominated over small changes in circulating vitamin D levels.

With respect to lean and fat mass changes in our cohort, total body lean mass increased while fat mass decreased (regardless of supplement group) in response to training. Our findings contrast with a similar randomized-control trials which suggest that vitamin D supplementation decreases biomarkers for skeletal muscle breakdown (myoglobin, creatine kinase) after ultramarathons [18] and eccentric exercise [19].

Fat mass changes, in our cohort, were positively associated with serum 25-OH vitamin D levels, so that increased fat mass augmented circulating vitamin D levels both pre- and post-intervention. Previous studies performed on basketball players [20], athletes [7], and non-athletes [21] demonstrated a tendency towards a negative relationship between 25-OH vitamin D and fat mass. Accordingly, it is widely thought that adipose tissue sequesters vitamin D, with an impaired release of vitamin D in obese individuals compared with normal weight controls [22]. The present data may extend these findings to suggest that

the capacity of adipose tissue to release stored vitamin D into the circulation may be enhanced in very lean and/or athletic individuals along this same continuum.

Secondary outcomes: As expected, our African American players demonstrated significantly lower baseline serum 25-OH vitamin D levels compared with Caucasian players (Table 2), as verified in other basketball player cohorts [23, 24]. Our African American players also lost significantly more body fat (%) despite a significant increase in total calories. These findings emphasize the importance of adequate caloric intake to sustain favorable anabolic effects of strength training, which are likely independent of ethnicity. Why African American players seem to adapt more favorably (i.e. higher lean mass to fat mass ratio) to a standardized strength training program remains unclear and warrants further investigation.

An unexpected racial difference, however, was our finding that male African American players spent significantly less time in the sun than male Caucasian players. Leisure time in the sun during the summer [14] and use of tanning beds in the spring [7] have been previously (and positively) associated with serum 25-OH vitamin D levels, although another study conducted on basketball players demonstrated no correlation between sun exposure and serum 25-OH vitamin D levels [24]. The biological explanation suggests that African Americans have less Vitamin D binding protein (VDBP) and equal biologically active vitamin D levels as white Americans [9]:[15]. However, our data supports the possibility of a novel *behavioral* component to sustained low serum 25-OH vitamin D levels in African American athletes living in the Midwest, worthy of further examination from a cultural perspective (i.e. anecdotally, our African American players strongly preferred remaining indoors, even during summer).

Tertiary outcomes: Bone mass was our main (body composition) tissue of interest and like other randomized control trials, we did not see an augmentation of bone mass with Vitamin D₃ supplementation. We thereby performed preliminary analyses on mineral ions to assess other possible influencers of bone mass. As such, previous research has suggested that under-replaced sweat calcium losses may contribute to the paradoxical osteopenia seen in runners [25]:[26], cyclists [27], and basketball players [1] over a competitive season. Sweat calcium losses, however, have yet to be associated with changes in BMD or bone resorption markers as expected [28]. Alternatively, interest in sweat sodium (rather than calcium) losses as a contributor to athletic osteopenia has been similarly hypothesized [29]. With ~30% of total body sodium located within the skeleton [30] and osteopenia associated with chronic hyponatremia in humans [31]:[32], it is tempting to speculate that consistent sweat [Na⁺] losses over time may contribute to decreased bone mass in athletes. We thereby tested this hypothesis by measuring the sodium content in pharmacologically stimulated sweat during pre-intervention testing. Paradoxically, resting sweat sodium concentrations ([Na⁺]) were positively associated with both total body BMC and BMD (Figure 5a). We hypothesized that the positive relationship between sweat [Na⁺] and total bone mineral content represented an additional (extrarenal) regulatory route for sodium secretion/excretion, in response to increased sodium ingestion when the capacity for skeletal sodium storage has been maximized. Accordingly, the estimated dietary sodium intake of our collective cohort averaged >3000mg/day (Tables 1 and 2), which was well above the IOM recommendations of 1500-2300mg/day

[33]. There were tendencies for total body BMC to be related to self-reported dietary intakes of sodium and calcium (Figure 5b and 5c), and between sweat $[Na^+]$ vs. sodium intake (Figure 5d) (as demonstrated elsewhere [34]) which would trend towards supporting this hypothesis in larger cohorts. These trends encourage further exploration of the complex interplay between sodium, calcium, bone metabolism, and vitamin D which have been proposed but under-investigated [35];[36].

Of final note, two male athletes, allocated into the vitamin D supplement group during summer training, sustained fifth metatarsal fractures after our supplement trial ended. A cross-sectional study of professional basketball players support a significant relationship between history of stress fractures and *higher* vitamin D levels [23]. However, outside of basketball players, the literature remains mixed with regards to vitamin D and fracture risks in young, active, populations, as one report suggested that stress fractures were associated with lower (<40ng/mL) serum 25-OH vitamin D levels in soldiers [37] while another demonstrated no relationship between injury and serum 25-OH vitamin D levels in swimmers and divers [14]. Any potential disadvantage of vitamin D supplementation on bone health and fracture risk in basketball players thereby warrants further exploration.

Limitations: We acknowledge the limitations of extrapolating our largely negative results to a broader population, due to our small sample size (N=18), modest weekly dosage (4000IU), short intervention period (12-weeks), highly specialized population (collegiate basketball players) and mix of ethnicities and genders within group analyses. However, we hope these data can launch future investigations involving larger cohorts of competitive athletes which are historically difficult to study. To justify our small cohort, it is important to note that the number of basketball players per team remain limited (10-15/team), with small cohort numbers representative of the sport in general [1, 20, 24]. Additionally, we acknowledge that higher dosages of vitamin D (>4000IU/day) have been suggested to promote ergogenic benefits,[1] especially in athletes who are deficient. However, excessive supplementation (>70,000 IU/week) has also been shown to be detrimental [38]. We chose this conservative dosage because it reflects the current guidelines for healthy individuals [3];[16] and the maximum dosage we could reliably dispense within our Institutions' regulatory constraints for individuals with normal (mean) baseline levels (>30ng/mL) of serum 25-OH vitamin D. Lastly, the dietary intakes of vitamin D, in our cohort of basketball players, were below recommended thresholds (~200 IU/day), but similar to a previous cross-sectional study performed on 41 collegiate athletes [7]. Increased dietary intake of vitamin D was positively associated with increased serum 25-OH vitamin D at baseline (pre-intervention) in our athletes, demonstrating a potential confounding effect of not controlling vitamin D in the athletes' diet during the intervention period.

Conclusions

In conclusion, modest Vitamin D₃ supplementation did not elicit statistically significant or meaningful changes in body composition or performance (peak power) over placebo supplementation in response to 12-weeks of standardized strength-training in our limited study sample. African American players demonstrated significantly lower vitamin D and greater fat mass losses compared with Caucasian players over 12-weeks of strength training. The influence of sweat sodium (rather than calcium) losses on

bone mass, at rest and during exercise, warrants further investigation as does the potential for enhanced fracture risks in basketball players given vitamin D supplements.

Declarations

Acknowledgments: We thank Lisa DeCeuninck, Amanda Lynch, Terry Sauerbry, Lorenzo Pace, Morgan Malaga and Zain Hameed for lab assistance. We sincerely appreciate the support from Men and Women's Basketball coaches, staff and particularly the players. these results to our participants, whose tenacity and enthusiasm inspired us both on and off the court.

Author Contributions: All authors were involved with the development of this article and contributed to the following: conceptualization, THB, CA, BB, AB; Methodology, THB, CA, BB, AB; Formal Analysis, THB, JS, MV, VSH; Investigation, THB, CA, BB; Data Curation, THB, CA, BB; Writing – Original draft presentation, THB; Funding acquisition, THB; Project administration, THB, CA, BB; Writing – Review and Editing, THB, CA, BB, JS, MV, VSH, AB. All authors read and approved the final version of the manuscript and agreed with the order of presentation of the authors.

Funding: This study was supported by an Oakland University Summer Research Fellowship Award (THB).

Conflicts of interest: Andy Blow is the owner and founder of Precision Hydration

Data availability: The data that support the findings of this study are available from the corresponding author upon reasonable request

References

1. Dahlquist DT, Dieter BP, Koehle MS: Plausible ergogenic effects of vitamin D on athletic performance and recovery. *J Int Soc Sports Nutr* 2015; 12:33.
2. Cannell JJ, Hollis BW, Sorenson MB, Taft TN, Anderson JJ: Athletic performance and vitamin D. *Med Sci Sports Exerc* 2009; 41(5):1102-1110.
3. Holick MF, Binkley NC, Bischoff-Ferrari HA, Gordon CM, Hanley DA, Heaney RP, Murad MH, Weaver CM: Evaluation, treatment, and prevention of vitamin D deficiency: an Endocrine Society clinical practice guideline. *J Clin Endocrinol Metab* 2011; 96(7):1911-1930.
4. Allison RJ, Close GL, Farooq A, Riding NR, Salah O, Hamilton B, Wilson MG: Severely vitamin D-deficient athletes present smaller hearts than sufficient athletes. *Eur J Prev Cardiol* 2015; 22(4):535-542.
5. 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.
6. Maroon JC, Mathyssek CM, Bost JW, Amos A, Winkelman R, Yates AP, Duca MA, Norwig JA: Vitamin D profile in National Football League players. *Am J Sports Med* 2015; 43(5):1241-1245.

7. 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.
8. Constantini NW, Arieli R, Chodick G, Dubnov-Raz G: High prevalence of vitamin D insufficiency in athletes and dancers. *Clin J Sport Med* 2010; 20(5):368-371.
9. Powe CE, Evans MK, Wenger J, Zonderman AB, Berg AH, Nalls M, Tamez H, Zhang D, Bhan I, Karumanchi SA et al: Vitamin D-binding protein and vitamin D status of black Americans and white Americans. *N Engl J Med* 2013; 369(21):1991-2000.
10. Klesges RC, Ward KD, Shelton ML, Applegate WB, Cantler ED, Palmieri GM, Harmon K, Davis J: Changes in bone mineral content in male athletes. Mechanisms of action and intervention effects. *JAMA* 1996; 276(3):226-230.
11. Webb AR, Kline L, Holick MF: Influence of season and latitude on the cutaneous synthesis of vitamin D3: exposure to winter sunlight in Boston and Edmonton will not promote vitamin D3 synthesis in human skin. *J Clin Endocrinol Metab* 1988; 67(2):373-378.
12. Hologic QDR Reference Manual, MAN-00732 Revision 002 edn. Bedford, MA: Hologic, Inc; 2007.
13. Ranchordas MK, Tiller NB, Ramchandani G, Jutley R, Blow A, Tye J, Drury B: Normative data on regional sweat-sodium concentrations of professional male team-sport athletes. *J Int Soc Sports Nutr* 2017; 14:40.
14. 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.
15. Allison RJ, Farooq A, Cherif A, Hamilton B, Close GL, Wilson MG: Why don't serum vitamin D concentrations associate with BMD by DXA? A case of being 'bound' to the wrong assay? Implications for vitamin D screening. *Br J Sports Med* 2018; 52(8):522-526.
16. Institute of Medicine of the National Academies: Dietary Reference Intakes for Calcium and Vitamin D. *Dietary Reference Intakes* 2010; November:1-4.
17. Kohrt WM, Barry DW, Schwartz RS: Muscle forces or gravity: what predominates mechanical loading on bone? *Med Sci Sports Exerc* 2009; 41(11):2050-2055.
18. Żebrowska A, Sadowska-Krępa E, Stanula A, Waśkiewicz Z, Łakomy O, Bezuglov E, Nikolaidis PT, Rosemann T, Knechtle B: The effect of vitamin D supplementation on serum total 25(OH) levels and biochemical markers of skeletal muscles in runners. *J Int Soc Sports Nutr* 2020; 17(1):18.
19. Pilch W, Kita B, Piotrowska A, Tota Ł, Maciejczyk M, Czerwińska-Ledwig O, Sadowska-Krepa E, Kita S, Pałka T: The effect of vitamin D supplementation on the muscle damage after eccentric exercise in young men: a randomized, control trial. *J Int Soc Sports Nutr* 2020; 17(1):53.
20. Sekel NM, Gallo S, Fields J, Jagim AR, Wagner T, Jones MT: The Effects of Cholecalciferol Supplementation on Vitamin D Status Among a Diverse Population of Collegiate Basketball Athletes: A Quasi-Experimental Trial. *Nutrients* 2020; 12(2).
21. Snijder MB, van Dam RM, Visser M, Deeg DJ, Dekker JM, Bouter LM, Seidell JC, Lips P: Adiposity in relation to vitamin D status and parathyroid hormone levels: a population-based study in older men

- and women. *J Clin Endocrinol Metab* 2005; 90(7):4119-4123.
22. Di NA, De TL, Sabovic I, Rocca MS, De F, V, Opocher G, Azzena B, Vettor R, Plebani M, Foresta C: Impaired Release of Vitamin D in Dysfunctional Adipose Tissue: New Cues on Vitamin D Supplementation in Obesity. *J Clin Endocrinol Metab* 2017 102(7):2564-2574.
23. Grieshaber JA, Mehran N, Photopolous C, Fishman M, Lombardo SJ, Kharrazi FD: Vitamin D Insufficiency Among Professional Basketball Players: A Relationship to Fracture Risk and Athletic Performance. *Orthop J Sports Med* 2018; 6(5):2325967118774329.
24. Fields JB, Payne DC, Gallo S, Busteed DR, Jones MT: Vitamin D Status Differs by Sex, Sport-Season, and Skin Pigmentation among Elite Collegiate Basketball Players. *Sports (Basel)* 2019; 7(11):239.
25. Hetland ML, Haarbo J, Christiansen C: Low bone mass and high bone turnover in male long distance runners. *J Clin Endocrinol Metab* 1993; 77(3):770-775.
26. Hind K, Truscott JG, Evans JA: Low lumbar spine bone mineral density in both male and female endurance runners. *Bone* 2006; 39(4):880-885.
27. Barry DW, Kohrt WM: BMD decreases over the course of a year in competitive male cyclists. *J Bone Miner Res* 2008; 23(4):484-491.
28. Barry DW, Hansen KC, van Pelt RE, Witten M, Wolfe P, Kohrt WM: Acute calcium ingestion attenuates exercise-induced disruption of calcium homeostasis. *Med Sci Sports Exerc* 2011; 43(4):617-623.
29. Hew-Butler T, Stuempfle KJ, Hoffman MD: Bone: an acute buffer of plasma sodium during exhaustive exercise? *Horm Metab Res* 2013; 45(10):697-700.
30. Forbes GB, Perley A: Estimation of total body sodium by isotopic dilution. I. Studies on young adults. *J Clin Invest* 1951; 30(6):558-565.
31. Sejling AS, Pedersen-Bjergaard U, Eiken P: Syndrome of inappropriate ADH secretion and severe osteoporosis. *J Clin Endocrinol Metab* 2012; 97(12):4306-4310.
32. Sejling AS, Thorsteinsson AL, Pedersen-Bjergaard U, Eiken P: Recovery from SIADH-associated osteoporosis: a case report. *J Clin Endocrinol Metab* 2014; 99(10):3527-3530.
33. Institute of Medicine of the National Academies: Dietary Reference Intakes for Water, Potassium, Sodium, Chloride, and Sulfate. Washington D.C.: The National Academies Press; 2004.
34. Hargreaves M, Morgan TO, Snow R, Guerin M: Exercise tolerance in the heat on low and normal salt intakes. *Clin Sci (Lond)* 1989; 76(5):553-557.
35. Harrington M, Bennett T, Jakobsen J, Ovesen L, Brot C, Flynn A, Cashman KD: The effect of a high-protein, high-sodium diet on calcium and bone metabolism in postmenopausal women and its interaction with vitamin D receptor genotype. *Br J Nutr* 2004; 91(1):41-51.
36. Palacios C, Wigertz K, Martin BR, Jackman L, Pratt JH, Peacock M, McCabe G, Weaver CM: Sodium retention in black and white female adolescents in response to salt intake. *J Clin Endocrinol Metab* 2004; 89(4):1858-1863.
37. Miller JR, Dunn KW, Ciliberti LJ, Jr., Patel RD, Swanson BA: Association of Vitamin D With Stress Fractures: A Retrospective Cohort Study. *J Foot Ankle Surg* 2016; 55(1):117-120.

38. Owens DJ, Tang JC, Bradley WJ, Sparks AS, Fraser WD, Morton JP, Close GL: Efficacy of High-Dose Vitamin D Supplements for Elite Athletes. *Med Sci Sports Exerc* 2017; 49(2):349-356.

Tables

Table 1. Demographics, peak power, and dietary intake variables in basketball players randomized into the vitamin D supplement and placebo groups. F=female athletes. Δ=post minus pre intervention.

| VARIABLE | VITAMIN D GROUP (n=10; 5F) | PLACEBO GROUP (n=8; 3F) |
|-------------------------------|-------------------------------|----------------------------|
| Age (years) | 20 ± 2 | 20 ± 1 |
| Height (m) | 1.83 ± 0.1 | 1.87 ± 0.1 |
| Pre-Weight (kg) | 84 ± 13 | 89 ± 12 |
| Δ Weight (kg) | 0.9 ± 1.7 | 2.4 ± 2.2 |
| Pre-Peak Power (W) | 5889.9 ± 1307.5 | 5997.5 ± 1016.8 |
| Δ Peak Power (W) | -127.4 ± 335.4 | 50.9 ± 209.2 |
| Pre-Vitamin D Intake (IU) | 232.9 ± 162.9 | 242.9 ± 183.5 |
| Δ Vitamin D Intake (IU) | 31.3 ± 190.2 | 63.6 ± 205.9 |
| Pre-Calcium intake (mg) | 944.2 ± 541.5 | 1026.5 ± 310.1 |
| Δ Calcium intake (mg) | 25.5 ± 453.7 | -71.9 ± 333.4 |
| Pre-Sodium intake (mg) | 3469.4 ± 1850.1 | 2980.4 ± 797.4 |
| Δ Sodium intake (mg) | -991.4 ± 986.1** | 174.1 ± 573.6 |
| Pre-Caloric Intake (kcals) | 2117.8 ± 1128.3 | 1900.2 ± 470.9 |
| Δ Caloric intake (kcals) | -526.2 ± 583.9* | -10.0 ± 400.0 |

p<0.05; **p<0.01; *p<0.001 between vitamin D vs. placebo supplement groups.*

Table 2. Differences in serum 25-OH Vitamin D, body composition, and dietary intake between African American and Caucasian players. F=female athletes. Δ=post minus pre intervention.

| VARIABLE | AFRICAN AMERICANS (n=10; 4F) | CAUCASIANS (n=8; 4F) |
|---------------------------------------|---------------------------------|-------------------------|
| Age (years) | 20.0 ± 1.3 | 20.1 ± 1.6 |
| Height (m) | 1.83 ± 0.1 | 1.86 ± 0.1 |
| Pre-Weight (kg) | 85.8 ± 12.4 | 86.4 ± 13.0 |
| Pre-Serum 25-OH Vitamin D (IU) | 25.8 ± 10.1** | 43.7 ± 14.7 |
| Δ Serum 25-OH Vitamin D (IU) | 2.5 ± 7.4 | -3.4 ± 5.0 |
| Pre-Total Body Fat (%) | 20.5 ± 5.3 | 20.2 ± 4.3 |
| Δ Total Body Fat (%) | -1.3 ± 0.8** | 0.0 ± 0.7 |
| Pre-Total Lean Mass (kg) | 65.0 ± 10.5 | 66.2 ± 11.0 |
| Δ Total Lean Mass (kg) | 3.8 ± 1.6 | 3.2 ± 1.9 |
| Δ Ratio Lean/Total Mass (%) | 141.0 ± 76.7* | 75.4 ± 12.1 |
| Pre-Total BMD (g/cm ²) | 1.33 ± 0.14 | 1.24 ± 0.10 |
| Δ Total BMD (g/cm ²) | 0.01 ± 0.02 | 0.01 ± 0.02 |
| Pre-Vitamin D Intake (IU) | 219.6 ± 130.4 | 259.5 ± 212.0 |
| Δ Vitamin D Intake (IU) | 18.9 ± 198.3 | 79.1 ± 191.6 |

| | | |
|------------------------------------|----------------------|---------------------|
| Pre-Calcium Intake (mg) | 1040.9 ± 493.3 | 992.6 ± 565.3 |
| Δ Calcium Intake (mg) | $-186.4 \pm 309.4^*$ | 193.1 ± 409.0 |
| Pre-Sodium intake (mg) | 3526.9 ± 1427.8 | 2908.6 ± 1524.8 |
| Δ Sodium intake (mg) | $-940.5 \pm 987.9^*$ | 110.5 ± 696.9 |
| Pre-Caloric Intake (kcals) | 2193.0 ± 864.3 | 1806.3 ± 39.9 |
| Δ Caloric Intake (kcals) | $565.3 \pm 516.1^*$ | 38.8 ± 440.3 |

* $p<0.05$; ** $p<0.01$; *** $p<0.001$ between the African American vs. Caucasian players.

Figures

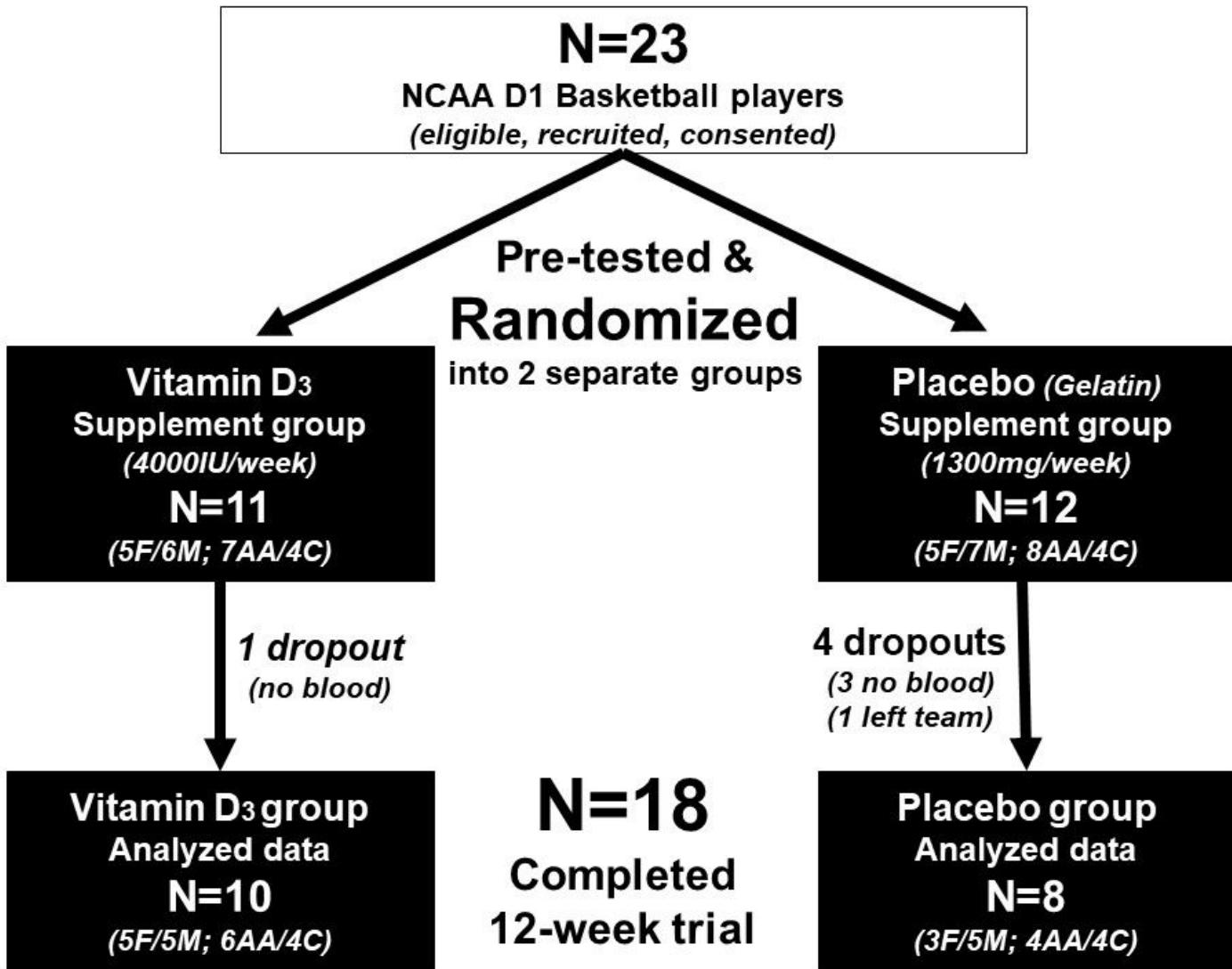
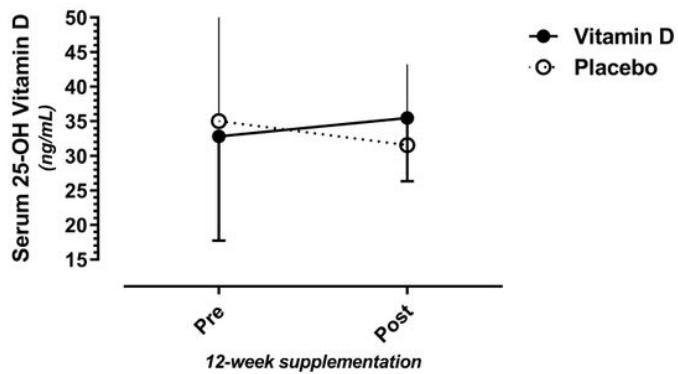


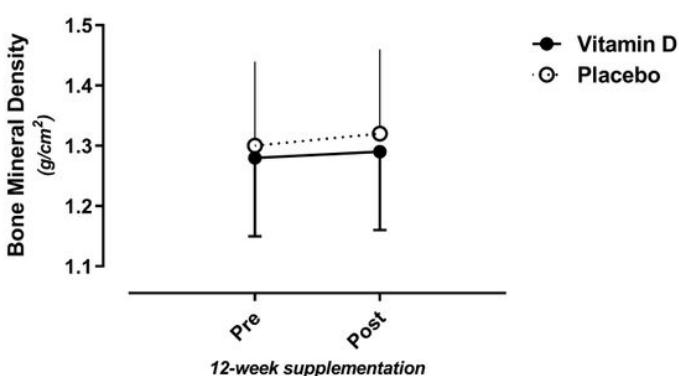
Figure 1

Study participant enrollment and randomization into vitamin D3 and placebo supplementation groups.

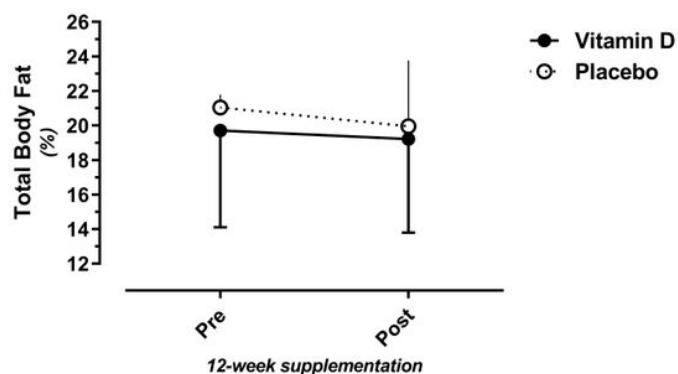
2a



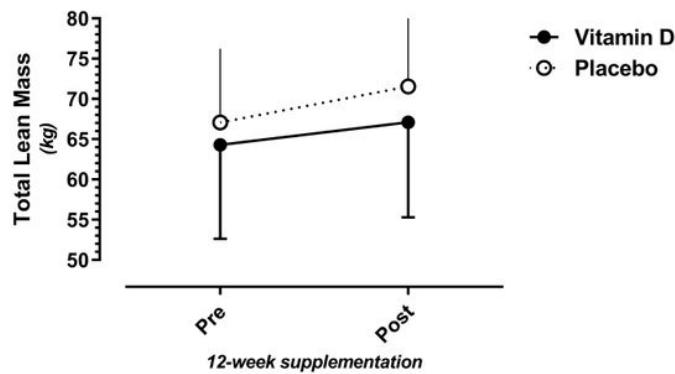
2b



2c

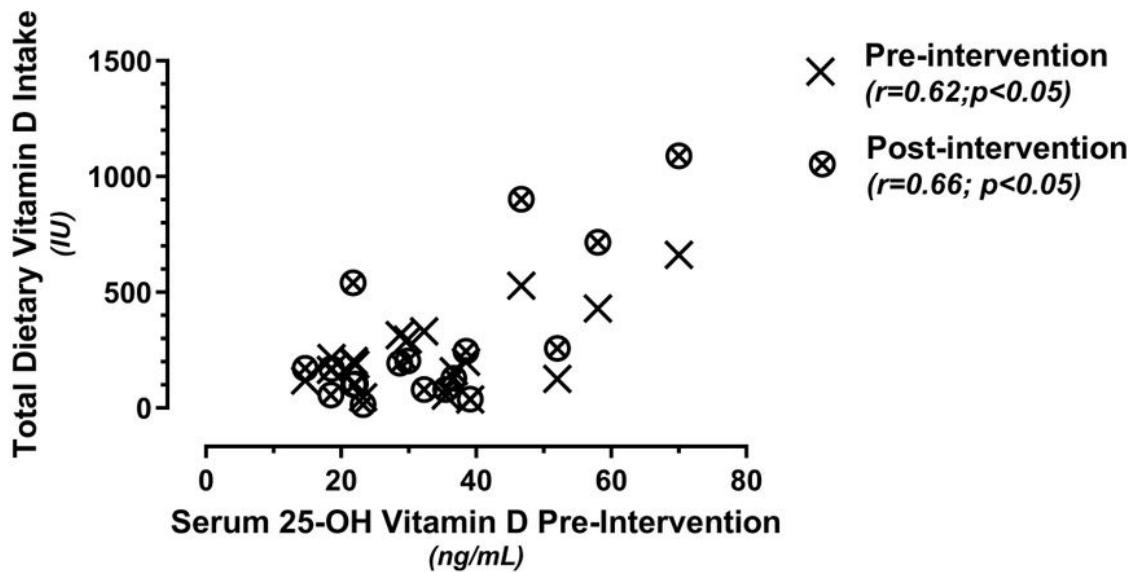


2d

**Figure 2**

Vitamin D and placebo supplement Group comparisons over Time (pre- to post-intervention) for serum 25-OH vitamin D (2a), bone mineral density (BMD)(2b), total body fat percent (2c), and total body lean mass (2d).

3a



3b

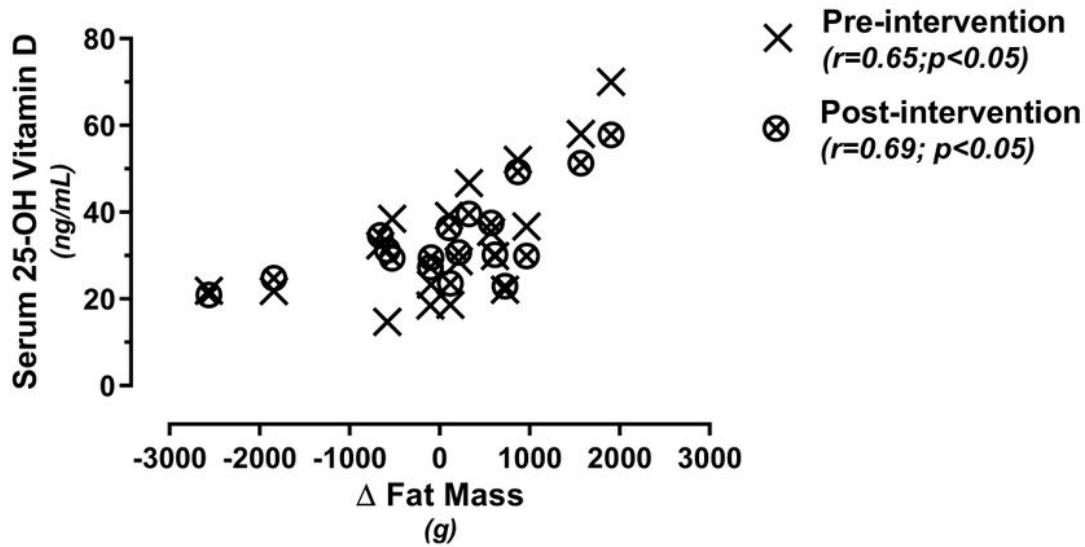
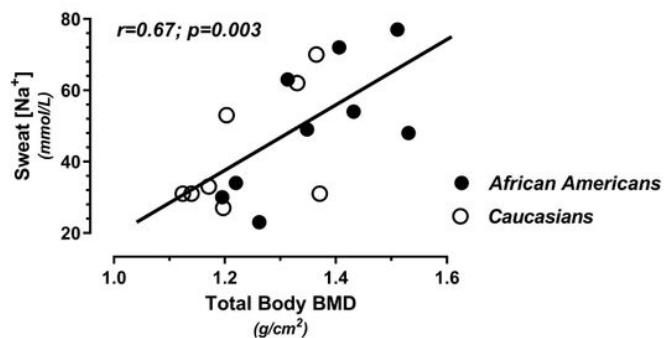


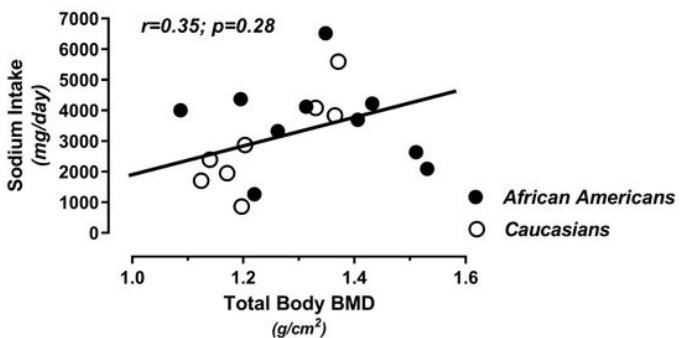
Figure 3

Relationships between total dietary vitamin D intake vs. serum 25-OH vitamin D (3a) and between serum 25-OH vitamin D vs. the change (Δ : post minus pre intervention)(3b) when the entire cohort was combined, both at pre-intervention (baseline) and post-intervention testing.

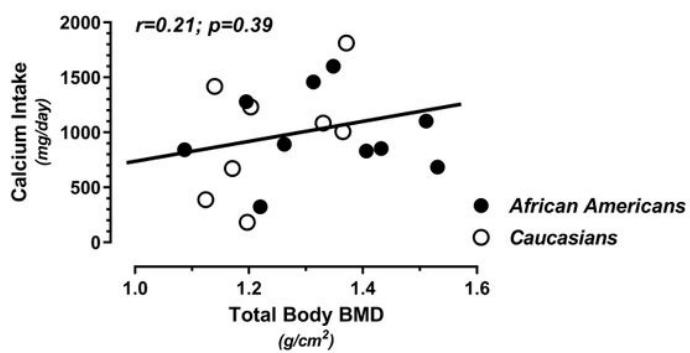
4a



4b



4c



4d

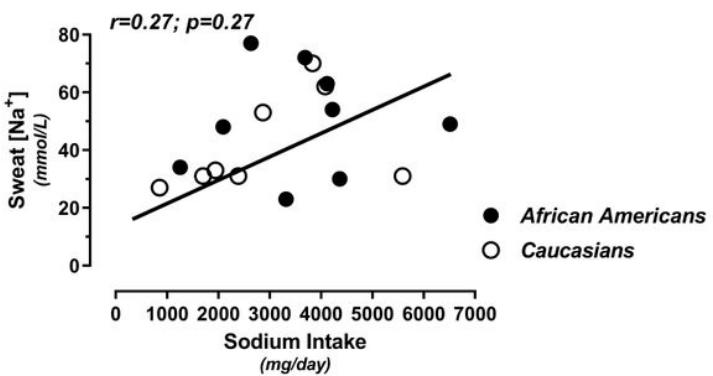


Figure 4

Relationships between total body bone mineral density (BMD) vs. sweat $[\text{Na}^+]$ (4a), total dietary sodium intake (4b), and total dietary calcium intake (4c) and between sweat $[\text{Na}^+]$ vs. total dietary sodium intake (4d) obtained at pre-intervention (baseline) testing.