The Association of Vitamin D Status in Lower Extremity Muscle Strains and Core Muscle Injuries at the National Football League Combine

Brian J. Rebolledo, M.D., Johnathan A. Bernard, M.D., Brian C. Werner, M.D., Andrea K. Finlay, Ph.D., Benedict U. Nwachukwu, M.D., M.B.A., David M. Dare, M.D., Russell F. Warren, M.D., and Scott A. Rodeo, M.D.

Purpose: To evaluate the association between serum vitamin D level and the prevalence of lower extremity muscle strains and core muscle injuries in elite level athletes at the National Football League (NFL) combine. **Methods:** During the 2015 NFL combine, all athletes with available serum vitamin D levels were included for study. Baseline data were collected, including age, race, body mass index, position, injury history specific to lower extremity muscle strain or core muscle injury, and Functional Movement Screen scores. Serum 25-hydroxyvitamin D was collected and defined as normal ($\geq$32 ng/mL), insufficient (20-31 ng/mL), and deficient ($<$20 ng/mL). Univariate regression analysis was used to examine the association of vitamin D level and injury history. Subsequent multivariate regression analysis was used to examine this relation with adjustment for collected baseline data variables. **Results:** The study population included 214 athletes, including 78% African American athletes and 51% skilled position players. Inadequate vitamin D was present in 59%, including 10% with deficient levels. Lower extremity muscle strain or core muscle injury was present in 50% of athletes, which was associated with lower vitamin D levels ($P = .03$). Athletes with a positive injury history also showed significantly lower vitamin D levels as compared with uninjured athletes ($P = .03$). African American/black race ($P < .001$) and injury history ($P < .001$) was associated with lower vitamin D. Vitamin D groups showed no differences in age ($P = .9$), body mass index ($P = .9$), or Functional Movement Screen testing ($P = .2$). Univariate analysis of inadequate vitamin D levels showed a 1.86 higher odds of lower extremity strain or core muscle injury ($P = .03$), and 3.61 higher odds of hamstring injury ($P < .001$). Multivariate analysis did not reach an independent association of low vitamin D with injury history ($P = .07$). **Conclusions:** Inadequate vitamin D levels are a widespread finding in athletes at the NFL combine. Players with a history of lower extremity muscle strain and core muscle injury had a higher prevalence of inadequate vitamin D. **Level of Evidence:** Level IV, retrospective study-case series.

From the Division of Orthopaedic Surgery, Scripps Clinic (B.J.R.), La Jolla, California; National Sports Medicine Institute (J.A.B.), Lansdowne; Department of Orthopaedic Surgery, University of Virginia (B.C.W.), Charlottesville, Virginia; Department of Orthopaedic Surgery, Stanford University (A.K.F.), Redwood City, California; and Department of Orthopaedic Surgery, Hospital for Special Surgery (B.U.N., D.M.D., R.F.W., S.A.R.), New York, New York, U.S.A.

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Address correspondence to Brian J. Rebolledo, M.D., Division of Orthopaedic Surgery, Scripps Clinic, 10666 North Torrey Pines Road, MS 116, La Jolla, CA 92037, U.S.A. E-mail: rebolledo.brian@scrippshealth.org

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Vitamin D deficiency has been described as a widespread global issue,[1,2] reportedly affecting nearly 42% of adults in the United States.[3] The physiologic impact of decreased vitamin D has been associated with numerous deleterious effects on the musculoskeletal system, including poor calcium absorption, increased fracture risk, and diminished muscle function.[4] Despite a previous focus on vitamin D deficiency in the elderly, recent reports have shown that professional athletes may also be a population at risk.[5,6] Furthermore, studies on the vitamin D profile of National Football League (NFL) players showed that 69% to 80% of players will have inadequate levels.[5,7] Importantly, these findings may ultimately confer consequences for sports performance and the risk of injury.[5,8,9]

In addition to concerns regarding possible musculoskeletal dysfunction, low levels of vitamin D may alter injury susceptibility. Vitamin D status has been linked

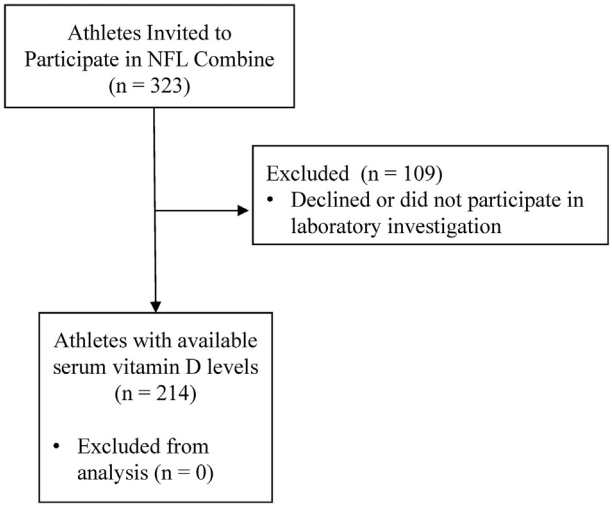

Fig 1. Study flowchart for study participants at the National Football League (NFL) Scouting Combine with available serum vitamin D.

to osseous and muscular function,[10,11] with insufficient levels having a negative impact. Muscle fiber atrophy, impairments in muscle contractile function, and musculoskeletal pain have been linked to low levels of vitamin D.[12-14] Type II fast-twitch muscle fibers, which are critical to athletic performance,[10] are especially affected by deficient levels of vitamin D with resultant fatty infiltration and atrophy.[15] Decreased vitamin D also has detrimental effects on the contractile function of skeletal muscle.[16] A parallel finding from a prior study revealed that NFL athletes with decreased vitamin D levels show higher rates of injury.[7]

Despite the recognized role of vitamin D in maintaining overall musculoskeletal health, the potential effect of low vitamin D in elite athletes remains largely unknown. The purpose of our study was to evaluate the association between serum vitamin D level and the prevalence of lower extremity muscle strains and core muscle injuries in elite level college athletes at the annual NFL Scouting Combine. We hypothesized that decreased levels of vitamin D would be associated with increased incidence of lower extremity muscle strains and core muscle injuries in this select population.

Methods

After Institutional Review Board approval, a retrospective case series was performed using data for prospective professional athletes who participated in the 2015 NFL Scouting Combine (Fig 1). Inclusion criteria involved all athletes with available vitamin D levels collected during the combine. Serum 25-hydroxyvitamin D (25(OH) vitamin D) was used for measurement, and defined as normal being $\geq$32 ng/mL.[1,17] Inadequate vitamin D levels were designated as levels of 25(OH) vitamin D $<$ 32 ng/mL, with further subcategorization of vitamin D insufficiency (25(OH) vitamin D = 20-31 ng/mL), and deficiency (25(OH) vitamin D $<$ 20 ng/mL).[1,5]

Baseline demographic data were collected, including age and race. Additional data included body mass index (BMI), player position, and injury history specific to lower extremity muscle strain or core muscle injury. As previously categorized for NFL athletes,[5] race was designated as African American/black or white (including Polynesian). Positions were grouped as either skilled (quarterback, running back, wide receiver, defensive back, and placekicker) or lineman/others (offensive line, defensive line, linebacker, and tight-end). Injury classification included lower extremity muscle strain defined as adductor/groin, hamstring, hip flexor, or quadriceps strain; and lower abdominal injury diagnosed as a core muscle injury. This information regarding injury history was garnered from the medical history obtained by the athletes along with reference to available medical records at the combine. Games that were missed because of a lower extremity strain or core muscle injury were also recorded for each player. In addition, Functional Movement Screen (FMS) testing scores were collected for each participating athlete. FMS has been used as an assessment of movement performance to identify individuals at risk of future injury,[18] including the previous use in professional football.[19]

Statistical Analysis

The primary analysis examined serum vitamin D level (independent factor) associated with any injury history (primary outcome) in NFL combine athletes. Secondary analyses examined group differences in player characteristics (age, BMI, vitamin D, FMS score) by injury history and vitamin D level associated with type of prior injury. Overall summary statistics were calculated in terms of means and standard deviations for continuous variables, and frequencies and percentages for categorical variables. Normal distribution of continuous variables (age, BMI, FMS score) was assessed using normal probability plots with all continuous variables normally distributed. Group differences for discrete variables were evaluated using χ-square, and independent sample *t*-tests were used for continuous variables. A 1-way analysis of variance was used to compare age, BMI, serum 25(OH) vitamin D, and FMS score based on vitamin D level categorization. To model the association between injury and those with inadequate vitamin D levels, we used a univariate logistic regression analysis to examine vitamin D level with overall injury. In addition, a multivariate logistic regression analysis was used for vitamin D level, adjusting for age, BMI, and FMS score based on vitamin D level. All players who participated in the 2015 combine were included in analyses. Data analysis was performed using the R statistical package.[20] Statistical significance was set at α equal to 0.05.

Table 1. Player Demographics and Profile Data

Variable	
Age, yr*	22.1 ± 1.0
Race, n (%)	
African American	167 (78)
White/Polynesian†	47 (22)
Body mass index*	31.3 ± 4.4
Position, n (%)	
Skilled	110 (51)
Lineman/others	104 (49)
LE muscle strain or sports hernia injury, n (%)	107 (50)
At least 1 missed game, n (%)	13 (6)

LE, lower extremity.
*Values are reported as mean ± standard deviation.
†Data includes both white (n = 40) and Polynesian (n = 7) athletes.

Results

A total of 214 NFL combine athletes with available serum vitamin D levels were available for study (Table 1). Low serum vitamin D was present in 126 players (59%) (25(OH) vitamin D < 32 ng/mL), including 22 of the athletes (10%) with severe deficiency (25(OH) vitamin D < 20 ng/mL) (Table 2). There were differences in race and injury history based on vitamin D level. Notably, athletes with a positive injury history had significantly lower mean serum vitamin D levels as compared with uninjured athletes (29.7 ± 11.2 ng/mL vs 34.0 ± 13.0; $P = .03$). For the 13 players who reported missing at least 1 game because of a lower extremity strain or core muscle injury, 86% had inadequate vitamin D levels. Post hoc power analysis indicated 0.59 power to detect an effect for overall injury.

African American/black athletes had significantly lower levels of vitamin D when compared with white athletes participating at the combine (29.5 ± 11.8 ng/mL vs 40.2 ± 10.5 ng/mL; $P < .001$). This included inadequate levels of vitamin D in 70% of African American/black athletes and 13% of white athletes. There was no difference in vitamin D levels between skilled position players and lineman/others (30.7 ± 13.5 vs 33.0 ± 10.8 ng/mL; $P = .17$).

Univariate regression analyses indicated that players with inadequate vitamin D levels had 1.86 higher odds (95% confidence interval [CI] = 1.08-3.26; $P = .03$) of having a lower extremity strain or core muscle injury compared with players with adequate vitamin D. Furthermore, players with inadequate vitamin D had 3.61 higher odds (95% CI = 1.76-7.88; $P < .001$) of a hamstring strain than players with normal vitamin D, after adjusting for all other parameters. The multivariate analysis of lower extremity strain or core muscle injury showed that an inadequate vitamin D level showed a trend toward a higher risk of injury (odds ratio = 1.78, 95% CI = 0.95-3.38; $P = .07$). BMI was independently associated with injury risk (odds ratio = 0.91, 95% CI = 0.84-0.97; $P = .006$) (Table 3).

Discussion

The primary finding of this study is that players with a history of lower extremity muscle strain or core muscle injury had significantly lower average vitamin D levels compared with athletes with normal vitamin D levels. Vitamin D has been shown to be critically important for musculoskeletal structure, function, and strength.[21,22] Although the impact of low vitamin D has been linked to functional impairments in high-risk groups, the impact of diminished vitamin D levels may also affect young athletic populations. We found that a majority of elite level athletes participating at the NFL combine had inadequate levels of vitamin D. This concerning figure translated to increased rates of lower extremity muscle strains and core muscle injuries. Diminished vitamin D levels in this group were associated with a history of lower extremity strain or core muscle injury, which may potentially have career or performance-based implications if not addressed. We found that 59% of athletes in our study had abnormal levels of serum vitamin D, which is less than previously reported for this population.[5,7] Maroon et al.[5] collected data from a single NFL team, and showed that nearly

Table 2. Group Comparisons of NFL Combine Athletes by Vitamin D Status

Variables	Normal Serum Vitamin D (25(OH) Vitamin D ≥ 32 ng/mL) (N = 88)	Vitamin D Insufficiency (25(OH) Vitamin D = 20-31 ng/mL) (N = 104)	Vitamin D Deficiency (25(OH) Vitamin D < 20 ng/mL) (N = 22)	*F*	χ-square	*P* Value
Age, yr	22.1 ± 0.8	22.0 ± 1.1	22.1 ± 0.9	0.09		.9
Race, n (%)					34.9	<.001
African American	54 (31)	96 (56)	22 (13)			
White/Polynesian	34 (81)	8 (19)	0 (0)			
Body mass index*	31.4 ± 4.3	30.8 ± 4.1	31.2 ± 4.5	0.16		.9
Serum 25(OH) vitamin D*, ng/mL	42.7 ± 11.4	26.0 ± 3.2	15.7 ± 3.9	163.8		<.001
LE muscle strain or core muscle injury, n (%)	36 (41%)	55 (53%)	16 (73%)		7.8	.02
FMS score	15.1 ± 2.6	14.6 ± 2.2	15.7 ± 3.9	1.5		.2

FMS, Functional Movement Screen; LE, lower extremity.
*Values are reported as mean ± standard deviation.

Table 3. Multivariate Model for Risk of Lower Extremity Muscle Strain or Core Muscle Injury

	P Value	Odds Ratio (95% CI)
Age	.2	1.22 (0.91-1.67)
Race	.9	1.02 (0.47-2.23)
Body mass index	.006	0.91 (0.85-0.97)
Inadequate vitamin D*	.07	1.78 (0.95-3.38)
FMS	.37	0.94 (0.83-1.07)

CI, confidence interval; FMS, Functional Movement Screen.
*25(OH) vitamin D < 32 ng/mL.

69% had inadequate levels of vitamin D. These levels were collected during preseason training camp or the preceding offseason period. Interestingly, those with the lowest vitamin D had a higher rate of being released from the team. Also, diminished vitamin D levels were linked to increased fracture risk after correcting for the number of seasons played. Shindle et al.[7] similarly evaluated players from a single professional football team, and found low levels of serum vitamin D present in 81%. They also reported an association between vitamin D deficiency (<20 ng/mL) and an increased rate of muscle injury. In addition, this high prevalence of vitamin D inadequacy has been found in elite level basketball players, with 79% having inadequate vitamin D levels.[6]

Our study captured elite level college athletes at the NFL combine before their NFL participation. Although less than previously reported, the prevalence of low vitamin D in our study is concerning for athletes performing at the professional level. The association between low vitamin D levels and an increased risk of lower extremity muscle strain or core muscle injury suggests that treatment should be considered to decrease the risk of future injury. We found that players with inadequate vitamin D levels had 1.86 higher odds of having a lower extremity muscle strain or core muscle injury. Interestingly, hamstring injuries were also associated with inadequate vitamin D levels, with 3.86 higher odds of associated injury. This may prompt the consideration of a laboratory work-up when encountered in the clinical setting. Although previous laboratory recommendations have been made for musculoskeletal assessment in the fracture patient,[23] these can be modified for the injured athlete when clinically indicated (Table 4). Concerning features found on clinical assessment to prompt laboratory investigation are not limited to but may include the athlete with recurrent musculoskeletal injury. In this study, BMI was also found to be independently associated with decreased vitamin D levels, which has been recognized previously.[24]

Similar to previous reports,[5,7] we found that African American/black football players had significantly decreased vitamin D levels compared with their white counterparts at the combine. Although numerous factors can contribute to vitamin D levels, including diet and sun exposure, decreased absorption has been tied to those with dark skin tones and high melanin production leading to poor synthesis of vitamin D3.[25] Another consideration is that black Americans have lower levels of vitamin D-binding protein.[26] Standard laboratory assays measure bound vitamin D, which has been shown to result in lower measured levels in black Americans. The significance and implications of the lower measured levels in blacks with current laboratory assays are unknown, as it appears that the bioavailable vitamin D in blacks is adequate because blacks do not generally have a higher rate of fracture and they often have higher bone mineral density.[27,28] Although 70% of the African American/black athletes had lower measured levels of vitamin D in our study, this is improved from population-based studies that report low levels in 82% of African Americans.[3] Increased awareness of the relatively high prevalence of vitamin D inadequacy with subsequent treatment may help explain the improved vitamin D profile in our study compared with the population at large.

NFL combine athletes in this study were at a greater risk of lower extremity muscle strain or core muscle injury when having lower levels of vitamin D. Our study revealed that 86% of players who missed competition because of strain injury had inadequate levels of vitamin D. This could be related to physiologic changes that occur in muscle composition in deficient states.[10,15] Muscle weakness can be severe in those with low vitamin D.[29] Animal studies have also corroborated these findings with vitamin D receptor mutations leading to profound muscle weakness, despite normal differentiation phenotypes.[30,31] Muscle biopsies in patients with low vitamin D levels showed apparent changes in muscle morphology including signs of fatty infiltration and widespread fibrosis.[10] However, these muscular effects may be reversible with supplementation. A recent prospective double-blind trial found that vitamin D supplementation has an acute positive effect on lower extremity muscle strength.[32] In this study, 22 high-level judo athletes with vitamin D insufficiency were given a single bolus of 150,000 IU vitamin D_3. Strength testing of the quadriceps and hamstrings showed improved isokinetic dynamometry, with serum vitamin D levels rising by 34% at just 8 days after supplementation. In addition, vitamin D supplementation has been previously shown as efficacious in reversing the adverse effects of low vitamin D.[33]

Table 4. Basic Laboratory Evaluation for Athletes With Muscle Strain Injury

- Complete blood cell count
- Serum chemistry: includes calcium, phosphorus, alkaline phosphatase, creatinine, and electrolytes
- Serum 25-hydroxyvitamin D
- Intact parathyroid hormone

Optimal levels of vitamin D remain a controversial topic, although an ideal range of 25(OH) vitamin D has been recommended between 30 and 50 ng/mL.[34] Shuler et al.[35] stated that performance enhancement can occur at levels of vitamin D higher than 30 ng/mL. Although our study did not address supplementation for athletes, we speculate that vitamin D supplementation could help prevent musculoskeletal injury in this group. Recommendations for vitamin D supplementation should also include routine laboratory surveillance to assess patient response and baseline levels.

Understanding the potential link between vitamin D and muscle injury should bring further awareness to this relation in high-performance athletes. Although further longitudinal studies are required to delineate the role of vitamin D and risk of muscle injury, we advocate for early recognition and intervention when appropriate to optimize muscular function and potentially decrease the risk of injury.

Limitations

Limitations of our study include NFL combine data that were analyzed in a retrospective manner, and do not include a prospective clinical evaluation coupled with injury history. Also, we do not have any data on injury recovery time and time to return to play. All vitamin D levels were collected during participation at the NFL combine, which does not capture vitamin D levels at the time of injury. It is known that vitamin D levels can fluctuate seasonally,[36] likely due to differences in sun exposure. Sun exposure and vitamin D supplementation were not included as part of the history obtained, and could have affected our results as well. Although serum vitamin D differences were found in our study between groups, we acknowledge that no minimally clinical important difference of vitamin D levels has been well established for use in this study. Furthermore, we acknowledge that our investigation did not capture every athlete invited to the combine.

In this study, our univariate regression analyses indicated an association between vitamin D level and injury history; however, the full multivariate model did not confirm this association as an independent variable for the 2015 NFL combine class. We recognize that the association of BMI and vitamin D in this population could be affected by increased muscle content or player position in this unique population of athletes. In addition, our study highlights injury association in a small subset of athletes that may differ in a larger population or could represent sport-specific findings.

Conclusions

Inadequate vitamin D levels are a widespread finding in athletes at the NFL combine. Players with a history of lower extremity muscle strain and core muscle injury had a higher prevalence of inadequate vitamin D.

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