P-ISSN: 2394-1685
E-ISSN: 2394-1693
Impact Factor (RJIF): 5.38
IJPESH 2024; 11(2): 148-154

www.kheljournal.com
Received: 23-01-2024
Accepted: 24-02-2024

Usha Sri Kaniganti
[1.] Scientific Officer, Department of Exercise Biochemistry, Sports Authority of India, NSSC, Bangalore, Karnataka, India
[2.] Ph.D. Scholar, Department of Biochemistry, Bangalore University, Bangalore, Karnataka, India

Dr. CS Karigar
Professor, Department of Biochemistry, Bangalore University, Bangalore, Karnataka, India

Corresponding Author:
Usha Sri Kaniganti
[1.] Scientific Officer, Department of Exercise Biochemistry, Sports Authority of India, NSSC, Bangalore, Karnataka, India
[2.] Ph.D. Scholar, Department of Biochemistry, Bangalore University, Bangalore, Karnataka, India

Customized reference ranges of 25 (Oh) Vitamin D Levels for Indian athletes: A comparative analysis with international standards

Usha Sri Kaniganti and Dr. CS Karigar

DOI: https://doi.org/10.22271/kheljournal.2024.v11.i2c.3271

Abstract
Vitamin D, an essential hormone, has gained attention for its potential impact on athletic performance and well-being. This study aimed to establish customized reference ranges of 25-hydroxyvitamin D (25(OH)D) for Indian athletes, considering factors such as gender, athletic disciplines, and indoor/outdoor sports. This study also assessed the prevalence of vitamin D deficiency or insufficiency among Indian athletes according to the standards set by the Endocrine Society and Institute of Medicine.
The study included 543 athletes (242 male, 301 female) from various sports in India. Standardized laboratory methods and questionnaires were used to assess 25(OH)D levels and to gather information on sunlight exposure, skin phototype, training experience, and dietary habits of the athletes. The 95% reference intervals for 25(OH)D levels among Indian athletes were calculated using Med Calc software 2016 according to CLSI guidelines C28-A3 and found to be 17.62-59 ng/mL, with slightly lower levels for females (15.1-58.8 ng/mL) compared to males (21.4-63.9 ng/mL). Indoor participants exhibited lower levels (13.8-79 ng/mL) compared to outdoor participants (18.1-63.4 ng/mL). These reference ranges closely align with the Institute of Medicine (IOM) standards. Based on IOM standards, Indian athletes exhibited a notably lower prevalence of vitamin D deficiency/insufficiency, with only 10% affected, in contrast to the guidelines of the Endocrine Society, which reported a higher prevalence of 37.7%.
These findings offer valuable insights into optimizing 25(OH)D levels for Indian athletes, aiding sports scientists, trainers, and nutritionists in evidence-based guidelines for preventing hypovitaminosis D and enhancing athletic performance and well-being.
These findings enable sports scientists, trainers, and nutritionists to accurately interpret the results, identifying suboptimal vitamin D levels in athletes. Consequently, these insights are valuable for optimizing 25(OH)D levels among Indian athletes, ultimately enhancing their performance and overall well-being.

Keyword: Reference ranges, reference Intervals, 25-hydroxyvitamin D, Hypovitaminosis D**,** Suboptimal Vitamin D

1. Introduction

Athletic performance is affected by multiple factors, like genetics, environment, nutrition, and training. Decades of exploration have substantiated that vitamin D is also essential for skeletal muscle growth, immune function, inflammatory modulation, athletic performance, and recovery beyond its established role in bone health and calcium homeostasis.

Suboptimal vitamin D levels were widely observed among the general population worldwide, and a high incidence of vitamin D deficiency or insufficiency has been documented in athletes from both outdoor and indoor sports (de La Puente Yagüe et al.,) [7]. In athletes, Vitamin D deficiency and sufficiency incidence vary by season, training location, sport, and skin color. Vitamin D levels will be comparatively low during the winter months. Athletes who predominantly train indoors and at higher latitudes generally have lower vitamin D levels when compared with those who train outdoors and at lower latitudes. However, suboptimal vitamin D status can be seen even in countries near the equator when the sun is avoided, or skin is shielded. In athletes, low vitamin D levels are associated with an increased risk of acute illness, inflammation, injury, stress fractures, muscle pain/weakness, and decreased muscle performance. On the other hand, optimum vitamin D levels may favor their performance in sports.

1.1 Plausible relation between Vitamin D and athletic performance

Vitamin D receptors (VDR) and vitamin D response elements (VDREs) are found in almost every human tissue, including skeletal muscle (Bouillon et al., 2008) [2]. Vitamin -D has been shown to play multiple roles in the human body and regulates about 2,000 genes that modulate protein synthesis, cell growth, and immune functions (Cannell et al., 2009) [3]. Hence, maintaining higher levels of vitamin D could benefit athletic performance.

Relation between Vitamin D and Skeletal muscle activity: Vitamin D3 receptors exist in human skeletal muscle tissue, showing that 1,25-dihydroxy vitamin D directly affects skeletal muscle activity. The experimental evidence implies that vitamin D influences skeletal muscle by turning on the expression of genes that control muscle growth and differentiation, particularly in fast-twitch (type II) fibers (Girgis et al., 2013) [11] observed a positive correlation between sufficient vitamin D levels and muscle function parameters such as muscle strength, jump height, jump velocity, power, capacity, and exercise performance.

Vitamin D and Recovery: Rapid recovery is essential for athletes who often train at high intensities. Human skeletal muscle responds to training stimuli or tissue damage through remodelling. During recovery, 1,25-dihydroxy vitamin D increases myogenic differentiation and proliferation and down-regulates myostatin, an inhibitory regulator of muscle synthesis.

Force and power production in skeletal muscle: Vitamin D3 has also been reported to enhance skeletal muscle muscular force and power output, possibly by acting on calcium-binding sites on the sarcoplasmic reticulum, leading to enhanced cross-bridge formation and muscular contraction. Recent investigations have indicated that vitamin D3 may have the potential to enhance both the size and the number of type II muscle fibres.

Association between Vitamin D and Testosterone: Testosterone is a steroid hormone involved in muscular adaptations to training. A cross-sectional study done on 2299 older men (62 ± 11 years of age) showed that 25(OH) D levels correlated with testosterone and androgen levels in men. Low testosterone levels are associated with decreased protein synthesis, strength, beta-oxidation, and increased adipose deposition in young men. Thus, optimum Vitamin D levels may be needed in athletes to optimize natural androgenic production.

Role of Vitamin D in Inflammation: Vitamin D is also known to control inflammation. Vitamin D induces the production of numerous anti-inflammatory cytokines, including transforming growth factors and interleukins such as IL-4, IL-10, and IL-13, and reduces the production of pro-inflammatory cytokines, namely IL-2, IL-6, interferon-γ, and tumor necrosis factor (TNF-α), etc.

Influence of Vitamin D on Immunity: Vitamin D functions as an essential regulator of innate immunity, plausibly by turning on broad-spectrum antimicrobial peptides (AMP) gene expression. It is apparent that prolonged intense training suppresses innate immune function and increases the risk of upper respiratory tract infection. Vitamin D deficiency may also influence susceptibility to such infections in athletes.

Health and Vitamin D: Gagnon et al. [10] conducted a study among 4,164 adults (Meaning age 50 years) to evaluate the prospective association between Vitamin D levels and Metabolic Syndrome (MeS). After five years of follow-up, they found out that the adults with blood 25(OH)D levels of <18 ng/mL and 18–23 ng/mL had an increased risk for developing metabolic syndrome compared to adults who had a blood 25(OH) D level of >34 ng/mL (Gagnon et al., 2012) [10]. Other studies also validated the same (Deleskog et al., 2012) [8]. Many observational studies have correlated vitamin D deficiency with medical conditions such as autoimmune diseases, diabetes, cancer, and muscle weakness (Girgis et al., 2014; Holick, 2007b) [12].

Most studies have reported the health benefits of vitamin D in healthy sedentary persons and mobility-limited elderly men/women. They are yet to be assessed in the athletic population. On the other hand, few researchers have shown that the Vitamin D intervention could elicit improvement in the squat test, vertical jump test, maximal oxygen uptake ($V0_2$ max), power output (watts), and muscle strength.

1.2 Reference ranges of Vitamin D for athletes

No specific reference ranges are set for Vitamin D levels in Indian athletes, and the blood level of 25(OH)D defined as vitamin D deficiency remains uncertain. Two sets of standards for Vitamin D were framed. One is by the Institute of Medicine (IOM), and the other is by the Endocrine Society. The Institute of Medicine (IOM) considered the 25(OH)D level above 20 ng/mL as the sufficient level necessary for good bone health. However, considering the other additional benefits of optimum vitamin D in improving muscle function and reducing several chronic illnesses, the Endocrine Society referred to the 25(OH)D levels <20 ng/mL as a deficiency, levels between 21–29 ng/mL as vitamin D insufficiency and above 30 ng/ml as sufficiency (Holick, 2007b; Holick et al., 2011) [14, 16]. Moreover, in most of the labs, the 25(OH) Vitamin D levels between 32-100 ng/ml are considered the normal range. In addition to this, some studies have suggested that when 25(OH)D level is between 30 - 40 ng/mL, PTH levels decrease and reach the plateau indicating the maximum effect of vitamin D on calcium metabolism and bone health (Chapuy et al., n.d.; Elissa T Homas et al., 1998; Holick et al., 2005) [17].

Condition	IOM Guidelines		Endocrine Society Guidelines	
	ng/mL	nmol/L	ng/mL	nmol/L
Deficient	< 12	< 30	< 20	< 50
Insufficient	12 to 20	30-50	21-29	52.5-72.5
Sufficient	> 20	> 50	30-100	75-250
Ideal			40-60	100-150
Considered safe			< 100	< 250
Toxic			> 150	> 375

This study aimed to establish customized reference ranges of 25-hydroxyvitamin D (25(OH)D) for Indian athletes and assess the prevalence of vitamin D deficiency or insufficiency based on the standards set by the Endocrine Society and IOM.

2. Materials and Methods

A total of 543 athletes (242 male and 301 female) were recruited for this study. The participants, with an average age of 20.79±3.56 years, had an average weight of 58.03±10.95 kg and a height of 167.38±8.68 cm. These athletes represented diverse disciplines, including athletics, Taekwondo, Hockey, and Weightlifting. They were selected from the pool of athletes who regularly underwent biochemical evaluations at the Department of Exercise Biochemistry, Sports Authority of India, NSSC, Bengaluru.

To obtain additional details related to health status, history of hospitalization, medication usage, supplementation practices, dietary habits, and skin phototype, comprehensive questionnaires were administered to the participants. Before they participated in the study, all participants were thoroughly briefed about the study's objectives and procedures. Written informed consent was obtained from each participant, ensuring their understanding and voluntary agreement to take part in the research.

2.1 Inclusion and Exclusion criteria: athletes of both genders from indoor and outdoor games between the age of 12-36 years with no known comorbidities and who are not on Vitamin D supplementation from the past six months were included in the study. Athletes on vitamin D supplementation or with known illnesses of renal disease, liver disorder, and skin diseases are excluded from the study. Of the 643 athletes, 100 (37 male and 63 female athletes) were excluded from the study due to the recent /current history of Vitamin D supplementation, and the remaining 543 athletes (242 male and 301 female) aged 20.79±3.56 years with an average weight of 58.03±10.95 kg and height of 167.38±8.68 cm, were included in this study. Among these, 47 are from indoor sports, and 496 are from outdoor sports.

Training Experience: About 90% of the participants had training experience of more than three years in their specific sports discipline, and around 10% had 1-3 years of experience.

Skin Phototype: Details of the skin phototype were collected based on the classification of Fitzpatrick skin type (or phototype) since the cutaneous synthesis of vitamin D3 is greatly affected by the levels of the skin pigment melanin. Fitzpatrick's skin type is a way to classify the skin by its reaction to exposure to sunlight (as mentioned in Figure I).

Fig 1: The Fitzpatrick Skin Phototype Scale

The skin phototype of most of the participants was type III (45%), followed by Type II (22.8%), Type IV (20.8%), Type I (5.6%), Type V (5.1%), and type VI (0.4%). So, 88.8% of the participants fell into the categories between type II to IV. The same has been depicted in image II.

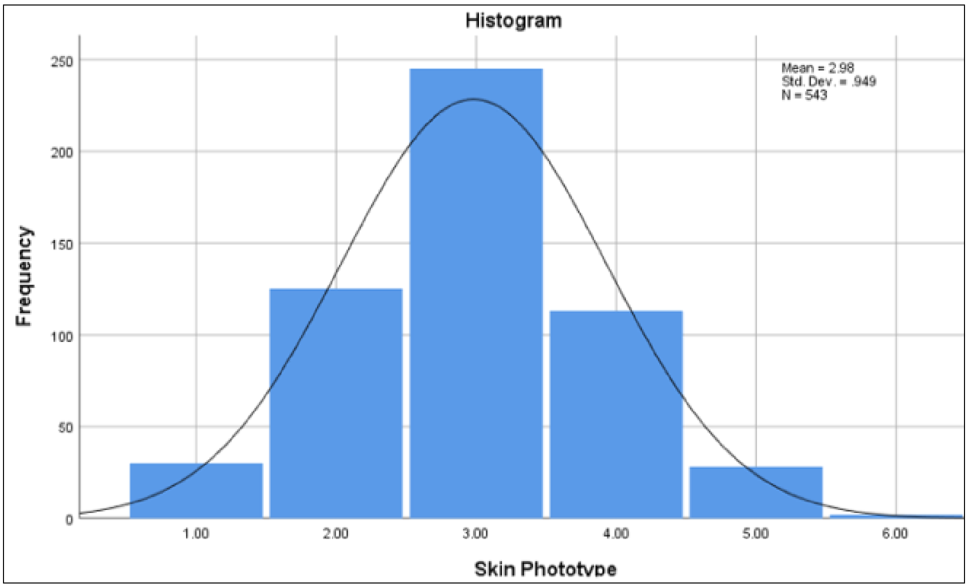

Fig 2: Skin Phototype Distribution of Participants.

Dietary habits: 89.5% of the participants (486 out of 543) were nonvegetarians, 5.7% (31 out of 543) were eggetarians, 4.2% (23 out of 543) were pure vegetarians, and 0.6% (3 out of 543) were following a vegan diet.

Daily sun exposure: The cutaneous synthesis of vitamin D by UVB rays is greatly affected by many factors such as season, time of day, latitude, altitude, Zenith angle, air pollution, skin pigmentation, sunscreen use, and aging (Wacker & Holick, 2013) [13].

The zenith angle will be increased at higher latitudes, early morning, and late afternoon. The solar zenith angle is more oblique during early morning and late afternoon; hence, very few UVB photons can reach the Earth. Therefore, less vitamin D_3 can be produced in the skin before 10 a.m. and after 3 p.m., even during summer (Holick, 2007a) [14]. The details of sun exposure duration were collected from the study participants, 60% of the participants reported less than 30 minutes of sun exposure, and 40% reported more than 30 minutes of daily exposure between 10 a.m. and 3 p. m.

3. Specimen collection and assay: All the participants refrained from sports training 24 hours before the sample collection (Pre-exercise) to avoid acute exercise-induced shifts in plasma volume. Overnight fasting blood samples were collected from the participants in a seated position from the antecubital vein into plain evacuated tubes with a clot activator. Following clotting, the sample is centrifuged at 1000 g for 10 minutes to separate the serum for 25(OH) vitamin D analysis. 25(OH)vitamin D levels were analyzed by using 25(OH) Vitamin D ELISA kit by Calbiotech.

4. Statistical Analysis

The numerical data obtained were analyzed using SPSS software (version 23.0). All values are expressed in mean±standard deviation. The Frequencies were used to understand the Vitamin D status among the athletic population. The Vitamin D deficiency and insufficiency prevalence were measured in the Indian athletic population as per the norms suggested by the IOM and Endocrine Society, Shapiro-Wilk test was used to check the normal distribution, the Tueky test was used for identifying the outliers (Horn et al., 2001) [18], and the 95% reference intervals were calculated by using Med Calc software 2016. Clinical and Laboratory Standard Institute (CLSI) guidelines C28-A2 and C28-A3 were used for estimating percentiles and their 95% Reference intervals (Ozarda, 2016). The robust method was used as an alternative to the percentile method where the sample size is less than 120.

5. Results

Table 1: Basic details of the participants (N= 543)

Variable	**Mean ±SD**
Age (years)	20.79±3.56
Height (cm)	167.38±8.68
Weight (Kg)	58.03±10.95

Table 2: 25 (OH) Vitamin D status in athletes as per Endocrine Society Guidelines

Groups	N statistic	25(OH) Vitamin D ng/mL (Mean± SD)	Deficiency%	Insufficiency%	Sufficiency%	Vit D >100 ng/ml
All athletes	543	36.49±20.13	10.1	27.6	61.1	1.1
Male Athletes	242	39.98±22.1	5.8	21.1	71.5	1.6
Female Athletes	301	34.48±18.14	13.6	32.9	52.8	0.6
Indoor athletes	47	36.26±15.83	14.9	27.7	57.4	0
Outdoor athletes	496	36.51±20.5	9.7	27.6	61.5	1.2

Table 3: 25 (OH) Vitamin D status in athletes as per IOM guidelines

Groups	N statistic	25(OH) Vitamin D ng/mL (Mean ±SD)	Deficiency%	Insufficiency%	Sufficiency%	Vit D >100 ng/ml
All athletes	543	36.49±20.13	1.5	8.6	88.8	1.1
Male Athletes	242	39.98±22.1	0.8	5	92.6	1.6
Female Athletes	301	34.48±18.14	2	11	86.3	0.6
Indoor athletes	47	36.26±15.83	0	14.9	85.1	0
Outdoor athletes	496	36.51±20.5	2	7.7	90.9	1.2

Table 4: 25 (OH) Vitamin D status in athletes of different sports as per Endocrine Society Guidelines

Sports Discipline	N statistic	25(OH) Vitamin D ng/mL (Mean± SD)	Deficiency %	Insufficiency %	Sufficiency%	Vit D >100 ng/ml
Athletics	246	40.27±26.5	10.2	28.5	58.9	2.4
Hockey	250	32.8±10.8	9.2	26.8	64	0
Taekwondo	29	36.33±15.48	10.3	31	58.6	0
Weightlifting	18	36.2±16.85	22.2	22.2	55.6	0

Table 5: 95% Confidence Interval of 25 (OH) Vitamin D in athletes (CLSI C28-A3)

Groups	N statistic*	25(OH) Vitamin D ng/mL		Lower Limit	90%CI for Lower Limit	Upper Limit	90% CI for the Upper limit
		Mean	Median				
All Athletes	479	32.2	32.1	17.62	16.88-19.09	59	56.2 -59.7
Male Athletes	222	36	33.6	21.4	20.43-23.16	63.9	59-69.9
Female Athletes	267	30.9	30	15.1	14.7 -16.7	58.85	54.4-59.7
Outdoor Athletes	453	33.2	32.6	18.1	16.8- 19.2	63.4	60.7-69.4
Indoor athletes#	47	33.3	32.4	13.8	11.82-16.11	79.3	65.3-93.4
Athletics	236	34.7	32.1	14.1	12.2-16.2	90.8	70.5-99.3
Hockey	229	32.6	33	20	18.8-20.7	54.8	52.1-57.5

N Statistic* after excluding the outliers; # The robust method was used as an alternative to the percentile method.

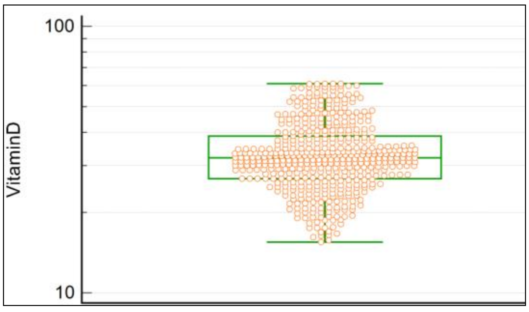

Fig 3: Distribution of 25(OH)Vitamin D in Indian Athletes

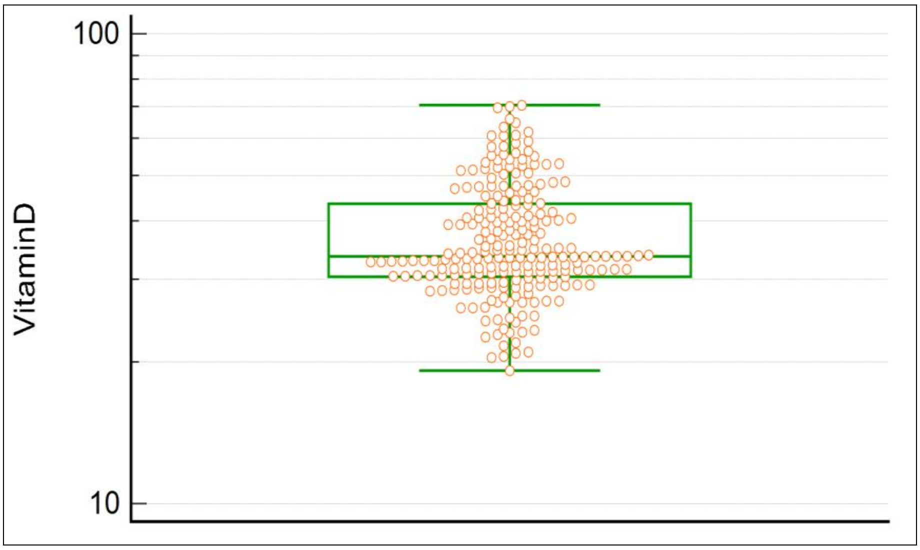

Fig 4: Distribution of 25(OH)Vitamin D in Male Athletes

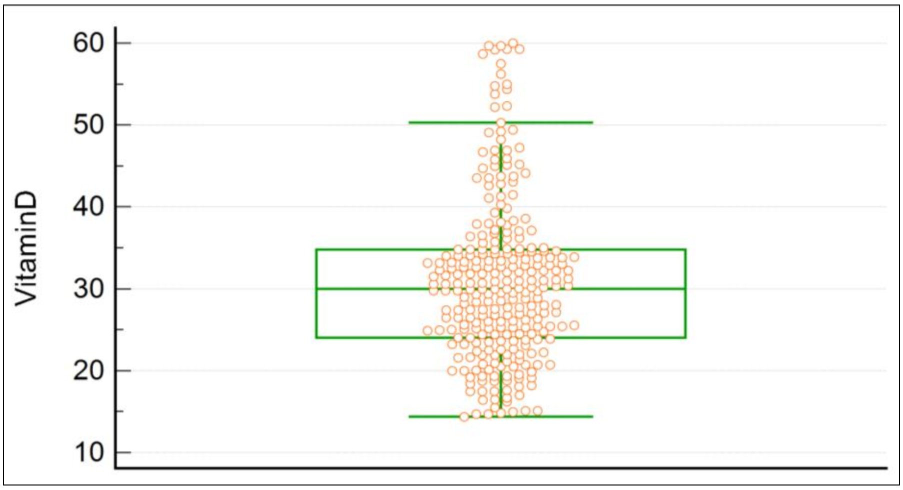

Fig 5: Distribution of 25(OH)Vitamin D in Female Athletes

6. Discussions

Out of 543 athletes who participated in this study, 242 were male athletes, and 301 were female athletes. Forty-seven out of 543 were from indoor sports, such as Taekwondo (29 participants) and Weightlifting (18 participants), and the remaining 496 were from outdoor sports, such as athletics (246 participants), and hockey (250 participants). The mean age of the participants was 20.79±3.56 years. The average 25(OH) Vit D levels of participants from both genders were 36.49±20.13. In male athletes, it was 39.98±22.1, and in female athletes, it was 34.48±18.14.

Comparison of 25(OH)Vitamin D levels as per the standards of the Endocrine Society: As per the standards set by the Endocrine Society, 10.1% of Indian athletes were vitamin D deficient, 27.6% were insufficient and 61.1% of the total athletes had sufficient Vitamin D levels. (i.e., 30-100ng/ml). The prevalence of Vitamin D deficiency observed in this study was less than that of north Indian athletes reported by Gupta. R et al. in 2021 [13]. According to their study, 69.9% of the participants from North India were vitamin D Deficient (Gupta et al., 2021) [13]. This can be due to the availability of sunlight in the southern part of India.

Female athletes exhibited higher incidences of both Vitamin D deficiency and insufficiency compared to their male counterparts. Vitamin D deficiency percentage was 13.6% in female athletes, which is 2.3 times more compared with male athletes (i.e.,5.8%), Additionally, 32.9% of female athletes were vitamin D insufficient, while the proportion of male athletes, with insufficiency, was 21.1%.%. Interestingly, a higher percentage of male athletes (71.5%) demonstrated sufficient Vitamin D levels in contrast to 52.8% of female athletes.

Another crucial observation was that Vitamin D deficiency prevalence was high among indoor athletes when compared to outdoor athletes. Vitamin D deficiency in indoor athletes (14.9%) was 1.53 times higher when compared with that of outdoor athletes (i.e., 9.7%). However, the vitamin D insufficiency percentages were almost similar in indoor and outdoor athletes (27.7% & 27.6%). In indoor athletes, the range of vitamin D was narrow with a minimum of 12.7 ng/ml and a maximum of 68.68 ng/ml, on the other hand, outdoor athletes had a wider range of Vitamin D levels, spanning from 4.96 ng/ml to 227.7 ng/ml. None of the indoor athletes have shown 25 (OH) Vitamin D levels above 100 ng/ml, but 1.2% of outdoor athletes have shown vitamin D levels above 100 ng/ml.

Comparison of 25(OH)Vitamin D levels as per the standards of IOM: As per the standards set by the IOM, only 1.5% of the Indian athletes were vitamin D deficient, and 8.6% were insufficient. 88.8% of the total athletes had sufficient Vitamin D levels. (i.e.,25(OH) vit D levels > 20 ng/ml). However, the Vitamin D deficiency and insufficiency proportions were more in female athletes when compared to male athletes. Vitamin D deficiency percentage was 2% in female athletes, which is 2.5 times more compared with male athletes (i.e.,0.8%), and 11% of female athletes were vitamin D insufficient, whereas, in male athletes, it was around 5%. As per this evaluation, 86.3% of female and 92.6% of male athletes have displayed vitamin D sufficiency.

When 25(OH) vitamin D levels are compared between the participants of different sports disciplines, the highest incidence of vitamin D insufficiency/deficiency (49%) was observed in weightlifters followed by taekwondo (41.3%), athletics (38.7%) and Hockey (36%). However, it is important to note that only eighteen subjects from the weightlifting discipline participated in this study. To establish more robust conclusions, further research should be conducted with a larger sample. Despite this limitation, the study's results clearly indicate a noteworthy trend: indoor athletes in taekwondo and weightlifting show a higher incidence of vitamin D deficiency/ insufficiency compared to outdoor athletes in athletics and hockey.

Customized reference range of 25(OH)Vitamin D levels for Indian athletes: The results showed that the 95% confidence intervals for 25(OH)D in all athletes ranged from 17.62 to 59 ng/mL. the same has been depicted in image III.

As depicted in images IV & V, Male athletes exhibited a slightly higher confidence interval for 25 (OH) vitamin D, ranging from 21.4 to 63.9 ng/mL, whereas female athletes had a slightly lower range of 15.1 to 58.85 ng/mL.

Furthermore, the study explored the differences in 25(OH)D levels between athletes participating in outdoor and indoor sports. Outdoor athletes displayed a reference interval of 18.1 to 63.4 ng/mL, while indoor athletes had a wider range of 13.8 to 79.3 ng/mL. These findings suggest that exposure to sunlight, which is a primary source of vitamin D, might have contributed to the elevated lower limit of 25(OH)D in outdoor athletes. Since the sample size of indoor athletes was small (48), the robust method with bootstrap was performed to derive the 90% confidence interval. A critical drawback of this approach is that the 90% CIs can be very wide if the sample size is smaller than 80 (Ceriotti et al., 2009) [4].

Additionally, the study analyzed specific sports and found variations in 25(OH)D levels among athletes participating in different disciplines. Athletes involved in athletics exhibited a reference interval of 14.1 to 90.8 ng/mL, indicating a wider range compared to hockey. This might be attributed to the diverse events encompassed within the discipline. Athletics encompasses a broad range of activities, including sprinting, long-distance running, jumping, and throwing, each with varying levels of outdoor exposure and intensity. These factors could potentially influence vitamin D synthesis and absorption, resulting in a wider distribution of 25(OH)D levels among athletes participating in athletics. Alternatively, Hockey players demonstrated a narrower Reference interval of 20 to 54.8 ng/mL, indicating a more consistent pattern of Vitamin D levels within this group.

Due to the small sample sizes, Taekwondo and Weightlifting were not considered for developing the sports-specific analysis of reference intervals.

These variations in reference intervals highlight the influence of factors such as gender, sport type, and indoor/outdoor environments on 25(OH)D levels in athletes. The wider confidence intervals observed in certain groups may indicate a higher degree of variation in Vitamin D levels, possibly due to differences in exposure to sunlight or dietary habits. Hence it is crucial to consider these factors when assessing vitamin D status and designing interventions to optimize athletes' health and performance.

From the present study, it was noticed that there is a huge gap in the standards set by the Endocrine Society and IOM regarding the vitamin D range and as per the standards set by the Endocrine Society, the deficiency and insufficiency incidence of Vitamin D in Indian athletes was more. To determine whether the suboptimal 25(OH) vitamin D levels are a result of true deficiency or insufficiency, it is recommended to assess additional parameters such as free vitamin D levels, Parathyroid Hormone (PTH) levels, and Bone Mineral Density (BMD), etc. Hypovitaminosis D could cause decreased bone mineral density (Arya et al., 2004) [1], secondary hyperparathyroidism (Chandran et al., 2011) [5], and Sarcopenia; it is important to monitor these parameters periodically to avoid injury risks and to maintain optimum bone and muscle health in athletes.

7. Conclusion

Based on the findings of the study, it is evident that the incidence of vitamin D deficiency/insufficiency among Indian athletes was approximately 37.7% based on the norms provided by the Endocrine Society. Notably, deficiency and insufficiency were more common in female athletes compared to their male counterparts, and indoor athletes exhibited a higher prevalence of deficiency/insufficiency compared to outdoor athletes.

Conversely, the reference ranges of 25(OH) vitamin D among Indian athletes align well with the standards set by the Institute of Medicine (IOM), with a lower prevalence of vitamin D deficiency and insufficiency observed at approximately 10%.

The discrepancies in reference ranges provided by the IOM and the Endocrine Society pose significant challenges for clinicians, researchers, and public health officials striving to establish consistent guidelines for assessing and managing vitamin D status. These variations have implications that extend beyond clinical practice, affecting public health initiatives, nutritional recommendations, and research outcomes. Therefore, it is crucial to consider population-specific factors and establish reference ranges tailored to athletic populations to ensure accurate assessment and management of vitamin D status.

Moreover, mild to moderate vitamin D deficiency is known to be associated with osteoporosis, secondary hyperparathyroidism, and decreased bone mineral density in athletes. Therefore, routine vitamin D assessment is crucial to identify deficiencies at an early stage, mitigate associated risk factors, and promote optimal health among athletes.

Further research is warranted to explore alternative biochemical markers for detecting true vitamin D deficiency, as well as to investigate specific factors contributing to the observed prevalence rates and the long-term health consequences associated with vitamin D deficiency/insufficiency in athletes.

8. Limitations: The results of this study are limited by the small sample sizes of participants from indoor sports, which prevented the derivation of sports-specific Reference Intervals for Taekwondo and Weightlifting.

9. Conflicts of Interest: There are no conflicts of interest.

10. References

1. Arya V, Bhambri R, Godbole MM, Mithal A. Vitamin D status and its relationship with bone mineral density in healthy Asian Indians. Osteoporos Int. 2004;15(1):56–61. doi: 10.1007/s00198-003-1491-3
2. Bouillon R, Carmeliet G, Verlinden L, van Etten E, Verstuyf A, Luderer HF, *et al*. Vitamin D and Human Health: Lessons from Vitamin D Receptor Null Mice. Eur J Endocrinol. 2008. Doi:10.1210/er.2008-0004
3. Cannell JJ, Hollis BW, Sorenson MB, Taft TN, Anderson JJB. Athletic performance and vitamin D. Med Sci Sports Exerc. 2009;41(5):1102–1110. Doi:10.1249/MSS.0B013E3181930C2B
4. Ceriotti F, Hinzmann R, Panteghini M. Reference intervals: The way forward. Ann Clin Biochem. 2009;46(Pt 1):8–17. Doi:10.1258/ACB.2008.008170
5. Chandran M, Hoeck HC, Wong HC, Zhang RF, Dimai HP. Vitamin D status and its relationship with bone mineral density and parathyroid hormone in southeast Asian adults with low bone density. Endocr Pract. 2011;17(2):226–234. Doi:10.4158/EP10202.OR
6. Chapuy MC, Schott AM, Garnero P, Hans D, Delmas PD, Meunier PJ. Healthy Elderly French Women Living at Home Have Secondary Hyperparathyroidism and High Bone Turnover in Winter. J Clin Endocrinol Metab. 1996;81(3):1129-1133. Doi:10.1210/jcem.81.3.8772585
7. de La Puente Yagüe M, Collado Yurrita L, Cabañas MJC, Cenzual MAC. Role of Vitamin D in Athletes and Their Performance: Current Concepts and New Trends. Nutrients. 2020;12(2):579. Doi:10.3390/nu12020579
8. Deleskog A, Hilding A, Brismar K, Hamsten A, Efendic S, Östenson CG. Low serum 25-hydroxyvitamin D level predicts progression to type 2 diabetes in individuals with prediabetes but not with normal glucose tolerance. Diabetologia; c2012. doi: 10.1007/s00125-012-2529-x
9. Holick MF. Hypovitaminosis D in Medical Inpatients. N Engl J Med. 1998;338(12):777–783.
10. Gagnon C, Lu ZX, Magliano DJ, Dunstan DW, Shaw JE, Zimmet PZ, et al. Low serum 25-hydroxyvitamin D is associated with increased risk of the development of the metabolic syndrome at five years: Results from a national, population-based prospective study (The Australian Diabetes, Obesity and Lifestyle Study: AusDiab). J Clin Endocrinol Metab; c2012. doi: 10.1210/jc.2011-3187
11. Girgis CM, Clifton-Bligh RJ, Hamrick MW, Holick MF, Gunton JE. The roles of vitamin D in skeletal muscle: Form, function, and metabolism. Endocr Rev; c2013. doi: 10.1210/er.2012-1012
12. Girgis CM, Clifton-Bligh RJ, Turner N, Lau SL, Gunton JE. Effects of vitamin D in skeletal muscle: Falls, strength, athletic performance and insulin sensitivity. Clin Endocrinol. 2014;80(2):169–181. Doi:10.1111/cen.12368
13. Gupta R, Bohat V, Kapoor A, Singhal A, Soni A, Masih G. High prevalence of Vitamin D deficiency among North Indian athletes. Indian J Community Med. 2021;46(3):559–561. Doi:10.4103/ijcm.IJCM_170_21
14. Holick MF. Sunlight, UV-Radiation, Vitamin D and Skin Cancer: How Much Sunlight Do We Need? J Invest Dermatol; c2007.
15. Holick MF. Vitamin D Deficiency. N Engl J Med. 2007;357(3):266–281. Doi:10.1056/NEJMra070553
16. 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; c2011. doi: 10.1210/jc.2011-0385
17. Holick MF, Siris ES, Binkley N, et al. Prevalence of vitamin D inadequacy among postmenopausal North American women receiving osteoporosis therapy. J Clin Endocrinol Metab; c2005. Doi:10.1210/jc.2004-2364
18. Horn PS, Feng L, Li Y, Pesce AJ. Effect of outliers and nonhealthy individuals on reference interval estimation. Clin Chem; c2001. p. 47 (12), 2137–2145
19. Morelli S, Buitrago C, Boland R, de Boland AR. The stimulation of MAP kinase by 1,25(OH)2-vitamin D3 in skeletal muscle cells is mediated by protein kinase C and calcium. Molecular and Cellular Endocrinology. 2001;173(1-2):41-52. https://doi.org/10.1016/S0303-7207(00)00435-4
20. Ozarda Y. Special issue: Responsible writing in science Reference intervals: current status, recent developments and future considerations. Biochemia Medica. 2016;26(1):5-16. https://doi.org/10.11613/BM.2016.001
21. Ross Catharine A. Institute of Medicine (U.S.). Committee to Review Dietary Reference Intakes for Vitamin D and Calcium. DRI, Dietary Reference Intakes : Calcium, Vitamin D. National Academies Press, 2011.
22. Shuler FD, Wingate MK, Moore GH, Giangarra C. Sports Health Benefits of Vitamin D. Sports Health. 2012;4(6):496-501. https://doi.org/10.1177/1941738112461621
23. Sørensen OH, Lund B, Saltin B, Lund B, Andersen RB, Hjorth L, *et al*. Myopathy in Bone Loss of Ageing: Improvement by Treatment with 1α-hydroxycholecalciferol and Calcium. Clinical Science. 1979;56(2):157-161. https://doi.org/10.1042/CS0560157
24. Testosterone Deficiency in Young Men: Marked Alterations in Whole Body Protein Kinetics, Strength, and Adiposity*. In J Clin Endocrinol Metab. 1998, Vol. 83. https://academic.oup.com/jcem/article/83/6/1886/2865200
25. Visser M, Deeg DJH, Lips P. Low Vitamin D and High Parathyroid Hormone Levels as Determinants of Loss of Muscle Strength and Muscle Mass (Sarcopenia): The Longitudinal Aging Study Amsterdam. Journal of Clinical Endocrinology and Metabolism. 2003;88(12):5766-5772. https://doi.org/10.1210/jc.2003-030604
26. Wacker M, Holick MF. Sunlight and Vitamin D: A global perspective for health. In *Dermato-Endocrinology*. Landes Bioscience. 2013;5(1):51-108. https://doi.org/10.4161/derm.24494
27. Wehr E, Pilz S, Boehm BO, März W, Obermayer-Pietsch B. Association of vitamin D status with serum androgen levels in men. Clinical Endocrinology. 2010;73(2):243-248. https://doi.org/10.1111/J.1365-2265.2009.03777.X
28. Willis KS, Smith DT, Broughton KS, Larson-Meyer E. Vitamin D status and biomarkers of inflammation in runners. Open Access Journal of Sports Medicine. 2012;2012:3-35. https://doi.org/10.2147/OAJSM.S31022