The annual vitamin D status of world-class British swimmers following a standardised supplementation protocol for three years

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Abstract

British swimmers are at a heightened risk of vitamin D deficiency (serum 25-hydroxyvitamin D (25(OH)D): <50 nmol•L^{-1}) as their large indoor training volumes often restrict sunlight exposure, especially during the winter when daylight hours are reduced. Previous research has recommended 4000 IU•day^{-1} vitamin D_3 from October to March to offset vitamin D losses. However, no current study has analysed this approach over multiple seasons to assess if this is an appropriate strategy. Twenty-nine world-class British swimmers (aged 16–30 years) provided a 10 mL venous blood sample as part of their routine haematological screening in the September of three consecutive years (2018, 2019, 2020). Serum 25(OH)D was determined by radioimmunoassay and this result determined the length of the standardised vitamin D_3 protocol (< 30 nmol•L^{-1}: 4000 IU•day^{-1} from September to March, 30–79 nmol•L^{-1}: 4000 IU•day^{-1} from October to March, > 75 nmol•L^{-1}: no supplementation). Mean serum 25(OH)D concentrations increased each year (2018: 76.4 ± 28.4 nmol•L^{-1}, 2019: 91.5 ± 24.8 nmol•L^{-1}, 2020: 115.0 ± 36.6 nmol•L^{-1}, $p < 0.001$), which coincided with the eradication of vitamin D deficiency after one season (prevalence, 2018: 10%, 2019: 0%, 2020: 0%). In September 2020, 35% of swimmers had a serum 25(OH)D > 125 nmol•L^{-1}, although it is currently debated whether this is a concern or a benefit for athletic populations. Supplementing with 4000 IU•day^{-1} of vitamin D_3 throughout the winter can therefore increase the vitamin D status of swimmers. However, more frequent testing may be required to ensure that serum 25(OH)D remains within the sufficient across the season (75–125 nmol•L^{-1}).

Key Points

- A vitamin D_3 supplement strategy based on 4000 IU•day^{-1} eradicated vitamin D deficiency (serum 25(OH)D: <50 nmol•L^{-1}) within world-class British swimmers in just one year.
- The percentage of swimmers achieving a sufficient vitamin D status (serum 25(OH)D: >75 nmol•L^{-1}) increased each swimming season (2018: 34%, 2019: 69%, 2020: 93%). However, this also coincided with an increasing number of swimmers with 'high' serum 25(OH)D (> 125 nmol•L^{-1}) concentration (2018: 10%, 2020: 35%).
- Since vitamin D was only analysed in September each year, further research is needed to ensure that the current supplement regime offsets serum 25(OH)D losses in the winter months.

1. Introduction

The past decade has overseen an emergence of evidence detailing the importance of vitamin D for optimal physiological function, including essential roles in immunity, skeletal muscle remodelling, protein synthesis, and bone health [1–3]. With each of these functions also associated with long-term physical performance, it is unsurprising that athletes are encouraged to maintain a sufficient vitamin D status (serum 25-hydroxyvitamin D (25(OH)D) concentration ≥ 75 nmol•L^{-1}) year-round to support training adaptations and reduce injury risks [3, 4]. Approximately 80–90% of 25(OH)D is synthesised through a complex reaction involving ultraviolet-B radiation (e.g., sunlight) and the skin [3], therefore maintaining a sufficient status can be problematic in the autumn and winter due to poor weather conditions and diminishing hours of daylight in Britain [2, 5]. Furthermore, athletes that complete a large quantity of indoor training (e.g., swimmers) are at a heighted risk of insufficient vitamin D (serum 25(OH)D < 75 nmol•L^{-1}) as direct sun exposure can easily be avoided throughout the year [4, 6]. Indeed, studies have identified a high prevalence of vitamin D insufficiency in swimmers from Denmark (45% [7]) and Virginia, USA (79% [8]), whereas the mean 25(OH)D of swimmers from the warm weather climates of Israel were still unable to reach the sufficient threshold (56.9–69.3 nmol•L^{-1} [9–11]). Considering that British swimmers cannot solely rely on sunlight exposure to obtain a sufficient vitamin D status, it is clear that this population could benefit from increasing their dietary vitamin D intake.

A dietary intake of 400 IU•day^{-1} (10 µg•day^{-1}) is currently recommended to avoid vitamin D deficiency (serum 25(OH)D < 50 nmol•L^{-1}) in Great Britain [12, 13]. This is equivalent to consuming 70 g herring, 85 g salmon, or 5 large eggs (250 g) every day [14], which a target that is often not achieved in the diets of swimmers (84–368 IU•day^{-1} [7, 15–17]. Combined with a lack of sunlight exposure, a failure to consume adequate vitamin D has been shown to cause − 30 nmol•L^{-1} decrements in 25(OH)D within the first 3–4 months of the swimming season (August to November/December) [8, 18]. Over the same timeframe, however, supplementation with 4000 IU•day^{-1} or 5000 IU•day^{-1} of vitamin D_3 increased 25(OH)D concentrations by + 20 nmol•L^{-1} (August to December [18]) and + 14 nmol•L^{-1} (August to November [8]), respectively. Interestingly, Lewis et al. [18] continued supplementation for a further three months (August to March), yet this extended time did not continuously increase 25(OH)D concentrations (March vs. August: +3 nmol•L^{-1}). Based on this evidence, indoor athletes are encouraged to supplement with 4000 IU•day^{-1} of vitamin D_3 in the autumn and winter in order to sustain a sufficient vitamin D status throughout the entire competitive season [19]. Despite this suggestion, no research to date has investigated the cumulative effect that vitamin D_3 might have on the annual vitamin D status of swimming athletes. This study therefore retrospectively analysed the three-year change in 25(OH)D that was collected from world-class British swimmers following their annual ingestion of 4000 IU•day^{-1} of vitamin D_3.

2. Methods

2.1 Participants

Twenty-nine world-class swimmers (aged 16–30 years) were involved in this study. Each participant was a nationally funded athlete that was competing at the international level between 2018 and 2021 (mean age, 2018: 21.0 ± 3.0 years; 2019: 22.0 ± 3.0 years; 2020: 23.0 ± 3.0 years). All swimmers trained in indoor venues in Great Britain, which are all located at latitudes > 51° N. In September of each year, all swimmers provided a venous blood sample that was analysed for serum 25(OH)D as part of wider haematological screen. All swimmers gave their informed consent to have their 25(OH)D data anonymised for the purpose of this study. The study was granted ethical approval by Birmingham City University (Newbury/#10152/sub2/R(A)/2022/Jan/HELS FAEC)

2.2 Blood Sampling Procedure

All swimmers attended British Swimming's medical facilities to give a 10 mL blood sample from antecubital vein of the forearm. Blood was drawn by a clinically trained phlebotomist and stored at room temperature for < 60 min until all selected swimmers had given their sample for that day. Once blood collection was complete, the samples were immediately couriered to an independent laboratory (2018 and 2019: Queen's Medical Centre, Nottingham; 2020: Nationwide Pathology, Lutterworth, Leicestershire) for radioimmunoassay analysis. For the purpose of this study, serum 25(OH)D concentrations were interpreted as severely deficient': <25 nmol•L^{-1}, 'deficient': 25–49 nmol•L^{-1}, 'insufficient': 50–74 nmol•L^{-1}, 'sufficient': 75–125 nmol•L^{-1}, 'high, but reportedly safe': 126–250 nmol•L^{-1}, and 'potentially toxic': >250 nmol•L^{-1} in accordance with previous research [3, 20, 21].

2.3 Supplement Protocol

All swimmers were provided with a sufficient amount of vitamin D_3 capsules (4000 IU, Elite Vitamin D_3, Healthspan, Guernsey, UK) to last the entire dosing period (Table 1) and were instructed to request a repeat provision should their supply run out. Alongside verbal communication, a short advice sheet was provided to the swimmers to improve their understanding of vitamin D_3 supplementation. No prescriptive instructions were given on when to take the supplement, but advice was given to take at a time that the individual was most likely to keep consistent (e.g., with breakfast, last thing at night). Importantly, no further guidance was given regarding other sources of either dietary or supplemental vitamin D, therefore most swimmers may have also consumed an additional 200 IU•day^{-1} through a daily multivitamin (Elite Gold A-Z, Healthspan, Guernsey, UK). Whereas each swimmer was allocated the same amount of daily vitamin D_3, the advised timeframes for supplementation differed per individual based upon the results of their September 25(OH)D screening results. Supplement protocols were selected and managed by British Swimming's Chief Medical Officer and experienced sport nutritionists in collaboration with the English Institute of Sport. The protocols coincide with recommendations from previous research in swimmers [18] and are within the safe upper limit for adults and adolescents [13]. Throughout the study, there were no systematic attempts to monitor supplement adherence.

Table 1
The vitamin D_3 supplement protocols that were assigned to assigned to swimmers based upon their baseline serum 25-hydroxyvitamin-D (25(OH)D) concentration.

Serum 25(OH)D Concentration	Supplementation	Timeframe	Further Recommendation
< 30 nmol•L^{-1}	4000 IU•day^{-1}	Immediately (September – March)	Retest 25(OH)D after six weeks, including parathyroid hormone and alkaline phosphatase
30–50 nmol•L^{-1}	4000 IU•day^{-1}	Immediately (September – March)	Retest 25(OH)D after six weeks
51–80 nmol•L^{-1}	4000 IU•day^{-1}	24 weeks (October – March)	Safely increase sunlight exposure in the summer months
80–125 nmol•L^{-1}	4000 IU•day^{-1}	24 weeks (October – March)	
> 125 nmol•L^{-1}	No supplementation		

2.4 Statistical Analyses

Data was normally distributed (Shapiro-Wilks) and sphericity was not violated (Mauchly) prior to statistical analysis. A repeated measures ANOVA was performed to establish mean differences between the serum 25(OH)D concentrations at each time point (2018, 2019, 2020). Post hoc comparisons were determined by the Bonferroni correction and main effect sizes are reported as partial eta squared (Pη^2). Main effect sizes were interpreted as ‘small’ (0.01–0.05), ‘medium’ (0.06–0.13), and ‘large’ (> 0.13) [22]. In addition, Cohen’s *d* effect sizes were calculated for yearly 25(OH)D comparisons (2018 vs. 2019, 2019 vs. 2020, and 2018 vs. 2020), which were interpreted as ‘trivial’ (< 0.20), ‘small’ (0.20–0.49), ‘medium’ (0.50–0.79), and ‘large’ (≥ 0.80) [22]. Coefficient of variation (CV) was calculated for the inter-individual differences in 25(OH)D change over time using SD/mean x 100. All statistical tests were completed using Statistical Package for the Social Sciences (SPSS), version 25 (IBM, Chicago, USA). All data are reported as mean ± SD with statistical significance set at $p \leq 0.05$.

3. Results

Mean 25(OH)D concentrations increased across the sampling timeframe ($p < 0.001$, pη^2=0.47), with these changes occurring in an incremental fashion from 2018 (76.4 ± 28.4 nmol•L^{-1}) to 2019 (91.5 ± 24.8 nmol•L^{-1}, $p = 0.035$, $d = 0.57$), and again from 2019 to 2020 (115.0 ± 36.6 nmol•L^{-1}, $p = 0.001$, $d = 0.75$;

Fig. 1). Over the two-year supplement period, there was a 50.5% increase in the mean serum 25(OH)D concentrations of world-class British swimmers (+ 38.6 nmol•L^{-1}, $p < 0.001$, $d = 1.18$).

Figure 1 Yearly change (2018–2020) in the serum 25-hydroxyvitamin D (25(OH)D) concentrations of world-class British swimmers. ● signifies individual data points

Ten percent (3 of 29) of swimmers had a deficient vitamin D status in 2018, including one individual that was classified as severely deficient (23 nmol•L^{-1}). This was the only year that vitamin D deficiency was observed across the sampling timeframe with all remaining 25(OH)D concentrations ≥ 50 nmol•L^{-1} in 2019 and 2020 (Table 2). Insufficient 25(OH)D concentrations more than halved on a yearly basis, with 66% (n = 19) identified in 2018, 31% (n = 9) in 2019, and 7% (n = 2) in 2020. Similarly, the highest recorded 25(OH)D concentration increased each year from 136 nmol•L^{-1} in 2018 to 163 nmol•L^{-1} in 2019, and finally 193 nmol•L^{-1} in 2020.

Table 2
Breakdown of elite British swimmers' vitamin D status between 2018–2020.

Serum 25(OH)D Concentration (nmol•L^{-1})	Swimmers in Each Category					
	2018		2019		2020	
	%	n / 29	%	n / 29	%	n / 29
0–24	3.4%	1	0%	0	0%	0
25–49	6.9%	2	0%	0	0%	0
50–74	55.2%	16	31.0%	9	6.9%	2
75–125	24.1%	7	62.1%	18	58.6%	17
126–250	10.3%	3	6.9%	2	34.5%	10

Ranges are interpreted as: 0–24 nmol•L^{-1} = 'severely deficient', 25–49 nmol•L^{-1} = 'deficient', 50–74 nmol•L^{-1} = 'insufficient', 75–125 nmol•L^{-1} = 'sufficient', 126–250 nmol•L^{-1} = 'high, but reportedly safe'.

4. Discussion

This was the first study to have monitored the annual change in serum 25(OH)D concentrations in world-class British swimmers. Moreover, this study investigated how this cohort responded to an individualised 4000 IU•day^{-1} vitamin D_3 protocol. Within one year of supplementation, vitamin D deficiency (< 50 nmol•L^{-1}) was completely eradicated from within the group. Moreover, mean serum 25(OH)D increased on yearly basis until almost all swimmers (93%) displayed a sufficient vitamin D status (> 75 nmol•L^{-1}) by the 2020 timepoint. However, a limitation was that serum 25(OH)D was measured in the September of each year, therefore whether this protocol offset deficiency over the winter months remains unclear. In the final year of observations, 35% of the cohort had 'high, but reportedly safe' (126–250 nmol•L^{-1}) 25(OH) concentrations, which suggests that that toxicity may occur when utilising this strategy for over two years. More frequent haematological screening is therefore encouraged in order to identify appropriate supplementation approaches for each individual.

In September 2018, world-class British swimmers had a group mean 25(OH)D of 76.4 ± 28.4 nmol•L^{-1}, suggesting that the majority of this cohort had sufficient vitamin D concentrations [3, 6]. However, based on previous studies, an autumn 25(OH)D concentration above 122.5 nmol•L^{-1} may be necessary to sustain serum 25(OH)D > 75 nmol•L^{-1} throughout the winter months [23]. Indeed, a multi-cultural cohort of footballers based in Great Britain failed to maintain their ‘sufficient’ status (August: 104.4 ± 21.1 nmol•L^{-1}) even after 18 weeks of daily outdoor training (December: 51.0 ± 19.0 nmol•L^{-1} [24]). This is more concerning for swimmers when analysing individual data, which identified that September 25(OH)D levels were below 75 nmol•L^{-1} in two thirds of the current cohort. Given that this measurement was taken immediately following Britain’s peak sunlight hours (May to August), this would suggest that British swimmers could be at a high risk of deficiency during the winter without vitamin D_3 supplementation. Without a winter measurement, the current study cannot directly confirm how 4000 IU•day^{-1} affected the serum 25(OH)D concentrations of world-class swimmers. Nonetheless, based on previous research, NCAA Division I swimmers maintained mean concentrations of 100 nmol•L^{-1} from October to March when using the same supplemental dose [18]. Based on this evidence, it is purported that vitamin D status was maintained at a higher concentration in the winter before being increased by summer sunlight exposure. This would partly explain why incremental increases in serum 25(OH)D that were observed each year. Future studies are therefore required with increased sampling frequencies (i.e., September, December, April) to assess whether supplementation protocols ensure sufficient vitamin D concentrations across the entire season.

The increases in group mean 25(OH)D that occurred each year resulted in almost all participants (93%) achieving a ‘sufficient’ vitamin D status for the beginning of the 2020/21 season. Though this outcome is seemingly beneficial, a controversial finding was that ‘high’ 25(OH)D concentrations became more commonplace (> 125 nmol•L^{-1}; 2018: 10%, 2020: 35%). Based on the Endocrine Society guidelines, there are no risks of toxicity (i.e., hypercalcemia) when 25(OH)D is < 375 nmol•L^{-1} [25]. To ensure that this concentration is not exceeded, a safety threshold of < 250 nmol•L^{-1} is therefore recommended [25], which was not surpassed by any swimmer over research timeframe (peak recorded 25(OH)D: 193 nmol•L^{-1}). Conversely, the UK National Health Service (NHS) use more conservative guidelines akin to the American Dietetic Association (ADA), whereby serum 25(OH)D concentrations ≥ 150 nmol•L^{-1} are associated with possible adverse effects [13]. These alternative guidelines could place 24% of current swimmers at risk of symptoms, such as nausea, dehydration, and lethargy [26, 27]; though, this is uncertain since more intense dosing protocols (i.e., 10,000 IU•day^{-1} for 20 weeks) have previously been well tolerated in healthy adults [28, 29]. One explanation is that excessive vitamin D exposure increases the rate of vitamin D catabolism, subsequently creating a negative feedback loop that tightly regulates 25(OH)D < 250 nmol•L^{-1} [3, 30]. However, this study cannot support this notion since no side-effects of vitamin D toxicity were measured. Nonetheless, with no additional benefits to exceeding the 'sufficient' threshold [3], the current approach halted supplementation when serum 25(OH)D exceeded 125 nmol•L^{-1}. It is therefore speculated that serum 25(OH)D levels would decline in 'at risk' swimmers, though this requires a follow up investigation.

At present, there are no serum 25(OH)D guidelines that are considered to be optimal for world-class athletes. Due to the various metabolic roles of vitamin D, however, it has been recommended that athletes should maintain a 25(OH)D ≥ 100 nmol•L^{-1} to ensure that adequate amounts are available to support musculoskeletal health [4]. Moreover, sustaining serum 25(OH)D > 120 nmol•L^{-1} is associated with less frequent and severe upper respiratory tract infections (URTI) in endurance athletes during the winter [31]. Unpublished data from within this group found that URTIs accounted for 50% off missed training sessions in the 2016–2017 swimming season, with 56% of the world-class cohort experiencing at least one URTI instance. Therefore, fewer URTI cases would increase the consistency of training intensity, subsequently enabling greater training-induced adaptations over time [32]. Conversely, no direct ergogenic effects are expected with vitamin D_3 supplementation unless it involves the correction of neuromuscular defects caused by deficiency [2, 3, 33]. This has recently been contested, however, since 5000 IU•day^{-1} vitamin D_3 improved deadlift (vitamin D: +13.8%, placebo: +2.5%) and vertical jump (vitamin D: +13.5%, placebo: +2.1%) performance in collegiate swimmers [8]. Interestingly, both groups started (vitamin D: 112.1 ± 8.2 nmol•L^{-1}, placebo: 117.0 ± 15.4 nmol•L^{-1}) and ended the 12-week supplement protocol with a sufficient vitamin D status (vitamin D: 131.3 ± 28.6 nmol•L^{-1}, placebo: 81.3 ± 17.0 nmol•L^{-1}), although the group that supplemented with vitamin D_3 displayed a better maintenance of free testosterone levels and sex-hormone binding globulin over the research timeframe. Though unclear whether this would directly improve swimming performance, this collective evidence warrants further research to determine whether a 25(OH)D > 120 nmol•L^{-1} could support training adaptations whilst also maintaining health status.

Serum 25(OH)D is an appropriate marker of vitamin D status based on its long half-life and close association with vitamin D exposure (e.g., sunlight, food, supplementation) [3]. Whilst this measure has been discussed with relation to possible effects on illness and performance, a limitation is that other vitamin D metabolites (i.e., free 25(OH)D) have greater responsibilities within bone health [34–36]. Swimmers are consistently reported to have lower bone mineral density (BMD) compared to other athletes due to the non-weight bearing nature of their sport [37–39], therefore monitoring free 25(OH)D alongside serum 25(OH)D may be an important addition to the health screening process. Groups of ethnically diverse swimmers also warrant the measurement of multiple vitamin D metabolites since differences exist in skin pigmentation (i.e., ultraviolet-B exposure) and genetic polymorphisms (i.e., vitamin D binding protein, vitamin D receptor phenotypes) [40–42]. Consequently, Black swimmers could be considered at risk of deficiency and prescribed higher doses of vitamin D_3 despite having similar free 25(OH)D and higher BMD compared to White swimmers [42]. Due to these limitations, world-class swimming programmes are encouraged to screen for multiple vitamin D markers to accurately determine the ‘true’ vitamin D status of their athletes. However, with no current guidelines for interpreting optimal free or serum 25(OH)D in athletes, swimmers should continue to strive towards maintaining concentrations > 75 $nmol{\bullet}L^{-1}$ until more research is available.

5. Conclusions

Within just one season, recommendations to supplement with 4000 $IU{\bullet}day^{-1}$ vitamin D_3 from October to March (dependent on annual serum 25(OH)D concentration) successfully eradicated vitamin D deficiency (< 50 $nmol{\bullet}L^{-1}$) in world-class British swimmers. Furthermore, this approach was successful in aiding swimmers to achieve the ‘sufficient’ threshold (> 75 $nmol{\bullet}L^{-1}$), with the percentage of swimmers in this category increasing year-on-year throughout the observation period (2018: 35%, 2019: 69%, 2020: 93%). These consistent increases in serum 25(OH)D also led to 35% of swimmers developing ‘high’ concentrations (> 125 $nmol{\bullet}L^{-1}$), which raises concerns regarding toxicity when this supplement strategy is used for more than two years. Alternatively, research in athletes suggests that maintaining serum 25(OH)D concentrations > 120 $nmol{\bullet}L^{-1}$ may be beneficial for offsetting illness and enhancing training adaptations, though this was beyond the scope of the present study. Further research is therefore required to determine whether there is an optimal serum 25(OH)D range that benefits the immunity and physical performance of highly trained athletes.

Declarations

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Conflict of Interests

Richard J. Chessor and Guy M. Evans are employees of British Swimming, who as an organisation list Healthspan Elite as an Official Supplier. Josh W. Newbury, Richard J. Allison, and Lewis A. Gough declare they have no conflict of interests.

Author Contributions

Conceptualisation: Josh W. Newbury, Richard J. Chessor, Lewis A. Gough; Methodology: Richard J. Chessor, Guy M. Evans; Formal analysis and investigation: Josh W. Newbury; Writing – original draft preparation: Josh W. Newbury; Writing – review and editing: Richard J. Chessor, Guy M. Evans, Richard J. Allison, Lewis A. Gough; Resources: Richard J. Chessor, Guy M. Evans. All authors approved the final version of the manuscript.

Ethics Approval

The study was granted ethical approval by Birmingham City University (Newbury /#10152/ sub2/ R(A)/ 2022/ Jan/ HELS FAEC).

Consent to Participate

All participants provided written informed consent prior to data collection.

Consent for Publication

All parties agree to the publication of this research.

Data Availability

The datasets generated during and/or analysed during the current study are available from the corresponding author on reasonable request.

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Figures

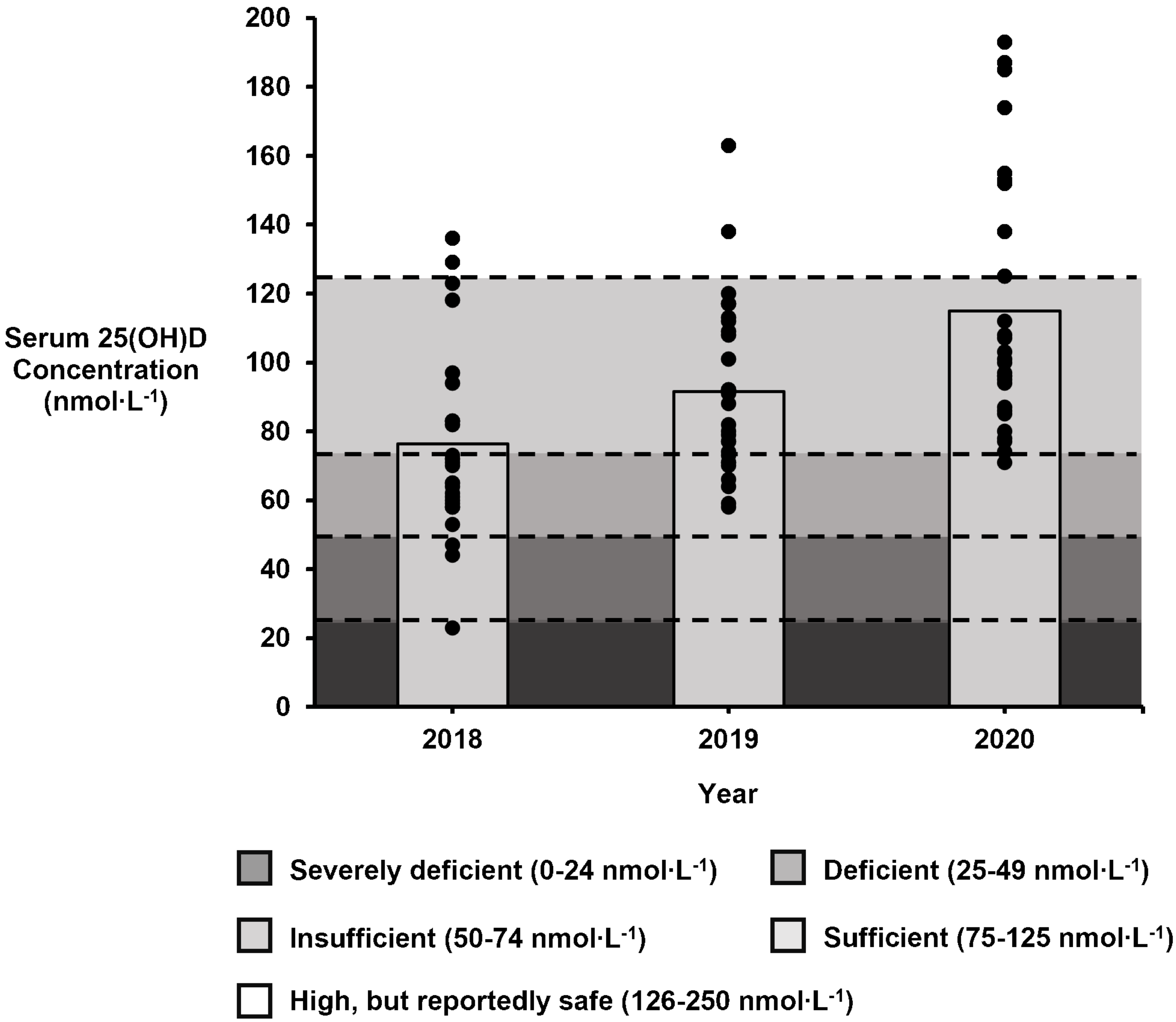

Figure 1

Yearly change (2018-2020) in the serum 25-hydroxyvitamin D (25(OH)D) concentrations of world-class British swimmers. ● signifies individual data points