Acute Effects of Vitamin D₃ Supplementation on Muscle Strength in Judoka Athletes: A Randomized Placebo-Controlled, Double-Blind Trial

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Objective: Indoor athletes have been shown to be prone to vitamin D₃ deficiency. The aim of the study was to examine the acute effects of vitamin D supplementation on muscle function using isokinetic dynamometry.

Design: Randomized placebo-controlled, double-blind study.

Setting: Institutional.

Participants: Adult male white national level judoka athletes (n = 22) who were involved in full-time training. Exclusion criteria were vitamin supplementation, overseas travel to sunny climes, and/or an injury incurred during the last 3 months before testing.

Interventions: Subjects were randomly allocated to the treatment (150 000IU vitamin D₃) or placebo and given blinded supplements by an independent researcher. Participants were tested twice, 8 days apart, on a Monday morning before the start of judo training and after 2 days of rest. A 5 to 7 mL of blood sample was collected followed by isokinetic concentric quadriceps and hamstring muscle function assessments on the right leg at 30 and 200°·s⁻¹.

Main Outcome Measures: Repeated-measures analysis of variance was used to analyze isokinetic muscle force and serum 25(OH)D₃. Regression to the mean was used to examine changes in 25(OH)D₃ levels over the study period.

Results: The treatment group demonstrated a significant increase in serum 25(OH)D levels (34%, P = 0.001) and muscle strength (13%, P = 0.01) between days 1 and 8. No significant differences were found for the placebo group for the same period.

Conclusions: A single bolus of 150 000IU vitamin D₃ had a significant positive effect on serum 25(OH)D levels and muscle function in vitamin D insufficient elite indoor athletes.

Clinical Relevance: Serum 25(OH)D₃ levels of indoor athletes should be monitored throughout the year and especially during winter months. Beneficial responses, in muscle strength and serum 25(OH)D₃, to 1 dose of vitamin D₃ supplementation can be observed within 1 week of ingestion. Muscle strength is linked to serum 25(OH)D levels.

Key Words: human, muscle strength, calcium, vitamin D, randomized controlled trial

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INTRODUCTION

Vitamin D is now increasingly recognized as a complex hormone involved in a wide range of functions from calcium homeostasis¹ to the integrity of the innate immune system.² Vitamin D can be obtained through food products, such as fatty fish, vitamin D fortified milk, margarine, and cereals, and the use of multivitamins. However, the main intake is by photoconversion of 7-dehydrocholesterol to previtamin D₃ in the skin when exposed to ultraviolet radiation. It is subsequently hydroxylated to 25(OH)D₃ in the liver. Serum concentrations of 25(OH)D₃ constitute a storage facility similar to other steroid hormones.³

Serum vitamin D insufficiency has been defined when values are between 10 and 30 ng/mL and deficiency for levels below 10 ng/mL⁴–⁶ Holick and Chen⁴ highlighted in their review that the increases in worldwide vitamin D (25(OH)D₃) deficiency are due to the use of sunblock and skin coverings to reduce the risk of skin cancer; this is exacerbated for indoor athletes,⁵ and dancers⁶,⁷ have been shown to be at risk of deficiency mainly because of decreased sunlight exposure.⁸ Birge and Haddad⁹ were the first to confirm the link between muscle function and 25(OH)D₃. Improved muscle cell protein synthesis and growth has been demonstrated when 25(OH)D₃ binds to the muscle nuclear hormone receptor, vitamin D receptor (VDR).¹⁰ Human muscle biopsy studies have reported atrophic changes of predominantly the type

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II fibers because of vitamin D deficiencies, with increases in fibrosis and glycogen granules. Interventions in older adults, through vitamin D and calcium supplementation, reverse these changes in type II fiber composition. The effects of vitamin D supplementation on younger and athletic performance have also been studied but hampered by a lack of muscle biopsy and randomized controlled trials (RCT). Some authors reported improved muscle power and strength in adolescent girls and muscular strength in healthy male adults as a result of vitamin D supplementation; similarly, Wolman et al and Wyon et al indicated improved muscle function in dancers. In contrast, other authors failed to find any effects of vitamin D supplementation on muscular strength and physical performance parameters such as 1 repetition maximum (1-RM) bench press and vertical jump height.

Previous research has focused either on cross-sectional or long-term supplementation intervention designs, and there have been very few RCT studies. Vitamin D supplementation doses have also varied considerably with interventions of 200 to 100 000 IU over 3 to 12 month of periods. However, the longer the intervention the more likely, it is that other variables could affect the final outcome. Wyon et al noted an improvement in muscle strength and power, and a decrease in injury incidence over a 4-month supplementation intervention period (2000IU/d). The reduction in the observed injury incidence could be linked to the reported improvements in muscle function as reported by Koutedakis et al. Therefore, it could be assumed that if supplementation was beneficial as observed in Wyon et al’s study, muscle function adaptations would be observable at the early stages of the intervention. Therefore, the hypothesis for the present study was to examine whether 150 000 IU vitamin D supplementation would significantly increase serum 25(OH)D and muscle function, as determined by isokinetic dynamometry.

METHODS

Subjects

Participants were male white national level judoka athletes involved in full-time training (4-6 hours a day), which included competition, mat work, and conditioning (Table). For the period of the study and for 3 weeks previously, all participants engaged in the same training schedule to reduce potential confounding factors. This involved 2-hour strength and conditioning, 1-hour technical training, and 2-hour randori. Exclusion criteria were inability to perform other tasks, or long-term supplementation intervention designs, and there have been very few RCT studies. Vitamin D3 supplementation; similarly, Wolman et al and Wyon et al indicated improved muscle function in dancers. In contrast, other authors failed to find any effects of vitamin D supplementation on muscular strength and physical performance parameters such as 1 repetition maximum (1-RM) bench press and vertical jump height.

Pre and Post Descriptive Data (Mean ± SD) for Treatment and Placebo Groups

<table>
<thead>
<tr>
<th>Group</th>
<th>Age, yrs</th>
<th>Height, cm</th>
<th>Mass, kg</th>
<th>Serum 25(OH)D, ng/mL</th>
<th>Isokinetic Speed, °·s⁻¹</th>
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<tbody>
<tr>
<td></td>
<td>Pre</td>
<td>Post</td>
<td>Pre</td>
<td>Post</td>
<td>Δ</td>
</tr>
<tr>
<td>Treatment</td>
<td>29 ± 10.6</td>
<td>175.3 ± 6.5</td>
<td>80.6 ± 19.7</td>
<td>13.16 ± 3.75</td>
<td>16.76 ± 3.21</td>
</tr>
<tr>
<td>Placebo</td>
<td>26 ± 7.4</td>
<td>178.3 ± 10.1</td>
<td>76.9 ± 12.1</td>
<td>16.33 ± 2.73</td>
<td>16.33 ± 2.56</td>
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</table>

<table>
<thead>
<tr>
<th>Group</th>
<th>Quadriceps, Nm</th>
<th>Hamstrings, Nm</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre</td>
<td>Post</td>
</tr>
<tr>
<td>Treatment</td>
<td>232 ± 37.44</td>
<td>265 ± 45.56</td>
</tr>
<tr>
<td></td>
<td>163 ± 28.25</td>
<td>183 ± 32.97</td>
</tr>
<tr>
<td>Placebo</td>
<td>239 ± 65.93</td>
<td>239 ± 63.73</td>
</tr>
<tr>
<td></td>
<td>145 ± 29.27</td>
<td>148 ± 28.21</td>
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Statistical Analysis

Kolmogorov–Smirnov tests were initially performed to establish distribution of all the variables. Isokinetic muscular function was analyzed with a 4-way analysis of variance (ANOVA) with repeated measures; the between-subject factors were “treatment” (intervention and control), and the within-subject factors were “muscle” (quadriceps and hamstrings), “speed” (30 and 200°·s⁻¹), and “time” (before and after intervention). Serum 25(OH)D₃ levels were analyzed using a 2-way repeated-measures ANOVA with the between-subject factor being treatment and the within-subject factor time. Regression to the mean²³ was used to examine changes in 25(OH)D₃ levels over the study period. Significance was set at  P ≤ 0.05.

RESULTS

Twenty-two volunteers met the current inclusion criteria and were randomly assigned to either the treatment or placebo group (Table 1). Although the participants were randomly assigned to the treatment or placebo group by an independent researcher, the treatment group had a significantly lower pre-treatment serum 25(OH)D levels than the placebo group ( P < 0.05); there were no significant difference between the groups for the other variables. The treatment group demonstrated a 34% increase in serum 25(OH)D levels between days 1 and 8, whereas the placebo group remained constant; ANOVA of the blood data reported a main effect of time ( P ≤ 0.001) and more importantly “treatment by time” interaction ( P ≤ 0.001) (Figure 1). Regression of the mean analysis of the whole cohort reported a nonsignificant trend ( r = −0.337, P = 0.125) with evidence of posttest shrinkage in the SD compared with the pretest. This was achieved by participants with the lowest preintervention serum 25(OH)D levels saw the greatest increase over the 1-week monitoring period (Figure 2).

Muscle strength data identified an overall 13% mean increase in muscle strength between days 1 and 8 for the treatment group (Figure 3), the placebo group’s strength increased by 3% over the same period. Statistical analysis reported a main effects for muscle ( P ≤ 0.001), speed ( P ≤ 0.001), and time ( P = 0.001); most importantly time by treatment ( P = 0.01) interaction, see (Figure 3), and “muscle-by-time by treatment” ( P = 0.027) interaction.

DISCUSSION

The previously reported prevalence of serum 25(OH)D insufficiency and deficiency in indoor athletes⁵,⁶,⁸,¹⁰ have also been confirmed by the present cohort of judoka athletes who were found to have insufficient levels at baseline. The aim of this study was to examine the acute effects of vitamin D supplementation on selected muscle function parameters. The intervention group significantly increased serum 25(OH)D levels, 1 week after ingestion, but still remained clinically insufficient (10-30 ng/mL). A review on high-dose vitamin A supplementation on deficient patients²⁴ suggested
that short-term serum levels are only increased moderately as replenishing cellular storages take precedence. A similar phenomenon could have occurred in this study with serum levels continuing to rise in the subsequent weeks. Regression of the mean analysis also indicated that participants with the lowest pretreatment serum 25(OH)D revealed most of the benefits to the supplementation; similar effects have been previously noticed with different physiological parameters. However, direct comparisons with published data are not possible as this is the first known study to examine the acute effects of vitamin D3 supplementation.

Early work by Birge and Haddad emphasized the importance of serum 25(OH)D3 on muscle intracellular phosphate levels. Further studies highlighted the direct effect serum 25(OH)D3 had on metabolic muscle activity including increased cell protein synthesis and growth through combining with the VDR to promote gene transcription. Animal studies have shown that vitamin D supplementation increased protein synthesis and muscle mass through the activation of the mitogen-activated protein kinase signaling pathway. These long-term adaptations are unlikely to cause the observed acute muscle strength improvements in this study. The 13% increase in strength for the treatment group over a 1-week period is a significant enhancement for elite athletes and highlights the importance of monitoring serum 25(OH)D3 levels before competition. These increases in strength are possibly due to vitamin D interacting with a specific cell surface receptor, which activates messenger pathways that are believed to directly influence muscle calcium transport and regulation in muscle cells. The authors know of no theoretical basis for the observed greater strength improvements in quadriceps compared to hamstrings for the treatment group. The recent study by Close et al on the effect of different supplementation doses failed to note improved muscle performance in club-level athletes over a 12-week period, despite increases in serum 25(OH)D3. These authors

**FIGURE 3.** Mean ± SD muscle strength changes for the treatment and placebo groups’ pre-and-post intervention.
suggested that this could be due to skeletal muscle needing a higher serum level than other tissues to illicit a beneficial response. Heaney and Holick\textsuperscript{23} suggested that serum 25(OH)D₃ levels of 120 to 225 nmol/L may be required to activate this response.

Previous studies have shown a negative correlation between muscle strength and injury incidence.\textsuperscript{21,30} The benefits of prolonged, 3 to 12 months, vitamin D₃ supplementation on improved muscle function\textsuperscript{31} and decrease in injuries or falls\textsuperscript{14} in a variety of populations have already been reported in the literature. This study has demonstrated for the first time that muscle strength significantly improved even within 1 week of vitamin D₃ ingestion. These data highlight the short-term benefits of supplementation on muscle strength of deficient elite sportsmen who not only could have a possible direct effect on their sport performance but also an indirect effect on injury occurrence. Unlike previous studies, that have mainly used isometric strength\textsuperscript{18} or dynamometry (hand-grip or pinch),\textsuperscript{31} we used isokinetic dynamometry at 30 and 200°·s\textsuperscript{-1} in an attempt to determine whether vitamin D₃ adaptation is fiber specific; Thorstensson et al\textsuperscript{32} reported a correlation between % fast twitch fibers and peak torque at angular velocities above 180°·s\textsuperscript{-1}. The percentage improvements in peak torque at the 2 angular velocities used in this study were of similar magnitude. Therefore, the present data could not bring greater clarity as to whether muscle function improvements, due to vitamin D₃ supplementation, are muscle fiber specific. Nor are we able to compare the present findings with existing data on elderly, which suggested a type II fiber focused response to vitamin D₃ supplementation.\textsuperscript{11,17} Based on the fact that muscle strength indices were assessed by isometric testing, and that within elderly populations’ type II fiber size degenerates at a faster rate than type I fibers, these conclusions need to be treated with caution.

It is reasonable to assume that although we have reported novel data, the present results may have been influenced by methodological limitations such that the significantly lower serum 25(OH)D₃ levels shown by the intervention participants at baseline and the seasonality of serum 25(OH)D₃, since the data were collected at a specific month of the year. Another limitation might be associated with the single 150 000 IU dose of vitamin D₃ and whether this dose was actually appropriate. Future studies should look at serial measurements of serum 25(OH)D₃ and muscle strength on a weekly basis and compare the differences between a single bolus dose of vitamin D₃ with weekly or daily supplementations.

CONCLUSIONS

In conclusion, and within the study’s limitations, we demonstrated the beneficial acute effects of a single bolus of 150 000IU vitamin D₃ on serum 25(OH)D levels and isokinetic muscle strength in vitamin D deficient elite indoor athletes during the winter months. However, despite significant improvements, serum 25(OH)D₃ deficiency still remains an issue for these athletes, probably because of a reduce exposure to sunlight. Further research is required into the optimal supplementation methods and serum 25(OH)D in elite athletes.

Clinical Implications

- Serum 25(OH)D levels of indoor athletes should be monitored throughout the year and especially during winter months.
- Muscle strength is linked to serum 25(OH)D levels.
- Beneficial responses to 1 dose of vitamin D₃ supplementation can be observed within 1 week of ingestion.
- Athletes might require higher serum 25(OH)D levels (120-225 nmol/L) than the general population.