

High-intensity Interval Training and Vitamin D Supplementation Improves Low-Grade Systemic Inflammation in Overweight/Obese Vitamin D-deficient men

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Abstract

Aims. This study investigated the effects of high-intensity interval training (HIIT) and vitamin D supplementation on inflammatory indices in overweight/obese vitamin D deficient men.

Methods: 48 sedentary obese/overweight (mean BMI = 29.66 ± 4.5 kg/m²) men with vitamin D deficiency were randomly allocated into four groups (n = 12/group), including; Control, Vitamin D, HIIT + placebo, and HIIT + Vitamin D. The HIIT performed on ergometer at an intensity of 80–110% of participants peak power for 12 weeks (3 days/week). Pre-inflammatory indices were measured before and after the intervention. Data analyzed using one-way repeated measures analysis of variance in SPSS version 27.

Results: After the intervention, significant reductions were observed in serum concentration of TNF- α , IL-6, and IL-1 β in the HIIT + vitamin D and HIIT + placebo groups, and a significant decrease in hs-CRP level in the HIIT + vitamin D group ($p < 0.001$). At the post-intervention stage, serum levels of TNF- α , IL-6, and IL-1 β in the HIIT + vitamin D and HIIT + placebo groups were significantly lower than those in the vitamin D and control groups ($p < 0.05$). No significant differences were detected between the HIIT + vitamin D and HIIT + placebo groups, nor in the comparison between the vitamin D and the control group ($p > 0.05$).

Conclusion: There was a decrease in systemic inflammatory markers in overweight and obese men following HIIT training, but there were no significant effects with vitamin D supplementation alone. Also, despite greater effects on systemic inflammation, no significant synergistic effects were observed.

Introduction

Obesity, as a global health problem, is one of the risk factors for diseases like type 2 diabetes mellitus, cardiovascular diseases, asthma, rheumatoid arthritis and several kinds of cancer [1]. The number of overweight people above 18 years old globally in 2022 was around 2.5 billion (approximately one third of the world's population), of which 890 million were obese [2].

Being an active regulatory tissue in metabolism, adipose tissue can secrete a range of factors like adipokines that are involved in numerous bodily systems. Low-grade systemic inflammation associated with obesity has been found to be several times higher than normal [3] and is a leading cause of death from chronic diseases, killing 3 out of 5 people [4]. Accordingly, a positive association has been found between excess fat mass and the secretion of IL-1 β , TNF- α , and IL-6 as the most important pro-inflammatory cytokines [5, 6]. These cytokines also have an influence on the liver and cause it to produce C-reactive protein [7–9]. A positive correlation has been described between CRP and body mass index (BMI), with CRP levels reducing following surgical weight loss, which indicates that there is a considerable link between body weight and CRP levels [9].

With regard to reducing systemic inflammation and the prevention and therapy of chronic diseases, the discovery of suitable interventions to prevent it is a priority topic in current research. Conversely, a sedentary lifestyle has been shown to increase the probability of developing metabolic and cardiovascular diseases, as well as other types of cancer[10]. Exercise training has anti-inflammatory effects, resulting in enhanced inflammatory function [11]; nevertheless, the type of exercise intervention that is able to reduce body fat and to reduce low-grade inflammation is not clearly defined. High intensity interval training (HIIT) is currently very popular among athletes and the public for the advantage it has in reducing training time by recruiting more systems at the same time. In this regard, a review study reported that HIIT needed 40% less time than moderate-intensity continuous training to improve body composition [12]. Therefore, HIIT might be a good strategy for reducing low-grade systemic inflammation. It has already been found that only high-volume interval training (14 min/session), compared with different training modes like single-set resistance training and whole body electromyostimulation training, improved CRP and IL-6 levels [13].

On the other hand, it has been demonstrated that overweight and obese people are at risk of vitamin D deficiency [14]. Adipose tissue is thought to be responsible for the decrease in bioactivity and a decrease in the intestinal absorption, as well as the hepatic synthesis of vitamin D. Furthermore, low-grade systemic inflammation through oxidative stress mechanisms results in oxidative catabolism of vitamin D [15]. The administration of vitamin D supplementation for 8 weeks demonstrated a decrease in the parameters of glucose metabolism and inflammatory indicators in diabetic patients with both vitamin D deficiency and hyperlipidemia [16]. It seems that vitamin D supplementation decreases the synthesis of TNF- α and IL-6 by suppressing P38 MAP kinase in monocytes [17]. In a previous study, a decrease in IL-6 was seen after 12 weeks of vitamin D supplementation and resistance exercise in diabetic patients, but 3-month supplementation of vitamin D did not lead to a decrease in TNF- α and CRP [18]. Also, physical activity contributes to lower systemic inflammation through its role in altering adipose tissue and muscle mass [13]. In general, physical activity has the effect of lowering body fat and possibly, to some extent, systemic inflammation; however, the effects of vitamin D intervention and the combined effect of both interventions are not adequately researched, particularly for overweight/obese men with vitamin D deficiency. Accordingly, the aim of the current study was to determine the combined effect of HIIT and vitamin D supplementation on systemic inflammation in overweight / obese vitamin D deficient men.

Methods

Participants

Participants in the current study was selected from overweight/obese (BMI > 25 kg/m²) men with 25(OH)D deficiency (less than 20 ng/mL). In accordance with previous studies, 66 individuals with vitamin D levels less than 20 ng/mL were voluntarily selected from sports clubs in Sanandaj (Iran). Inclusion criteria were male gender, 20 to 35-year-old, BMI between 25 and 40 kg/m², not physically active for more than 2 times per week in the last year prior to the trial, without chronic disease (cardiovascular, kidney, hepatic, or musculoskeletal), do not take vitamin D supplements, therapeutic and

sport supplements (in last 6 months before the trial), do not taking anti-inflammatory drugs, do not smoking and drinking. So, there are 8 participants had been exclusion: two of them because of having a chronic cold, 3 because of taking anti-inflammatory drugs, 4 because of smoking, 7 because of not interesting in take part in this study and 2 for other reasons. The remaining 48 individuals were randomly allocated into four groups (n=12 for each group): control, vitamin D supplementation, HIIT + placebo (edible paraffin), and HIIT + vitamin D. Subjects were excluded from the study if they refused to start or continue the intervention, did not participate in 5 study sessions in a non-consecutive manner/or missed 3 consecutive intervention sessions, developed any illness during the study that required rest and treatment, and took anti-inflammatory drugs. Statistical analysis was performed on all 48 participants which met exclusion criteria in the study protocol and Figure 1 shows the participant selection plan used in the study and the type of intervention for each group. The present study was carried out according to the principles of Declaration of Helsinki with the approval of Ethics Committee of Research, Islamic Azad University, Sanandaj, Iran. Before and after intervention means $\pm$ SD of subject's anthropometric variables, VO₂max and serum level vitamin D were shown in table1.

Table 1. Participants parameter scores before and after the intervention.

parameter	Groups							
	Control		Vitamin D		HIIT + Placebo		HIIT + Vitamin D	
Age _y	23.4 $\pm$ 4.9		25.1 $\pm$ 5.3		24.5 $\pm$ 6.2		24.8 $\pm$ 6.4	
Hight _{cm}	174.6 $\pm$ 6.8		173.9 $\pm$ 5.8		176.8 $\pm$ 7.9		176.2 $\pm$ 8.3	
	Before	After	Before	After	Before	After	Before	After
Weight _{kg}	89.9 $\pm$ 11.8	90.4 $\pm$ 10.9	91.9 $\pm$ 8.9	90.9 $\pm$ 9.4	91.4 $\pm$ 10.6	87.7 $\pm$ 11.4 ^{††&}	90.7 $\pm$ 9.6	86.8 $\pm$ 9.9 ^{††&}
BMI _{kg/m2}	29.4 $\pm$ 4.9	29.65 $\pm$ 5.5	30.3 $\pm$ 4.8	29.9 $\pm$ 3.7	29.2 $\pm$ 4.3	28.0 $\pm$ 5.8 ^{††&}	29.2 $\pm$ 4.0	27.9 $\pm$ 5.9 ^{††&}
WHR	1.02 $\pm$ 0.08	1.03 $\pm$ 0.22	1.10 $\pm$ 0.08	1.06 $\pm$ 0.06	1.00 $\pm$ 0.21	0.97 $\pm$ 0.10 ^{††&}	1.04 $\pm$ 0.12	0.99 $\pm$ 0.09 ^{††&}
BF _%	29.6 $\pm$ 4.1	29.1 $\pm$ 6.3	30.0 $\pm$ 5.2	29.4 $\pm$ 4.6	29.8 $\pm$ 4.7	28.9 $\pm$ 3.9 ^{††}	28.7 $\pm$ 3.7	26.3 $\pm$ 4.5 ^{††}
Vo ₂ max _{ml.kg⁻¹.min⁻¹}	34.6 $\pm$ 6.3	35.2 $\pm$ 4.8	36.1 $\pm$ 5.2	36.5 $\pm$ 4.3	34.7 $\pm$ 3.9	41.1 $\pm$ 5.4 ^{††&}	35.5 $\pm$ 4.1	42.3 $\pm$ 6.3 ^{††&}
Seum 25[OH]D _{ng/ml}	18.5 $\pm$ 3.1	19.9 $\pm$ 2.8	17.8 $\pm$ 2.1	29.7 $\pm$ 3.1 [*]	18.3 $\pm$ 3.6	19.2 $\pm$ 2.7 ^{&}	19.1 $\pm$ 3.8	30.7 $\pm$ 4.2 ^{*€}

* = significant difference when before and after the intervention data compared. † = significant difference when compared to Control group. & = significant difference when compared to Vitamin D group. € = significant difference when compare HIIT + Placebo with HIIT + vitamin D groups. Data are presented as mean $\pm$ SD. All comparisons are made in $\alpha = 0.05$.

Orientation session and before and after intervention assessment

During an Orientation session the participants were advised of the research protocol, aims and the possible risk. All Demographic characteristics was recorded and voluntary informed written consent was also obtained. During this session all participants were informed that participation in the study is voluntarily and they could retract their consent at any stage of study. Subjects were requested to attend the gym one week prior to the start of study protocols in order to recording heights (cm), weight (kg) and BMI (kg/m²)(Seca, Model 769, Germany). During this session subject's body fat percent (BFP) was estimated according to three site Jackson-Pollock method [19] using the skinfold caliper (Harpenden, United Kingdom).

Hip and waist circumferences were measured by a circumference measuring tape (Seca, model 201, Germany), and waist-to-hip ratio (WHR) was determined. On the same day, subjects' VO₂max was estimated through the ergometer (Technogym Excite Line 700, Italy) Astrand test [20]. All the above-mentioned tests were replicated one week after the intervention, maintaining an identical testing environment, personnel, and experimental protocols. First blood sampling was performed from all subjects 48 hrs post-orientation session at 8 a.m., in the fasted state with 12-hour overnight fasting to assess vitamin D levels and inflammatory markers. 48 hours after the last training session fasting blood samples, under the same conditions were collected by the same technicians.

Vitamin D supplementation

vitamin D groups intakes 50 μ g/day (2000 IU) of this vitamin as soft gels (Dana Pharmaceutical Company, Iran) with lunch [21]. The doses of 100 μ g/day (4000 IU) were claimed as physiological threshold to make vitamin D a non-toxic dose on healthy individuals [22]. In the present study, even though the subjects were vitamin D deficient (lower than 20 ng /mL)v, we treated vitamin D dose by 50 μ g/day (2000 IU) to make sure the treatment dose is not toxicity. Also, because the study period was set in winter and limited sunshine for skin, the endogenic synthesis of vitamin D was limited. The HIIT + placebo group ingested an edible paraffin capsule (Dana Pharmaceutical Co, Iran). The capsules were identical in shape size and color to the vitamin D capsules, with timing and administration regimen the same as that in the vitamin D group. The double-blinding procedure involved two technicians and medical staff besides researchers; none but these knew the content of the capsule. The whole double-blinding procedure involved two technicians and medical staff in addition to the researchers; no one except these two individuals knew the contents of the capsules.

High-intensity interval training

The HIIT protocol was performed for 12 weeks, 3 sessions per week on an ergometer (Technogym Excite Line 700 hk, Italy), lasting a total of 36 sessions. The HIIT protocol consisted of a 5-minute warm up at 30 watts, followed by 8 to 13 60-second intervals of high-intensity sprinting at 80-110% of maximum power, each with 1 minute of active recovery at 30 watts between intervals. 5 minutes active recovery at 30 watts was performed at the end of each session. The HIIT protocol was constructed according to the principle of overload-which means the number of intervals and intensity increases from the first to the last week (modified from Matos 2018) [23]. See Table 2 for more details.

Table 2. High-intensity interval training (HIIT) protocol.

Weeks	Intensity (% maximum power)	Number of sprints	sprint duration (s)	Session duration
1	80	8	60	16
2	80	8	60	16
3	85	9	60	18
4	85	9	60	18
5	90	10	60	20
6	90	10	60	20
7	95	11	60	22
8	95	11	60	22
9	100	12	60	24
10	100	12	60	24
11	110	13	60	26
12	110	13	60	26

Biochemical measurements

The laboratory technician collected 5 cc blood samples from the left antecubital vein, and putting the samples in sterile tubes filled with K3EDTA. Blood samples were allowed to stand in an ice container and then room temperature for a few minutes, after which the serum was obtained via centrifugation at 3500 RPM for 10 minutes using heparin or EDTA tubes which yielded identical results. All the serum samples were preserved at -80°C for later use in biochemical analyses. Blood was sampled between 8:00–10:00 am. ELISA kits was used to determine hs-CRP (Pars Gen kit, Iran), TNF- α , IL-1 β and IL-6 (Merck Millipore,

EZHIL6, Feltham, UK) and also 25(OH)D (Ideal Tashkhis Atieh, Iran) concentrations in serum according to manufacturer's protocols.

Statistical Analysis

The data distribution showed no signs of violation of normality, therefore, the Shapiro-Wilk test was applied, while the homogeneity of variances of the groups was checked through the Levene's test. Next, an analysis of variance with repeated measures (RM-ANOVA) and Bonferroni post hoc test were used to compare variables mean across the different groups. Data analysis performed using IBM SPSS version 25 at a Significance level of $P < 0.05$ and finally graphs were constructed using GraphPad Prism version 10.

Results

Anthropometric characteristics, VO₂max, and 25(OH)D.

The comparison between before and after intervention values revealed a statistically significant reduction in weight in the HIIT + Vitamin D (4.3%) and HIIT + Placebo (4.0%) groups, and no statistically significant reduction (1.0%) in the Vitamin D group. After the intervention, the HIIT + Vitamin D and HIIT + Placebo groups showed a significant reduction in BMI (4.2% and 4.4%, respectively) and WHR (3.0% and 4.8%, respectively). A statistically significant elevation in VO₂max was observed in the HIIT + Vitamin D (19.7%) and HIIT + Placebo (18.4%) groups. In addition, a significant decrease in BFP was observed in the HIIT + Vitamin D and HIIT + Placebo groups (5.2% and 4.7%, respectively). It should also be noted that the Vitamin D and HIIT + Vitamin D groups had a statistically significant increase in serum 25[OH]D (66.8% and 60.7%, respectively). See Table 1 for more information and comparisons.

hs-CRP

Results for the hs-CRP showed significant time ($F = 22.82$; $P < 0.0001$), group ($F = 8.37$, $P < 0.0001$), and time $\times$ group interaction ($F = 7.29$; $P = 0.0002$) effects. With before vs. after intervention comparison: hs-CRP declined significantly for the HIIT + vitamin D group ($P < 0.0001$), but did not decrease in the HIIT + placebo group ($P = 0.1621$). Post-intervention values for hs-CRP were significantly lower in the HIIT + Vitamin D group vs. the vitamin D and control groups ($p < 0.01$); however, no significant differences were found for vitamin D vs. the control group ($p = 0.9663$) or HIIT + Vitamin D vs. HIIT + placebo ($P = 0.0574$) (see Fig. 2 A).

TNF- α

Serum levels of TNF- α were significant for time ($F = 6.79$, $p = 0.0004$), group ($F = 25.90$, $p < 0.0001$) and time $\times$ group interaction ($F = 3.36$, $p = 0.0223$) effects. There was a significant decrease in TNF- α from before to after intervention values in the HIIT+ Vitamin D ($P = 0.0001$) and HIIT+ Placebo ($P < 0.0001$) groups. After 12 weeks of intervention there were significant decreases in TNF- α levels between HIIT + Vitamin D group and vitamin D group ($P < 0.05$); and between HIIT+ Placebo and control group ($P < 0.05$).

Nevertheless, there were no significant changes in serum TNF- α levels between Vitamin D and control group ($P=0.1199$); and nor between HIIT + Vitamin D group and HIIT+ Placebo group ($P=0.6237$). All within-group and between-group comparisons of serum TNF- α levels are presented in Fig. 2B.

IL-6

Additionally, a RM-ANOVA on the IL-6 concentration demonstrated significant effects of time ($F= 4.71$, $P= 0.0043$), group ($F= 23.31$, $P< 0.0001$), and time $\times$ group interaction ($F= 8.45$, $P< 0.0001$) effects. Before and after intervention values showed a significant reduction in IL-6 for the HIIT + Vitamin D ($P= 0.0001$) and HIIT + Placebo ($P< 0.0001$) groups. After the 12-weeks intervention, IL-6 levels were significantly reduced in the HIIT + Vitamin D and HIIT + Placebo groups compared to the Vitamin D and control ($P< 0.01$). Nevertheless, Vitamin D and Control showed no significant difference ($p= 0.9413$), nor did the HIIT + Vitamin D vs HIIT + Placebo treatments ($P= 0.5792$). The results for IL-6 are shown in Figure 2C.

IL-1 β

Significant time ($F=4.53$, $P=0.0053$) and group ($F=27.90$, $P<0.0001$) effects and a group $\times$ time interaction ($F=11.27$, $P<0.0001$) were also seen in serum levels of IL-1 β . From before to after intervention values, there was a significant decrease in IL-1 β in the HIIT + Vitamin D ($P<0.0001$) and HIIT + Placebo ($P<0.0003$) groups. At the end of the 12-week intervention, serum IL-1 β concentrations in HIIT + Vitamin D and HIIT + Placebo were significantly lower than those in the control and vitamin D groups ($P<0.02$). There was no significant difference between the control and vitamin D groups ($P=0.8150$), nor between the HIIT + Vitamin D and HIIT + Placebo groups ($P=0.2031$). Intra- and intergroup comparisons of IL-1 β values are summarized in Figure 2D.

Discussion

Body fat accumulation and a physically inactive lifestyle are the risk factors for a variety of chronic diseases. Excess fat storage seems to causes vitamin D deficiency. As far as these findings concerned, the vitamin D deficiency would then increase systemic inflammation [24]. The objective of current study was to evaluate the effects of 12 weeks of HIIT and vitamin D supplementation on the markers of low-grade inflammation in overweight / obese men with vitamin D deficiency. Altogether, our results demonstrate a decrease of roughly 4.2%, 4.3%, and 5% in weight, BMI and BFP in the HIIT groups. While the reduction in these variables was not significant in the group taking only vitamin D (approximately 1%). In a case comparable, there was a very similarity between the current investigation results for weight, BMI and the body composition for overweight individuals with study by Sheikholeslami-Vatani et al., (2022) [25]. Similarly, aerobic training, alone or concomitant with the supplementation with vitamin D in individuals who suffer from Diabetes mellitus, causes significant reduction in BFP, WHR, BMI and body weight [26].

However, our primary study interest was to examine the effect of HIIT and the Vitamin D supplementation on markers of systemic Low-grade inflammation but the results concerned to body

compositions may help support the interpretation of findings about those markers. Another aspect is that in current study, vitamin D supplementation groups demonstrated average increase of serum vitamin D about 63.7%. Several studies reported that serum vitamin D below 20 ng/mL is vitamin D deficient and serum vitamin D above 30 ng/mL is vitamin D sufficient [27]. The participants in current study were vitamin D deficient at baseline and 50 µg/day (2000 IU) treatment showed adequate serum level of vitamin D in supplementation groups. So, in comparison to this condition, weight, BMI and BFP had significantly decreased while there was no significant increment in 25(OH)D level in HIIT+ placebo group. A review demonstrated that weight loss does not increase vitamin D levels and vitamin D supplementation is not related to weight loss [28]. In the current study, the average VO₂max increased by 18.7% with HIIT training groups. In this concern Di Matos et al. have reported an increase of around 12% following 8 weeks of HIIT training in obese individuals. The discrepancy in the rate of VO₂max increase within this study compared to Di Matos et al is likely explained by longer training duration in the current study and higher BMI and fat mass in Di Matos et al. study [23].

In our study, serum hs-CRP, TNF-α, IL-1β, and IL-6 levels were detected as markers of systemic inflammation. CRP is acute phase protein that responds to diverse pathological conditions and increases the expression in liver especially in the case of system inflammation. TNF-α, the product mainly released from macrophages and monocytes, is one of the key regulators of apoptosis, inducing increase of NF-κB expression, which up-regulates inflammatory gene in nucleus [29]. IL-1β acts as an indispensable pro-inflammatory cytokine which governs an immune response to a certain type of infection and induces a synergistic effect together with TNF-α in apoptosis. IL-1β also participates in inflammation as a result of its secretion by adipocytes under pathological condition [30]. IL-6 has also been reported to have potential to both pro-inflammatory and anti-inflammatory activities. There seem to be differences in the expression levels of the subunits for the IL-6 receptor (sIL-6R or IL-6R) across the different cell types, and the cell type has an important role in dictating the pro- or anti-inflammatory actions of IL-6 [30]. In agreement with the current findings, it has been documented that exercise training has the potential to reduce inflammatory cytokines like CRP in overweight individuals with improvements in body weight and body fat mass [31]. Body weight was significantly decreased in both the HIIT + Placebo and HIIT + vitamin D groups in the current study, which may be partially responsible for the changes in inflammatory markers. In agreement with the findings in the present study, it has been found that all three interventions, aerobic training, weekly vitamin D supplementation (50,000 IU), and aerobic training + vitamin D, reduced CRP in diabetic patients [26]; however, the mechanisms for exercise training to reduce CRP levels have not yet been elucidated.

In this research, we observed a marked reduction in serum levels of TNF-α, IL-1β, and IL-6 after the 12 weeks of HIIT, whereas vitamin D supplementation per se did not cause a change in the levels of inflammatory cytokines, and no synergistic effects was detected between vitamin D supplementation and HIIT. Similar results were observed in a previous review including a meta-analysis, in which no decrease in inflammatory markers was found with vitamin D supplementation [32]. Another study demonstrated that eight weeks of HIIT failed to reduce inflammatory markers in overweight and obese postmenopausal women [33]. It has been seen in eight weeks of HIIT that IL-6 was reduced (but not IL-

1β) in subjects with obesity [34]. An intervention mixing nutrition (using BCAA, vitamin D, and calcium) and eight weeks of resistance training reduced markers of inflammation in a sarcopenic individual [29].

In contrast to the present study findings, vitamin D administration resulted in a significant reduction in the gene expression of pro-inflammatory proteins, including IL-6, MCP-1, TNF-α and MCP-1 in diet-obese mice supplemented with a high-fat diet [24]. However, similar to the findings of our present research, vitamin D supplementation for 12 weeks did not affect inflammation parameters in vitamin D-deficient, overweight, and normal-weight subjects [35]. Moreover, the research of Gawryjock et al. demonstrates no significant difference in pro-inflammatory markers in orthopedic patients in acute or chronic states who consumed 100 µg/day (4000 IU daily) of vitamin D for three months [36], while one study demonstrates that six months' supplementation influenced a reduction in inflammatory biomarkers [15]. This suggests that baseline vitamin D levels modulate the response to exercise and vitamin D supplementation interventions [27]. Based on this, it may be suggested that supplementation for most participants, particularly those with vitamin D deficit, would have a more noticeable impact on inflammatory outcomes, and also that a higher dose of vitamin D supplementation for a shorter time period may have had a stronger influence [27, 37]. Additionally, perhaps supplementing before beginning training can affect the synergistic effects of vitamin D and exercise training. This may be another direction for study.

Conclusion

To our knowledge, no study has examined the effect of HIIT training and vitamin D supplementation in obese individuals with vitamin D deficiency. We demonstrate in this study the superiority of 12 weeks of HIIT training regarding the effects on body composition and some pro-inflammatory biomarkers. Supplementation with vitamin D, as observed during this study, helped raise the level of vitamin D above the minimal level for sufficiency (> 30ng/mL) but had no benefit on other anthropometric measurements or on systemic inflammation, and provided no additional value when used concurrently with the exercise training program. More research needs to be conducted in order to identify the mechanism of the combination effect of exercise training and vitamin D supplementation on inflammation markers.

Declarations

Conflict of Interest

The authors explicitly declare that no conflict of interest exists.

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Author Contribution

F.H. and K.MS. study concept and design. K.MS. analysis and interpretation of data. F.H. drafting of the manuscript. K.MS. critical revision of the manuscript for important intellectual content and supervision. K.MS. writing- review and editing.

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Figures

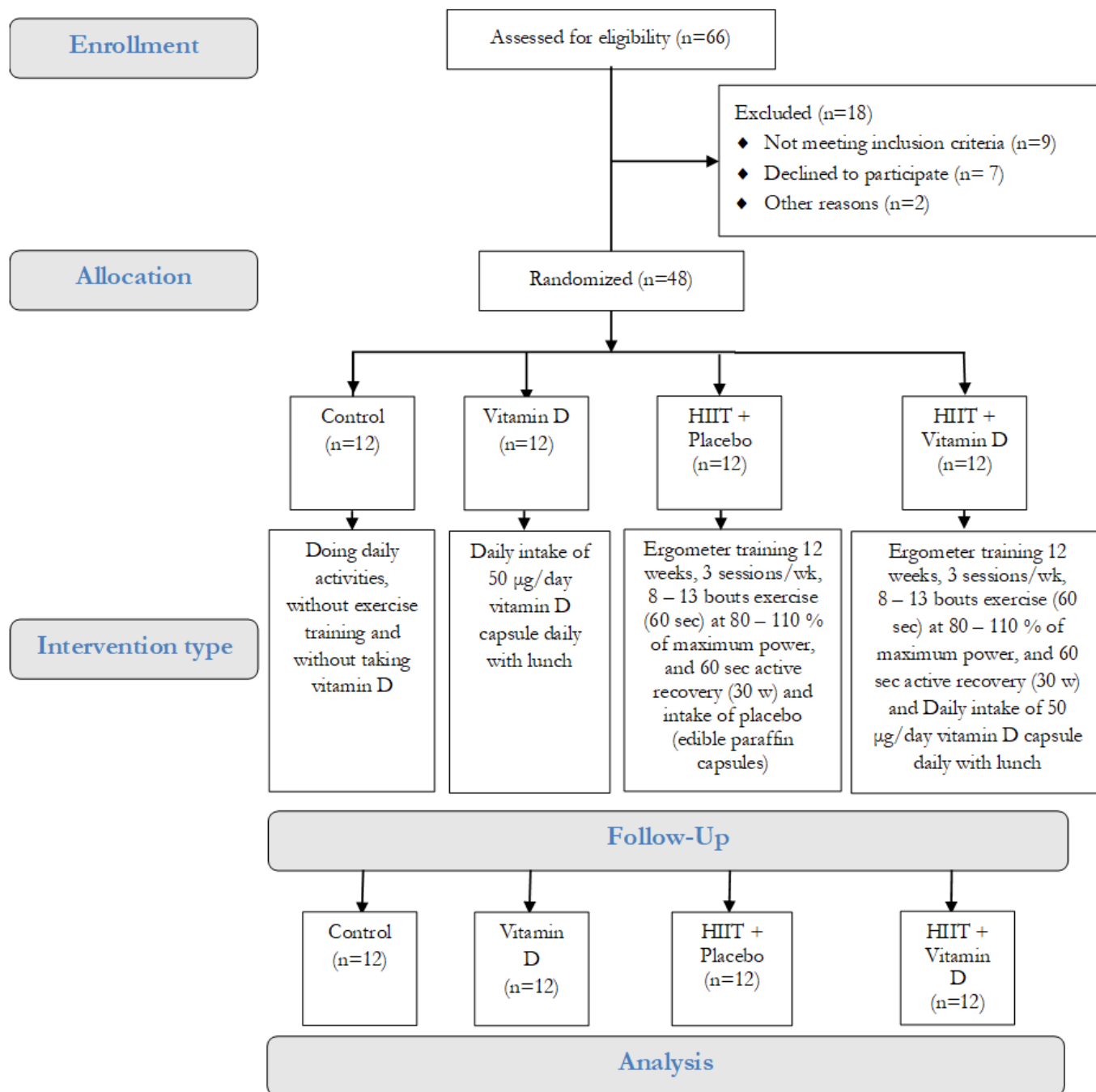


Figure 1

Consort trial flow chart

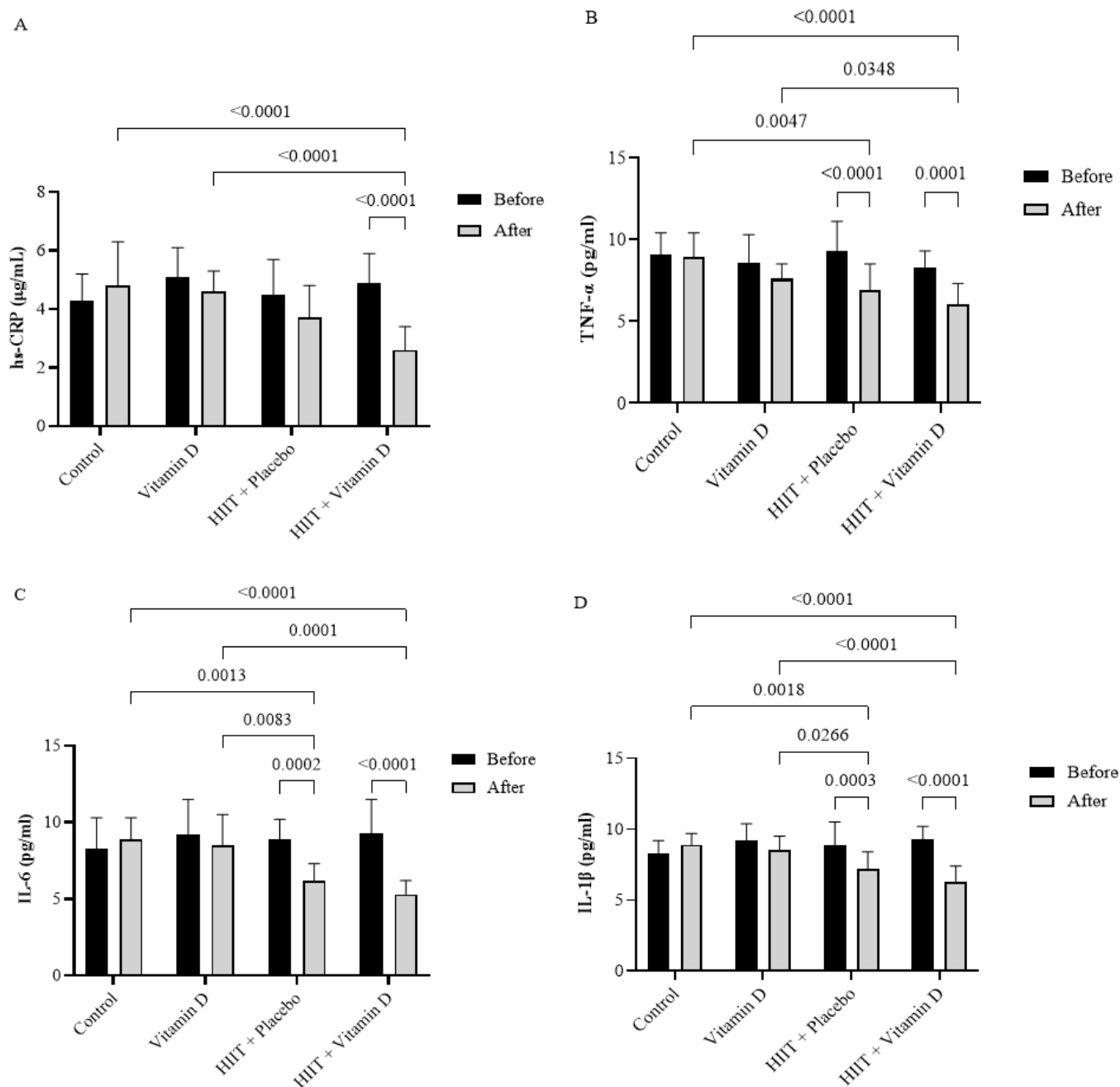


Figure 2

Comparison of the levels of hs-CRP (A), TNF-α (B), IL-6 (C), and IL-1β (D) before and after the 12-week intervention in overweight and obese males. Data are presented as the mean ± standard deviation. All comparisons are made at $\alpha = 0.05$.