Journal of Food, Nutrition and Diet Science
https://ojs.luminescience.cn/FNDS

LUMINESCIENCE
https://luminescience.cn

Original Research

Effects of spirulina supplementation combined with resistance training on anthropometric muscle size and strength in adolescent novice bodybuilders: A randomized controlled trial

Morteza Khademian[1], Elaheh Heidarnia[1], Fatemeh Khademian[2*]

[1] Department of Exercise Physiology, Shiraz Branch, Islamic Azad University, Shiraz, Iran
[2] School of Nutrition, Faculty of Community Services, Toronto Metropolitan University, Toronto, Canada

[*] Corresponding to: Fatemeh Khademian, Email: fatemeh.khademian@torontomu.ca

Abstract: Background: Resistance training improves muscle size and maximal strength, particularly in novice trainees. However, evidence regarding the additional benefits of spirulina supplementation remains limited, especially at relatively low doses and among adolescent populations. Unlike previous studies primarily investigating higher spirulina doses, the present study employed a four-arm randomized controlled design to evaluate the independent and combined effects of low-dose spirulina supplementation and resistance training on anthropometric muscle size and maximal strength in adolescent novice male bodybuilders. **Methods:** In this eight-week, four-arm randomized controlled trial, 40 adolescent male novice bodybuilders aged 16–21 years were randomly allocated to four groups (n = 10 each): resistance training (RT), spirulina supplementation (SP), combined resistance training and spirulina supplementation (RT + SP), or non-intervention control (CON). Resistance training was performed three times weekly using progressive overload, while spirulina was administered at a relatively low dose of 1,000 mg on three days per week (3 g/week). Arm and thigh circumferences were measured using standardized anthropometric procedures, and maximal strength was assessed using one-repetition maximum (1RM) tests for bench press and shoulder press. Data were analyzed using two-way repeated-measures analysis of variance (ANOVA), with effect sizes expressed as partial eta squared (ηp^2). Trial registration: This trial was not prospectively registered in a publicly accessible clinical trial registry. Therefore, no trial registration platform or registration number is available. **Results:** Significant time × group interactions were observed for arm circumference ($p < 0.001$, $\eta p^2 = 0.66$), thigh circumference ($p = 0.004$, $\eta p^2 = 0.30$), bench press 1RM ($p = 0.038$, $\eta p^2 = 0.21$), and shoulder press 1RM ($p < 0.001$, $\eta p^2 = 0.46$). The RT + SP group demonstrated the greatest mean increases in arm (+5.88 cm) and thigh (+3.02 cm) circumference, compared with RT alone (+1.88 and +2.01 cm, respectively). The estimated difference in arm circumference change between RT + SP and RT was 4.00 cm (95% CI: 1.79 to 6.21), whereas the corresponding difference for thigh circumference was 1.01 cm (95% CI: –0.31 to 2.33). Bench press 1RM increased by 10.00 kg in both RT and RT + SP, while shoulder press 1RM increased by 16.67 and 13.12 kg, respectively. No clear additional benefit of spirulina supplementation was observed for maximal strength compared with resistance training alone. **Conclusion:** Resistance training, alone or combined with spirulina supplementation, was associated with improvements in anthropometric muscle size and maximal strength among adolescent novice male bodybuilders. The combined intervention showed a potentially greater improvement in arm circumference but no clear additional benefit for thigh circumference or maximal strength compared with resistance training alone. Larger studies incorporating direct measures of muscle morphology and standardized dietary assessment are needed to clarify the potential effects of spirulina supplementation on resistance-training adaptations.

Received: Aug. 4, 2026; Revised: Sep. 3, 2026; Accepted: Nov. 12, 2026; Published: Nov. 25, 2026
Copyright © 2026 Fatemeh Khademian, et al.
DOI: https://doi.org/10.55976//fnds.420261678133-145
This is an open-access article distributed under a CC BY license (Creative Commons Attribution 4.0 International License)
https://creativecommons.org/licenses/by/4.0/

Keywords: Resistance training, Spirulina supplementation, Anthropometric muscle size, Maximal strength, One-repetition maximum, Adolescent bodybuilders

1. Introduction

Resistance training is widely recognized as an effective intervention for increasing skeletal muscle mass, muscular strength, and overall physical performance. These adaptations are particularly evident in novice trainees, who typically experience substantial early improvements in strength due primarily to neural adaptations, followed by progressively greater morphological changes with continued progressive resistance training [1, 2]. Initial strength gains are largely attributed to neural adaptations, with subsequent increases in muscle size occurring with continued training exposure, underscoring the importance of structured resistance programs during the early phases of participation.

Beyond mechanical loading, nutritional factors play a critical role in modulating resistance training–induced adaptations. Adequate protein availability is essential for stimulating muscle protein synthesis, facilitating post-exercise recovery, and supporting muscle hypertrophy [3]. Evidence indicates that targeted nutritional strategies can enhance the magnitude of training-induced adaptations when combined with resistance exercise, particularly in physically active and athletic populations [4].

Muscle hypertrophy and strength development involve multiple physiological adaptations, with mechanical stimuli and intracellular signaling pathways playing central roles, while metabolic stress and exercise-induced muscle damage may also contribute to the hypertrophic response [5, 6]. While resistance training provides the primary anabolic stimulus, sufficient nutrient availability is required to optimize muscle protein synthesis and recovery. As a result, nutritional supplementation has become a common adjunct to resistance training programs, particularly among recreational athletes and bodybuilders seeking non-pharmacological strategies to enhance performance and physique-related outcomes.

Spirulina (*Arthrospira platensis*) is a blue–green cyanobacterium rich in protein and vitamins, and contains bioactive compounds such as phycocyanin [7, 8]. Owing to its antioxidant, anti-inflammatory, and immunomodulatory properties, spirulina has attracted interest as a potential exercise and recovery-support supplement [9, 10]. However, any contribution of spirulina as a source of dietary protein is dose-dependent and should be distinguished from potential effects of its bioactive components. Experimental and clinical evidence suggests that spirulina supplementation may attenuate exercise-induced oxidative stress, improve muscular endurance, and support metabolic health [11, 12].

Despite these promising properties, evidence regarding the effects of spirulina supplementation on muscle hypertrophy and maximal strength remains limited and inconsistent. Previous exercise-related studies have generally administered spirulina at doses substantially higher than those used in the present investigation. For example, Kalafati et al. [12] administered 6 g/day for four weeks, while Gurney and Spendiff [13] used 6 g/day for seven days. A recent GRADE-assessed dose–response meta-analysis also reported effects of spirulina supplementation on body composition, with larger effects observed at higher doses and longer intervention durations [14]. However, most available evidence comes from adult populations, and the appropriate dose for adolescent novice resistance-trained individuals remains uncertain. Given the inclusion of participants aged 16–21 years, the present study adopted an exploratory low-dose supplementation regimen. This approach provides an opportunity to investigate responses at a lower level of exposure, although its potential effectiveness cannot be inferred from studies using substantially higher doses. Consequently, findings from higher-dose supplementation studies should not be directly extrapolated to the present intervention. These findings suggest that spirulina may exert biologically meaningful effects on body composition that could complement exercise-induced adaptations. However, while some studies report modest improvements in body composition and physical performance, other studies have found no significant improvements in specific body composition indices or exercise performance following Spirulina supplementation alone or under habitual training conditions [15, 16]. Importantly, few randomized controlled trials have examined the combined effects of spirulina supplementation and resistance training on both anthropometric muscle size and maximal strength, particularly in novice resistance-trained populations.

Investigating the interaction between resistance training and spirulina supplementation is especially relevant in novice bodybuilders, who demonstrate heightened responsiveness to both mechanical and nutritional stimuli. Appropriate nutritional supplementation may enhance acute responses to resistance exercise and contribute to long-term training-induced adaptations in muscle size and strength [17]. Nevertheless, well-controlled studies evaluating whether spirulina supplementation enhances resistance training–induced gains in anthropometric muscle size and strength remain scarce.

Therefore, the purpose of the present study was to examine changes in anthropometric muscle size and maximal strength across resistance training, low-dose spirulina supplementation, combined resistance training

plus spirulina, and non-intervention control conditions. We hypothesized that resistance training would improve anthropometric muscle size and strength, while comparisons involving the exploratory low-dose spirulina regimen were intended to examine whether additional differences were observed when supplementation was provided alone or alongside resistance training.

2. Methods

2.1 Study design

This study was conducted as an eight-week randomized controlled trial (RCT) with a parallel-group design in Shiraz, Iran. Participants were randomly allocated to one of four groups: resistance training (RT) (n = 10), spirulina supplementation (SP) (n = 10), combined resistance training and spirulina supplementation (RT + SP) (n = 10), or a non-intervention control group (CON) (n = 10). Randomization was performed using a computer-generated random allocation sequence. Participants were allocated in a 1 : 1 : 1 : 1 ratio to the RT, SP, RT + SP, and CON groups. Group allocation was concealed until baseline assessments were completed to minimize allocation bias. The study followed a pretest–post-test design, with all outcome measures assessed before and after the intervention period. Due to the nature of the exercise and supplementation interventions, participant blinding was not feasible.

2.2 Participants

Forty male novice bodybuilders aged 16–21years, recruited from a local fitness centre in Shiraz, Iran, voluntarily participated in the study. The sample size was determined based on feasibility and participant availability, and an a priori power analysis was not performed.

Inclusion criteria were: (1) male sex; (2) age between 16 and 21 years; (3) less than six months of prior resistance training experience; and (4) absence of musculoskeletal injuries or chronic medical conditions that could affect participation. Participant eligibility and health status were assessed using the Physical Activity Readiness Questionnaire for Everyone (PAR-Q+) [18].

Exclusion criteria included the use of anabolic agents, regular consumption of nutritional supplements during the previous three months, or any contraindications to resistance training.

All participants were informed about the study procedures, potential benefits, and associated risks, and written informed consent was obtained prior to participation. For participants younger than 18 years, written informed consent was obtained from a parent or legal guardian, in addition to assent from the participant. The study protocol was conducted in accordance with the Declaration of Helsinki and was approved by the Ethics Committee of Islamic Azad University, Shiraz Branch, Iran (Ethics approval no. 1404-06-17). In addition to ethical approval, official authorization to conduct the study was obtained from the head of Islamic Azad University, Shiraz Branch, Iran, prior to participant recruitment and data collection. The trial was not prospectively registered in a publicly accessible clinical trial registry because registration was not incorporated into the initial study planning and administrative procedures before participant recruitment. Consequently, no clinical trial registration platform or registration number is available.

Participant recruitment, randomization, allocation, follow-up, and analysis are summarized in Figure 1. A total of 40 participants were randomly allocated to four groups (n = 10 per group), and all participants completed the eight-week intervention and were included in the final analysis.

2.3 Data privacy and confidentiality

Participant confidentiality was maintained throughout the study in accordance with the approved research protocol and applicable institutional ethical and data protection requirements. All participants were assigned unique identification codes, and research data, including demographic, anthropometric, and muscle strength measurements, were de-identified prior to analysis. Data were securely stored in password-protected electronic files, with access restricted to the three investigators (Morteza Khademian, Elaheh Heidarnia, and Fatemeh Khademian). Data transfers between investigators were conducted using secure methods to maintain confidentiality. Only de-identified data were used for statistical analysis, and study findings were reported in aggregate form to prevent identification of individual participants. De-identified research data may be shared upon reasonable request to the corresponding author, subject to applicable ethical and confidentiality requirements.

2.4 Resistance training protocol

Participants in the RT and RT + SP groups performed a supervised resistance training program three times per week for eight consecutive weeks. All training sessions were conducted in a gym-based setting and supervised by qualified resistance training personnel to ensure proper technique, participant safety, and adherence to the training protocol. The resistance training program was designed based on established principles of strength training and conditioning, as outlined in *Essentials of Strength Training and Conditioning* [19], and followed a progressive overload model consistent with established guidelines for hypertrophy and strength development [20].

The training program was standardized across participants and consisted of exercises targeting all major muscle groups. Training sessions were organized using

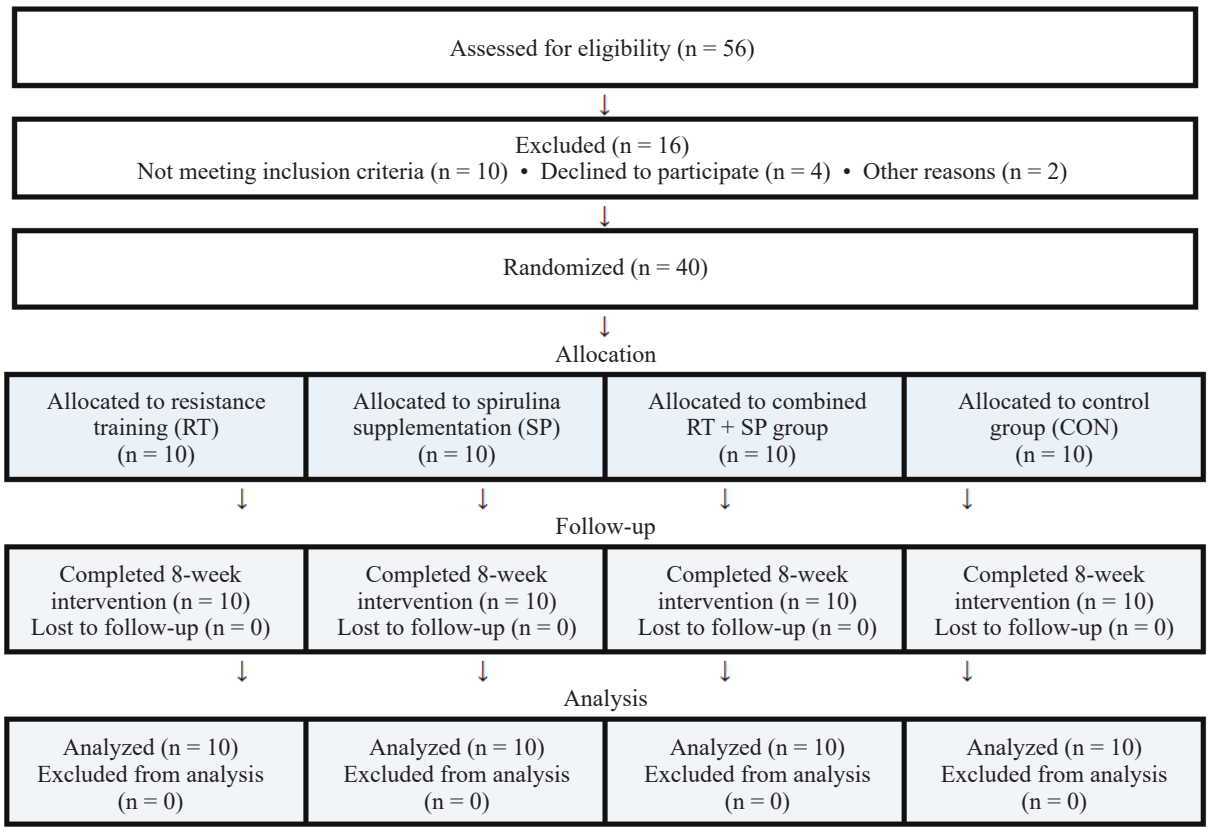


Figure 1. CONSORT-style flow diagram of participant enrollment, allocation, follow-up, and analysis

a split routine as follows: Day 1 included chest and back exercises, Day 2 included shoulder and biceps exercises, and Day 3 included lower body and triceps exercises. All prescribed exercises were performed for three sets of 10 repetitions, with one-minute rest intervals between sets and exercises. Training intensity began at approximately 50% of one-repetition maximum (1RM) during the first week and was progressively increased to approximately 85% of 1RM by the final week.

Each training session included standardized warm-up and cool-down routines lasting approximately 10 minutes. Attendance and training adherence were monitored throughout the intervention period.

A detailed description of the resistance training program, including the specific exercises performed on each training day, is presented in Table 1.

2.5 Spirulina supplementation

Participants in the SP and RT + SP groups received spirulina supplementation in capsule form throughout the eight-week intervention period. Each capsule contained 500 mg of spirulina. Participants consumed one capsule at approximately 4:00 PM and another at 6:00 PM on three days per week, corresponding to two capsules (1,000 mg) per supplementation day, a total weekly intake of 3,000 mg, and an average daily dose of approximately 429 mg across the seven-day week. The relatively low spirulina dose was selected as a conservative, exploratory supplementation approach, taking into consideration the young age of the participants (16–21 years), including individuals younger than 18 years, and the limited evidence regarding optimal spirulina dosing in adolescent resistance-trained populations. The administered regimen of 1 g on three days per week (3 g/week; equivalent to approximately 0.43 g/day when averaged over seven days) was substantially lower than doses commonly investigated in previous exercise-related studies. For example, Kalafati et al. [12] administered 6 g/day for four weeks, while Gurney and Spendiff [13] administered 6 g/day for seven days. These regimens corresponded to weekly intakes of 42 g, approximately 14 times the weekly dose used in the present study. However, the lower dose selected for this study should not be interpreted as an established age-specific recommendation or as having demonstrated superior safety in adolescents. Rather, it represents an exploratory regimen, as evidence establishing an optimal effective dose for muscle-related outcomes in this population remains insufficient. The spirulina supplement was produced by Reyhan Naghsh Jahan Pharmaceutical Company, a certified pharmaceutical manufacturer in Iran, holding a valid product registration license (IRC: 9080218987590713) and manufacturing license (No. 9080218987590713) issued by the Iranian Ministry of

Table 1. Resistance training program performed during the 8-week intervention

Training day	Muscle group	Exercises	Volume
Day 1	Chest	Machine chest press; barbell bench press; dumbbell chest fly; butterfly chest press machine	3 × 10
	Back	Wide-grip lat pulldown; seated cable row; high cable pullover; decline crunches	3 × 10
Day 2	Shoulders	Seated dumbbell shoulder press; standing dumbbell lateral raise; double cable front raise; machine reverse fly	3 × 10
	Biceps	Cable biceps curl; machine preacher curl; dumbbell hammer curl; standing barbell twist	3 × 10
Day 3	Lower body	Leg extension machine; lying leg curl; dumbbell squat; hip adduction; hip abduction; seated calf raise	3 × 10
	Triceps	Cable triceps pushdown; one-arm dumbbell skull crusher; bench dips; back extension	3 × 10

Health and Medical Education, Deputy of Food and Drug. The product complied with all applicable national quality standards. Participants in the RT and CON groups did not receive any supplementation.

Supplementation compliance was monitored throughout the intervention period. All participants were instructed to maintain their habitual dietary intake and physical activity levels outside the intervention.

3. Outcome measures

3.1 Anthropometric measurements

Body weight was measured using a calibrated digital scale, with participants wearing light clothing and no shoes. Measurements were recorded to the nearest 0.1 kg. Standing height was measured using a wall-mounted stadiometer to the nearest 0.1 cm, with participants barefoot, standing upright, and with the head positioned in the Frankfort horizontal plane. All anthropometric measurements were conducted at the same time of day to minimize measurement variability.

3.2 Anthropometric muscle size

Anthropometric muscle size of the arm and thigh was assessed using standardized anthropometric circumference measurements obtained at predefined anatomical landmarks. Arm circumference was measured at the midpoint between the acromion process of the scapula and the olecranon process of the ulna, with participants standing upright, their arms hanging naturally at their sides, and their muscles relaxed. Thigh circumference was measured at the midpoint between the inguinal crease and the proximal border of the patella, with participants standing upright, their weight evenly distributed between both legs, and their thigh muscles relaxed. Measurements were performed using a non-elastic measuring tape positioned horizontally around each anatomical site without compressing the underlying soft tissue. Three consecutive measurements were obtained at each site, and the mean value was recorded for analysis. All measurements were performed by the same trained assessor to minimize inter-observer variability. Circumference-based anthropometric methods are widely used in exercise and nutrition research as practical field-based indicators of muscle-related body dimensions and can provide reliable estimates when standardized measurement procedures are applied [21].

3.3 Muscle strength

Maximal muscle strength was assessed using 1RM testing for the bench press and shoulder press exercises. Standardized 1RM testing procedures were followed, including appropriate warm-up sets and progressive loading until the maximum load that could be lifted once with proper technique was identified [22, 23].

3.4 Statistical analysis

Data were analyzed using SPSS software (version 27), and Microsoft Excel (version 2019) was used to create the figures. Descriptive statistics are presented as mean ± standard deviation (SD). Normality of data distribution was assessed using the Kolmogorov–Smirnov test, and the homogeneity of covariance matrices was examined using Box's M test. A two-way repeated-measures analysis of variance (ANOVA) was used to examine the effects of time (pre- vs. post-intervention), group (RT, SP, RT + SP, CON), and their interaction on all outcome

variables. Effect sizes for the main effect of time and the time × group interaction were expressed as partial eta squared (ηp^2). Within-group changes were calculated as the difference between post- and pre-intervention values. Between-group differences in mean changes were also reported. Between-group differences were calculated by subtracting the mean change in the comparison group from the mean change in the intervention group. Mean changes and between-group differences were presented with corresponding 95% confidence intervals (CIs), calculated using the standard errors of the mean differences. Statistical significance was set at $p \leq 0.05$. Tukey's post hoc test was used for pairwise comparisons among the four groups, accounting for multiple comparisons within each outcome. The pretest–post-test design and repeated-measures ANOVA allowed changes over time and differences in responses among the intervention groups to be evaluated. Changes from baseline were also reported to describe the magnitude of the observed responses over the eight-week intervention.

4. Results

4.1 Participant characteristics

All forty participants completed the eight-week intervention, and no training-related injuries or adverse events were reported. The participants were adolescent males, with an overall mean age of 16.55 years. Baseline characteristics, including age, height, and body mass, are presented in Table 2. Baseline anthropometric muscle size and maximal strength measurements are presented in Table 3.

4.2 Intervention adherence

Training attendance and supplementation adherence were monitored throughout the eight-week intervention. Participants in the RT and RT + SP groups were scheduled to complete 24 resistance training sessions each, corresponding to 240 scheduled sessions per group. Participants in the SP and RT + SP groups were prescribed 48 spirulina capsules each over the intervention period, corresponding to 480 scheduled capsules per group. All 40 participants completed the eight-week study and were included in the final analysis.

4.3 Arm circumference

Repeated-measures ANOVA revealed a significant main effect of time ($F = 73.39$, $p < 0.001$, $\eta p^2 = 0.67$) and a significant time × group interaction ($F = 23.72$, $p < 0.001$, $\eta p^2 = 0.66$; Table 4). The greatest mean increase in arm circumference was observed in the RT + SP group (+5.88 cm; 95% CI: 3.88 to 7.88), followed by RT (+1.88 cm; 95% CI: 0.66 to 3.10), SP (+0.57 cm; 95% CI: −0.36 to 1.50), and CON (+0.45 cm; 95% CI: −0.34 to 1.24; Table 3). Between-group comparisons showed greater increases in RT + SP than in CON (mean difference: 5.43 cm; 95% CI: 3.35 to 7.51) and RT (mean difference: 4.00 cm; 95% CI: 1.79 to 6.21; Table 5).

4.4 Thigh circumference

A significant main effect of time ($F = 20.50$, $p < 0.001$, $\eta p^2 = 0.36$) and a significant time × group interaction ($F = 5.20$, $p = 0.004$, $\eta p^2 = 0.30$) were observed for thigh circumference (Table 4). The greatest mean increase was observed in RT + SP (+3.02 cm; 95% CI: 1.95 to 4.09), followed by RT (+2.01 cm; 95% CI: 1.08 to 2.94), SP (+0.71 cm; 95% CI: −0.08 to 1.50), and CON (+0.35 cm; 95% CI: −0.29 to 0.99; Table 3). Compared with CON, the mean increases were greater in RT (mean difference: 1.66 cm; 95% CI: 0.60 to 2.72) and RT + SP (mean difference: 2.67 cm; 95% CI: 1.49 to 3.85). The difference between RT + SP and RT was 1.01 cm (95% CI: −0.31 to 2.33; Table 5).

4.5 Maximal strength – bench press (1RM)

Bench press 1RM demonstrated a significant main effect of time ($F = 25.45$, $p < 0.001$, $\eta p^2 = 0.41$) and a significant time × group interaction ($F = 3.12$, $p = 0.038$, $\eta p^2 = 0.21$; Table 4). Mean bench press strength increased by 10.00 kg in both RT (95% CI: 5.71 to 14.29) and RT + SP (95% CI: 6.42 to 13.58), compared with 9.38 kg in SP (95% CI: 2.23 to 16.53) and no change in CON (95% CI:

Table 2. Baseline characteristics of participants (mean ± SD)

Variable	RT (n = 10)	SP (n = 10)	RT + SP (n = 10)	CON (n = 10)
Age (years)	16.90 ± 1.37	16.60 ± 0.52	16.20 ± 1.55	16.50 ± 1.78
Height (cm)	175.00 ± 5.03	173.80 ± 4.44	179.80 ± 5.27	175.70 ± 5.64
Weight (kg)	64.60 ± 9.19	62.20 ± 6.16	63.00 ± 9.09	62.60 ± 10.47

CON: control; SP: spirulina supplementation; RT: resistance training; RT + SP: combined intervention; SD: standard deviation.

Table 3. Changes in anthropometric muscle size and maximal strength outcomes

	Outcome	Group	Pre (mean ± SD)	Post (mean ± SD)	Mean change (95% CI)
Anthropometric muscle size	Arm circumference (cm)	CON	19.64 ± 5.97	20.09 ± 5.46	0.45 (–0.34, 1.24)
		SP	21.86 ± 3.03	22.43 ± 2.61	0.57 (–0.36, 1.50)
		RT	23.22 ± 4.41	25.10 ± 5.24	1.88 (0.66, 3.10)
		RT + SP	23.43 ± 5.47	29.31 ± 6.90	5.88 (3.88, 7.88)
	Thigh circumference (cm)	CON	44.13 ± 4.22	44.48 ± 4.31	0.35 (–0.29, 0.99)
		SP	47.16 ± 5.06	47.87 ± 5.26	0.71 (–0.08, 1.50)
		RT	49.17 ± 4.30	51.18 ± 4.21	2.01 (1.08, 2.94)
		RT + SP	46.16 ± 4.18	49.18 ± 4.78	3.02 (1.95, 4.09)
Maximal strength (1RM)	Bench press 1RM (kg)	CON	47.70 ± 13.19	47.70 ± 13.35	0.00 (–1.43, 1.43)
		SP	47.50 ± 5.97	56.88 ± 13.07	9.38 (2.23, 16.53)
		RT	65.56 ± 18.10	75.56 ± 16.66	10.00 (5.71, 14.29)
		RT + SP	55.00 ± 7.56	65.00 ± 7.56	10.00 (6.42, 13.58)
	Shoulder press 1RM (kg)	CON	40.50 ± 7.24	40.90 ± 6.95	0.40 (–1.03, 1.83)
		SP	41.25 ± 5.82	43.75 ± 9.16	2.50 (–1.08, 6.08)
		RT	53.33 ± 10.01	70.00 ± 11.18	16.67 (11.66, 21.68)
		RT + SP	45.63 ± 6.23	58.75 ± 8.76	13.12 (8.11, 18.13)

CON: control; SP: spirulina supplementation; RT: resistance training; RT + SP: combined intervention; 1RM: one-repetition maximum; SD: standard deviation; CI: confidence interval.

Table 4. Repeated-measures ANOVA results

Outcome	Time effect (F)	Partial η^2	p	Time × group (F)	Partial η^2	p
Arm circumference (cm)	73.39	0.67	< 0.001	23.72	0.66	< 0.001
Thigh circumference (cm)	20.50	0.36	< 0.001	5.20	0.30	0.004
Bench press 1RM (kg)	25.45	0.41	< 0.001	3.12	0.21	0.038
Shoulder press 1RM (kg)	42.18	0.54	< 0.001	10.35	0.46	< 0.001

1RM: one-repetition maximum; η^2: eta squared.

Table 5. Between-group differences in changes in anthropometric muscle size and maximal strength

Outcome	Comparison	Mean difference (95% CI)
Arm circumference (cm)	RT vs CON	1.43 (0.07, 2.79)
	RT + SP vs CON	5.43 (3.35, 7.51)
	RT + SP vs RT	4.00 (1.79, 6.21)
Thigh circumference (cm)	RT vs CON	1.66 (0.60, 2.72)
	RT + SP vs CON	2.67 (1.49, 3.85)
	RT + SP vs RT	1.01 (–0.31, 2.33)
Bench press 1RM (kg)	RT vs CON	10.00 (5.60, 14.40)
	RT + SP vs CON	10.00 (5.88, 14.12)
	RT + SP vs RT	0.00 (–5.30, 5.30)
Shoulder press 1RM (kg)	RT vs CON	16.27 (11.17, 21.37)
	RT + SP vs CON	12.72 (7.62, 17.82)
	RT + SP vs RT	–3.55 (–10.13, 3.03)

CON: control; SP: spirulina supplementation; RT: resistance training; RT + SP: combined resistance training and spirulina supplementation; 1RM: one-repetition maximum; CI: confidence interval.
Note: Values represent between-group differences in mean changes from baseline to post-intervention, with corresponding 95% confidence intervals.

−1.43 to 1.43; Table 3). Compared with CON, the mean difference in change was 10.00 kg for both RT (95% CI: 5.60 to 14.40) and RT + SP (95% CI: 5.88 to 14.12). No difference in mean change was observed between RT and RT + SP (0.00 kg; 95% CI: −5.30 to 5.30; Table 5).

4.6 Maximal strength – shoulder press (1RM)

Shoulder press 1RM demonstrated a significant main effect of time ($F = 42.18$, $p < 0.001$, $\eta p^2 = 0.54$) and a significant time × group interaction ($F = 10.35$, $p < 0.001$, $\eta p^2 = 0.46$; Table 4). The greatest mean increase was observed in RT (+16.67 kg; 95% CI: 11.66 to 21.68), followed by RT + SP (+13.12 kg; 95% CI: 8.11 to 18.13), SP (+2.50 kg; 95% CI: −1.08 to 6.08), and CON (+0.40 kg; 95% CI: −1.03 to 1.83; Table 3). Compared with CON, the mean increases were greater in RT (mean difference: 16.27 kg; 95% CI: 11.17 to 21.37) and RT + SP (mean difference: 12.72 kg; 95% CI: 7.62 to 17.82). The difference between RT + SP and RT was −3.55 kg (95% CI: −10.13 to 3.03; Table 5).

5. Discussion

The present randomized controlled trial examined the independent and combined effects of resistance training and spirulina supplementation on anthropometric muscle size and maximal strength in adolescent novice male bodybuilders. The findings indicated that resistance training, either alone or combined with spirulina supplementation, was associated with improvements in arm and thigh circumference and maximal strength. Significant time × group interactions were observed across all outcomes, suggesting that the magnitude of change differed among the intervention groups. The combined RT + SP intervention demonstrated the greatest numerical improvements in arm and thigh circumference, whereas the addition of spirulina did not demonstrate an additional benefit for bench press or shoulder press 1RM compared with resistance training alone. These findings suggest that the effects of spirulina supplementation may vary across anthropometric and strength outcomes. However, the study was not designed to formally evaluate additive or synergistic effects, and the observed differences should not be interpreted as evidence of synergy.

5.1 Effects of resistance training on anthropometric muscle size and strength

Resistance training alone was associated with improvements in both anthropometric muscle size and maximal strength. Compared with the control group, the RT group demonstrated greater increases in arm circumference (+1.43 cm), thigh circumference (+1.66 cm), bench press 1RM (+10.00 kg), and shoulder press 1RM (+16.27 kg). These findings are consistent with previous research demonstrating that progressive resistance training promotes muscular adaptations through mechanical loading and associated physiological responses [1, 2].

The observed improvements in arm and thigh circumference are consistent with the established role of resistance exercise in promoting muscle hypertrophy. Mechanical tension generated during resistance training stimulates anabolic signaling pathways involved in muscle protein synthesis and structural adaptation [2]. However, because muscle size was estimated using anthropometric measurements rather than direct imaging techniques, changes in circumference should not be interpreted as definitive evidence of increased muscle mass.

The improvements in maximal strength were also consistent with previous findings indicating that resistance training enhances neuromuscular performance through neural and morphological adaptations [24]. Early strength adaptations may be influenced by improvements in motor unit recruitment, coordination, and movement efficiency, alongside morphological changes that develop with continued training. The increases observed in bench press and shoulder press 1RM reinforce the importance of progressive mechanical loading in strength development.

5.2 Effects of spirulina supplementation on anthropometric muscle size and strength

Spirulina supplementation alone was associated with relatively small numerical increases in arm circumference (+0.57 cm) and thigh circumference (+0.71 cm). Although the SP group also demonstrated increases in bench press (+9.38 kg) and shoulder press (+2.50 kg) strength, the present comparisons do not establish whether these changes were significantly greater than those observed in the control group. Therefore, the findings do not provide sufficient evidence to conclude that spirulina supplementation alone improved anthropometric muscle size or maximal strength.

Spirulina contains protein, essential amino acids, and bioactive compounds with antioxidant and anti-inflammatory properties that may influence exercise-related physiological responses [9]. Previous studies have suggested that spirulina supplementation may reduce exercise-induced oxidative stress and skeletal muscle damage. For example, Lu et al. [10] reported protective effects of spirulina against exercise-induced skeletal muscle damage, while Kalafati et al. [12] described potential ergogenic and antioxidant effects in humans.

Nevertheless, these proposed benefits do not necessarily translate into improvements in muscle circumference or maximal strength. The effects of spirulina may depend on supplementation dose, intervention duration, exercise modality, and participants' training status. Furthermore, the present study did not assess oxidative stress, inflammatory markers, or muscle protein synthesis, limiting the ability to explain the observed responses through specific biological mechanisms.

5.3 Combined effects of resistance training and spirulina supplementation

The combined RT + SP intervention was associated with improvements in both anthropometric muscle size and maximal strength, although the magnitude of these improvements varied by outcome.

For arm circumference, RT + SP demonstrated the greatest mean increase (+5.88 cm), compared with RT alone (+1.88 cm). The estimated between-group difference in change was 4.00 cm (95% CI: 1.79 to 6.21), suggesting a potentially greater anthropometric response with the combined intervention.

For thigh circumference, RT + SP also demonstrated a greater numerical increase (+3.02 cm) than RT alone (+2.01 cm). However, the between-group difference was relatively small (1.01 cm; 95% CI: −0.31 to 2.33), providing insufficient evidence of an additional benefit from spirulina supplementation.

In contrast, the combined intervention did not demonstrate greater improvements in maximal strength compared with resistance training alone. Bench press 1RM increased by 10.00 kg in both RT and RT + SP, with no difference in mean change between the groups. Shoulder press 1RM increased by 16.67 kg in RT and 13.12 kg in RT + SP, with a between-group difference of −3.55 kg (95% CI: −10.13 to 3.03). These findings suggest that adding spirulina to resistance training did not produce a clear additional strength benefit over the eight-week intervention.

Several mechanisms have been proposed through which spirulina could influence exercise adaptations, including antioxidant activity, attenuation of exercise-induced muscle damage, and modulation of oxidative metabolism [25, 26]. Vignaud et al. [25] investigated the combined effects of spirulina supplementation and endurance training on aerobic performance and muscle metabolic adaptations in Wistar rats. Although their findings provide potentially relevant preclinical evidence regarding the physiological effects of spirulina, results from animal models cannot be directly extrapolated to humans, particularly adolescent resistance-trained individuals. Therefore, these findings should be considered preliminary mechanistic evidence rather than direct support for the outcomes observed in the present

study. Furthermore, evidence regarding spirulina's effects remains inconsistent. Krokidas et al. [27] reported no significant attenuation of exercise-induced muscle damage markers following short-term spirulina supplementation in healthy adults, suggesting that physiological responses may depend on the intervention protocol and study population.

A recent meta-analysis also examined the effects of spirulina supplementation on body composition in adults [14]. However, findings from adult populations may not be directly generalizable to adolescents undergoing resistance training, particularly given differences in growth, maturation, and physiological responses to exercise.

An important consideration when interpreting these findings is the relatively low spirulina dose administered in the present study. Participants received 1 g on three days per week, corresponding to an average daily intake of approximately 0.43 g, whereas previous exercise-related studies have commonly investigated continuous daily supplementation at substantially higher doses, including 6 g/day [12, 13]. The lower and intermittent dosing schedule used in the present investigation limits direct comparisons with previous studies and may have influenced the observed responses. Although the RT + SP group demonstrated a greater increase in arm circumference than the RT group, no clear additional benefit was observed for maximal strength. These findings should therefore be interpreted specifically within the context of the low-dose regimen investigated, rather than as evidence regarding the effectiveness of spirulina supplementation at higher doses. Furthermore, because the study included participants aged 16–21 years, including minors, the limited evidence on age-appropriate dosing and long-term supplementation in adolescents warrants consideration. Future studies should evaluate different supplementation doses and schedules, while incorporating appropriate safety monitoring and accounting for biological maturation, to clarify potential dose–response relationships in this population.

Overall, the present findings indicate that resistance training was the principal intervention associated with improvements in maximal strength. Although the combined intervention demonstrated greater numerical improvements in anthropometric outcomes, particularly arm circumference, these findings require confirmation in larger trials using direct measures of muscle morphology. Future studies should investigate whether spirulina supplementation provides additional benefits beyond resistance training alone, while accounting for dietary intake, biological maturation, supplementation dose, and intervention duration.

6. Limitations

Several limitations should be acknowledged. First, anthropometric muscle size was assessed using anthropometric measurements rather than imaging techniques such as ultrasound or magnetic resonance imaging, which may limit precision. Second, the relatively small sample size and inclusion of only young male participants restrict the generalizability of the findings to other populations, including females and older adults. Third, participant blinding was not feasible due to the nature of the interventions, which may have introduced performance and expectancy biases and influenced self-reported adherence. Fourth, dietary intake was not quantitatively assessed or monitored during the intervention. Although participants were instructed to maintain their habitual diets, total energy and macronutrient intake, particularly protein intake, were not assessed. Given that dietary protein intake can influence gains in lean body mass and muscle strength during resistance training [28], unmeasured differences in dietary intake may have influenced the observed outcomes and represent a potential confounding factor. Additionally, the relatively low and intermittent spirulina supplementation regimen, selected partly in consideration of the participants' young age, limits comparisons with previous studies using higher daily doses. As only one supplementation dose was investigated, the study could not determine an optimal dose or evaluate a dose-response relationship. The inclusion of participants at different stages of adolescent development, without assessment of biological maturation, further limits the interpretation and generalizability of the findings. Future studies employing larger samples, longer intervention periods, appropriate blinding procedures, advanced imaging methods, and standardized dietary assessment and monitoring of energy and protein intake are warranted to further clarify the role of spirulina in resistance training adaptations. Finally, the trial was not prospectively registered in a publicly accessible clinical trial registry before participant recruitment, as registration was not incorporated into the initial study planning and administrative procedures. The absence of prospective registration may limit the transparency of the study protocol and the independent verification of prespecified outcomes. In future studies, the authors will ensure that clinical trials are registered in a publicly accessible registry before participant recruitment to enhance research transparency and methodological accountability.

7. Conclusion

In conclusion, resistance training, either alone or combined with spirulina supplementation, was associated with improvements in anthropometric muscle size and maximal strength in adolescent novice male bodybuilders. The combined intervention demonstrated the greatest increase in arm circumference, with a potentially greater benefit compared with resistance training

alone, while no clear additional benefit was observed for thigh circumference. However, adding spirulina supplementation to resistance training did not produce greater improvements in bench press or shoulder press 1RM, suggesting no additional benefit for maximal strength under the supplementation regimen used in this study. These findings should be interpreted cautiously given the small sample size, limitations of anthropometric measurements, and the absence of a formal statistical assessment of additive or synergistic effects. Further adequately powered studies incorporating direct measures of muscle morphology, standardized dietary assessment, and well-characterized spirulina dosing are warranted to clarify the potential benefits of combining spirulina supplementation with resistance training in adolescent populations.

Health and safety statement

All resistance training sessions were supervised by qualified personnel, and standard laboratory and exercise safety procedures were followed throughout the study. No adverse events or injuries were reported.

Generative artificial intelligence (AI) use disclosure

The authors declare that no generative AI tools or AI-assisted technologies were used in the research process, including study conception, methodology development, data analysis, interpretation of results, manuscript drafting, or revision. The manuscript was entirely prepared and reviewed by the authors.

Author contributions

Morteza Khademian: Conceptualization, Methodology, Investigation, Data Curation, Formal Analysis, Writing—Original Draft, Writing—Review & Editing.

Elaheh Heidarnia: Supervision, Writing—Review & Editing.

Fatemeh Khademian: Writing—Original Draft, Writing—Review & Editing, Formal Analysis (Supporting), Data Interpretation, Correspondence.

Morteza Khademian conceived and designed the study, conducted the intervention, collected and analyzed the data, and contributed to manuscript preparation and revision. Elaheh Heidarnia supervised the research. Fatemeh Khademian contributed substantially to manuscript preparation, supported the statistical analysis and interpretation of the findings, and serves as the corresponding author.

All authors reviewed and approved the final version of the manuscript and agree to be accountable for their contributions to the work.

Funding

This research received no external funding. The study was conducted without financial support from any public, commercial, or not-for-profit funding agency. The spirulina supplements used in the study were purchased independently by the researchers.

Data availability

The data supporting the findings of this study are available from the corresponding author, Fatemeh Khademian, upon reasonable request, subject to applicable ethical and confidentiality requirements. Statistical analyses were performed using IBM SPSS Statistics (version 27), and Microsoft Excel (version 2019) was used for figure preparation. No custom code or software was developed specifically for this study.

Conflict of interest

The authors declare no conflicts of interest. The spirulina supplements were independently purchased from Reyhan Naghsh Jahan Pharmaceutical Company, Iran. The manufacturer provided no financial or material support and had no involvement in the study design, data collection, analysis, interpretation of results, manuscript preparation, or publication decisions.

References

[1] Kraemer WJ, Ratamess NA. Fundamentals of resistance training: progression and exercise prescription. *Medicine & Science in Sports & Exercise*. 2004; 36(4): 674-688. doi:10.1249/01.MSS.0000121945.36635.61.

[2] Schoenfeld BJ. The mechanisms of muscle hypertrophy and their application to resistance training. *Journal of Strength and Conditioning Research*. 2010; 24(10): 2857-2872. doi:10.1519/JSC.0b013e3181e840f3.

[3] Tipton KD, Wolfe RR. Exercise, protein metabolism, and muscle growth. *International Journal of Sport Nutrition and Exercise Metabolism*. 2001; 11(1): 109-132. doi:10.1123/ijsnem.11.1.109.

[4] Phillips SM, Van Loon LJC. Dietary protein for athletes: from requirements to optimum adaptation. *Journal of Sports Sciences*. 2011; 29(Suppl 1): S29-S38. doi:10.1080/02640414.2011.619204.

[5] Wackerhage H, Schoenfeld BJ, Hamilton DL, Lehti M, Hulmi JJ. Stimuli and sensors that initiate skeletal muscle hypertrophy following resistance exercise. *Journal of Applied Physiology*. 2019; 126(1): 30-43. doi:10.1152/japplphysiol.00685.2018.

[6] Folland JP, Williams AG. Morphological and neurological contributions to increased strength. *Sports Medicine*. 2007; 37(2): 145-168. doi:10.2165/00007256-200737020-00004.

[7] Belay A. Biology and industrial production of *Arthrospira* (*Spirulina*). In: Richmond A, Hu Q. (eds.) *Handbook of Microalgal Culture: Applied Phycology and Biotechnology*. 2nd ed. Wiley-Blackwell; 2013. p.339-358. doi:10.1002/9781118567166.ch17.

[8] Wu Q, Liu L, Miron A, Klímová B, Wan D, Kuča K. The antioxidant, immunomodulatory, and anti-inflammatory activities of Spirulina: an overview. *Archives of Toxicology*. 2016; 90(8): 1817-1840. doi:10.1007/s00204-016-1744-5.

[9] Finamore A, Palmery M, Bensehaila S, Peluso I. Antioxidant, immunomodulating, and microbial-modulating activities of the sustainable and ecofriendly *Spirulina*. *Oxidative Medicine and Cellular Longevity*. 2017; 2017: 3247528. doi:10.1155/2017/3247528.

[10] Lu HK, Hsieh CC, Hsu JJ, Yang YK, Chou HN. Preventive effects of *Spirulina platensis* on skeletal muscle damage under exercise-induced oxidative stress. *European Journal of Applied Physiology*. 2006; 98(2): 220-226. doi:10.1007/s00421-006-0263-0.

[11] Fu Z, Zhou S, Gu X. Effects of spirulina supplementation alone or with exercise on cardiometabolic health in overweight and obese adults: a systematic review and meta-analysis. *Frontiers in Nutrition*. 2025; 12: 1624982. doi:10.3389/fnut.2025.1624982.

[12] Kalafati M, Jamurtas AZ, Nikolaidis MG, Paschalis V, Theodorou AA, Sakellariou GK, et al. Ergogenic and antioxidant effects of spirulina supplementation in humans. *Medicine & Science in Sports & Exercise*. 2010; 42(1): 142-151. doi:10.1249/MSS.0b013e3181ac7a45.

[13] Gurney T, Spendiff O. Spirulina supplementation improves oxygen uptake in arm cycling exercise. *European Journal of Applied Physiology*. 2020; 120(12): 2657-2664. doi:10.1007/s00421-020-04487-2.

[14] Lak MY, Karimi M, Akhgarjand C, Mohammadi SG, Pam P, Ashtary-Larky D, et al. Effects of spirulina supplementation on body composition in adults: a GRADE-assessed and dose-response meta-analysis of RCTs. *Nutrition & Metabolism*. 2025; 22: 61. doi:10.1186/s12986-025-00959-4.

[15] Ali Y, Aubeeluck R, Gurney T. Fourteen-days spirulina supplementation increases hemoglobin, but does not provide ergogenic benefit in recreationally active cyclists: A double-blinded randomized crossover trial. *Journal of Dietary Supplements*. 2024; 21(3): 261-280. doi:10.1080/19390211.2023.2263564.

[16] Chaouachi M, Gautier S, Carnot Y, Bideau N, Guillemot P, Moison Y, et al. *Spirulina platensis* provides a small advantage in vertical jump and sprint performance but does not improve elite rugby players' body composition. *Journal of Dietary Supplements*. 2021; 18(6): 682-697. doi:10.1080/19390211.2020.1832639.

[17] Volek JS. Influence of nutrition on responses to resistance training. *Medicine & Science in Sports & Exercise*. 2004; 36(4): 689-696. doi:10.1249/01.mss.0000121944.19275.c4.

[18] Warburton DER, Jamnik VK, Bredin SSD, Gledhill N. The physical activity readiness questionnaire for everyone (PAR-Q+) and electronic physical activity readiness medical examination (ePARmed-X+). *The Health & Fitness Journal of Canada*. 2011; 4(2): 3-17. doi:10.14288/hfjc.v4i2.103.

[19] Haff GG, Triplett NT. *Essentials of Strength Training and Conditioning*. 4th ed. Champaign, IL: Human Kinetics; 2016.

[20] Kraemer WJ, Adams K, Cafarelli E, Dudley GA, Dooly CR, Feigenbaum MS, et al. Progression models in resistance training for healthy adults. *Medicine & Science in Sports & Exercise*. 2002; 34(2): 364-380. doi:10.1097/00005768-200202000-00027.

[21] Lohman TG, Roche AF, Martorell R. *Anthropometric Standardization Reference Manual*. Human Kinetics; 1988.

[22] Sigvaldsen E, Loturco I, Larsen F, Bruusgaard J, Kalhovde JM, Haugen T. Validity and reliability of upper body push and pull tests to determine one-repetition maximum. *PLoS One*. 2023; 18(7): e0288649. doi:10.1371/journal.pone.0288649.

[23] Seo DI, Kim E, Fahs CA, Rossow L, Young K, Ferguson SL, et al. Reliability of the one-repetition maximum test based on muscle group and gender. *Journal of Sports Science and Medicine*. 2012; 11(2): 221-225.

[24] Suchomel TJ, Nimphius S, Bellon CR, Stone MH. The importance of muscular strength: training considerations. *Sports Medicine*. 2018; 48(4): 765-785. doi:10.1007/s40279-018-0862-z.

[25] Vignaud J, Loiseau C, Côme M, Martin I, Rasoanarivo R, Hérault J, et al. Combined effects of spirulina liquid extract and endurance training on aerobic performance and muscle metabolism adaptation in Wistar rats. *Nutrients*. 2025; 17(2): 283. doi:10.3390/nu17020283.

[26] Chaouachi M, Gautier S, Carnot Y, Guillemot P, Pincemail J, Moison Y, et al. Spirulina supplementation prevents exercise-induced lipid peroxidation, inflammation and skeletal muscle

damage in elite rugby players. *Journal of Human Nutrition and Dietetics*. 2022; 35(6): 1151-1163. doi:10.1111/jhn.13014.

[27] Krokidas A, Gakis AG, Aktypi O, Antonopoulou S, Nomikos T. Effect of *Spirulina Nigrita*® supplementation on indices of exercise-induced muscle damage after eccentric protocol of upper limbs in apparently healthy volunteers. *Nutrients*. 2024; 16(11): 1651. doi:10.3390/nu16111651.

[28] Nunes EA, Colenso-Semple L, McKellar SR, Yau T, Ali MU, Fitzpatrick-Lewis D, et al. Systematic review and meta-analysis of protein intake to support muscle mass and function in healthy adults. *Journal of Cachexia, Sarcopenia and Muscle*. 2022; 13(2): 795-810. doi:10.1002/jcsm.12922.