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SYSTEMATIC REVIEW

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Clinical outcome changes in sarcopenic obesity: a meta-analysis of exercise training methods

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Abstract

Aim Assessing the effect of various forms of exercise training on patients with sarcopenic obesity.

Methods Two independent reviewers systematically searched English and Chinese databases (PubMed, Embase, Cochrane Library, Web of Science, CNKI) for randomized controlled trials on various exercise training effects in sarcopenic obesity patients until October 2023. Reference materials and grey literature were also included. Selected studies underwent screening, data extraction, and quality assessment. Meta-analysis was conducted using Review Manager 5.4 software.

Results A total of 8 studies were included in the final analysis. The Meta-analysis results indicated that resistance training (RT) significantly improved grip strength (MD = 3.85, 95%CI: 1.50 to 6.20, $P < 0.01$), percentage of body fat (MD = -2.96, 95%CI: -4.19 to -1.74, $P < 0.01$), walking speed (MD = 0.23, 95%CI: 0.01 to 0.46, $P = 0.04$), IGF-1(MD = 0.79, 95%CI: 0.05 to 1.52, $P = 0.04$) and knee extension strength (MD = 4.85, 95%CI: 1.97 to 7.72, $P < 0.01$). There was no statistically significant difference observed in weight (MD = -0.61, 95%CI: -4.06 to 2.84, $P = 0.73$). Aerobic training (AT) resulted in a significant reduction in weight among patients with SO (MD = -6.07, 95%CI: -9.89 to -2.25, $P < 0.01$), while no statistically significant differences were observed in other outcome measures. Mixed training (MT) significantly improved percentage of body fat (MD = -2.42, 95%CI: -3.58 to -1.26, $P < 0.01$), weight (MD = -4.40, 95%CI: -8.40 to -0.40, $P = 0.03$), IGF-1 (MD = 1.01, 95%CI: 0.45 to 1.56, $P < 0.01$), and walking speed (MD = 0.15, 95%CI: 0.04 to 0.26, $P < 0.01$). However, no statistically significant differences were observed in grip strength (MD = -0.70, 95%CI: -4.00 to 2.60, $P = 0.68$) and knee extension strength (MD = 1.73, 95%CI: -1.31 to 4.78, $P = 0.26$). RT, AT, and MT exercise could not significantly improve the level of serum IL-6 in patients with SO, and the difference was not statistically significant [MD = -0.01,95%CI:-0.27 to 0.24, $P = 0.92$].

Conclusion Various exercise training methods have differing effects on muscle-reducing obesity treatment. Compared to aerobic training, resistance training, and mixed training may offer more pronounced improvements, enhancing physical functioning in sarcopenic obesity patients. This underscores the clinical significance of exercise

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intervention in treating muscle-reducing obesity, suggesting future studies explore exercise intervention's role and mechanism, particularly related to IGF-1, IL-6, and other cytokines.

Keywords Sarcopenia, Obesity, Exercise, Muscle

Sarcopenic obesity (SO) was introduced in 2000, defined as an age-related condition characterized by reduced skeletal muscle mass or strength, muscle dysfunction, and concurrent obesity, forming a geriatric syndrome [1, 2]. Research conducted by Gao et al. [3] demonstrated that the global prevalence of SO among elderly individuals was 11%. Specifically, individuals aged 75 years or older exhibit a 23% prevalence rate of sarcopenic obesity. With the continuous growth of the elderly population and the extension of life expectancy, the incidence of SO is expected to gradually rise. It is projected that by 2051, the number of affected individuals will reach 100 to 200 million people [4]. Studies indicated that compared to elderly individuals with either sarcopenia or obesity alone, individuals with SO have a significantly increased risk of metabolic disturbances [5, 6], depression [7], cognitive impairments [8], falls and fractures [9], and even mortality [10]. This substantially jeopardizes the quality of life among the elderly, intensifying both medical and economic burdens.

Currently, various treatment approaches have been proposed for SO, including exercise and nutritional interventions, pharmacological therapies, and bariatric surgery [11]. Among these, exercise intervention is considered one of the most effective and suitable treatment strategies for SO. It aims to increase muscle protein and fiber synthesis, maintain the expression of muscle regeneration factors, and reduce inflammatory markers to prevent or delay the development of SO, thereby reducing the incidence of sarcopenic obesity [12]. In this process, some key cytokines, such as Insulin-like Growth Factor-1 (IGF-1) and Interleukin- 6(IL-6), play crucial roles. IGF-1 is an important growth factor that plays a key role in promoting muscle growth and enhancing muscle fibers. It engages satellite cells within the muscles, contributing to muscle fiber enlargement and aiding in enhancing muscle quality [11]. In contrast, IL-6 is a complex cytokine that, through inflammatory cascades, inhibits muscle protein synthesis, ultimately impacting muscle quality and accelerating the development of SO [12]. Therefore, the benefits of exercise for SO patients primarily lie in its ability to activate beneficial cytokines, thereby slowing muscle atrophy and improving muscle quality. However, it's important to consider the role of IL-6, and caution must be exercised regarding the impact of inflammatory responses on muscle quality.

At present, many studies have investigated the intervention effect of different sports training on SO.For instance, research by Ghiotto et al. [13] found that physical exercise, particularly resistance training (RT), can improve the physical functioning of individuals with SO. However, some studies [14] suggested that exercise intervention might not significantly improve the muscle status of individuals with SO. It is crucial to ascertain the effectiveness of various forms of exercise interventions to clinically enhance the health conditions of individuals affected by SO, and no relevant meta-analysis has been found to exploring changes in cytokine levels after exercise intervention, therefore, we conducted this meta-analysis to provide evidence for the treatment and management of patients with SO.

Material and methods

This meta-analysis followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement guidelines [15] and is registered in the International Prospective Register of Systematic Review (PROSPERO CRD42023414555).

Inclusion and exclusion criteria

Inclusion criteria: ①Studies involving subjects meeting the latest diagnostic criteria for SO as proposed by ESPEN and EASO in 2022 [16]; ②Research of randomized controlled trials (RCTs); ③Interventions: The experimental group receives exercise interventions, while the control group receives health education, placebos, or other non-exercise interventions; ④Outcome measures: grip strength (GS), percentage of body fat (PBF), walking speed (WS), IGF-1, IL-6, weight, knee extension strength (KES).

Exclusion criteria: ①Non-English or non-Chinese publications; ②Duplicate publications; ③Inaccessibility to full-text or articles containing only abstracts; ④ Articles with incomplete data.

Search strategy

The computer-based search will be conducted in the Cochrane Library, Web of Science, PubMed, Embase, Chinese Biomedical Literature Database (CBM), China National Knowledge Infrastructure (CNKI), Wanfang Database, and VIP Database. The search will cover the period from database inception untilAugst 2024, and supplementary searches will include reference lists of included studies and gray literature. A combination of subject headings and free-text terms will be used for the search strategy. The complete search strategy is shown in Supplementary Material 1.

Study selection and data extraction

Two researchers will independently conduct literature screening and data extraction based on the inclusion and exclusion criteria, cross-checking their results. In case of discrepancies, a third researcher will be involved to facilitate consensus. After screening titles and abstracts, studies potentially meeting the criteria will undergo further assessment by reviewing the full-text content. The extraction process encompassed the following information: authors of the included literature, sample size, intervention details, patient gender, patient age, sarcopenic obesity diagnostic, duration of intervention, and outcome measures.

Quality assessment

Two researchers will independently conduct a quality assessment of the included literature using the tool recommended in the Cochrane Handbook for Systematic Reviews of Interventions (Version 5.1.0) for evaluating randomized controlled trials (RCTs) [17]. In the assessment, there are seven criteria. In case of discrepancies, a third researcher will be involved to facilitate consensus. Each criterion requires the evaluators to determine if the risk of bias is "low," "high," or "unclear." If all criteria are completely met, the quality rating is designated as Grade A, partially met criteria receive Grade B, and if the criteria are not met at all, the rating is Grade C.

Statistical analyses

The included studies will be subjected to meta-analysis using Review Manager 5.4 software. As the study outcomes are continuous variables, the effect measures will be presented as either mean differences (MD) or standard mean differences (SMD), and the 95% confidence interval (CI) will serve as the statistical measure for effect analysis. Heterogeneity among the included studies will be assessed using the $\chi 2$ test and the I^2 statistic. A P-value > 0.1 and an $I^2 < 50\%$ indicate no significant statistical heterogeneity among the studies, warranting the use of a fixed-effects model for analysis. Conversely, if $P \leq 0.1$ and $I^2 \geq 50\%$, indicating significant heterogeneity among the studies, a random-effects model will be employed. Subgroup analysis, sensitivity analysis, or qualitative description will be performed.

A significance level of $P \leq 0.05$ denotes statistical significance in differences. Publication bias was assessed using a funnel plot.

Results

Study selection

After an initial search in the databases, a total of 4486 relevant articles were retrieved. Using Endnote 20 software, duplicates were removed, and after screening titles and abstracts, 39 articles were selected for full-text review. Eventually, 8 articles [18–25] were included in the study. The literature selection process is detailed in Fig. 1.

Study characteristics

This study included a total of 8 randomized controlled trials. Among these, 7 were in English [18–24] and 1 was in Chinese [25] The publications ranged from 2016 to 2019. The basic characteristics of the literature are presented in Table 1.

Exercise intervention protocols

Among the 8 studies, a total of 6 exclusively focused on RT [19–22, 24, 25]. The training regimen across the studies included bodyweight exercises [19, 25], elastic band exercises [21, 22, 24], and weight machines [20]. Exercise intensity was based on the Borg Scale, maintained at moderate to high levels. The training duration ranged from 30 to 60 minutes, the intervention frequency was 2 to 3 times per week, and the intervention period was 8 to 12 weeks. Studies exclusively focusing on aerobic training (AT) encompassed 2 trials [20, 25], primarily involving moderate-intensity aerobic exercises. Mixed training (MT) included 4 studies [18, 20, 23, 25], incorporating a combination of resistance and aerobic exercises, resistance exercises, weighted exercises, and aerobic exercises. The training duration varied from 30 to 80 minutes, intervention frequency ranged from 2 to 5 times per week, and the intervention period lasted from 8 to 24 weeks, with exercise intensity maintained at moderate to high levels.

Study quality

Eight articles were included, of which four were rated as grade A and the other four were rated as grade B. All articles [18–25] described the methods and process of randomization. Four articles [18–20, 25] mentioned allocation concealment and 6 articles used blinding for outcome assessors. In eight articles [18–25] complete data is reported. No reporting bias was observed in all articles. All articles [18–25] compared the baseline characteristics of the study subjects, such as age, gender, and disease. 6 articles did not describe the implementation of blinding. Although the blind method was not implemented, it had little impact on the analysis of objective outcome indicators. The quality assessment of the articles is shown in Fig. 2 (Risk of bias graph) and Fig. 3 (Risk of bias summary).

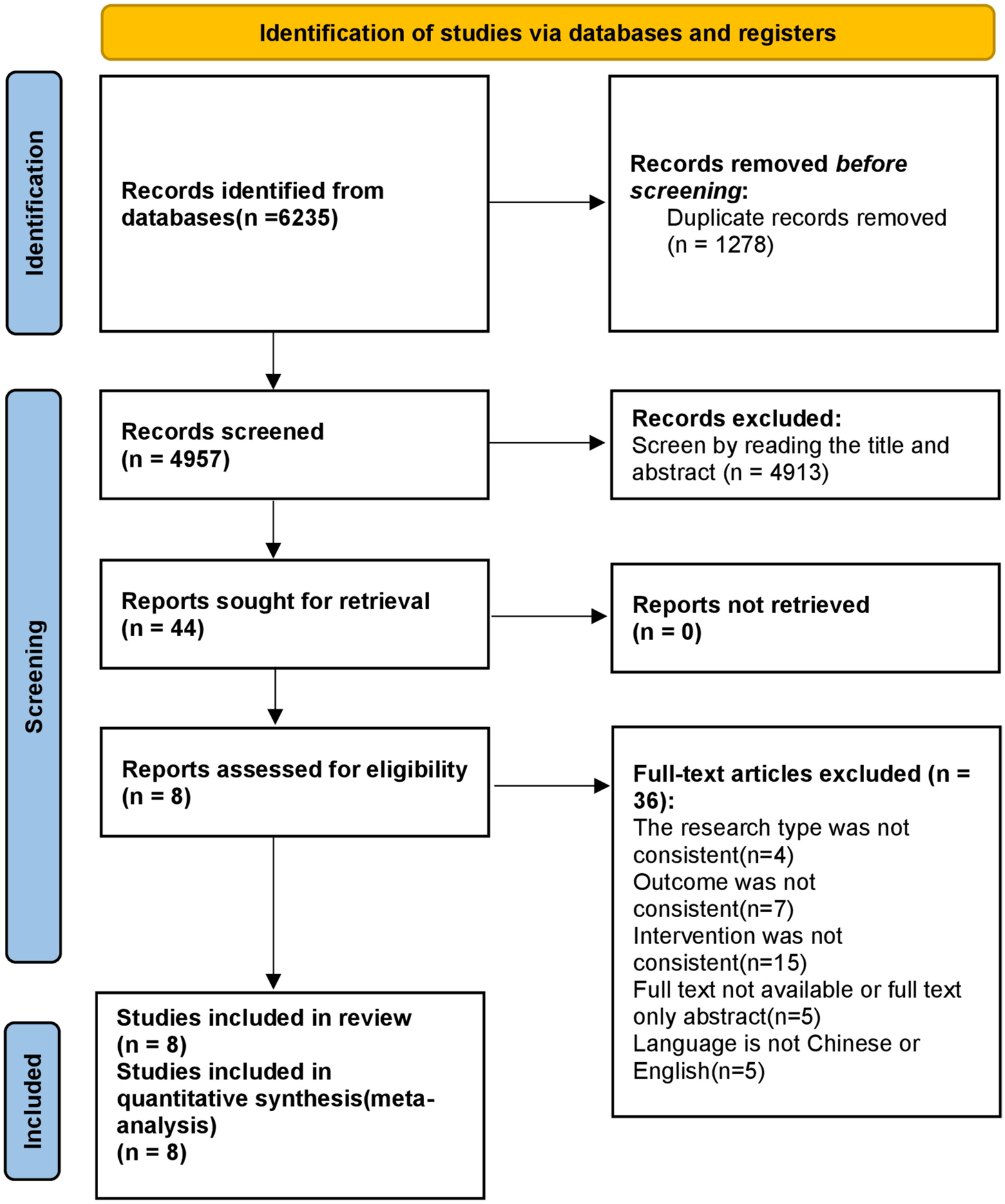

Fig. 1 Flowchart of studies included in this meta-analysis

Outcomes

Effects of different exercise training modes for sarcopenic obesity on GS

According to the information provided, four articles [18, 20, 22, 25] evaluated the effects of RT, AT, and MT on GS. There was heterogeneity among these studies ($P=0.05$, $I^2=51$) leading to the utilization of a random-effects model for the meta-analysis. The results indicate that there is a statistically significant difference in GS between the exercise and control groups, suggesting that exercise training significantly improves the GS of individuals with SO(MD = 2.02,95%*CI*:0.02 to 4.01, $P=0.05$). Subgroup analysis further revealed that compared to the control group, RT significantly enhanced GS (RT, MD = 3.85,95%*CI*:1.50 to 6.20, $P<0.01$), However, the differences in GS improvement were not statistically significant in the AT group and MT group compared to the control group(AT, MD = -0.70,95%*CI*:-4.00 to 2.60, $P=0.68$; MT, MD = 2.27,95%*CI*:-1.89 to 6.43, $P=0.28$). Detailed results can be found in Fig. 4.

Table 1 Characteristics of included studies

Study	Sample Size (Control/ AT/RT/Combination)	M/F	Age	Sarcopenic obesity Diagnostic	Time of intervention	Outcome
Park et al.	25/0/0/25	0/50	74.7 ± 5.1 73.5 ± 7.1	BMI ≥ 25.0 kg/m2 and ASM/weight < 25.1%	24 weeks	PBF, WS
Chen et al.	15/15/15/15	2/13 1/14 3/12 4/11	68.6 ± 3.1 69.3 ± 3.0 68.9 ± 4.4 68.5 ± 2.7	Sarcopenia combined with Obesity. Sarcopenia is defined as appendicular skeletal muscle mass (ASM) (kg)/Weight (kg)*100%. Obesity indicators are body mass index (BMI) ≥ 25 kg/m^2 and visceral fat area (VFA) ≥ 100 cm^2	8 weeks	Weight, PBF, GS, KES, IGF-1
Huang et al.	17/0/18/0	0/17 0/18	69.53 ± 5.09 68.89 ± 4.91	Sarcopenia combined with Obesity. Skeletal Muscle Mass Index (SMI) fell below 27.6%. Participants with a BF% exceeding 30% were categorized as obese	12 weeks	Weight, PBF
Kim et al.	34/35/0/0	0/34 0/35	81.1 ± 5.1 81.4 ± 4.3	Body fat percent of 32% or greater, as measured by dual x-ray energy absorptiometry (DXA, Hologic QDR 4500A), combined with a skeletal muscle mass index less than 5.67 kg/m2. Body fat percent of 32% or greater and grip strength less than 17.0 kg. Body fat percent of 32% or greater and a walking speed under 1.0 m/s	3 months	PBF, GS, WS
Liao et al.	21/0/25/0	0/21 0/25	68.42 ± 5.86 66.39 ± 4.49	Sarcopenia combined with Obesity. Skeletal muscle mass index lower than 7.15 kg/m^2 BF more than 30%	12 weeks	PBF, GS, WS
Liao et al.	23/0/33/0	0/23 0/33	68.32 ± 6.05 66.67 ± 4.54	Sarcopenia combined with Obesity. Skeletal muscle mass index less than 27.6% BF more than 30%	12 weeks	PBF, WS
Vasconcelos et al.	14/0/14/0	0/14 0/14	72 ± 3.6 72 ± 4.6	body mass index (BMI) ≥ 30 kg/m2 and handgrip strength ≤ 21 kg	10 weeks	WS
Wang et al.	20/20/20/20	10/10 10/10 11/9 12/8	64.1 ± 2.8 64.2 ± 3.0 65.1 ± 3.4 63.6 ± 5.2	①appendicular skeletal muscle mass: male < 7.0 kg/m^2, female < 5.4 kg/m^2 ②GS: male < 26 kg, female < 18 kg ③Limb lean mass was adjusted by body mass index: male < 0.789, female < 0.512	12 weeks	Weight, PBF, GS, KES, IGF-1

AT aerobic training, *RT* resistance training, *MT* mixed training, *BMI* body mass index, *ASM* appendicular skeletal muscle mass, *PBF* percentage of body fat, *WS* walking speed, *GS* grip strength, *KES* knee extension strength, *IGF-1* Insulin-like Growth Factor-1, *IL-6* Interleukin- 6

Effects of different exercise training modes for sarcopenic obesity on the PBF

Seven studies [18, 20–25] reported data on body fat in SO patients. There was no heterogeneity among these studies ($P = 0.91$, $I^2 = 0$), and a fixed-effects model was used for the meta-analysis. The results demonstrated that compared to the control group, the exercise group showed a statistically significant reduction in body fat

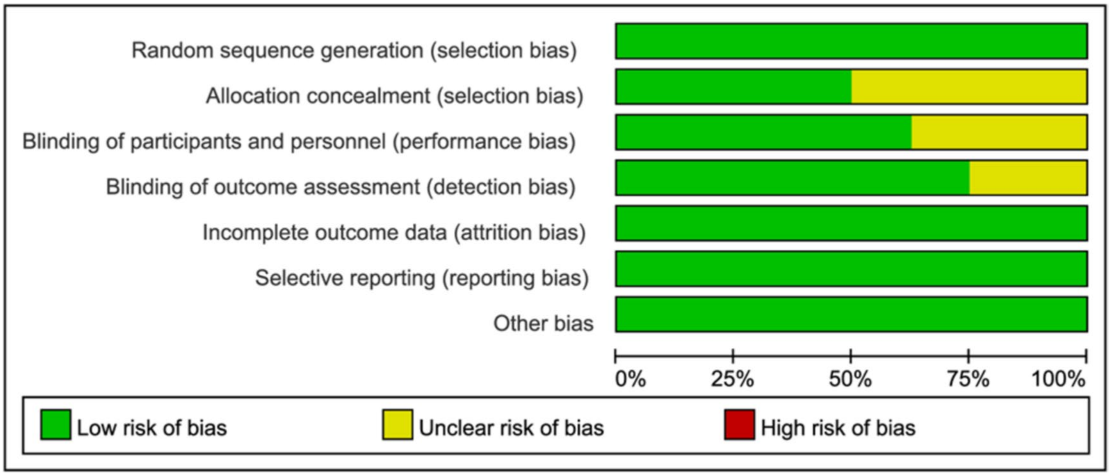

Fig. 2 Risk of bias graph

among SO patients [MD = -2.48,95%CI:-3.25 to -1.70, $P<0.01$]. Subgroup analysis indicated that both RT and MT were effective in reducing body fat compared to the control group, showing statistically significant differences. (RT, MD = -2.96,95%CI:-4.19 to -1.74, $P<0.01$; MT, MD = -2.42,95%CI:-3.58 to -1.26, $P<0.01$). The difference between AT alone and conventional treatment was not statistically significant (AT, MD = -1.40,95%CI:-3.33 to 0.53, $P=0.15$). Detailed results can be found in Fig. 5.

Effects of different exercise training modes for sarcopenic obesity on WS

Five studies [18, 19, 22–24] assessed the impact of RT and MT on WS. There was heterogeneity among these studies ($P<0.01$, $I^2=86$) leading to the utilization of a random-effects model for the meta-analysis. The results showed that compared with the control group, the exercise group could improve the WS of SO patients, and the difference was statistically significant [MD = 0.2,95%CI:0.07 to 0.33, $P<0.01$]. Subgroup analysis revealed that both RT and MT exercise training groups showed a statistically significant difference in comparison to the control group(RT, MD = 0.23,95%CI:0.01 to 0.46, $P=0.04$; MT, MD = 0.15,95%CI:0.04 to 0.26, $P<0.01$). as depicted in Fig. 6.

Effects of different exercise training modes for sarcopenic obesity on IGF-1

Two articles [20, 25] assessed the impact of exercise on IGF-1 in SO patients. There was no heterogeneity among the studies ($P=0.27$, $I^2=21$), thus a fixed-effects model was applied for the meta-analysis. The results revealed that compared to the control group, exercise increased the serum concentration of IGF-1 in SO patients, demonstrating a statistically significant difference[MD = 0.59,95%CI:0.24 to 0.95, $P<0.01$]. Subgroup analysis indicated that both RT and MT groups displayed a statistically significant difference compared to the control group[RT,MD = 0.79,95%CI:0.05 to 1.52,$P=0.04$;MT, MD = 1.01,95%CI:0.45to 1.56, $P<0.01$], however, when AT alone was compared to routine treatment, the difference did not reach statistical significance (AT, MD = 0.01,95%CI:-0.57 to 0.60, $P=0.96$), as shown in the Fig. 7.

Effects of different exercise training modes for sarcopenic obesity on IL-6

Two studies evaluated the effects of exercise on IL-6 in patients with SO. There was no heterogeneity among the studies ($P=0.27$, $I^2=21$), thus a fixed-effects model was applied for the meta-analysis. The results showed that compared with the control group, RT, AT, and CT exercise could not significantly improve the level of serum IL-6 in SO patients, and the difference was not statistically significant [MD = -0.01,95%CI:-0.27 to 0.24, $P=0.92$], as shown in Fig. 8.

Effects of different exercise training modes for sarcopenic obesity on weight

Three articles [20, 21, 25] assessed the impact of RT, AT, and MT on body weight in SO patients. There was no heterogeneity among the studies. ($P=0.22$,$I^2=27$), therefore a fixed-effects model was utilized for the meta-analysis. The findings revealed that compared to the control group, the exercise group was able to reduce the body weight of SO patients, and this difference was statistically significant [MD = -3.45,95%CI:-5.61 to -1.30, $P<0.01$]. Subgroup analysis indicated

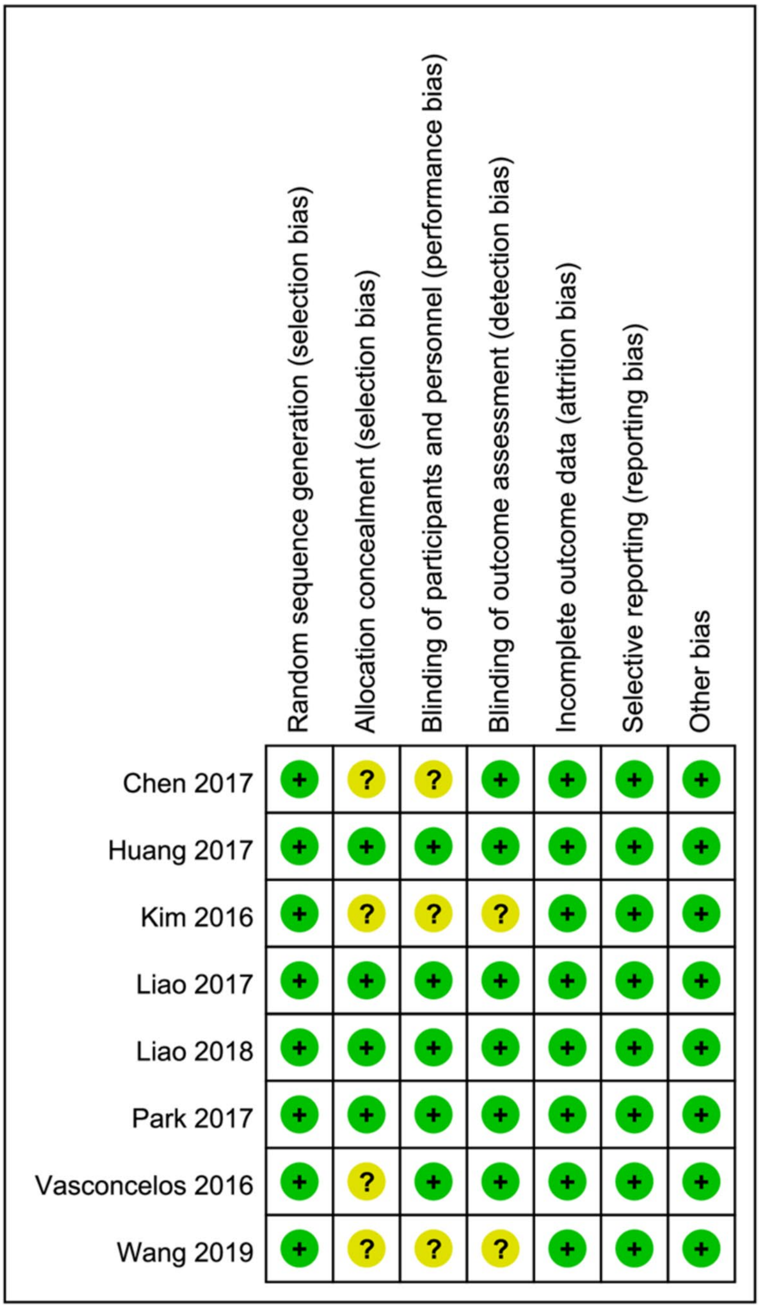

Fig. 3 Risk of bias summary

that both AT and MT groups showed a statistically significant difference when compared to the control group[AT, MD = -6.07,95%CI:-9.89 to-2.25, $P<0.01$; MT, MD = -4.40,95%CI:-8.40 to -0.40, $P=0.03$] However, when RT was compared to routine treatment, the difference was not statistically (RT, MD = -0.61,95%CI:-4.06 to 2.84, $P=0.73$), as displayed in the Fig. 9.

Effects of different exercise training modes for sarcopenic obesity on KES

Two articles [23, 25] assessed the impact of RT, AT, and MT on KES in SO patients. There was no heterogeneity among the studies($P=0.29$, $I^2=19$), hence a fixed-effects model was used for the meta-analysis. The findings indicated that compared to the control

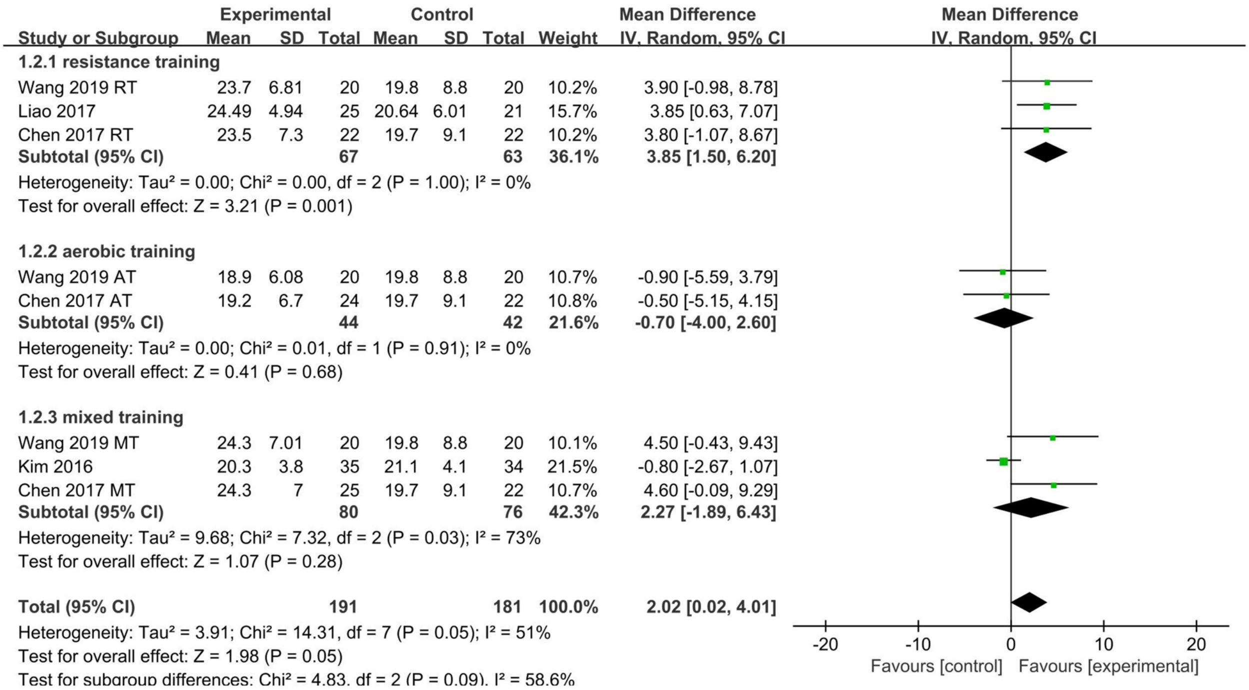

Fig. 4 Effect of different exercise training modes on the grip strength of sarcopenic obesity patients

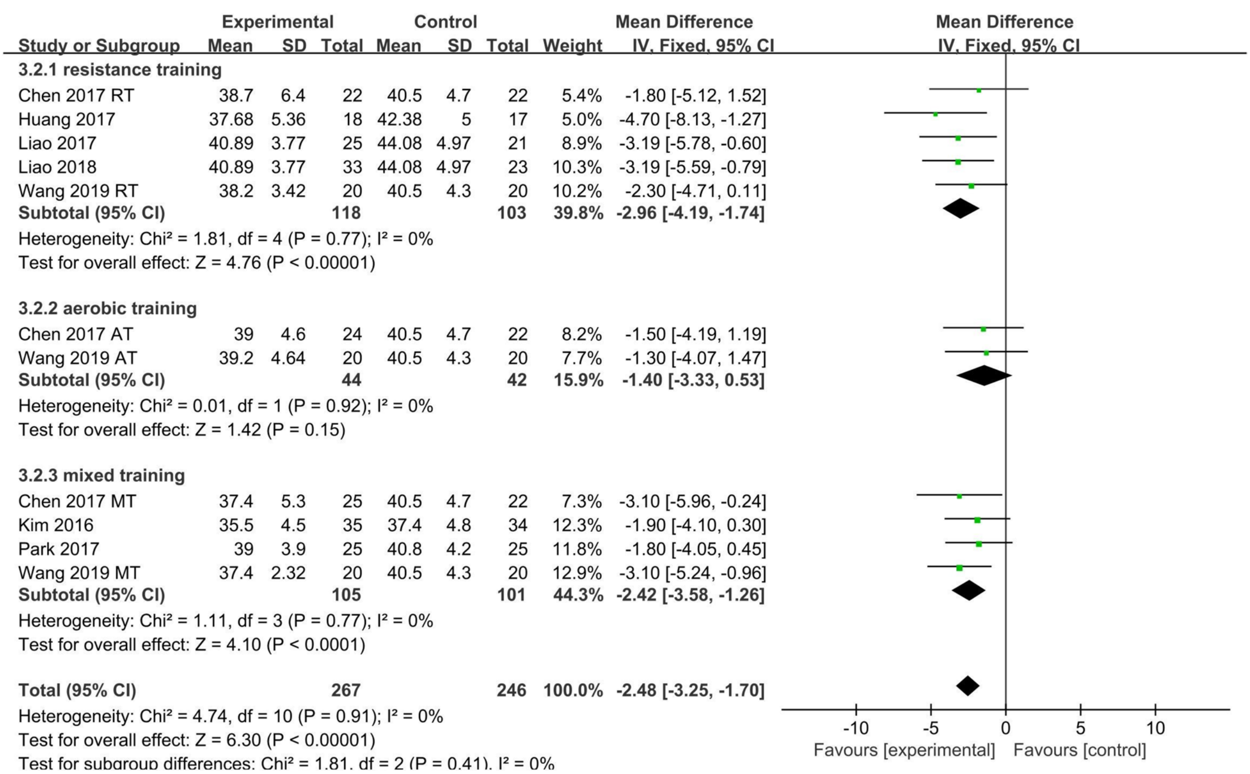

Fig. 5 Effect of different exercise training modes on the percentage of body fat of sarcopenic obesity patients

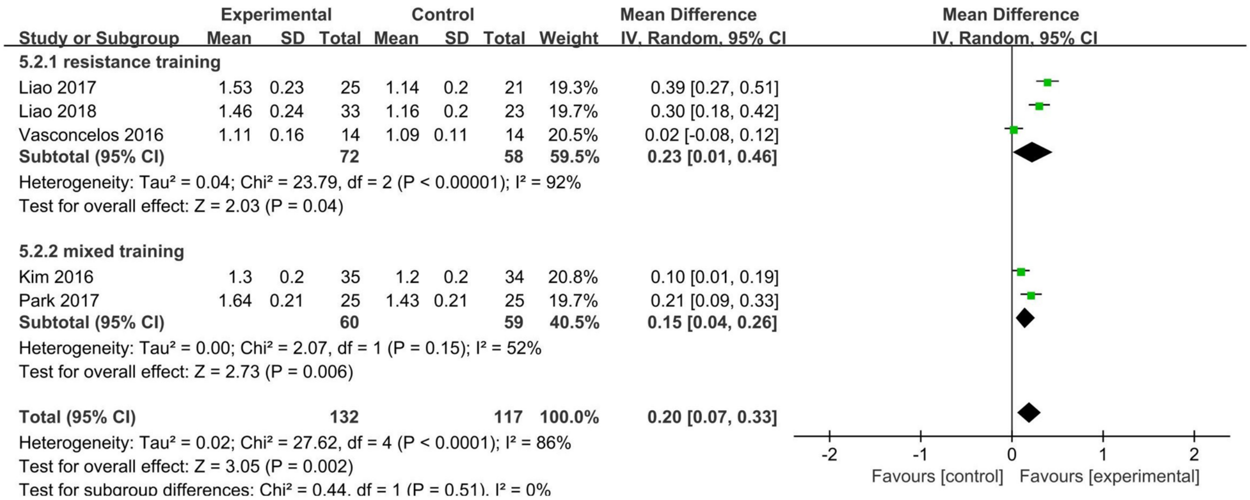

Fig. 6 Effect of different exercise training modes on the walking speed of sarcopenic obesity patients

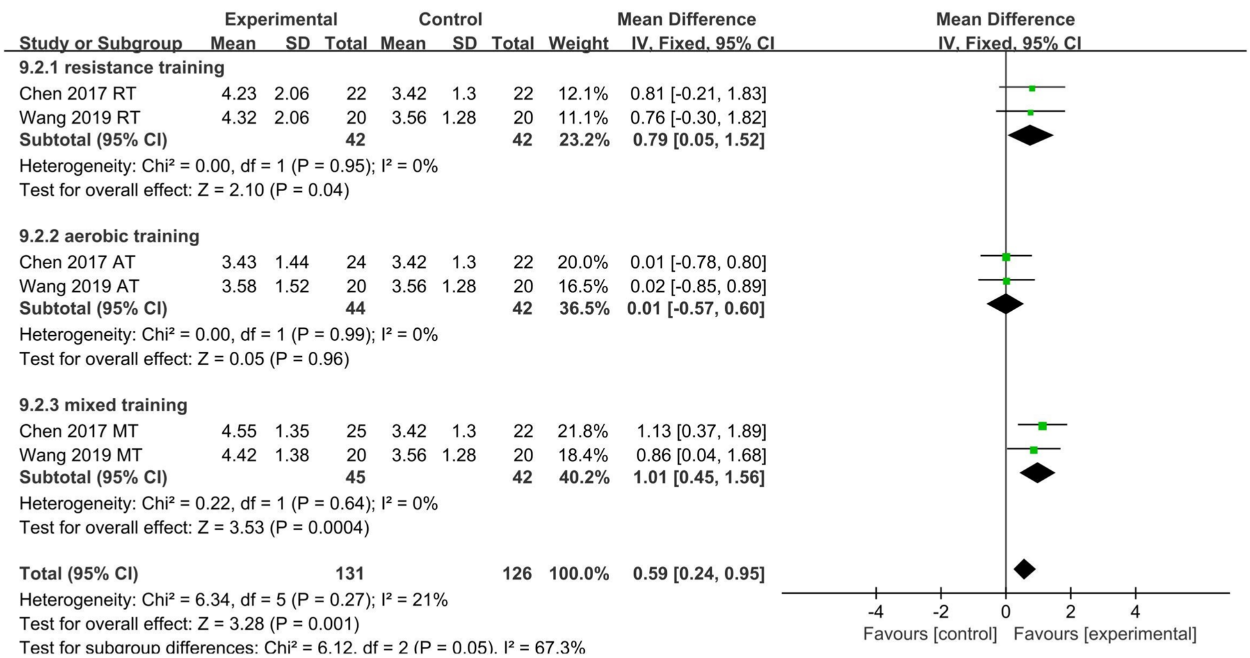

Fig. 7 Effect of different exercise training modes on IGF-1 of sarcopenic obesity patients

group, the exercise group showed an improvement in knee extension strength among SO patients, which was statistically significant[MD = 2.14,95%CI:0.47 to 3.82, P = 0.01]. Subgroup analysis revealed that the RT group exhibited a statistically significant difference when compared to the control group[RT, MD = 4.85,95%CI:1.97 to 7.72, P < 0.01] However when AT and MT were compared to routine treatment, the differences were not statistically significant (AT, MD = -0.08,95%CI:-2.88 to 2.73, P = 0.96; MT, MD = 1.73,95%CI:-1.31 to 4.78, P = 0.26), as shown in the Fig. 10.

Subgroup analysis

Based on intervention duration (< 12 weeks and ≥ 12 weeks), the analysis revealed the following:

The results showed no significant differences in body weight [Chi^2 = 0.16, P = 0.69, I^2 = 0%], grip strength [Chi^2 = 2.70, P = 0.1, I^2 = 62.9%], body fat[Chi^2 = 2.70, P = 0.1, I^2 = 62.9%], IL-6[Chi^2 = 1.80, P = 0.18, I^2 = 44.3%].

Publication bias

Funnel plot analysis was not performed in this study due to the inclusion of only 8 articles.

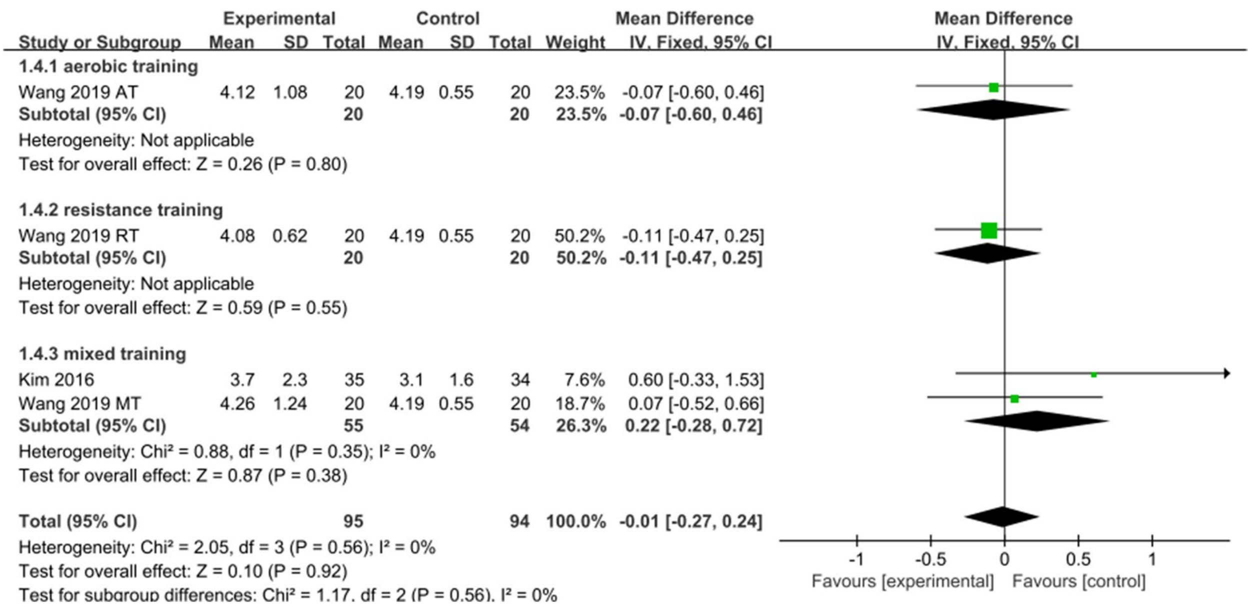

Fig. 8 Effect of different exercise training modes on IL-6 of sarcopenic obesity patients

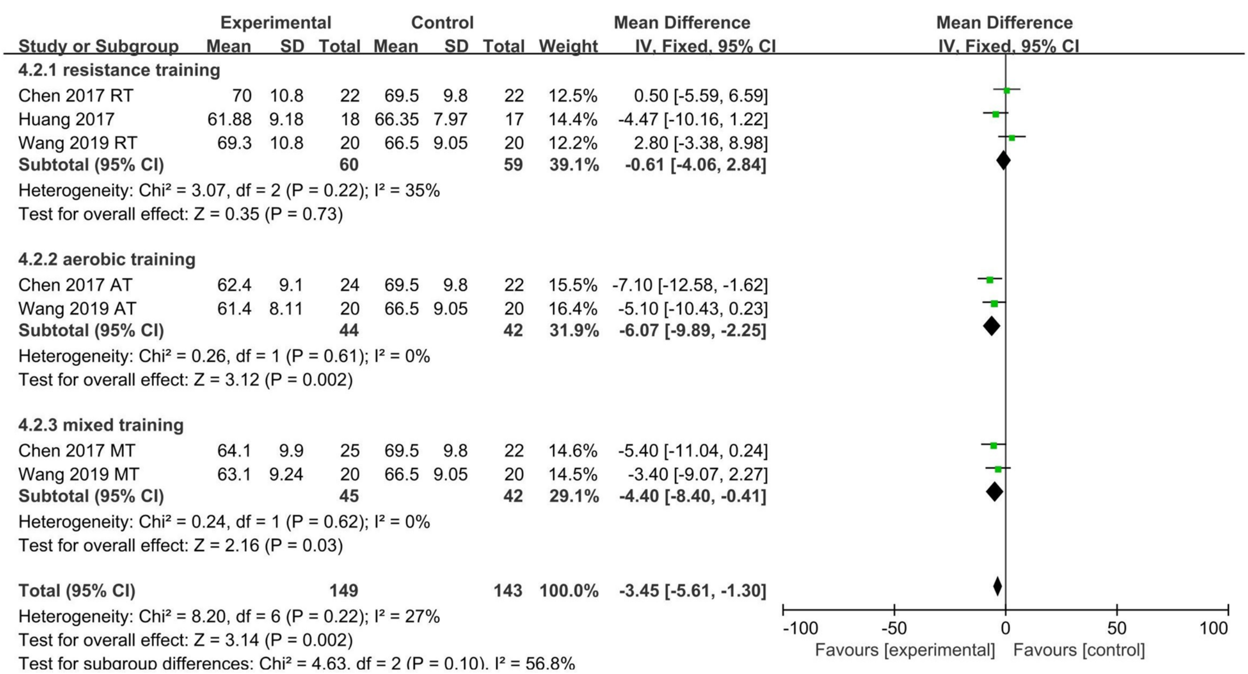

Fig. 9 Effect of different exercise training modes on weight of sarcopenic obesity patients

Discussion

In this study, we included a total of 8 articles that compared the effects of RT, AT, and MT on individuals with SO. The results demonstrated that RT improved GS, PBF, WS, IGF-1, and KES but did not significantly impact weight and IL-6. AT contributed to weight reduction but did not significantly affect GS, PBF, IGF-1, IL-6, and KES. MT showed a positive effect on PBF, IGF-1, WS, and weight but did not significantly improve GS, KES, and IL-6. These findings from the meta-analysis indicate that different exercise forms (RT/AT/MT) have distinct effects on improving clinical symptoms and signs in SO patients. Notably, not all exercise forms show significant intervention effects, emphasizing the importance of selecting targeted exercise interventions. To our knowledge, this is the first meta-analysis focusing on the effects

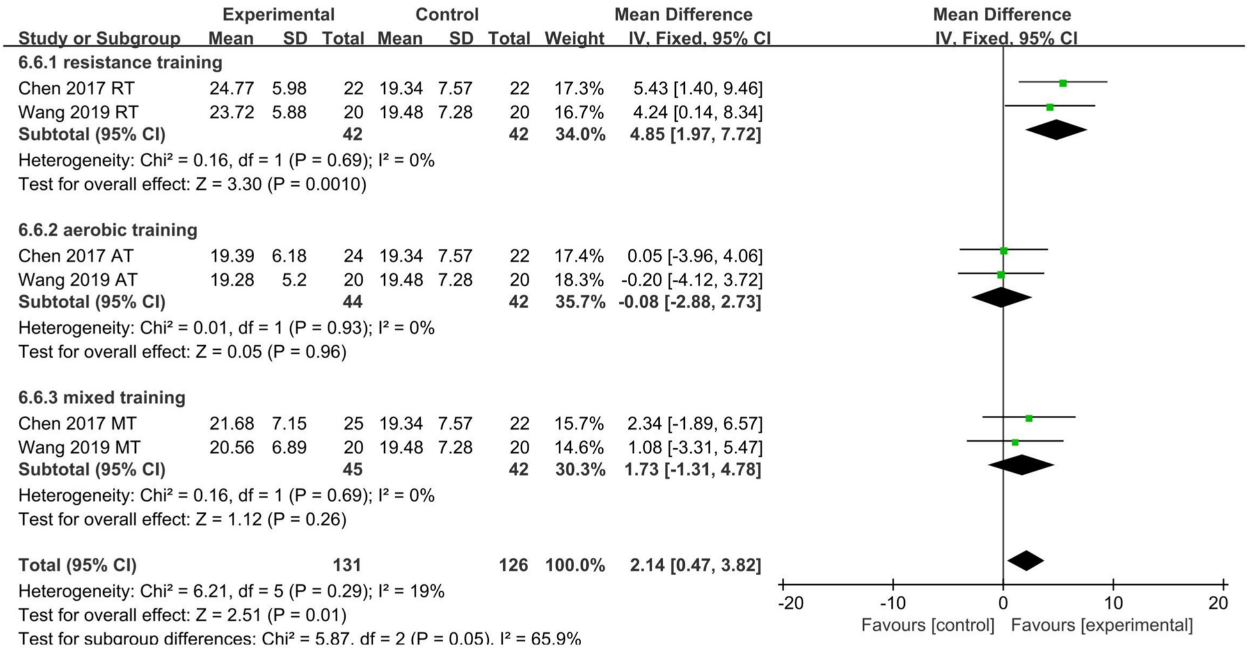

Fig. 10 Effect of different exercise training modes on knee extension strength of sarcopenic obesity patients

of various training modes on cellular regulatory factors and physical function in SO patients.

Reiter research [26, 27] indicated that RT could improve factors like GS and WS in patients, although it did not significantly affect patient weight, aligning with our study's results. The limited number of included studies in this analysis might contribute to uncertainty in effects. Additionally, RT, primarily involving anaerobic exercise, concentrates on specific muscle groups through activities such as working against resistance and using strength training equipment [28]. This focus may explain why it may not significantly impact weight reduction when compared to AT, which involves larger muscle groups and rhythmic movements. American College of Sports Medicine suggests that solely performing RT without AT or dietary control might not substantially contribute to weight loss and recommends a combination with AT [29].

The study findings indicate that AT primarily affects the weight of SO patients, showing no statistical significance in GS, WS, KES, IGF-1, and IL-6, consistent with Hsu et al.'s findings [30]. Notably, the duration of AT studies included in our research was 8 weeks, shorter compared to studies averaging 12–16 weeks for exercise interventions. This disparity might impact outcomes, as higher-intensity exercise, shown in studies by Mann et al. [31] might yield more benefits than moderate-intensity exercises like those in studies by Chen, Wang et al. [20, 25]. Outcome indicators such as grip strength and knee extension strength require more complex exercise designs than those incorporated in our AT study. Therefore, the intervention duration and exercise design of AT may influence its efficacy, suggesting extending intervention periods and adjusting designs to comprehensively improve lower limb muscle strength in SO patients [32, 33].

However, AT included in this study had fewer and simpler lower limb movements, emphasizing the quadriceps and calf muscles, which may have less impact on improving hip extensor muscle strength, consequently affecting the study results. Therefore, the intervention duration and exercise design of AT may influence its intervention effects. It is advisable to extend the intervention period appropriately in clinical practice and adjust exercise designs to comprehensively improve the lower limb muscle strength of SO patients.

Our study suggests that MT improves patients' weight, PBF, IGF-1, and WS, with no statistically significant effect on GS, KES, and IL-6. The combination of resistance and AT is one of the most common and effective forms of mixed exercise [34], primarily by increasing the cross-sectional area of muscle fibers, promoting growth factor release, inducing muscle activation, and signal transduction to generate these effects [11, 35]. However, other studies [14] suggest that MT enhances increased muscle strength in SO patients. Regarding this result, we speculate that AT, by increasing peak oxygen consumption, raising basal metabolic rate, and reducing abdominal and visceral fat, leads to a decrease in the weight of SO patients, which may not significantly improve muscle strength. Conversely, RT improves neuromuscular adaptability and significantly enhances muscle strength in SO patients [36]. When both methods are used together, there might be interference, potentially affecting patients' grip strength [37].

IGF-1, predominantly synthesized in the liver, holds a pivotal role in fostering muscle growth. Upon binding to specific IGF-1 receptors, it initiates a series of signaling pathways, notably involving MAPK/Erk and PI 3 K/Akt/mTOR. These pathways successively drive cellular proliferation while suppressing apoptosis, thus fostering the hypertrophy of muscle fibers. Additionally, IGF-1 triggers the activation of the Wnt/β-catenin pathway, mitigating osteoblast apoptosis and stimulating the generation of fresh osteoblasts. These multifaceted functions collectively contribute to slowing down the progression of muscular dystrophy [38, 39]. This study found that RT and MT can elevate the levels of IGF-1 in individuals with SO, consistent with the findings reported by Springer et al. [40]. Research indicates a close association between IGF-1 and muscle mass and strength, which has been validated in epidemiological and clinical studies. Engaging in RT and MT has been shown to increase the number of muscle cells and stimulate mitosis for the generation of new muscle fibers. This approach helps prevent the loss of muscle mass and strength, effectively promoting an enhancement in muscle strength and quality, consequently leading to an elevation in IGF-1 levels. However, aerobic exercise, while effective in improving cardiovascular function and mildly enhancing muscle health, falls short in effectively activating muscular activity. This limitation affects its efficacy in maintaining muscle mass in elderly individuals and might potentially influence research outcomes.IL-6, an essential pro-inflammatory cytokine, is rapidly released into the bloodstream during and after exercise, partially reflecting skeletal muscle contraction levels. During aerobic exercise, upon binding with its corresponding receptor, IL-6 activates the Erk/MAPK, PI3K, Akt, and AMPK signaling pathways, consequently increasing glucose uptake and fatty acid oxidation, and influencing mitochondrial coupling rates [41, 42]. Furthermore, IL-6 can induce hepatic glucose release, and stimulate the secretion of glucagon-like peptide in the intestine and pancreas, thereby increasing insulin secretion [43, 44]. Ultimately, IL-6 provides an energy reserve for aerobic exercise. In individuals with SO, excessive accumulation of fat cells in the body generates pro-inflammatory adipokines and free fatty acids, leading to the formation of a chronic inflammatory environment compared to individuals with isolated muscle atrophy [45]. SO patients experiencing prolonged inflammatory states will preferentially mobilize and consume muscles. Additionally, the accumulated inflammatory factors such as IL-6 inhibit the synthesis of muscle proteins, accelerating protein breakdown and the expression of muscle atrophy proteins, ultimately resulting in further loss of muscle mass [12]. The results of this study revealed that after RT intervention, the levels of IL-6 in the blood of SO patients decreased, while AT and CT interventions increased the levels of IL-6 in the blood. This observation is possibly due to the higher dependence of resistance exercise on anaerobic metabolism. Wang et al. [25] conducted a study over 8 weeks, demonstrating that moderate exercise led to a reduction in IL-6 levels, mitigating the loss of muscle mass, although statistical significance was not prominently exhibited. Therefore, based on the research findings, it is recommended to choose resistance training as the preferred exercise modality, and if physically feasible, to enhance exercise intensity as much as possible within the limits of individual health.

According to the subgroup analysis forest plots focusing on PBF, WS, and IGF-1 as outcomes, we observed that both RT and MT interventions improve these parameters in SO patients. RT's intervention effects might be more pronounced compared to MT, as the effect size for PBF, WS, and IGF-1 in each subgroup for RT was higher than that for MT. However, Donini et al. [16] suggest that a combination of RT and AT is more effective than either intervention alone. Moreover, in contrast to RT and MT, AT only affects the body weight of SO patients, without effectively improving other outcome measures. The efficacy of AT in treating SO patients might not match that of RT and MT in improving muscle strength and overall physical performance. Presently, there is a lack of studies comparing RT and MT or AT with RT and MT regarding muscle strength, and body composition in SO patients. Additionally, the number of included studies in this meta-analysis is limited. Therefore, conducting further research could provide more insights into the intervention effects and differences among these three exercise modalities for SO patients.

When conducting subgroup analysis based on intervention duration, it was observed that intervention time did not significantly impact the body weight, grip strength, IL-6 and body fat of SO patients. This aligns with the findings in the study conducted by Xu et al. [46].

Limitations

This study has several limitations. Firstly, the lack of standardized diagnostic criteria for SO introduces variability that may influence the results. To strengthen future research, it is essential to advocate for standardized diagnostic criteria for SO patients, ensuring consistency and comparability across studies. Based on a comprehensive literature review [46–48], we recommend defining SO using DXA measurements with body fat percentages > 25% for men and > 35% for women, combined with ESPEN criteria for sarcopenia.

Secondly, some outcomes showed significant heterogeneity, such as GS ($I^2 = 51\%$) and WS ($I^2 = 86\%$), likely due to differences in assessment methods and intervention plans among SO patients. To avoid similar discrepancies in future studies, we suggest adopting standardized assessment protocols and considering subgroup analyses to enhance the reliability and interpretability of results.

Thirdly, based on an extensive review of the literature, we included three types of exercise training (AT, RT, MT), with a sparse representation of articles related to the effects of AT. Moreover, there were a limited number of articles on some outcome indicators, such as KES, IGF-1, and IL-6. Therefore, future studies should explore a wider range of exercise interventions, including blood flow restriction training [48] balance training [49], and vibration therapy [50] to comprehensively assess their effects on muscle mass, strength, and body composition in SO patients.

Lastly, the small sample sizes and limited number of high-quality studies included in our analysis reduce the generalizability and robustness of our findings. Future research should aim to include more high-quality literature with larger sample sizes to validate intervention results and mitigate potential biases.

Conclusions

Overall, RT, AT, and MT are effective forms of exercise intervention, capable of improving the clinical symptoms and physical signs of SO to varying extents. Among these, RT and MT might exhibit more pronounced improvements compared to AT, enhancing the physical functionality of SO patients. This suggests that healthcare providers when devising exercise intervention plans for SO patients, should select the most effective intervention form based on the specific intervention requirements. This will allow for the development of scientific and systematic intervention strategies to achieve the best possible outcomes. In addition, Other meta-analyses did not find the relationship and influence between exercise training and IGF-1 and IL-6 in SO patients, which was discussed in this paper, and the results are of certain significance. It is hoped that future researchers can expand new research directions based on this paper for the benefit of patients. This meta-analysis examines the effects of RT, AT, and MT on SO patients and provides reasonable answers to the current controversies.

Abbreviations

SO	Sarcopenia Obesity
IGF-1	Insulin-like Growth Factor-1
IL-6	Interleukin- 6
RT	Resistance training
GS	Grip strength
PBF	Percentage of body fat
WS	Walking Speed
KES	Knee extension strength
MD	Mean Differences
SMD	Standard Mean Differences
CI	Confidence Interval
AT	Aerobic Training
MT	Mixed traning

Supplementary Information

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Supplementary Material 1.

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Authors' contributions

Lei Chen and Haojing Zhou contributed equally to this review. Lei Chen: Drafting of the article, Critical revision of the article for important intellectual content. Houjing Zhou: Drafting of the article, Critical revision of the article for important intellectual content. Yichen Gong: Revision of the article for important intellectual content. Yi Tang: Revision of the article for important intellectual content. Hai Su: Revision of the article for important intellectual content. Zhongyi Zhang: Revision of the article for important intellectual content. Guoqian Chen: Critical revision of the article for important intellectual content, Final approval of the article Peijian Tong: Final approval of the article, Obtaining of funding.

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Data availability

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

Declarations

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

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