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The Effect of Exercise Interventions on Lean Body Mass: A Meta-Analysis

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ABSTRACT

This meta-analysis was conducted to investigate the direct effects of exercise on lean body mass (LBM), based solely on randomized controlled trials (RCTs). The findings indicated that exercise led to a small increase in LBM; however, this effect was not statistically significant. The study was carried out on seven studies published between 2020 and 2024, all of which included exercise interventions. Various types of exercise (resistance, aerobic, HIIT, etc.) and their combinations were implemented in these studies. Participants ranged in age from 14 to 66 years and included both sexes. According to the results of the meta-analysis, no heterogeneity was detected among the studies; therefore, a fixed-effects model was applied. The mean effect size was calculated as 0.04, and since the confidence interval included zero, the effect of exercise on LBM was deemed insignificant. The results revealed that factors such as health status, age, gender, dietary habits, as well as the type, duration, and intensity of exercise, may change the direction and magnitude of this effect. Furthermore, the quality of the studies published and the potential publication bias among the individual studies included in the meta-analysis are also believed to impact the average effect size

1. INTRODUCTION

Exercise is widely recognized as a vital tool for improving physical health and optimizing body composition. Among its many benefits, lean body mass (LBM) which includes muscles, bones, water, and viscera-stands out as a key functional and metabolic component of the body [1,2]. Lean body mass (LBM) is essential for metabolic health and physical performance, offering benefits that go far beyond its aesthetic value. Maintaining a high LBM, particularly muscle mass, has been associated with better glucose metabolism and a reduced risk of insulin resistance [3]. Furthermore, the preservation of LBM is especially important with aging, as muscle loss and increased functional impairments pose significant health risks [4]. Beyond its role in muscle preservation, LBM contributes to bone health; exercise has been shown to increase bone mineral density and reduce the risk of conditions such as osteoporosis [5,6].

Studies exploring the impact of various exercise types on LBM emphasize the advantages of resistance training, which promotes muscle protein synthesis and hypertrophy [7]. Aerobic exercises also support LBM by enhancing cardiovascular fitness and decreasing fat mass [8]. In addition, high-intensity interval training (HIIT) has been demonstrated to maintain and increase LBM through short bursts of vigorous activity [9]. Incorporating a combination of resistance training, aerobic workouts, and flexibility-balance exercises are an effective way to maximize LBM [10]. Tailored exercise plans based on individual factors such as age, health status, and physical capacity further optimize these outcomes [11].

Although extensive research has been conducted on this topic, findings regarding the effects of exercise on LBM remain inconsistent. Differences in participant characteristics, such as age, gender, and physical fitness, along with variations in exercise protocols, may account for these inconsistencies [12]. Meta-analyses have often included supplementary factors, such as nutritional or pharmacological interventions, particularly in studies assessing the effects of resistance exercises. For instance, research has

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frequently incorporated protein supplementation or hormone therapy to amplify muscle mass gains, with large effect sizes reported in such cases [13,14].

The present study seeks to synthesize previous findings by focusing solely on the relationship between exercise and LBM, excluding the influence of additional variables. By doing so, it aims to provide a clearer, more holistic understanding of the direct effects of exercise on LBM and resolve inconsistencies in the literature.

This meta-analysis examined individual quantitative studies examining the effects of exercise on lean body mass (LBM) within certain criteria and aimed to contribute to the elimination of inconsistencies in the literature from a holistic perspective. In this way, more reliable and generally valid conclusions about the role of exercise in optimizing LBM will be obtained.

In this research, the relationship between exercise and LBM is examined solely based on exercise variables, independent of the effects of additional factors such as nutritional and pharmacological supplements or hormone therapies. This study is anticipated to significantly advance the field by clarifying the effects of exercise on LBM and identifying overarching trends in current research findings. Furthermore, it is anticipated that the findings will serve as a guide for future research, laying the groundwork for more specific analyses on different populations and types of exercise. This meta-analysis is also expected to contribute to the development of strategies aimed at increasing LBM in sports science and clinical practice.

2. MATERIALS AND METHODS

2.1. Study Design

The preparation and reporting of this review were undertaken according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines [15] and registered in International Prospective Register of Systematic Reviews PROSPERO with registration number CRD42024622332 on 15 December 2024.

2.2. Types of studies

This meta-analysis focused on randomized controlled trials (RCTs) investigating the impact of exercise interventions on lean body mass (LBM). Only studies published in English with full-text availability were included.

2.3. Electronic database search

A systematic search of electronic databases was conducted from their inception to September 1, 2024, using the following search term categories in combination: 'exercise,' 'lean body mass,' and 'LBM.' The search was performed across widely used scientific databases, including Web of Science, PubMed, and ScienceDirect [16]. Additionally, the reference lists of selected articles and relevant reviews were reviewed to identify any studies that may have been missed during the initial search.

2.4. Outcome measurements

The primary focus of this analysis is the alteration in lean body mass (LBM) levels following exercise interventions. LBM values are assessed through methods such as Dual-Energy X-ray Absorptiometry (DEXA) and Bioelectrical Impedance Analysis (BIA).

2.5. Eligibility Criteria

The titles and abstracts of the retrieved articles were screened by two independent reviewers (MS, AT). Full-text articles were subsequently reviewed and selected for analysis based on the following inclusion criteria: (1) studies published between 2020 and 2024, (2) published in English, (3) conducted on humans, (4) assessed lean body mass (LBM) as an outcome, (5) utilized an experimental study design, (6) included an exercise intervention, and (7) employed a randomized controlled trial (RCT) design. Exclusion criteria included: (1) animal studies, (2) no LBM measurements, (3) review articles, (4) no exercise intervention, (5) no RCT, and (6) use of combined interventions.

2.6. Quality Assessment

The methodological quality of the studies was assessed using the Physiotherapy Evidence Database (PEDro) scale, a reliable and validated checklist consisting of 11 items: (1) eligibility criteria, (2) random allocation, (3) concealed allocation, (4) baseline comparability, (5) blinding of participants, (6) blinding of therapists, (7) blinding of assessors, (8) adequate follow-up, (9) intention-to-treat analysis, (10) intergroup comparisons, and (11) reporting of point estimates and variability" [17]. Note that the eligibility criteria item does not contribute to the total score, resulting in a maximum possible score of 10. Studies were categorized according to their PEDro score as follows: Scores below 4 were considered as 'poor' quality, scores between 4-5 as 'fair' quality, scores between 6-8 as 'good' quality and scores between 9-10 as 'excellent' quality [18]. Two authors (MS, AT) independently assessed the quality of the studies. In case of disagreement, a third author (TA) reviewed the studies and discussions were held to reach consensus. Table 1 provides an overview of the PEDro scale scores reflecting the internal validity and methodological quality (publication quality) of the studies included in the meta-analysis

Table 1. PEDro scale scores

Researchers	PEDro Score	Rating
Cohen et al. (2021) [19]	9	Excellent
Fristrup et al. (2020) [20]	4	Fair
Hajj-Boutros et al. (2023) [21]	6	Good
Jeong et al. (2024) [22]	5	Fair
Ma et al. (2024) [23]	7	Good
Vlietstra et al. (2023) [24]	6	Good
Otsuka et al. (2022) [25]	5	Fair

The data presented in Table 1 show that the mean publication quality score of the studies is approximately 6 and at a good level.

2.7. Study selection

A two-step evaluation process was implemented, beginning with the assessment of titles and abstracts, and subsequently moving on to the examination of full texts. Population, intervention, comparison, outcome, and study design were used to guide the inclusion of the screened studies. In cases where the information of the studies was not available in the first screening phase, full text access was provided for these studies. The study selection process was reported according to the PRISMA 2020 flow diagram (Figure 1).

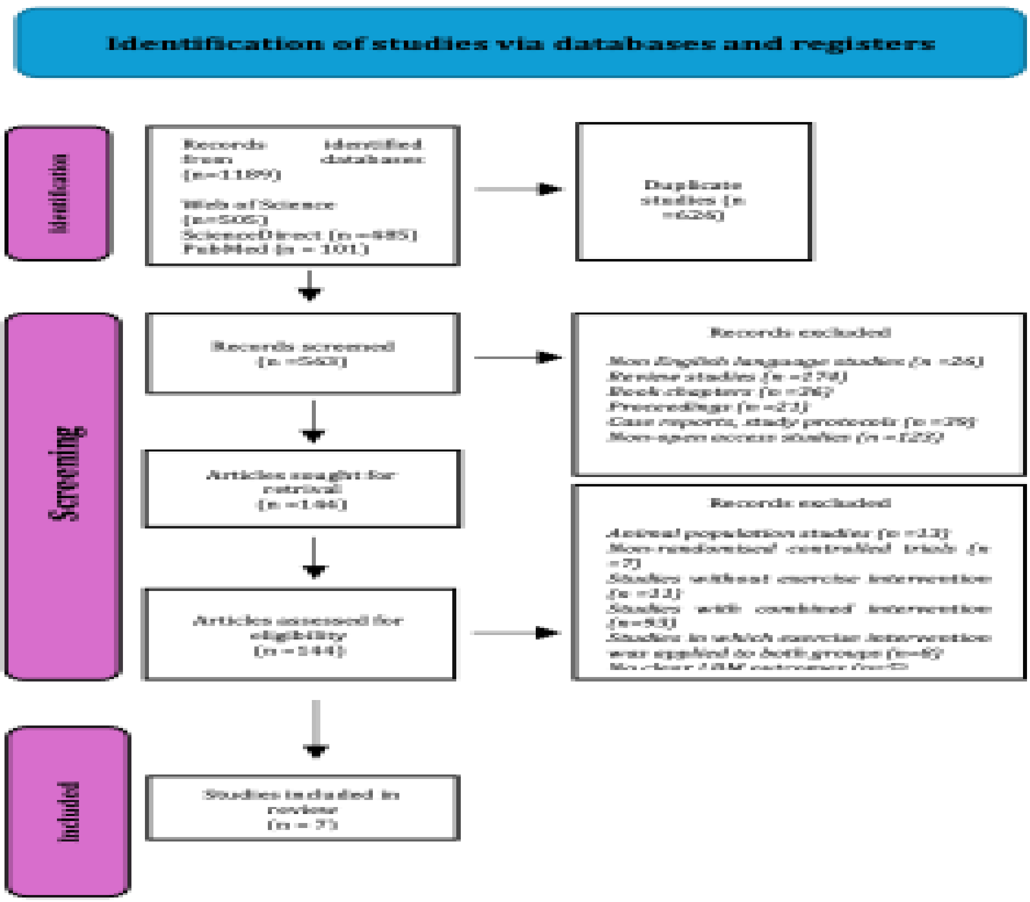

Figure 1. PRISMA diagram

A total of seven original studies were involved in the analysis. The search strategy initially identified 1,189 articles, of which 626 were duplicates. After removing duplicates, 419 articles remained for eligibility screening. Based on the titles and abstracts, 563 articles were excluded. Subsequently, 144 articles met the inclusion criteria, and their full texts were obtained for further evaluation. After a thorough examination of the complete texts, 137 more articles were discarded for not fulfilling all inclusion requirements, leaving a total of seven studies for the final evaluation.

2.8. Data Extraction

Data were extracted from each study, including details such as study design, population characteristics (e.g., condition), participant demographics (e.g., gender, age), intervention specifics, and study outcomes. Mean and standard deviation values for lean body mass (LBM) were collected from studies that provided this information. For studies reporting data in alternative formats, the authors were contacted to obtain the necessary details.

After duplicates were removed, two reviewers (MS, AT) conducted the screening process on articles identified through the systematic review and additional searches. The initial screening involved evaluating titles and abstracts, while final inclusion decisions were made after thoroughly reviewing the full texts to ensure they met the inclusion criteria. In cases of ambiguity regarding article eligibility, a third reviewer (TA) was consulted to achieve consensus. When absolute LBM values were not available in the published articles, the corresponding authors were reached out to request supplementary data.

2.9. Participants' characteristics

The included RCT 344 participants (166 and 178 in the control and exercise groups, respectively). The average age of the participants ranged between 14 and 66 years. Most of the studies involved participants of both genders.

2.10. Interventions' characteristics

In 2 studies [19,24] combined aerobic and resistance exercise, 2 studies [22,25] only resistance exercise, 1 study [20] combined handball training and resistance exercise, 1 study [21] combined cycling exercise and HIIT, and 1 study [23] combined resistance exercise and blood flow restricted resistance exercise. The duration of the exercise is between 2 and 24 weeks. The average duration of exercise in the studies was approximately 14.5 weeks.

2.11. Statistical analysis

The R software (version 4.4.2) was utilized to assess bias, conduct heterogeneity analysis, combine data, and produce both bias and forest plots. Statistical significance in all analyses was established using a threshold of $p < 0.05$.

3. RESULTS

The number of participants, average age of the participants, average body mass index of the participants, exercise model applied, Table 2 presents the LBM results and Hedge's g values for the seven studies included in the meta-analysis.

This analysis is based on seven studies. To assess inconsistencies among the study results, heterogeneity was evaluated using Cochran's Q statistics and I^2 indices [26] (Schmidt & Hunter, 2015). The heterogeneity test results, which guide the selection of the appropriate analytical method, are provided in Table 3.

The data presented in the Table 3 indicate that Cochran's Q value is 3.458 at 6 degrees of freedom. The p value of Cochran's Q test as 0.749 ($p=0.7495 > 0.05$) indicates the presence of statistically significant homogeneity. On the other hand, the I^2 value was found to be 0.00 %. Considering the reference intervals of I^2 indices, a value of 0.00% (I^2 <50%) indicates that there is no heterogeneity among the included studies. In addition, tau^2 value was determined as 0.00 [0.0000; 0.2223] at 95% CI. According to this result, the fact that the tau^2 value is zero and the lower limits of the confidence intervals are also zero indicates that there is no significant heterogeneity between the studies used in the meta-analysis.

As a result, after this heterogeneity analysis, the fixed effects model was preferred in calculating the average effect size.

The 7 studies included in the study and effect size values are presented in the figure. The average effect size value of the studies examining the effect of exercise on LBM level was found to be 0.04 at 95% CI [-0.17, 0,26] and the p value was $p=0.688>0.05$. Although the effect size was calculated as 0.04, the presence of a confidence interval (CI: [-0.17, 0.26]) that includes zero indicates that the exercise did not have a significant effect on LBM levels. As a result these values indicate that exercise has a small and statistically insignificant effect on LBM.

When all relevant studies are included in a meta-analysis, the funnel plot is expected to be symmetrical, with studies evenly distributed on both sides of the overall effect [27]. However, upon examining the funnel plot presented in the figure, the studies incorporated in the meta-analysis are unevenly distributed. This suggests the presence of publication bias in the individual studies analyzed in the study.

Table 2. Explanatory information of the studies and participants

Study	Participant	Average Age	BMI	Applied Exercise Model	Conclusion	Hedge's g
Cohen et al. (2021) [19]	Experiment (n= 40) Control (n= 30)	Experiment (15.0 ± 0.95) Control (14.7 ± 1.09)	Experiment (20.5±3) Control (19.4±2.6)	Resistance and aerobic exercises were performed twice a week over a duration of 16 weeks.	LBM ↔	0.05
Fitstrup et al. (2021) [20]	Experiment (n= 28) Control (n= 26)	Experiment (24.1 ± 2.6) Control (24.8 ± 3.1)	Experiment (25.8 ± 4.6) Control (25.2 ± 3.6)	12 weeks of handball training and low-intensity resistance exercise	LBM ↑	0.05
Hajj-Boutros et al. (2023) [21]	Experiment (n= 11) Control (n= 11)	Experiment (58.4 ± 3.4) Control (58.4 ± 3.9)	Experiment (72.4 ± 13.3 Control (67.5 ± 14.9)	2 weeks of low-intensity cycling and HIIT	LBM ↓	0.20
Jeong et al. (2024) [22]	Experiment (n= 10) Control (n= 8)	Experiment (21.80 ± 1.03) Control (20.63 ± 1.06)	Experiment (23.69 ± 2.12 Control (21.54 ± 1.85)	4 weeks of resistance training	LBM ↔	0.72
Ma et al. (2024) [23]	Experiment (n= 31) Control (n= 33)	Experiment (66.65 ± 4.94) Control (65.55 ± 4.41)	Experiment (26.02 ± 2.05) Control (26.56 ± 1.58)	Resistance exercise for 24 weeks, blood flow restricted resistance exercise	LBM ↔	0.11
Otsuka et al. (2022) [25]	Experiment (n= 17) Control (n= 17)	Experiment (63.5 ± 8.3) Control (63.5 ± 8.5)	Experiment (22.54 ± 5.32) Control (23.00 ± 5.26)	24 weeks of resistance training	LBM ↑	0.08
Vliestra et al. (2023) [24]	Experiment (n= 41) Control (n= 41)	Experiment (44.83 ± 3.25) Control (45.39 ± 2.90)	Experiment (25.80 ± 3.47) Control (26.40 ± 4.07)	20 weeks of high intensity aerobic and resistance exercise	LBM ↑	-0.21

Table 3. Heterogeneity Test Results

Cochran's Q	dF	p	I^2 (%)	tau^2
3.458	6	0.749	0.00	0.00

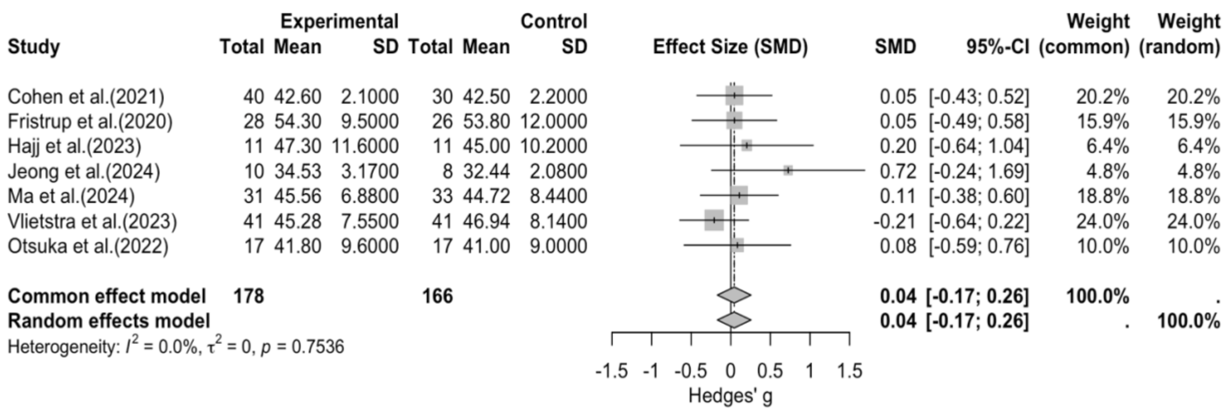

Figure 2. Forest plot of the studies

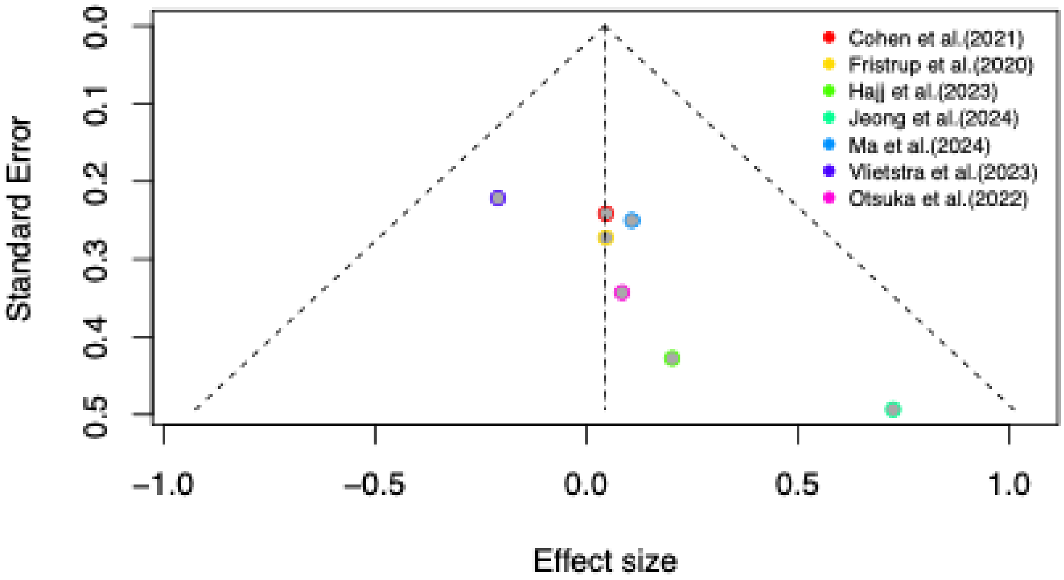

Figure 3. Funnel plot of the studies

4. DISCUSSON

This study is among the first meta-analyses to investigate the impact of exercise, without additional interventions, on LBM levels based solely on RCT studies. Our key findings indicate that exercise alone has a small effect on increasing LBM, but this effect is not statistically significant. Upon reviewing the methodological approaches of the seven studies included in the meta-analysis, we found that various types of exercise were applied either independently or in combination. Additionally, factors such as intensity, duration, volume, and frequency were varied in the exercise protocols of the studies. Furthermore, when examining the participant characteristics across the studies, the age range of participants was found to be between 14 and 66 years.

In line with the results of the current meta-analysis, Lai et al. (2018) [28] found that endurance and resistance exercises, as well as whole-body vibration exercise, did not significantly increase LBM in participants over 60 years of age. A small difference favoring resistance exercise was observed, and it was suggested that this difference might be attributed to neuro-muscular adaptation rather than an increase in myofibrillar mass [28]. On the other hand, O'Donoghue et al. (2021) [29] reported significant LBM gains in 3,566 obese participants aged 18-65 years through high-intensity aerobic and resistance exercises. This study highlighted the importance of combining both exercise types at high intensity for optimal results.

Furthermore, a network meta-analysis examining exercise with sub-dimensions like frequency, duration, and intensity provided useful reference points for obese participants across a wide age range. In Stoner et al. (2016) [30], the minimal LBM increases observed in obese participants aged 10-19 years could be explained by the underdevelopment of testosterone levels at that age [31]. Similarly, Collins et al. (2018) [32] found that resistance exercise did not produce a significant difference in LBM in participants aged 5-18 years. Supporting these findings, a study included in the current meta-analysis observed that neither type of exercise had a significant effect on LBM in adolescents aged 13-17 years [19]. Against sarcopenia [33], which is characterized by the loss of muscle mass with advancing age [34], the exercise responses that older individuals develop depending on their potential needs may be the determinant of the results. The meta-analysis of Thomas et al. (2021) [35], which targeted healthy post-menopausal women in a similar age range, reported moderately significant increases in LBM values due to resistance exercise in these participants. The findings of Peterson et al. (2011) [36], who emphasized that resistance exercise has a significant effect on LBM in individuals over 50 years of age, support the literature. However, according to the meta-regression analysis of the study, it is emphasized that LBM increases tend to decrease with increasing age and the aging process may be a limiting factor for muscle mass gain and LBM increase. In the light of the results of these studies, it can be said that the age factor may be effective in the LBM levels of exercise.

The present meta-analysis has the limitation of focusing on the pure effect of exercise on LBM without any additional intervention, in addition to aiming to provide important evidence for specific topic-specific outcomes. In the literature, the combined application of nutrition and exercise interventions appears to be an important factor in optimizing LBM and muscle mass gains according to the principle of supercompensation, especially during the post-exercise recovery period [37-40]. It is suggested that the combined application of exercise and nutritional interventions against sarcopenia may contribute to LBM increase by supporting muscle mass gain [41,42]. Weiss et al. (2017) [43] found that LBM could be maintained only in the exercise group in obese adults who were examined in three groups as calorie restriction only, exercise only and calorie restriction with exercise in order to get rid of excess weight. On the other hand, Merra et al. (2016) [44] found findings supporting that LBM can be maintained when a low-calorie diet is combined with amino acid supplementation. Similarly, Morton et al. (2018) [45] observed that resistance exercise alone had a statistically significant effect on LBM increase, although higher gains could be achieved by adding protein supplementation to resistance exercise. The literature appears to be controversial, with findings supporting significant effects of supplemental protein intake on LBM (Tagawa et al., 2020) [46] or no significant effect [47,48]. These findings suggest that it may be a better approach to link nutrition interventions with exercise by addressing sub-dimensions such as eating attitude and food intake.

In this study, only research focused on the impact of exercise interventions on LBM levels was included. Upon reviewing the characteristics of the studies, it is evident that participants from a wide range of age groups were involved, suggesting that age may influence LBM levels. However, the literature review also indicates that nutrition could play a role in LBM levels. It is believed that future clinical studies and meta-analyses that thoroughly examine the influence of age and nutrition will make valuable contributions to the literature. Additionally, exploring these factors through subgroup or meta-regression analyses in future meta-analyses will provide a more comprehensive understanding of the topic.

5. Conclusion

The results of the current meta-analysis indicate that exercise intervention has a small but statistically insignificant effect on LBM. However, factors such as health status, age, gender, dietary habits, as well as the type, duration, and intensity of exercise, may influence the direction and magnitude of this effect. Furthermore, the quality of the studies published and the potential publication bias among the individual studies included in the meta-analysis are also believed to impact the average effect size.

Conflict of Interest

No conflict of interest is declared by tehe authors. In addition, no financial support was received.

Author Contributions

Study Design, TA, MS, AT; Data Collection, AT; Statistical Analysis, MS; Data Interpretation, MS, AT; Manuscript Preparation, TA, MS; Literature Search, TA, MS, AT. All authors have read and agreed to the published version of the manuscript.

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