Resistance training effectiveness on body composition and body weight outcomes in individuals with overweight and obesity across the lifespan: A systematic review and meta-analysis

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Funding information
NHMRC CRE

Summary
To systematically review and analyze the effects of resistance-based exercise programs on body composition, regional adiposity, and body weight in individuals with overweight/obesity across the lifespan. Using PRISMA guidelines, randomized controlled trials were searched in nine electronic databases up to December 2020. Meta-analyses were performed using random-effects model. One hundred sixteen articles describing 114 trials (n = 4184 participants) were included. Interventions involving resistance training and caloric restriction were the most effective for reducing body fat percentage (ES = -3.8%, 95% CI: -4.7 to -2.9%, p < 0.001) and whole-body fat mass (ES = -5.3 kg, 95% CI: -7.2 to -3.5 kg, p < 0.001) compared with groups without intervention. Significant results were also observed following combined resistance and aerobic exercise (ES = -2.3% and -1.4 kg, p < 0.001) and resistance training alone (ES = -1.6% and -1.0 kg, p < 0.001) compared with no training controls. Resistance training alone was the most effective for increasing lean mass compared with no training controls (ES = 0.8 kg, 95% CI: 0.6 to 1.0 kg, p < 0.001), whereas lean mass was maintained following interventions involving resistance training and caloric restriction (ES = -0.3 kg, p = 0.550–0.727). Results were consistently observed across age and sex groups (p = 0.001–0.011). Reductions in regional adiposity and body weight measures were also observed following combined resistance and aerobic exercise and programs including caloric restriction (p < 0.001). In conclusion, this study provides evidence that resistance-based exercise programs are effective and should be considered within any multicomponent therapy program when caloric restriction is utilized in individuals with overweight or obesity.

KEYWORDS
body composition, obesity, resistance training

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Multicomponent lifestyle and therapy interventions are considered the cornerstone for the management of obesity.\textsuperscript{1,2} Several guidelines recommend exercise, dietary, and behavioural interventions to improve weight loss in this population.\textsuperscript{2–4} In regard to exercise interventions, aerobic exercise (i.e., activity involving large muscle groups and performed in a continuous or intermittent fashion over an extended period of time, such as cycling, swimming, jogging, or running) is recommended as the main exercise component for additional weight loss.\textsuperscript{2–5} Whereas resistance exercise (i.e., anabolic exercise: performing sets of repeated movements against a resistance) has been considered less critical due to insufficient evidence on the effects on reducing body weight or body mass index (BMI).\textsuperscript{2–5} However, determining the effectiveness of resistance exercise is challenging due to the reliance on body weight rather than overall body composition in individuals with overweight/obesity, as resistance exercise can result in body weight increases due to the accrual of lean mass, which is highly associated with metabolic health and physical function. Although body weight and BMI are important and extensively used in clinical practice, they do not differentiate lean from fat mass or depots of adiposity (i.e., visceral vs. subcutaneous adipose tissue), underestimating the importance of these tissues for overall health. Consequently, this precludes identifying the potential use of resistance training in individuals with overweight/obesity. Moreover, despite previous systematic reviews investigating exercise and dietary effects on body composition\textsuperscript{6–7} and visceral adipose tissue,\textsuperscript{8–12} the specific effects of resistance exercise on fat mass and lean mass have not been investigated in depth in those overweight/obese. For instance, it is not well understood if resistance exercise, alone or combined with other exercise components and dietary interventions, results in meaningful effects on fat mass while maintaining or increasing lean mass in this population. This information may improve exercise prescription for obese individuals, increasing potential treatment options for this population.

As a result, the present study aimed to systematically review and analyze the effects of resistance-based exercise programs (i.e., interventions including resistance exercise as one of the components) compared with no intervention control groups on body fat percentage, whole-body fat mass, trunk fat mass, visceral and subcutaneous adipose tissue and whole-body lean mass in participants with overweight/obesity (i.e., as defined in the studies included). Studies involving children and adolescents (<18 years), young adults (18 to 35 years), middle-aged adults (>35 to 59 years), and older adults (≥ 60 years) who are overweight or obese were included. The primary outcomes for this review were body fat, fat mass, trunk fat mass, visceral adipose tissue (VAT), subcutaneous adipose tissue (SAT), and lean mass. Secondary outcomes were body weight and BMI. The exclusion criteria were (1) studies involving individuals with other chronic conditions such as type II diabetes or cancer because of the interaction between treatments and outcomes; (2) studies involving participants with overweight/obesity enrolled in water-based resistance training as the only study intervention; (3) studies with interventions lasting less than 4 weeks; (4) studies comprising control groups receiving any active exercise or dietary interventions that constituted an intervention for body composition; and (5) studies written in a language other than English, Portuguese, or Spanish. This review included peer-review published and unpublished studies. The search was conducted in CINAHL, Cochrane Library, EMBASE, LILACS, PubMed, SciELO, SportDiscus, and Web of Science databases for peer-review published studies and MedNar, OpenGrey, and OpenThesis databases for unpublished studies. The date of the search was December 2020, with no limitation for publication date. A manual search was undertaken in the reference lists provided in all retrieved studies. Eligibility was assessed independently and evaluated in triplicate (P. L., E. R. N., and V. M. W. and P. L., R. N. B., and D. J. P. T.). The search strategy is presented in Data S1.

\subsection*{2.2 | Data extraction}

Data extraction was performed via a standardized form. For each study, details including sample size, sex, age, overweight/obesity criteria, baseline BMI, baseline body fat, experimental design (intervention groups and their respective sample sizes), resistance-based exercise program (i.e., intervention duration, volume, and intensity), and dietary program prescription were extracted along with the outcomes of interest. In addition, retention (i.e., number of participants that completed the study) and attendance (i.e., number of sessions attended) were assessed from the studies. For the outcomes assessed, baseline and post-intervention assessment and within- and between-group mean difference were extracted in their absolute units and for the longest period of the intervention. When studies did not provide dispersion values of change such as standard deviation (SD), standard errors or 95% confidence intervals (95% CI), the SD of the change
was calculated assuming a correlation of \( r = 0.5 \) between the baseline and post-intervention assessment measures by the square root of \( \left( \frac{SD_{Baseline}^2 + SD_{Post–intervention}^2}{2} - (2 \times r \times SD_{Baseline} \times SD_{Post–intervention}) \right) \).\(^{16}\) For studies containing multiple intervention arms versus control groups, only data from those comprising resistance exercise as part of the intervention were extracted. When graphs were used instead of numerical data, the graphs were measured through their plots using a specific tool for data extraction (WebPlotDigitizer, San Francisco, CA).\(^{17}\)

### 2.3 Risk of bias assessment

The risk of bias was evaluated according to the 2nd version of the Cochrane risk-of-bias tool for randomized trials (RoB 2), with each assessment focused on the outcome level.\(^{18}\) The six-domain instrument includes (1) randomization process, (2) deviation from intended interventions, (3) missing outcome data, (4) measurement of the outcome, (5) selection of the reported result, and (6) overall bias. The study quality assessment for all included studies was performed independently by two reviewers (E. R. N. and V. M. W. or R. N. B. and D. J. P. T.), with disagreements resolved by a third reviewer (P. L.).

### 2.4 Statistical analysis

For the meta-analysis, the pooled effect estimates from body fat percentage, fat mass, trunk fat mass, lean mass, body weight, and BMI were obtained and expressed as mean difference (MD) of baseline to the final assessment of the intervention versus control group. For VAT and SAT, results were expressed as standardized mean difference (SMD) due to the different units reported in the studies included. Meta-analyses were conducted independently by reviewers (E. R. N. and V. M. W. or R. N. B. and D. J. P. T.), with disagreements resolved by a third reviewer (P. L.).

Four-thousand seven-hundred and fifty-six studies were retrieved from our search, with 2737 potential records retained for screening after duplicate removals. After excluding 1080 records due to their irrelevance to the research question, 1657 were considered eligible for full-text assessment (Figure 1). A total of 116 articles describing 114 independent trials were included in this systematic review and meta-analysis with 23 articles examining children or adolescents,\(^{24–46}\) 30 articles examining young adults,\(^{47–76}\) 38 articles examining middle-aged adults,\(^{77–114}\) and 25 articles examining older adults who are overweight or obese.\(^{115–139}\)

A total of 4184 participants with overweight/obesity were included in this systematic review, involving 878 children/adolescents [median age = 14.8 years (interquartile range [IQR]: 11.8 to 15.4 years), median BMI = 30.1 kg m\(^{-2}\) (IQR: 26.4 to 33.4), and body fat percentage = 36.7% (IQR: 34.1 to 43.2%)], 658 young adults [median age = 23.6 years (IQR: 21.9 to 27.2), median BMI = 29.6 kg m\(^{-2}\) (IQR: 26.9 to 31.4), and body fat percentage = 31.7% (IQR: 28.1 to 37.4)], 1416 middle-aged adults [median age = 47.0 years (IQR: 39.9 to 52.4), median BMI = 30.4 kg m\(^{-2}\) (IQR: 28.7 to 32.7), and body fat percentage = 38.5% (IQR: 32.0 to 44.7)] and 1232 older adults [median age = 67.3 years (IQR: 64.1 to 68.9), median BMI = 29.6 kg m\(^{-2}\) (IQR: 28.1 to 31.7), and body fat percentage = 37.4% (IQR: 35.3 to 42.7)].

In summary, most studies included resistance training alone (56 out of 114 studies, 49.1%), followed by combined resistance and aerobic exercise (51 out of 114 studies, 44.7%), combined resistance and aerobic exercise + caloric restriction (8 out of 114 studies, 7.0%), and resistance training + caloric restriction (6 out of 114 studies, 5.3%). Regarding exercise prescription characteristics, the mean intervention duration was 14.6 ± 11.0 weeks (range: 4 to 96 weeks) with frequency ranging from 1 to 5 sessions per week. Information about resistance training volume was reported by 75 studies (65.8%) and ranged from 20 to 165 weekly resistance exercise sets, whereas resistance training peak intensity was reported by 64 studies (56.1%) and ranged from 20% to 97% of one-repetition maximum (1-RM). The characteristics of the individual studies are presented in Tables S1 to S4.
3.1 Risk of bias

High risk of bias was observed in 70 out of 98 studies (71.4%) examining body fat percentage, 37 out of 62 studies (59.7%) examining fat mass, 6 out of 15 studies (40.0%) examining VAT, 3 out of 8 studies (37.5%) examining SAT, and 43 out of 70 studies (61.4%) examining lean mass. For body weight and BMI, 23 out of 98 studies (23.5%) had a high risk of bias in the overall risk of bias assessment.

The individual risk of bias assessment for children/adolescents, young adults, middle-aged adults, and older adults are presented in Tables S5 to S8.

3.2 Body fat percentage and whole-body fat mass

Resistance-based exercise programs resulted in significant reductions in body fat percentage (number of studies $k = 89$, ES = $-2.2\%$, 95% CI: $-2.4$ to $-2.0\%$) and whole-body fat mass ($k = 52$, ES = $-1.6$ kg, 95% CI: $-1.9$ to $-1.3$ kg) (Table 1). These effects were consistent across children/adolescents (ES = $-2.1\%$, 95% CI: $-2.8$ to $-1.3\%$ and ES = $-1.9$ kg, 95% CI: $-2.9$ to $-0.8$ kg), young adults (ES = $-2.7\%$, 95% CI: $-3.7$ to $-1.7\%$ and ES = $-1.0$ kg, 95% CI: $-1.4$ to $-0.5$ kg), middle-aged adults (ES = $-2.4\%$, 95% CI: $-2.5$ to $-2.3\%$ and ES = $-1.2$ kg, 95% CI: $-2.1$ to $-0.4$ kg), and older adults (ES = $-1.9\%$, 95% CI: $-2.4$ to $-1.4\%$ and ES = $-1.7$ kg, 95% CI: $-2.3$ to $-1.2$ kg). Results are presented for body fat percentage and whole-body fat mass across the lifespan before sensitivity analysis procedure adjustments in Figure 2 and Figure 3, respectively. In addition, significant effects were observed in studies involving female (ES = $-2.4\%$, 95% CI: $-2.5$ to $-2.3\%$ and ES = $-1.0$ kg, 95% CI: $-1.3$ to $-0.7$ kg), males (ES = $-2.8\%$, 95% CI: $-3.4$ to $-2.2$% and ES = $-2.6$ kg, 95% CI: $-3.8$ to $-1.4$ kg), and mixed participants (ES = $-1.7\%$, 95% CI: $-2.1$ to $-1.2$% and ES = $-2.0$ kg, 95% CI: $-2.6$ to $-1.5$ kg). The most effective exercise modality for reducing body fat percentage was resistance training + caloric restriction, with changes of $-3.8\%$ (95% CI: $-4.7$ to $-2.9$%). For reducing fat mass, both resistance training + caloric restriction and combined resistance

FIGURE 1 Flow chart of study selection process
### Overall and subgroup analyses of resistance-based exercise effects on body fat percentage and whole-body fat mass in participants who are overweight or obese

| Table 1 | Random effect meta-analysis | Heterogeneity |
|---------|-----------------------------|--------------|
|         | k  | ES  | 95% CI       | p-value | Q  | I²  | p-value |
| Body fat percentage, % | | | | | | | |
| Overall effect | 99 | −2.3 | −2.7 to −1.9 | <0.001 | 651.2 | 85% | <0.001 |
| Without outlier<sup>a</sup> | 89 | −2.2 | −2.4 to −2.0 | <0.001 | 95.6 | 8% | 0.273 |
| Age | | | | | | | |
| Children/adolescent | 19 | −2.1 | −2.8 to −1.3 | <0.001 | 26.4 | 32% | 0.090 |
| Young adults<sup>4</sup> | 26 | −2.7 | −3.7 to −1.7 | <0.001 | 24.2 | 0% | 0.507 |
| Middle-aged adults<sup>4</sup> | 27 | −2.4 | −2.5 to −2.3 | <0.001 | 19.7 | 0% | 0.805 |
| Older adults | 19 | −1.9 | −2.4 to −1.4 | <0.001 | 36.3 | 51% | 0.006 |
| Sex | | | | | | | |
| Female<sup>c</sup> | 45 | −2.4 | −2.5 to −2.3 | <0.001 | 41.1 | 0% | 0.599 |
| Male<sup>c</sup> | 25 | −2.8 | −3.4 to −2.2 | <0.001 | 35.3 | 32% | 0.064 |
| Mixed<sup>d</sup> | 20 | −1.7 | −2.1 to −1.2 | <0.001 | 17.0 | 0% | 0.593 |
| Exercise modality<sup>b</sup> | | | | | | | |
| RET<sup>c</sup> | 45 | −1.6 | −1.9 to −1.2 | <0.001 | 46.8 | 6% | 0.360 |
| RET + Caloric restriction | 3 | −3.8 | −4.7 to −2.9 | <0.001 | 0.4 | 0% | 0.817 |
| COMB<sup>c</sup> | 40 | −2.3 | −2.7 to −1.9 | <0.001 | 45.2 | 14% | 0.229 |
| COMB + Caloric restriction | 6 | −3.0 | −4.1 to −1.8 | <0.001 | 4.8 | 0% | 0.439 |
| COMB + Healthy diet | 2 | −2.3 | −2.8 to −1.8 | <0.001 | 1.6 | 38% | 0.203 |
| Fat mass, kg | | | | | | | |
| Overall effect | 63 | −2.1 | −2.7 to −1.6 | <0.001 | 219.0 | 72% | <0.001 |
| Without outlier<sup>c</sup> | 52 | −1.6 | −1.9 to −1.3 | <0.001 | 39.5 | 0% | 0.879 |
| Age | | | | | | | |
| Children/adolescent | 13 | −1.9 | −2.9 to −0.8 | <0.001 | 20.8 | 42% | 0.053 |
| Young adults<sup>4</sup> | 14 | −1.0 | −1.4 to −0.5 | <0.001 | 11.9 | 0% | 0.540 |
| Middle-aged adults<sup>4</sup> | 14 | −1.2 | −2.1 to −0.4 | 0.003 | 17.8 | 27% | 0.166 |
| Older adults<sup>4</sup> | 17 | −1.7 | −2.3 to −1.2 | <0.001 | 22.7 | 30% | 0.121 |
| Sex | | | | | | | |
| Female<sup>c</sup> | 26 | −1.0 | −1.3 to −0.7 | <0.001 | 23.3 | 0% | 0.558 |
| Male<sup>c</sup> | 15 | −2.6 | −3.8 to −1.4 | <0.001 | 22.1 | 37% | 0.076 |
| Mixed<sup>d</sup> | 17 | −2.0 | −2.6 to −1.5 | <0.001 | 20.8 | 23% | 0.186 |
| Exercise modality<sup>b</sup> | | | | | | | |
| RET<sup>c</sup> | 33 | −1.0 | −1.4 to −0.7 | <0.001 | 22.0 | 0% | 0.908 |
| RET + Caloric restriction | 5 | −5.1 | −6.3 to −3.8 | <0.001 | 8.5 | 53% | 0.074 |
| RET + Low-sugar diet | 2 | 0.2 | −1.7 to 2.0 | 0.880 | 0.1 | 0% | 0.782 |
| RET + Protein supplementation | 2 | −0.7 | −3.4 to 2.1 | 0.640 | 0.0 | 0% | 0.889 |
| COMB<sup>c</sup> | 22 | −1.4 | −2.0 to −0.8 | <0.001 | 38.3 | 45% | 0.012 |
| COMB + Caloric restriction | 7 | −5.3 | −7.2 to −3.5 | <0.001 | 23.6 | 75% | <0.001 |

Abbreviations: COMB, combined resistance and aerobic exercise; ES, effect size; I², percentage of variation across studies that is due to heterogeneity; k, number of studies; Q, Cochran’s Q test of heterogeneity; RET, resistance training.

<sup>a</sup>Exercise modalities excluded due to insufficient evidence for body fat percentage: RET + Ginger supplementation, ES = −4.9% (95% CI: −13.4 to 3.6); RET + Green tea, ES = −12.4% (95% CI: −15.3 to 9.3); RET + Protein supplementation, ES = −0.8% (95% CI: −3.1 to −1.6); COMB + Amino acids, ES = −0.3% (95% CI: −2.5 to 1.9); COMB + Caffeine supplementation, ES = −0.6% (95% CI: −3.4 to 2.1); COMB + Caloric restriction + Protein supplementation, ES = −2.7% (95% CI: −5.5 to 0.1); COMB + Fatty acids, ES = −1.2% (95% CI: −5.9 to 3.5); COMB + Isoflavones supplementation, ES = −2.0% (95% CI: −4.9 to 0.9); COMB + Protein supplementation, ES = −2.1% (95% CI: −3.2 to −1.0).

<sup>b</sup>Exercise modalities excluded due to insufficient evidence for fat mass: RET + Ginger supplementation, ES = −3.1 kg (95% CI: −10.2 to 4.0); RET + Green tea, ES = −11.7 kg (95% CI: −15.3 to −8.1); COMB + Amino acids, ES = −0.2 kg (95% CI: −2.4 to 2.0); COMB + Caffeine supplementation, ES = 0.3 kg (95% CI: −4.9 to 5.5); COMB + Caloric restriction + Protein supplementation, ES = −3.8 kg (95% CI: −8.7 to 1.1); COMB + Fatty acids, ES = −1.8 kg (95% CI: −7.0 to 3.4); COMB + Healthy diet, ES = −2.0 kg (95% CI: −3.4 to −0.6); COMB + Isoflavones supplementation, ES = 1.1 kg (95% CI: −1.9 to 4.1); COMB + Low-sugar diet, ES = −1.8 kg (95% CI: −3.0 to −0.6); COMB + Protein supplementation, ES = −2.3 kg (95% CI: −3.4 to −1.2).

<sup>c</sup>Adjustment after omitting studies in which the confidence intervals did not overlap the estimated pooled effect.
and aerobic exercise + caloric restriction were the most effective with changes of \(-5.1\) kg (95% CI: \(-6.3\) to \(-3.8\) kg) and \(-5.3\) kg (95% CI: \(-7.2\) to \(-3.5\) kg), respectively (Table 1). Results were also significant for studies prescribing combined resistance and aerobic exercise + metabolic syndrome (ES = \(-2.3\)%) and resistance training alone (ES = \(-1.6\)%) on body fat percentage (\(p < 0.001\)), and combined resistance and aerobic exercise + caloric restriction (ES = \(-3.0\)%) compared with control.

![FIGURE 2](image-url)

**FIGURE 2**  Mean difference effects of resistance-based exercise compared with control on body fat percentage in children/adolescents (A), young adults (B), middle-aged adults (C), and older adults with overweight/obesity (D). Overall subgroup analyses conducted with a random-effects model. \(I^2\) represents the heterogeneity test; diamonds represent pooled estimates of random-effect meta-analysis; studies deemed outliers are highlighted in gray.
aerobic exercise ($ES = -1.4$ kg) and resistance training alone ($ES = -1.0$ kg) on fat mass ($p < 0.001$) (Table 1). Forest plots for each exercise modality before sensitivity analysis procedure adjustments are presented in Figures S1 and S2.

Heterogeneity ranged from $I^2 = 0\%$ to $8\%$ after removing outliers.\textsuperscript{33,54,66,73,77,84,85,95,98,102,105,109,115,121,122,131} No evidence of publication bias was identified in body fat percentage or whole-body fat mass ($\tau = 1.8$ to $0.4$, $p = 0.069$ to $0.690$).

### 3.3 | Trunk fat mass, visceral adipose tissue, and subcutaneous adipose tissue

Regarding the different depots of adiposity, VAT ($k = 13$, $ES = -0.4$ SMD, 95% CI: $-0.5$ to $-0.2$) and SAT ($k = 9$, $ES = -0.4$ SMD, 95% CI: $-0.5$ to $-0.2$) were significantly reduced following resistance-based exercise programs (Table 2). Studies assessed VAT by magnetic resonance imaging (MRI)\textsuperscript{32,74,83,101,118} and bioelectrical impedance...
While SAT was assessed by MRI, CT, and ultrasound, significant changes in trunk fat mass were not observed ($k = 7, ES = -0.4 kg, 95% CI: -1.1 to 0.2 kg, p < 0.219$). Results were maintained for studies examining VAT in middle-aged adults ($ES = -0.3 SMD, 95% CI: -0.6 to -0.1$) and older adults ($ES = -0.5 SMD, 95% CI: -0.9 to -0.1$), and studies examining SAT in older adults ($ES = -0.5 SMD, 95% CI: -0.9 to -0.1$). Results are presented before sensitivity analysis procedure adjustments in Figure 4.

### 3.4 Lean mass

Resistance-based exercise programs resulted in significant increases in lean mass ($k = 67, ES = 0.7 kg, 95% CI: 0.5 to 0.8 kg$) (Table 3). These effects were consistent across the lifespan with significant results observed in children/adolescents ($ES = 0.8 kg, 95% CI: 0.4 to 0.8$), young adults ($ES = 0.7 kg, 95% CI: 0.5 to 0.8$), middle-aged adults ($ES = 0.7 kg, 95% CI: 0.5 to 0.8$), and older adults with overweight/obesity ($ES = 0.7 kg, 95% CI: 0.5 to 0.8$).
1.1 kg), young adults (ES = 1.4 kg, 95% CI: 0.9 to 1.9 kg), middle-aged adults (ES = 0.3 kg, 95% CI: 0.1 to 0.6 kg), and older adults (ES = 0.8 kg, 95% CI: 0.6 to 1.1 kg). Results are presented across the lifespan before sensitivity analysis procedure adjustments in Figure 5. Significant and similar results were also observed for studies involving females and mixed participants (ES = 0.6–0.8 kg, p < 0.001). Resistance training alone and combined resistance and aerobic exercise were the most effective for increasing lean mass with changes of 0.8 kg (95% CI: 0.6 to 1.0 kg) and 0.6 kg (95% CI: 0.3 to 0.9 kg), respectively (Table 3). Changes in lean mass were not observed following resistance training + caloric restriction (ES = −0.2 kg, p = 0.727), resistance training + low-sugar diet (ES = 1.2 kg, p = 0.143), and combined resistance and aerobic exercise + caloric restriction (ES = −0.3 kg, p = 0.550) (Table 3). Heterogeneity was I² = 0% after removing four studies considered outliers in the analyses.54,59,73,131 Publication bias was not observed (t = 0.4, p = 0.687). Forest plots for each exercise modality before sensitivity analysis procedure adjustments are presented in Figure S4.

### 3.5 | Body weight and body mass index

Reductions in body weight (k = 93, ES = −1.6 kg, 95% CI: −1.9 to −1.3 kg) and BMI (k = 74, ES = −0.6 kg.m², 95% CI: −0.7 to −0.5 kg.m²) were observed following resistance-based exercise programs (Table 4). Resistance-based exercise programs resulted in significant reductions in children/adolescents (ES = −1.1, 95% CI: −2.2 to −0.0), young adults (ES = −1.3 kg, 95% CI: −2.0 to −0.6) and ES = −0.4 kg.m², 95% CI: −0.8 to −0.0 kg.m²), middle-aged adults (ES = −0.5 kg, 95% CI: −1.0 to −0.1 kg and ES = −0.5 kg.m², 95% CI: −0.8 to −0.2 kg.m²), and older adults (ES = −1.8 kg, 95% CI: −2.3 to −1.2 kg and ES = −0.6 kg.m², 95% CI: −0.9 to −0.4 kg.m²), whereas changes in BMI were not observed in children/adolescents (ES = 0.3 kg.m², p = 0.163). Results are presented for body weight and BMI across the lifespan before sensitivity analysis procedure adjustments in Figure 6 and Figure 7, respectively. Studies involving female, male, and mixed participants presented significant reductions in body weight and BMI.
| TABLE 2 | Overall and subgroup analyses of resistance-based exercise effects on trunk fat mass, visceral adipose tissue and subcutaneous adipose tissue in participants who are overweight or obese |
| Random effect meta-analysis | Heterogeneity |
| | | k | ES | 95% CI | p-value | Q | I² | p-value |
| **Trunk fat mass, kg** | | | | | | | |
| Overall effect | | 7 | −0.4 | −1.1 to 0.2 | 0.219 | 1.3 | 0% | 0.970 |
| Without outlier | | - | - | - | - | - | - | - |
| **Age** | | | | | | | |
| Children/adolescent | | - | - | - | - | - | - | - |
| Young adults | | 1 | −0.3 | −1.4 to 0.8 | - | - | - | - |
| Middle-aged adults | | 2 | −1.0 | −2.8 to 0.9 | 0.308 | 0.1 | 0% | 0.772 |
| Older adults | | 4 | −0.3 | −1.2 to 0.5 | 0.431 | 0.8 | 0% | 0.841 |
| **Sex** | | | | | | | |
| Female | | 5 | −0.4 | −1.2 to 0.4 | 0.346 | 0.9 | 0% | 0.919 |
| Male | | 1 | −0.3 | −1.4 to 0.8 | - | - | - | - |
| Mixed | | 1 | −1.3 | −4.2 to 1.6 | - | - | - | - |
| **Exercise modality** | | | | | | | |
| RET | | 3 | −0.5 | −1.5 to 0.5 | 0.298 | 0.5 | 0% | 0.776 |
| COMB | | 3 | −0.3 | −1.3 to 0.7 | 0.577 | 0.1 | 0% | 0.963 |
| **Visceral adipose tissue, SMD** | | | | | | | |
| Overall effect | | 15 | −0.7 | −1.1 to −0.3 | <0.001 | 88.5 | 84% | <0.001 |
| Without outlier | | 13 | −0.4 | −0.5 to −0.2 | <0.001 | 12.0 | 0% | 0.446 |
| **Age** | | | | | | | |
| Children/adolescent | | 1 | −0.3 | −1.0 to 0.4 | - | - | - | - |
| Young adults | | 3 | 0.8 | −2.1 to 0.5 | 0.221 | 23.0 | 91% | <0.001 |
| Middle-aged adults | | 7 | −0.3 | −0.6 to −0.1 | 0.005 | 5.5 | 0% | 0.485 |
| Older adults | | 3 | −0.3 | −0.9 to −0.1 | 0.011 | 5.1 | 61% | 0.080 |
| **Sex** | | | | | | | |
| Female | | 7 | −0.3 | −0.5 to −0.1 | <0.001 | 4.7 | 0% | 0.582 |
| Male | | 1 | −0.3 | −1.1 to 0.5 | - | - | - | - |
| Mixed | | 5 | −0.4 | −0.8 to −0.0 | 0.032 | 6.3 | 36% | 0.179 |
| **Exercise modality** | | | | | | | |
| RET | | 6 | −0.4 | −0.6 to −0.1 | 0.002 | 2.5 | 0% | 0.772 |
| RET + Caloric restriction | | 2 | −0.5 | −1.2 to 0.2 | 0.142 | 0.0 | 0% | 0.932 |
| COMB | | 9 | −0.7 | −1.2 to −0.2 | 0.005 | 40.3 | 80% | <0.001 |
| **Subcutaneous adipose tissue, SMD** | | | | | | | |
| Overall effect | | 9 | −0.4 | −0.5 to −0.2 | <0.001 | 7.5 | 0% | 0.485 |
| Without outlier | | - | - | - | - | - | - | - |
| **Age** | | | | | | | |
| Children/adolescent | | 1 | −0.6 | −1.3 to 0.1 | - | - | - | - |
| Young adults | | 2 | −0.2 | −0.7 to 0.4 | 0.475 | 0.0 | 0% | 0.936 |
| Middle-aged adults | | 3 | −0.3 | −0.5 to 0.0 | 0.067 | 0.1 | 0% | 0.965 |
| Older adults | | 3 | −0.5 | −0.9 to −0.1 | 0.011 | 5.1 | 61% | 0.080 |
| **Sex** | | | | | | | |
| Female | | 4 | −0.3 | −0.5 to −0.1 | 0.003 | 1.0 | 0% | 0.808 |
| Male | | 1 | −0.2 | −1.0 to 0.6 | - | - | - | - |
| Mixed | | 4 | −0.6 | −0.9 to −0.2 | 0.004 | 3.9 | 24% | 0.269 |
| **Exercise modality** | | | | | | | |
| RET | | 6 | −0.3 | −0.6 to −0.1 | 0.003 | 2.3 | 0% | 0.813 |
| COMB 6 | ES | 95% CI | p-value | Q | I² | p-value |
|-------|----|--------|---------|----|----|---------|
|       | -0.5 | -0.9 to -0.2 | 0.002 | 9.7 | 49% | 0.084 |

Abbreviations: COMB, combined resistance and aerobic exercise; ES, effect size; I², percentage of variation across studies that is due to heterogeneity; k, number of studies; Q, Cochran’s Q test of heterogeneity; RET, resistance training; SMD, standardized mean difference.

*Exercise modalities excluded due to insufficient evidence for trunk fat mass: COMB + Amino acids, ES = 0.0 kg (95% CI: -1.2 to 1.2); COMB + Fatty acids, ES = -1.3 kg (95% CI: -4.2 to 1.6); COMB + Isoflavones, ES = -0.9 kg (95% CI: -4.0 to 2.2).

*Exercise modalities excluded due to insufficient evidence for visceral adipose tissue: COMB + Caloric restriction, ES = -0.2 SMD (95% CI: -1.3 to 0.9); COMB + Fatty acids, ES = -0.0 SMD (95% CI: -0.8 to 0.8).

*Adjustment after omitting studies in which the confidence intervals did not overlap the estimated pooled effect.

### Regional adiposity

#### (A) Trunk fat mass

| Study or Subgroup | Experimental | Control | Mean Difference |
|-------------------|--------------|---------|-----------------|
| Meisinger et al., 2018 | -1.5 | 0.6 | 2.6 |
| Hargrove et al., 2020 | -1.4 | 0.3 | 1.8 |
| Shin et al., 2014 | -1.4 | 0.3 | 1.5 |
| Davidson et al., 2009 | -1.4 | 0.3 | 1.7 |
| Fernández-Real et al., 2009 | -1.4 | 0.3 | 1.8 |
| Chen et al., 2017 | -1.4 | 0.3 | 1.8 |
| Davies et al., 2011 | -1.4 | 0.3 | 1.8 |
| Donges et al., 2013 | -1.4 | 0.3 | 1.8 |
| Davis et al., 2011 | -1.4 | 0.3 | 1.8 |
| Schmidt et al., 2007 | -1.4 | 0.3 | 1.8 |
| Irwin et al., 2003 | -1.4 | 0.3 | 1.8 |
| Miller et al., 2018 | -1.4 | 0.3 | 1.8 |
| Mendham et al., 2020 | -1.4 | 0.3 | 1.8 |
| Kreating et al., 2017 | -1.4 | 0.3 | 1.8 |
| Komstorn et al., 2018 | -1.4 | 0.3 | 1.8 |
| Oh et al., 2018 | 0.3 | 0.3 | 0.6 |

Total (95% CI): 237 (130 to 360)

#### (B) Visceral adipose tissue

| Study or Subgroup | Experimental | Control | Mean Difference |
|-------------------|--------------|---------|-----------------|
| Hargrove et al., 2020 | -1.4 | 0.3 | 1.8 |
| Shin et al., 2014 | -1.4 | 0.3 | 1.8 |
| Davidson et al., 2009 | -1.4 | 0.3 | 1.8 |
| Fernández-Real et al., 2009 | -1.4 | 0.3 | 1.8 |
| Chen et al., 2017 | -1.4 | 0.3 | 1.8 |
| Davies et al., 2011 | -1.4 | 0.3 | 1.8 |
| Donges et al., 2013 | -1.4 | 0.3 | 1.8 |
| Davis et al., 2011 | -1.4 | 0.3 | 1.8 |
| Schmidt et al., 2007 | -1.4 | 0.3 | 1.8 |
| Irwin et al., 2003 | -1.4 | 0.3 | 1.8 |
| Miller et al., 2018 | -1.4 | 0.3 | 1.8 |
| Mendham et al., 2020 | -1.4 | 0.3 | 1.8 |
| Kreating et al., 2017 | -1.4 | 0.3 | 1.8 |
| Komstorn et al., 2018 | -1.4 | 0.3 | 1.8 |
| Oh et al., 2018 | 0.3 | 0.3 | 0.6 |

Total (95% CI): 569 (373 to 715)

#### (C) Subcutaneous adipose tissue

| Study or Subgroup | Experimental | Control | Mean Difference |
|-------------------|--------------|---------|-----------------|
| Hargrove et al., 2020 | -1.4 | 0.3 | 1.8 |
| Shin et al., 2014 | -1.4 | 0.3 | 1.8 |
| Davidson et al., 2009 | -1.4 | 0.3 | 1.8 |
| Fernández-Real et al., 2009 | -1.4 | 0.3 | 1.8 |
| Chen et al., 2017 | -1.4 | 0.3 | 1.8 |
| Davies et al., 2011 | -1.4 | 0.3 | 1.8 |
| Donges et al., 2013 | -1.4 | 0.3 | 1.8 |
| Davis et al., 2011 | -1.4 | 0.3 | 1.8 |
| Schmidt et al., 2007 | -1.4 | 0.3 | 1.8 |
| Irwin et al., 2003 | -1.4 | 0.3 | 1.8 |
| Miller et al., 2018 | -1.4 | 0.3 | 1.8 |
| Mendham et al., 2020 | -1.4 | 0.3 | 1.8 |
| Kreating et al., 2017 | -1.4 | 0.3 | 1.8 |
| Komstorn et al., 2018 | -1.4 | 0.3 | 1.8 |
| Oh et al., 2018 | 0.3 | 0.3 | 0.6 |

Total (95% CI): 367 (268 to 466)

### FIGURE 4

Mean difference effects of resistance-based exercise compared with control on trunk fat mass (A), visceral adipose tissue (B), and subcutaneous adipose tissue (C) in participants who are overweight or obese participants. Overall subgroup analyses conducted with a random-effects model. I² represents the heterogeneity test; diamonds represent pooled estimates of random-effect meta-analysis; studies deemed outliers are highlighted in gray.
Resistance training + caloric restriction and combined resistance and aerobic exercise + caloric restriction were the most effective for reducing body weight with changes of −5.3 kg (95% CI: −7.6 to −3.0 kg) and −5.6 kg (95% CI: −7.8 to −3.4), respectively. Results were also significant for studies prescribing combined resistance and aerobic exercise (ES = −1.9 kg, p < 0.001). Combined resistance and aerobic exercise + caloric restriction was the most effective for reducing BMI (ES = −1.2 kg/m², 95% CI: −1.8 to −0.6 kg/m²), whereas results were also significant for studies prescribing combined resistance and aerobic exercise (ES = −0.7 kg/m², p < 0.001). Heterogeneity was I² = 0% after removing studies which were considered outliers in body weight and BMI analyses.27,33,38,59,73,77,84,95,101,102,105,131 No effect of publication bias was observed (t = −0.7 to −0.1, p = 0.161–0.472). Forest plots for each exercise modality before sensitivity analysis procedure adjustments are presented in Figures S5 and S6.

4 | DISCUSSION

In the present systematic review and meta-analysis, we examined the effects of resistance-based exercise programs compared with groups without intervention in individuals with overweight/obesity across the lifespan. The main findings of this study are (1) supervised resistance-based exercise programs significantly reduces body fat percentage and whole-body fat mass in participants with overweight and obesity regardless of age and sex, with supervised resistance-based exercise programs combined with a caloric restriction being the most effective intervention; (2) regional adiposity measures were significantly reduced following resistance-based exercise programs, with greater effects observed in middle-aged and older adults as well as following combined resistance and aerobic exercise; (3) supervised resistance training alone is the most effective intervention for increasing lean mass, whereas lean mass was preserved in interventions undertaking a caloric restriction component that included resistance exercise; and (4) body weight and

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**TABLE 3** Overall and subgroup analyses of resistance-based exercise effects on lean mass in participants who are overweight or obese

| Exercise modalitya | Random effect meta-analysis | Heterogeneity |
|---------------------|-----------------------------|--------------|
|                     | k  | ES  | 95% CI | p-value | Q | I² | p-value |
| Lean mass, kg       |    |     |        |         |   |   |        |
| Overall effect      | 71 | 0.9 | 0.4 to 1.4 | 0.001 | 636.4 | 89% | <0.001 |
| Without outlierb    | 67 | 0.7 | 0.5 to 0.8 | <0.001 | 40.9 | 0%  | 0.994  |
| Age                 |    |     |        |         |   |   |        |
| Children/adolescent | 15 | 0.8 | 0.4 to 1.1 | <0.001 | 10.4 | 0%  | 0.731  |
| Young adultsb       | 15 | 1.4 | 0.9 to 1.9 | <0.001 | 10.1 | 0%  | 0.755  |
| Middle-aged adults  | 18 | 0.3 | 0.1 to 0.6 | 0.009  | 6.9 | 0%  | 0.985  |
| Older adultsb       | 20 | 0.8 | 0.6 to 1.1 | <0.001 | 9.7 | 0%  | 0.960  |
| Sex                 |    |     |        |         |   |   |        |
| Femaleb             | 33 | 0.6 | 0.4 to 0.9 | <0.001 | 6.7 | 0%  | 0.999  |
| Male                | 17 | 0.5 | −0.1 to 1.0 | 0.087 | 5.4 | 0%  | 0.994  |
| Mixedb              | 17 | 0.8 | 0.4 to 1.2 | <0.001 | 28.1 | 43% | 0.031  |

Abbreviations: COMB, combined resistance and aerobic exercise; ES, effect size; I², percentage of variation across studies that is due to heterogeneity; k, number of studies; Q, Cochran’s Q test of heterogeneity; RET, resistance training.

aExercise modalities excluded due to insufficient evidence for lean mass: RET + Ginger supplementation, ES = 3.0 kg (95% CI: −22.0 to 28.0); RET + Green tea, ES = 8.9 kg (95% CI: 6.1 to 11.7); RET + Protein supplementation, ES = 0.8 kg (95% CI: −5.6 to 7.2); COMB + Caffeine supplementation, ES = 2.0 kg (95% CI: −6.8 to 10.7); COMB + Caloric restriction + Protein supplementation, ES = −0.3 kg (95% CI: −4.4 to 3.7); COMB + Fatty acids, ES = −0.6 kg (95% CI: −5.1 to 3.9); COMB + Healthy diet, ES = 0.6 kg (95% CI: −0.5 to 1.7); COMB + Isoflavones supplementation, ES = 1.1 kg (95% CI: −1.9 to 4.1); COMB + Low-sugar diet, ES = 0.6 kg (95% CI: −0.7 to 1.9); 95% CI, 95% confidence interval; COMB + Protein supplementation, ES = 0.8 kg (95% CI: −0.3 to 1.9).

bAdjustment after omitting studies in which the confidence intervals did not overlap the estimated pooled effect.
BMI were significantly reduced by supervised resistance-based exercise programs in all age categories except children/adolescents, with greater effects when undertaking resistance training + caloric restriction or combined resistance and aerobic exercise + caloric restriction. Therefore, resistance-based training is an effective option within multicomponent therapy programs for targeting fat and weight loss while maintaining lean mass in individuals with overweight/obesity. These results are clinically relevant and can be immediately used to improve current practice by expanding the exercise modalities within multicomponent therapy programs targeting obesity.

Our findings that resistance training alone and combined resistance and aerobic exercise can significantly reduce fat mass were in agreement with previous systematic reviews and meta-analyses. However, among the interventions investigated in this study, resistance-based exercise programs combined with caloric restriction were the most effective for reducing body fat percentage and whole-body fat mass in participants who are overweight or obese. Interestingly, the results achieved by either resistance training alone + caloric restriction or combined resistance and aerobic exercise + caloric restriction were similar and comparable to changes observed in adults with overweight/obesity undertaking aerobic exercise alone plus caloric restriction when compared with no intervention control groups. In the studies from Marks et al., Kraemer et al., Villareal et al., and Yoshimura et al., for example, the aerobic exercise program combined with caloric restriction resulted in an average fat mass reduction of ~5 kg following 12 to 26 weeks of intervention in adults with overweight/obesity. In addition, the effects derived from the resistance-based exercise programs combined with caloric restriction in our study were observed in 12 to 48 weeks, without an apparent effect for intervention duration. Apart from...
contributing to successful weight loss in individuals with obesity, the
\~5 kg reduction in fat mass observed following resistance-based
exercise programs combined with a caloric restriction compared
with groups without intervention is critical for cardiometabolic
health.\textsuperscript{142,143} As previously reported,\textsuperscript{142,143} both body fat
percentage and fat distribution are associated with an increased risk
for hypertension and cardiovascular disease. Therefore, our results
expand current recommendations for individuals with overweight/
obesity,\textsuperscript{2,3} indicating that resistance training could be used as a sole
exercise intervention within a multicomponent therapy program for
individuals undergoing caloric restriction interventions, potentially
reducing the risk for cardiovascular disease in this population.

Beyond the clinical relevance of whole-body fat mass, both vis-
ceral and subcutaneous fat mass depots are also associated with car-
diometabolic health and systemic inflammation in individuals with
obesity. Both VAT and SAT were significantly reduced following
resistance-based exercise programs in the present study, with some-
what greater effects observed when undertaking combined resistance
and aerobic exercise. The reduction of 0.7 SMD observed following
combined resistance and aerobic exercise in VAT is larger to those
reported in previous meta-analyses,\textsuperscript{8–12} although the effects are still
considered small-to-moderate. In the study of Maillard et al.,\textsuperscript{11} for
example, high-intensity interval training was associated with a reduc-
tion in VAT of \(~0.2\) SMD in adults with overweight/obesity. Likewise,
general aerobic exercise promoted a reduction in VAT of \(~0.3\) SMD,
as observed in the study of Ismail et al.\textsuperscript{8} A potential explanation for
the different findings reported previously,\textsuperscript{8–12} and this study could be
related to the additional effect derived from combined resistance
and aerobic exercise, resulting in a higher effect on VAT and SAT. There-
fore, even without a dietary intervention, combined resistance and
aerobic exercise can significantly reduce abdominal fat with greater
effects than interventions comprising only aerobic exercise

FIGURE 5 (Continued)
**TABLE 4** Overall and subgroup analyses of resistance-based exercise effects on body weight and body mass index in participants who are overweight or obese

|                        | Random effect meta-analysis | Heterogeneity  |
|------------------------|-------------------------------|----------------|
|                        | k    | ES     | 95% CI    | p-value | Q   | \(i^2\) | p-value |
| **Body weight, kg**    |      |        |           |         |     |        |         |
| Overall effect         | 103  | -1.8   | -2.6 to -1.0 | <0.001  | 815.8 | 88%    | <0.001  |
| Without outlier\(^c\) | 93   | -1.6   | -1.9 to -1.3 | <0.001  | 60.5  | 0%     | 0.996   |
| **Age**                |      |        |           |         |     |        |         |
| Children/adolescent    | 21   | -1.1   | -2.2 to -0.0 | 0.043   | 33.4  | 40%    | 0.031   |
| Young adults\(^d\)     | 23   | -1.4   | -2.1 to -0.8 | <0.001  | 10.5  | 0%     | 0.981   |
| Middle-aged adults\(^e\)| 33  | -0.6   | -1.0 to -0.1 | 0.021   | 30.4  | 0%     | 0.549   |
| Older adults\(^e\)     | 20   | -1.7   | -2.2 to -1.2 | <0.001  | 14.6  | 0%     | 0.748   |
| **Sex**                |      |        |           |         |     |        |         |
| Female\(^c\)           | 48   | -1.4   | -1.9 to -0.9 | <0.001  | 31.7  | 0%     | 0.958   |
| Male\(^c\)             | 26   | -1.1   | -2.1 to -0.1 | 0.032   | 32.9  | 24%    | 0.133   |
| Mixed\(^c\)            | 23   | -1.2   | -1.8 to -0.6 | <0.001  | 29.6  | 26%    | 0.128   |
| **Exercise modality**  |      |        |           |         |     |        |         |
| RET\(^c\)              | 50   | -0.1   | -0.5 to 0.3 | 0.511   | 30.1  | 0%     | 0.985   |
| RET + Caloric restriction | 6  | -5.3   | -7.6 to -3.0 | <0.001  | 17.0  | 71%    | 0.005   |
| RET + Low-sugar diet   | 2    | 2.7    | 1.1 to 4.3   | 0.001   | 0.2   | 0%     | 0.676   |
| COMB\(^e\)             | 44   | -1.9   | -2.5 to -1.3 | <0.001  | 65.1  | 34%    | 0.017   |
| COMB + Caloric restriction | 8  | -5.6   | -7.8 to -3.4 | <0.001  | 36.7  | 81%    | <0.001  |
| COMB + Healthy diet    | 2    | -3.1   | -7.1 to 0.9  | 0.127   | 3.1   | 68%    | 0.078   |
| **Body mass index, kg\(m^2\)** | | | | | | | |
| Overall effect         | 83   | -0.6   | -0.9 to -0.3 | <0.001  | 396.2 | 79%    | <0.001  |
| Without outlier\(^c\) | 74   | -0.6   | -0.7 to -0.5 | <0.001  | 33.7  | 0%     | 0.999   |
| **Age**                |      |        |           |         |     |        |         |
| Children/adolescent    | 18   | -0.3   | -0.8 to 0.1  | 0.163   | 30.7  | 45%    | 0.022   |
| Young adults\(^d\)     | 22   | -0.5   | -0.8 to -0.2 | 0.003   | 19.3  | 0%     | 0.563   |
| Middle-aged adults\(^e\)| 27  | -0.5   | -0.8 to -0.2 | 0.001   | 37.8  | 31%    | 0.064   |
| Older adults\(^e\)     | 14   | -0.6   | -0.8 to -0.4 | <0.001  | 3.2   | 0%     | 0.997   |
| **Sex**                |      |        |           |         |     |        |         |
| Female\(^c\)           | 37   | -0.4   | -0.6 to -0.2 | <0.001  | 24.5  | 0%     | 0.928   |
| Male\(^c\)             | 19   | -0.5   | -0.8 to -0.2 | <0.001  | 15.5  | 0%     | 0.630   |
| Mixed\(^c\)            | 21   | -0.5   | -0.7 to -0.2 | <0.001  | 21.8  | 8%     | 0.351   |
| **Exercise modality**  |      |        |           |         |     |        |         |
| RET\(^c\)              | 43   | -0.1   | -0.3 to 0.1  | 0.209   | 25.6  | 0%     | 0.978   |
| RET + Caloric restriction | 2  | -2.1   | -3.8 to -0.4 | 0.017   | 0.2   | 0%     | 0.622   |
| RET + Low-sugar diet   | 2    | 1.6    | 1.0 to 2.1   | <0.001  | 0.5   | 0%     | 0.497   |
| RET + Protein supplementation | 2  | -0.0   | -1.3 to 1.3  | 0.980   | 0.0   | 0%     | 0.879   |
| COMB\(^e\)             | 36   | -0.7   | -0.9 to -0.6 | <0.001  | 31.6  | 0%     | 0.632   |
| COMB + Caloric restriction | 3  | -1.2   | -1.8 to -0.6 | <0.001  | 1.1   | 0%     | 0.588   |

Abbreviations: COMB, combined resistance and aerobic exercise; ES, effect size; \(i^2\), percentage of variation across studies that is due to heterogeneity; k, number of studies; Q, Cochran's Q test of heterogeneity; RET, resistance training.

\(^a\)Exercise modalities excluded due to insufficient evidence for body weight: RET + Green tea, ES = 1.7 kg (95% CI: -3.0 to 6.4); RET + Protein supplementation, ES = 0.1 kg (95% CI: -0.8 to 8.5); COMB + Caloric restriction + Protein supplementation, ES = -4.1 kg (95% CI: -11.7 to 3.4); COMB + Fatty acids, ES = -1.5 kg (95% CI: -8.7 to 5.7); COMB + Isoflavones supplementation, ES = -0.2 kg (95% CI: -8.0 to 7.6); COMB + Low-sugar diet, ES = -0.5 kg (95% CI: -2.0 to 1.0); COMB + Protein supplementation, ES = -1.5 kg (95% CI: -3.7 to 0.7).

\(^b\)Exercise modalities excluded due to insufficient evidence for body mass index: RET + Ginger supplementation, ES = -0.4 kg m\(^2\) (95% CI: -7.3 to 6.5); RET + Green tea, ES = 1.6 kg m\(^2\) (95% CI: 0.2 to 3.3); COMB + Fatty acids, ES = -0.6 kg m\(^2\) (95% CI: -3.1 to 1.9); COMB + Isoflavones supplementation, ES = -0.1 kg m\(^2\) (95% CI: -2.2 to 2.0).

\(^c\)Adjustment after omitting studies in which the confidence intervals did not overlap the estimated pooled effect.
modalities previously deemed the most effective modality for reducing overall abdominal fat. Moreover, our findings are that middle-aged and older adults benefit the most from exercise on VAT and SAT outcomes. These age groups are the most affected by cardiovascular risk factors, and therefore, our findings are of particular interest. In previous studies, increased visceral and subcutaneous fat was associated with increased risk of incident hypertension, hypertriglyceridemia, and metabolic syndrome in middle-aged and older adults. Furthermore, the benefits observed in VAT and SAT could reduce the progression of metabolic syndrome, attenuating the chronic side effects from comorbidities in these age groups.

Although greater effects were observed when undertaking resistance training or combined resistance and aerobic exercise, as previously reported, the result that resistance training can at least help...
preserve lean mass while undergoing caloric restriction is meaningful for this population. In the systematic review of Weinheimer et al., the authors reported that 70% of studies only undertaking caloric restriction present reductions ≥1.5 kg of lean mass in middle-aged and older adults. Similarly, Garrow and Summerbell predicted that 20% to 30% of weight loss following caloric restriction could be unrelated to fat mass in adults. Substantial reductions of 2–3 kg are also observed in lean mass following aerobic exercise alone plus caloric restriction. Additionally, our results are in agreement with a previous meta-analysis, demonstrating that resistance training is associated with an increase of ~0.8 kg in lean mass compared with caloric restriction interventions in older adults with obesity, although
they were not compared with caloric restriction only programs in the present study. These results are of great importance as resistance training can reduce the risk of sarcopenia and frailty as well as improve physical function and quality of life in this population.\textsuperscript{152,153} Moreover, the clinical implications of lean mass have become clearer with advances in the investigation of myokines.\textsuperscript{154} Several myokines, including myostatin,\textsuperscript{155} interleukin 6 (IL-6),\textsuperscript{156} and brain-derived neurotrophic factor (BDNF),\textsuperscript{157} are produced, expressed, and released by muscle contraction and may account for protection against proinflammatory adipokines under conditions of obesity.\textsuperscript{154} Therefore, maintenance or accrual of lean mass, only achieved with resistance exercise in this population, is of clinical importance as it can potentially improve resting energy expenditure and accrue benefits for weight loss\textsuperscript{158} as well as promote reductions in chronic inflammation.\textsuperscript{154}

A substantial reduction in body weight was observed following either resistance training or combined resistance and aerobic exercise with caloric restriction when compared with no intervention control groups. This result is of importance for clinical practice as resistance exercise can be used regardless of an aerobic exercise component when combined with caloric restriction and still lead to a reduction of

**FIGURE 7** Mean difference effects of resistance-based exercise compared with control on body mass index in children/adolescents (A), young adults (B), middle-aged adults (C), and older adults with overweight/obesity (D). Overall subgroup analyses conducted with a random-effects model. $I^2$ represents the heterogeneity test; diamonds represent pooled estimates of random-effect meta-analysis; studies deemed outliers are highlighted in gray.
~5.5 kg in body weight compared with no intervention control groups. In addition, this substantial change may be explained by reductions in fat rather than lean mass given the anabolic effect from resistance training which attenuated a reduction in lean mass during weight loss. The magnitude of weight loss we observed with resistance-based programs + caloric restriction is similar to previous studies examining aerobic training only + caloric restriction. Therefore, our results support the utilization of resistance training + caloric restriction as part of multicomponent therapy programs for adults with overweight or obesity to reduce body weight and BMI.

The strength of the present review are as follows: (1) inclusion of 116 studies with ~4000 participants who are overweight or obese; (2) a broad eligibility criteria and control of different definitions and cut-off points for individuals with overweight or obesity; (3) inclusion of published and unpublished studies written in three different languages; (4) a conservative approach of assuming a correlation of 0.5 for studies not reporting sufficient data for meta-analysis; and (5) a range of subgroup analyses based on population characteristics and exercise modalities. However, the present study also has limitations. First, most studies included were of high risk of bias because of concerns regarding the randomization process, measurement of outcomes, and selection of reported results, and this may affect the precision and magnitude of effects of resistance-based exercise interventions. Second, most data were pooled from different methods of body composition assessment such as dual energy X-ray absorptiometry, bioelectrical impedance, and anthropometry (i.e., skinfolds), and this...
may increase the heterogeneity across studies. Third, age groups were categorized based on the average age, and this may not fully represent the sample of each study included. Fourth, we did not include comparisons between resistance-based exercise programs and dietary interventions only. This might be considered a limitation to estimate the direct contribution of resistance exercise or caloric restriction to weight loss and lean mass accruing. Additional research is required to evaluate the individual impact of exercise or caloric restriction on body composition in individuals with overweight/obesity.

In conclusion, this study provides evidence that resistance-based exercise programs are effective and should be considered as part of a multicomponent therapy program when caloric restriction is utilized in adults with overweight or obesity. Considering the similar effect on fat and weight loss and unique effect on lean mass, resistance training rather than aerobic exercise alone should be considered within any multicomponent fat loss prescription for individuals with overweight/obesity. These results expand current guidelines to improve existing exercise clinical practice with the potential to counteract cardiometabolic complications associated with increased fat mass and body weight while avoiding loss of muscle mass.

ACKNOWLEDGMENTS
Pedro Lopez is supported by the National Health and Medical Research Council (NHMRC) Centre of Research Excellence (CRE) in Prostate Cancer Survivorship Scholarship. Daniel A. Galvão and Robert U. Newton are funded by a NHMRC CRE in Prostate Cancer Survivorship. The results of the study are presented clearly, honestly, without fabrication, falsification, or inappropriate data manipulation. No financial support was received to conduct the present study or for the preparation or publication of this manuscript. Sponsors were not involved in the study design, analysis or interpretation of data, manuscript writing, and decision to submit the manuscript for publication. Open access publishing facilitated by Edith Cowan University, as part of the Wiley - Edith Cowan University agreement via the Council of Australian University Librarians.

CONFLICT OF INTERESTS
No conflict of interest statement in the first proofs.

AUTHOR CONTRIBUTIONS
Pedro Lopez had full access to all of the data in the study and takes responsibility for the for the integrity of the data and the accuracy of the data analysis. Concept and design: Pedro Lopez and Anderson Rech. Acquisition, analysis, or interpretation of data: Pedro Lopez, Elisa R. Nonemacher, Victória M. Wendt, Renata N. Bassanesi, Douglas J. P. Turella, and Anderson Rech. Drafting of the manuscript: Pedro Lopez, Dennis R. Taaffe, Daniel. A. Galvão, Robert U. Newton, Elisa R. Nonemacher, Victória M. Wendt, Renata N. Bassanesi, Douglas J. P. Turella, Anderson Rech. Critical revision of the manuscript for important intellectual content: Pedro Lopez, Dennis R. Taaffe, Daniel. A. Galvão, Robert U. Newton, Elisa R. Nonemacher, Victória M. Wendt, Renata N. Bassanesi, Douglas J. P. Turella, Anderson Rech. Statistical analysis: Pedro Lopez.

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How to cite this article: Lopez P, Taaffe DR, Galvão DA, et al. Resistance training effectiveness on body composition and body weight outcomes in individuals with overweight and obesity across the lifespan: A systematic review and meta-analysis. Obesity Reviews. 2022;23(5):e13428. doi:10.1111/obr.13428