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Physical activity and obesity: what we know and what we need to know*

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Summary

Creating a negative energy balance by decreasing caloric consumption and increasing physical activity is a common strategy used to treat obesity. A large number of review and original research papers have considered the role of physical activity in weight loss and maintenance. However, their conclusions are at times conflicting. In this review, we have critically evaluated the findings of systematic reviews and meta-analyses and supplemented their conclusions with recently published, high-quality clinical trials. We have eliminated studies that were methodologically flawed in an attempt to reduce the ambiguity in the literature. We further sought, through selective review of these publications, to isolate the effects of various types of exercise, independent of dietary interventions, to further clarify their independent contributions. Thus, our review describes (i) combined calorie restriction with physical activity interventions, (ii) physical activity interventions without calorie restriction and (iii) the role of physical activity on maintenance of weight loss. Through this critical examination of the literature, we have provided conclusions to address certain ambiguities regarding the role of physical activity in obesity treatment that will inform clinical practice. We have also identified several long-standing gaps in knowledge that will inform future research.

Keywords: Aerobic exercise, obesity, resistance exercise, weight loss.

Abbreviations: AE, aerobic exercise; BF, body fat; BMI, body mass index; BW, body weight; CI, confidence interval; DBP, diastolic blood pressure; DI, dietary intervention; FFM, fat-free mass; FM, fat mass; HR, heart rate; RCT, randomized controlled trial; RM, repetition maximum; RMR, resting metabolic rate; RT, resistance training; SBP, systolic blood pressure; SMR, sleeping metabolic rate; VO_2 max, maximum rate of oxygen consumption; WC, waist circumference; WL, weight loss.

Introduction

More than two-thirds (68.5%) of US adults were reported to be overweight with the prevalence of obesity and extreme obesity being 34.9% and 6.4%, respectively, in 2011–2012(1,2). More recently (2013), The Global Burden of Disease Study suggested that the prevalence of overweight and obesity in the USA was 70.9% in men (≥20 years old) and was 61.9% in women (≥20 years old) (3). Obesity increases the risk of developing several chronic diseases, such as coronary heart disease, type 2 diabetes mellitus and certain types of cancers. It also reduces quality of life and is associated with increased mortality. The estimated annual cost of medical management of obesity-related illnesses in the USA is more than $200bn (4). The recent AHA/ACC/TOS Guidelines for the management of overweight and obesity in adults state that a sustained 3–5% loss of initial body weight (BW) is recommended in order to give rise to clinically meaningful reductions in the risks of developing obesity-related chronic diseases (5).

Creating a negative energy balance, by decreasing energy intake, increasing energy expenditure or both, is a common strategy for achieving weight loss (WL) (6). While calorie restriction has been consistently shown to be effective in inducing initial WL, findings on the effects of increased physical activity on weight continue to be debated. In the public and scientific discourse on the role of physical activity in weight management, there appears at times to be a considerable disconnect among commonly held public opinions, beliefs in medical settings and the findings of well-designed clinical studies. Clarification is needed both to better inform clinical practice and to identify gaps in the research literature that should be addressed. A large number of reviews and/or meta-analyses have been published on the topic of physical activity in weight management, at times producing conflicting conclusions. To address this issue, we began by critically evaluating the findings of systematic reviews and meta-analyses conducted within the last 15 years, choosing, when available, high-quality reviews with minimal methodological challenges. We then examined recent literature from high-quality clinical trials to further supplement the findings derived from our 'review of reviews'.

Process of review

Three authors independently conducted the literature search using combinations of key words such as exercise, physical activity, weight loss, diet, calorie restriction and maintenance in PubMed and Google Scholar databases (2000–2015). Initially, each author screened the abstracts for relevance to the theme of the review paper (i.e. the ability to address the issue of the independent impacts of exercise with and without calorie restriction on WL in obesity). Focus was primarily on available systematic reviews and meta-analyses, and these were supplemented with available individual studies. In the cases of methodologically flawed systematic reviews and meta-analyses (e.g. quantitative synthesis of the outcomes of heterogeneous interventional studies, not sufficiently reporting the study selection criteria and the statistical methods) or those that included studies that fell outside of the scope of the review, the more methodologically rigorous or germane individual studies cited within the meta-analyses were reviewed independently. All studies that targeted specific populations (e.g. pregnant women, children and individuals suffering from specific diseases) were excluded. Also excluded were studies with relevant limitations in study design (e.g. not having a control/comparison group, not describing the methods sufficiently and clearly enough to determine study quality and/or applicability and inconsistencies in results shown in the tables vs. the text of the manuscripts that impact interpretation). Finally, studies were conceptually synthesized with a goal of informing both current practice and future research with regard to the potential role of (i) combined calorie restriction with physical activity interventions and (ii) physical activity interventions without calorie restriction on WL. We further sought to provide initial assessment of the need for additional, specific research to inform the role of physical activity on maintenance of WL based on the lack of available research to clearly address the unique role of physical activity on WL maintenance.

Combined calorie restriction and physical activity interventions

Throughout the obesity literature, the majority of studies combine numerous types of dietary interventions (DIs) with various types of recommendations to increase physical activity ranging from basic advice to increase steps taken throughout the day (habitual activity) to carefully select and monitor exercise 'prescriptions'. In this section, we will consider the relative impact of these types of physical activity interventions in the context of comprehensive approaches to weight management. Franz *et al.* (7) conducted a meta-analysis of WL studies published from 1997 to 2004. Randomized controlled trials (RCTs) with obese subjects that included diet, exercise and these combined were reviewed. Results indicated that pooled mean WLs at 6 months in the diet + exercise combined interventions compared with the diet-only controls were 7.8 ± 5.2 vs. 3.7 ± 4.3 kg, respectively. While the meta-analysis included other time points (12, 24 and 36 months), the extended interventions were methodologically heterogeneous as the summarized outcomes included both treatment-induced WL and WL maintenance. However, based on the homogenous 6-month outcomes in this meta-analysis, the diet + exercise combined intervention was superior to the diet-only intervention during the 6-month treatment.

In another meta-analysis of studies published from 1966 to 2007, Wu *et al.* (8) also concluded that the combination of diet and exercise interventions induced superior WL compared with diet-only interventions. In a pooled comparison of 10 RCTs, comparing the effects of 3- to 18-month diet-only vs. diet + exercise combined interventions, diet-only interventions resulted in a change of −1.78 kg (95% confidence interval [CI]: −4.86, 1.30), while diet + exercise combined interventions were found to result in a mean weight change of −3.6 kg (95% CI:

−6.74, −0.46), with the difference in WL between diet-only and diet + exercise combined interventions being −1.14 kg (95% CI: −2.07, −0.21). Similarly, in a pooled analysis of the results of seven other RCTs, in which the outcomes were reported as mean body mass index (BMI) changes, diet + exercise combined interventions resulted in a mean BMI change of $-1.83\,\mathrm{kg\,m^{-2}}$ (95% CI: −2.45, −1.21) compared with the mean BMI change of $1.38\,\mathrm{kg\,m^{-2}}$ (95% CI: −1.92, −0.84) seen in diet-only groups. The difference in mean BMI between diet-only and diet + exercise combined interventions was $-0.5\,\mathrm{kg\,m^{-2}}$ (95% CI: −0.79, −0.21). However, out of the 18 considered studies, end-point outcomes of only 12 studies were measured immediately after completing the WL interventions (with six extending into maintenance phases). When only study periods that did not have an additional follow-up period were included, the mean weight or BMI change in the diet + exercise combined interventions was seen to be −0.32 standard deviations (95% CI: −0.46, −0.19) different than outcomes of the diet-only interventions. Therefore, we conclude from this meta-analysis, similar to the previous one, that diet + exercise combined interventions are superior to diet-only interventions in inducing greater initial weight or BMI reductions.

In addition to the studies considered in these meta-analyses, some recent trials have sought to further elucidate the relative contributions of diet and exercise in weight management. Study details are found in Table 1. In 2010, Goodpaster *et al.* (9) reported the effects of the combination of a DI in the context of initial-onset vs. delayed-onset exercise interventions in subjects with class II obesity. For our purposes, only those comparisons made during the 'initial-onset' phase (first 6 months) will be discussed. Subjects were provided liquid diet/pre-packaged meals, and they were instructed to gradually increase exercise time/frequency/intensity to reach moderate intensity (brisk walking), 60 min/day (continuous or accumulated via 10-min bouts), 5 days/week. At the end of 6 months, the exercise + diet group had a significantly greater WL, reduction in waist circumference (WC) and reduction in fat percentage (% BF) compared with the diet-only group. Thus, as evidenced by the outcomes of the first 6 months of the study, the combination of moderate restriction of calorie intake and moderate-intensity aerobic exercise (AE) seems to induce greater WL and to result in improvement in several key anthropometric indicators.

In another study of overweight/obese postmenopausal women, the diet + exercise combined intervention was also found to be superior in inducing WL compared with diet-only interventions. Foster-Schubert *et al.* (10) conducted a 12-month RCT with 439 overweight or obese postmenopausal women. Participants were divided into four groups, which were control, diet only, exercise only and diet + exercise. The controls were asked to maintain their baseline physical activity and dietary intake. The diet-only and diet + exercise groups were assigned a typical low-calorie diet (1,200–2,000 kcal/day), and the exercise-only and diet + exercise groups underwent supervised moderate-to-vigorous exercise, gradually building from 15 min per session at five sessions per week to 45 min per session (and a target heart rate [HR] goal of 60–70%) by the end of the seventh week. This level of exercise was maintained throughout the remainder of the intervention. Compared with the control group, all intervention groups achieved significantly greater weight reductions, with the diet group losing 7.1 kg, the exercise group losing 2.0 kg and the diet + exercise group losing 8.9 kg. Thus, the combination of diet and exercise was shown to reduce weight to a greater extent compared with diet-only interventions (i.e. by 1.8 kg), and the difference was statistically significant. In addition, all intervention groups had significant reduction of WC compared with the control group, and the WC reduction was also significantly greater in the diet + exercise group compared with the exercise-only group and the diet-only group. Moreover, % BF was significantly reduced in all intervention groups than in the control group, and reductions in % BF were significantly greater in the diet + exercise group than in the diet-only group. However, the reduction of % BF in the diet-only group was significantly greater than that in the exercise-only group. Lean body mass increased from the baseline only in the exercise-only group (+0.3 kg). Although the change from baseline to 12 months was not significantly different in the control group, it was significantly greater compared with that in the diet-only and diet + exercise groups, both of which lost lean body mass during the intervention. Overall, the findings of this study showed both clinically and statistically significant benefits of diet + exercise over diet-only interventions when considering WL alone. Moreover, there seems to be a more favourable effect on % BF and WC reduction among postmenopausal women in the diet + exercise condition. These findings highlight not only the importance of future research closely examining the challenges faced by postmenopausal women in achieving meaningful WL via diet and exercise but also the relative value of WL vs. body composition changes in this uniquely challenged subgroup of individuals with obesity.

When published individually, most of the studies summarized in the systematic review and meta-analyses conducted by Wu *et al.* (8) failed to show significant differences in WL between diet-only interventions and diet + exercise interventions; however, for some, there were significant differences noted. Nevertheless, when the data were pooled in order to increase the power, diet + exercise interventions were seen to be superior to diet-only interventions in causing WL. This result was compatible with the results seen in the previously conducted meta-analyses (7,11). Thus, a simple review of literature or attention to

Table 1 Changes in weight, BMI, WC, % BF, FM, FFM and VO_2 max observed in recent studies with diet-only, exercise-only and diet + exercise combined interventions

Reference	Sample gender (%), BMI (kg m^{-2}), age (years)	Duration (month)	Group (*n*)	Intervention		Weight (kg)	BMI (kg m^{-2})
Goodpaster *et al.* (9)	M + F (88.5), 35–39.9, 30–55	6	DI (63)	Energy intake 1,200–2,100 kcal/day	Pre $\bar{x}$ ± SD Post $\bar{x}$ ± SD Δ [Δ (%)]	117.4 ± 17.3 109.2 ± 16.3 −8.2 [−7.0] [b, f]	43.7 ± 5.3 40.6 ± 5.1 −3.1 [−7.1][b, f*]
			DI + AE (67)	DI – energy intake 1,200–2,100 kcal/day AE – moderate, 300 min/week	Pre $\bar{x}$ ± SD Post $\bar{x}$ ± SD Δ [Δ (%)]	120.6 ± 17.4 109.7 ± 16.5 −10.9 [−9.0][b, d]	43.5 ± 5.3 39.6 ± 5.1 −3.9 [−8.9][b, d*]
Foster-Schubert *et al.* (10)	F[1], ≥25 (≥23 for Asian–American), 50–75	12	DI (118)	Energy intake 1,200–2,000 kcal/day, achieved 10% WL in 6 months	Pre $\bar{x}$ ± SD Post $\bar{x}$ ± SD Δ [Δ (%)]	84.0 ± 11.8 76.9 ± 13.4 −7.1 [−8.5][b*, c, e, f]	31.0 ± 3.9 28.4 ± 4.6 −2.6 [−8.6][b*, c, e, f]
			AE (117)	70–85% maximal heart rate, 225 min/week	Pre $\bar{x}$ ± SD Post $\bar{x}$ ± SD Δ [Δ (%)]	83.7 ± 12.3 81.7 ± 12.4 −2.0 [−2.4][b*, c, d, f]	30.7 ± 3.7 29.9 ± 3.8 −0.8 [−2.4][b*, c, d, f]
			DI + AE (116)	DI – energy intake 1,200–2,000 kcal/day, achieved 10% WL in 6 months AE – 70–85% maximal heart rate, 225 min/week	Pre $\bar{x}$ ± SD Post $\bar{x}$ ± SD Δ [Δ (%)]	82.5 ± 10.8 73.6 ± 11.5 −8.9 [−10.8][b*, c, d, e]	31.0 ± 4.3 27.6 ± 4.5 −3.4 [−10.8][b*, c, d, e]
			C (87)		Pre $\bar{x}$ ± SD Post $\bar{x}$ ± SD Δ [Δ (%)]	84.2 ± 12.5 83.5 ± 12.3 −0.7 [−0.8][d, e, f]	30.7 ± 3.9 30.5 ± 4.1 −0.2 [−0.7][d, e, f]

[1]Participants were postmenopausal.
[b]Significant difference between pre-intervention and post-intervention ($P < 0.05$).
[c]Significant difference compared with control ($P < 0.05$).
[d]Significant difference compared with the diet-only group ($P < 0.05$).
[e]Significant difference compared with the exercise-only group ($P < 0.05$).
[f]Significant difference compared with the diet + exercise group ($P < 0.05$).
*Cannot be derived from the available data.
[†]Calculated outcomes that were not available in original manuscripts (calculated fat percentage is defined as fat mass/BW, and calculated fat-free mass is defined as BW − fat mass).
% BF, body fat percentage; AE, aerobic exercise intervention; BMI, body mass index; C, control group; DI, dietary intervention; FFM, fat-free mass; FM, fat mass, RT, resistance training intervention; VO_2 max, maximum rate of oxygen consumption; WC, waist circumference; WL, weight loss.

single, recently publicized studies may be misleading those attempting to inform their patients or the public at large about the value of combining diet with exercise to achieve initial WLs. A popular lore often stated among many healthcare professionals is that exercise is only useful for maintaining weight lost. However, when one considers the literature that exclusively considers active treatment (as opposed to mixed-treatment maintenance studies), a different picture emerges. Specifically, in these meta-analyses, the pooled mean WL resulting from diet + exercise combined interventions was seen to be greater than the WL observed in diet-only interventions. Goodpaster *et al.* (9) also substantiated the earlier evidence. Other well-controlled studies have reported similar results (12,13). Furthermore, in almost all studies, the diet + exercise combined interventions resulted in at least a 3–5% or even greater WL as shown in Table 1.

In conducting our review of the literature, we found that failing to adequately segregate active treatment from follow-up periods was a common contributor to

Table 1 *Continued*

Reference	WC (cm)	% BF	FM (kg)	FFM (kg)	VO2 max (mL kg^{-1} min^{-1})
Goodpaster *et al.* (9)	121.7 ± 12.0	50.47†	59.2 ± 12.5	56.6 ± 8.7	*
	116.5 ± 12.0	48.8†	53.3 ± 11.9	54.5 ± 8.6	*
	−5.17 [−4.2][b, f]	−1.6 [−3.2]*	−5.9 [−10.0][b, f]	−2.1 [−3.7][b, f*]	*
	124.4 ± 12.0	50.09†	60.4 ± 12.3	58.7 ± 8.7	*
	115.8 ± 12.3	47.17†	51.7 ± 11.7	56.3 ± 8.8	*
	−8.6 [−6.9][b, d]	−2.9 [−5.8]*	−8.7 [−14.3][b, d]	−2.4 [−4.1][b, d*]	*
Foster-Schubert *et al.* (10)	94.6 ± 10.2	47.0 ± 4.3	39.7 ± 8.1	44.3†	*
	90.2 ± 11.5	42.8 ± 6.6	33.6 ± 10.0	43.3†	*
	−4.4 [−4.7][b*, c, e, f]	−4.2 [−8.9][b*, c, e, f]	−6.1 [−15.6][b*, c, e, f]	−1.0 [−2.3]*	*
	95.1 ± 10.1	47.3 ± 4.1	39.9 ± 8.2	43.8†	*
	93.1 ± 9.8	45.7 ± 4.9	37.8 ± 8.7	43.9†	*
	−2.0 [−2.1][b*, c, d, f]	−1.6 [−3.3][b*, c, d, f]	−2.1 [−5.3][b*, c, d, f]	0.1 [0.2]*	*
	93.7 ± 9.9	47.4 ± 4.5	39.4 ± 7.9	43.1†	*
	86.7 ± 11.6	41.5 ± 7.0	31.2 ± 9.5	42.4†	*
	−7 [−7.5][b*, c, d, e]	−5.9 [−12.4][b*, c, d, e]	−8.2 [−20.8][b*, c, d, e]	−0.7 [−1.6]*	*
	94.8 ± 10.2	47.3 ± 4.4	40.1 ± 8.5	44.1†	*
	95.7 ± 9.6	47.1 ± 5.2	39.7 ± 8.7	43.8†	*
	0.9 [1.0][d, e, f]	−0.2 [−0.3][d, e, f]	−0.4 [−1.0][d, e, f]	−0.3 [−0.7]*	*

misinterpretation of outcomes. This practice obscures the ability to look more exclusively at the unique contribution of exercise to WL during the 'active' phases of treatment. When this limitation of the body of evidence is attended to, a clearer picture of the value-added benefit of combining diet with physical activity in order to lose weight becomes apparent.

Physical activity interventions without calorie restriction

From the results reviewed in the previous section, it is evident that in the context of comprehensive weight management interventions, the combination of exercise with dietary prescriptions results in better outcomes in terms of WL and other anthropometric changes over diet alone. In this section, we consider the effect of various types of physical activity (in the absence of prescriptive DI) in overweight and obese populations. We review the literature examining the effects of prescribed AE and walking interventions, resistance training (RT) and also habitual activity (steps accumulated throughout the day) in programmes where food intake is not prescriptively controlled in order to determine whether these types of exercise interventions play an independent role in inducing WL.

Aerobic exercise and walking interventions without calorie restriction

Aerobic exercise is commonly applied in the management of obesity in order to achieve WL. Several systematic reviews and meta-analyses have attempted to examine the effects of

Table 2 Changes in weight, BMI, WC, % BF, FM, FFM and VO_2 max observed in recent studies with aerobic exercise interventions

Reference	Sample gender (%), BMI ($kg\,m^{-2}$), age (years)	Duration (month)	Group (*n*)	Intervention		Weight (kg)	BMI ($kg\,m^{-2}$)
Alves *et al.* (17)	F[2], ≥25, 20–60	6	AE (78)	40–60% heart rate reserve, 150 min/week	Pre $\bar{x}$ ± SD	71.2 ± 7.8	29.8 ± 3.1
					Post $\bar{x}$ ± SD	69.9 ± 8.2	29.2 ± 3.5
					Δ [Δ (%)]	−1.26 [−1.83][b,c]	−0.6 [−2.0][b,c]
			C (78)		Pre $\bar{x}$ ± SD	74.5 ± 11.0	30.3 ± 3.4
					Post $\bar{x}$ ± SD	74.9 ± 11.3	30.4 ± 3.5
					Δ [Δ (%)]	0.4 [0.5][e]	0.1 [0.3][e]
Nishijima *et al.* (18)	M[3] + F[3] (58.3), ≥30, 40–89	6	AE (281)	70% VO_2 max, 80–160 min/week	Premedian	65.2 ± *	26.5 ± *
					Postmedian	*	*
					Δ [Δ (%)]	−1.9 [*][b,c]	*
			C (280)		Premedian	65.3 ± *	26.5 ± *
					Postmedian	*	*
					Δ [Δ (%)]	−0.3 [*][b,e]	*
Donnelley *et al.* (19)	M, 25–40, 18–30	10	AE – 600 kcal/ session (19)	70–80% maximal heart rate, five sessions/ week	Pre $\bar{x}$ ± SD	102.1 ± 11.7	32.1 ± 3.5
					Post $\bar{x}$ ± SD	96.2 ± 14.2	30.2 ± 4.3
					Δ [Δ (%)]	−5.9 [−5.8][b,c]	−1.9 [−5.9][b,c]
			AE – 400 kcal/ session (18)	70–80% maximal heart rate, five sessions/ week	Pre $\bar{x}$ ± SD	99.9 ± 19.4	32.0 ± 5.5
					Post $\bar{x}$ ± SD	96.1 ± 19.0	30.8 ± 5.5
					Δ [Δ (%)]	−3.8 [−3.8][b,c]	−1.2 [−3.8][b,c]
			C (9)		Pre $\bar{x}$ ± SD	96.2 ± 11.1	30.6 ± 4.2
					Post $\bar{x}$ ± SD	96.7 ± 12.5	30.7 ± 4.4
					Δ [Δ (%)]	0.5 [0.5][e1,e2]	0.2 [0.7][e1,e2]
	F, 25–40, 18–30	10	AE – 600 kcal/ session (18)	70–80% maximal heart rate, five sessions/ week	Pre $\bar{x}$ ± SD	81.3 ± 13.0	29.1 ± 3.8
					Post $\bar{x}$ ± SD	76.9 ± 12.8	27.5 ± 3.7
					Δ [Δ (%)]	−4.4 [−5.4][b,c]	−1.6 [−5.5][b,c]
			AE – 400 kcal/ session (19)	70–80% maximal heart rate, five sessions/ week	Pre $\bar{x}$ ± SD	83.3 ± 18.9	30.4 ± 5.6
					Post $\bar{x}$ ± SD	79.2 ± 18.1	28.9 ± 5.4
					Δ [Δ (%)]	−4.1 [−4.9][b,c]	−1.5 [−4.9][b,c]
			C (9)		Pre $\bar{x}$ ± SD	78.7 ± 12.6	28.9 ± 3.4
					Post $\bar{x}$ ± SD	79.2 ± 14.1	29.1 ± 4.4
					Δ [Δ (%)]	0.5 [0.6][e1,e2]	0.2 [0.7][e1,e2]
Irwin *et al.* (20)	F[1], ≥25, 50–75	12	AE (87)	60–75% maximal heart rate, 225 min/week	Pre $\bar{x}$ ± SD	81.6 ± 14.8	30.5 ± 4.2
					Post $\bar{x}$ ± SD	80.3 ± *	30.1 ± *
					Δ [Δ (%)]	−1.3 [−1.6][b,c]	−0.3 [−1.0][b,c]
			C (86)		Pre $\bar{x}$ ± SD	81.7 ± 12.1	30.6 ± 3.7
					Post $\bar{x}$ ± SD	81.8 ± *	30.9 ± *
					Δ [Δ (%)]	0.1 [0.1][e]	0.3 [1.0][e]

[1]Participants were postmenopausal.
[2]Participants were Brazilian.
[3]Participants were Japanese.
[b]Significant difference between pre-intervention and post-intervention ($P < 0.05$).
[c]Significant difference in weight loss compared with control ($P < 0.05$).
[e]Significant difference compared with the aerobic exercise group ($P < 0.05$).
[e1]Significant difference compared with the AE 600-kcal-per-session group ($P < 0.05$).
[e2]Significant difference compared with the AE 400-kcal-per-session ($P < 0.05$).
[er]Significant difference compared with the AE + RT group ($P < 0.05$).
[r]Significant difference compared with the RT group ($P < 0.05$).
*Cannot be derived from the available data.
[†]Calculated outcomes that were not available in original manuscripts (calculated fat-free mass is defined as BW – fat mass).
% BF, body fat percentage; AE, aerobic exercise intervention; BMI, body mass index; C, control group; FFM, fat-free mass; FM, fat mass; RT, resistance training intervention; VO_2 max, maximum rate of oxygen consumption; WC, waist circumference.

exercise interventions on WL outcomes. Franz *et al.* (7) included four trials, published between 1 January 1997 and 1 September 2004, in a subanalysis in their paper in an attempt to examine the effects of AE alone. Our review of this study, however, concluded that heterogeneity of included study designs and exercise interventions between the

Table 2 *Continued*

Reference	WC (cm)	% BF	FM (kg)	FFM (kg)	VO2 max (mL kg^{-1} min^{-1})
Alves	*	*	*	*	*
et al. (17)	*	*	*	*	*
	*	*	*	*	*
	*	*	*	*	*
	*	*	*	*	*
	*	*	*	*	*
Nishijima	89.0 ± *	*	*	*	20.7 ± *
et al. (18)	*	*	*	*	*
	−4.4 [*][b,c]	*	*	*	2.4 [*][b,c]
	88.8 ± *	*	*	*	21.0 ± *
	*	*	*	*	*
	−2.6 [*][b,e]	*	*	*	0.4 [*][b,e]
Donnelley	*	37.0 ± 5.0	36.4 ± 7.5	65.0 ± 7.3	36.4 ± 6.4
et al. (19)	*	32.5 ± 6.8	30.5 ± 10.1	65.4 ± 7.4	44.2 ± 7.6
	*	−4.5 [−12.2][b,c]	−5.9 [−16.2][b,c]	0.4 [0.6]	7.8 [21.4][b,c]
	*	35.4 ± 6.8	34.5 ± 11.6	64.4 ± 9.9	37.1 ± 6.5
	*	32.8 ± 7.5	31.1 ± 11.4	64.4 ± 9.2	42.9 ± 8.0
	*	−2.7 [−7.6][b]	−3.6 [10.4][b]	0.0 [0.0]	5.8 [15.6][b,c]
	*	36.9 ± 4.4	34.1 ± 7.9	60.7 ± 5.0	34.3 ± 5.8
	*	35.8 ± 5.6	34.0 ± 9.5	62.8 ± 6.2	33.0 ± 6.4
	*	−1.1 [−3.0][e1]	−0.1 [−0.3][e1]	2.1 [3.5]	−1.3 [−3.8][e1,e2]
	*	43.5 ± 5.7	34.1 ± 9.4	46.1 ± 5.3	31.6 ± 3.8
	*	39.4 ± 6.8	29.7 ± 9.6	46.9 ± 4.8	37.2 ± 4.7
	*	−4.1 [−9.4][b,c]	−4.4 [−12.9][b,c]	0.8 [1.7]	5.6 [17.7][b,c]
	*	43.6 ± 5.8	34.8 ± 11.1	46.9 ± 8.0	29.8 ± 4.1
	*	40.5 ± 7.3	31.7 ± 12.2	47.0 ± 7.7	35.9 ± 6.2
	*	−3.2 [−7.3][b]	−3.4 [−10.0][b]	0.1 [0.2]	6.1 [20.5][b,c]
	*	45.1 ± 4.6	34.1 ± 7.8	43.5 ± 5.1	30.2 ± 3.3
	*	45.0 ± 5.5	34.5 ± 9.2	43.7 ± 6.3	29.8 ± 3.7
	*	−0.1 [−0.2][e1]	0.4 [1.2][e1]	0.3 [0.7]	−0.4 [−1.3][e1,e2]
Irwin	93.1 ± 11.7	47.6 ± 4.9	38.5 ± 9.9	43.1[†]	20.1 ± 3.8
et al. (20)	92.1 ± *	46.4 ± *	37.1 ± *	43.2[†]	31.8 ± *
	−1.0 [−1.1][b]	−1.2 [−2.5][b,c]	−1.4 [−3.6][b,c]	0.1 [0.2]*	11.7 [58.2][b,c]
	93.5 ± 10.5	47.4 ± 4.7	38.4 ± 8.4	43.3[†]	20.4 ± 3.0
	93.6 ± *	47.2 ± *	38.3 ± *	43.5[†]	21.1 ± *
	0.1 [0.1]	−0.2 [−0.4][e]	−0.1 [−0.3][e]	0.2 [0.5]*	0.7 [3.4][e]

included trials was too extensive to allow for meaningful conclusions to be drawn. For instance, in one study, conducted by Pichard *et al.* (14), the exercise intervention was unsupervised and varied from walking to attending scheduled programmes at a gymnasium. Another study (15) did not have a control group, limiting the accuracy of the comparison of the results of this study with the pooled outcomes of controls of other studies. Therefore, this meta-analysis was excluded.

More recently, Thorogood *et al.* (16) conducted a systematic review and a meta-analysis to directly examine the effects of isolated AE on WL, WC and blood pressure. They included 14 RCTs that were published between 1 January 1970 and 20 January 2010, which compared an exercise-only (no prescribed diet) group to an inactive control group. From their pooled analysis of the results of two studies, 6-month exercise programmes were seen to induce a modest weight reduction of 1.6 kg (95% CI: 1.56, 1.64). In a pooled analysis of three other studies, the mean WL seen in 12-month AE interventions was found to be 1.7 kg (95% CI: 1.11, 2.29). One limitation involves the fact that the exercise modalities (e.g. walking, cycling, aerobics and jogging), intensity of exercise and frequency of exercise were not uniform across the considered trials, which limits our ability to draw specific conclusions about the relative contributions of these factors. Nevertheless, the results of this meta-analysis confirmed that AE interventions seem to reduce weight by approximately 1.6 kg at 6 months and 1.7 kg at

12 months. However, based on several limitations of this meta-analysis, we will review these studies independently here in order to better understand the significance. Results are summarized in Table 2.

Alves *et al*. (17) conducted an RCT examining the effects of a supervised exercise programme on weight and BMI reduction in overweight and obese adult Brazilian women. The exercise programme was aerobic in nature and included 5 min of warm-up exercises, 40 min of moderate-intensity exercises such as brisk walking or stepping to high-tempo music and 5 min of cool-down exercises. The treatment group took part in exercise sessions 3 days/week for a period of 6 months. The controls were not exposed to any intervention during the 6-month period. Results indicated that for weight and BMI the AE group was superior. Therefore, at the end of this well-designed and adequately powered RCT, the authors concluded that AE interventions conducted for a period of 6 months could give rise to a modest (approximately 2%) WL.

In another study conducted in Japan, involving 40- to 89-year-old overweight and obese men and women, Nishijima *et al*. (18) found similar results. They randomized 561 eligible individuals who were free from cardiovascular disease or other uncontrolled medical conditions into exercise and control groups. Participants in the exercise group engaged primarily in prescribed AE using a bicycle ergometer were instructed to gradually increase intensity, which was objectively increased from 40% of maximum rate of oxygen consumption (VO_2 max) to 70% of VO_2 max in two to three steps. They completed two to four sessions of exercise each week, and the duration was increased concurrently from 20 to 40 min per session. Light RT was also added to the regime towards the end of the intervention. The control group was instructed to maintain their physical activity at baseline levels. At the end of the 6-month intervention period, the mean WL and reduction of WC (corrected for baseline differences) for the exercise group were significantly greater than those for the control group.

In 2013, Donnelley *et al*. (19) reported the results of Midwest Exercise Trial 2, a 10-month RCT designed to compare the effects of different volumes of prescribed AE without energy restriction in sedentary overweight or obese participants. In it, they compared three groups based on different levels of energy expenditure per session (i.e. control, 400 kcal per session and 600 kcal per session). Participants in the exercise groups attended five supervised exercise sessions per week, which were primary walking or jogging, starting from 150 kcal of energy expenditure per session and increasing gradually to 400 or 600 kcal per session at the end of 4 months. All participants were asked to maintain their habitual physical activity (outside of planned sessions) and dietary intake at a constant level throughout the 10-month intervention. The level of physical activity in the control group did not deviate from the baseline throughout the study, and energy intake did not differ between the groups. Compared with the control group, each of the exercise groups achieved a statistically significant WL, reduction of BMI and increased aerobic capacity. The 600-kcal-per-session group had significant reduction in % BF and BF at the end of the trial. The 400- and 600-kcal-per-session groups were found to have lost 4.3% and 5.7% of initial BW, respectively, compared with 0.5% weight gain observed in the control group. There were no differences between the exercise groups in physical activity, WL, aerobic capacity or % BF reduction. Therefore, results showed that supervised exercise, even in the absence of a dietary restriction, is an effective intervention for achieving clinically meaningful WL in overweight or obese young adults.

In 2003, Irwin *et al*. (20) published the results of the Physical Activity for Total Health Study, which was a 12-month RCT that examined physical activity and WL in overweight postmenopausal women. The intervention consisted of five 45-min sessions per week, of which three sessions per week were supervised during the first 3 months and one session per week was supervised thereafter. Exercise was predominantly aerobic and included walking, aerobics and bicycling. The intensity was increased from maintaining 40% of the maximum HR for 16 min initially to a goal of 60–75% of the maximum HR for 45 min. Strength training was also recommended at a low intensity but not required, and only 5.8% of the participants engaged in strength training. The controls engaged in stretching exercises only and followed a similar schedule as the exercise group. At the end of the 12-month intervention WL and BMI, fat mass (FM) and % BF reductions were greater in the exercise vs. control group. There were no reported differences in caloric intake among groups, and dropout rates were reported as extremely low in this trial. Therefore, as evidenced by the results of this well-controlled study, AE interventions, even after being conducted for as long as 1 year, seem to reduce BW modestly in postmenopausal women.

Our review of literature suggests that the WL seen in 6- to 12-month structured AE interventions, in the absence of a DI, is typically 2–3% of the initial BW. This finding has been a consistent observation, not only in the studies we have described earlier but also in several other studies that examined AE-induced WL as an indirect or secondary outcome (21–27). In only one case, the Midwest Exercise Trial 2(19), was a WL that exceeded the AHA/ACC/TOS Guidelines recommendation (5) (3–5% loss of initial BW) achieved. This outcome was observed in the high-dose, 600-kcal/day group within a period of just 4 months. This finding is important for several reasons. When combined with the findings related to interventions using diet + exercise combined, it suggests that there may be a somewhat synergistic effect of diet and exercise. In addition, it tends to support the notion that higher volumes of exercise may produce benefit independent of short-term lapses in ideal caloric control. In terms of the more modest WLs achieved in most studies involving AE without dietary restriction, some have argued that the myopic focus on 5–10% or greater WLs as mandatory for health benefit may be misguided. In fact, it has been suggested and that even modest WLs of less than 3%, when achieved via physical activity, have similar health and quality-of-life benefits to greater amounts of weight lost without exercise (28). In our review thus far, we have noted consistent improvement in WC related to both diet + exercise and also exercise alone in the pursuit of WL. Moreover, as Blaire *et al.* (28) have discussed in their recent review, marked improvements in lipid profiles, insulin sensitivity and inflammatory markers have been observed in many studies examining the effects of exercise, in which the observed WL had been less than 3% of the initial weight. Therefore, AE interventions, even in the absence of an associated dietary restriction, seem to be an effective modality of achieving meaningful WL and associated health benefit.

Whether a dose–response relationship exists between the AE volume and the WL outcome is another important consideration. Our review of the literature suggested that a 6-month AE intervention typically results in a 2–3% WL, as compared with the 3–5% WL recommended in the AHA/ACC/TOS Guidelines. However, on close examination of the interventions, the intensity of exercise, the frequency of exercise sessions and the target groups appear to predict the WL outcomes to a greater extent than the duration of exercise interventions. For instance, the 6-month interventions conducted by Nishijima *et al.* (18) and Alves *et al.* (17) were moderate-intensity interventions lasting for 40 min/day conducted at a frequency of two to four sessions/week. The mean WL outcomes in the two interventions were 1.59 and 1.69 kg, respectively. On the other hand, Donnelly *et al.*(19) conducted their interventions daily at a higher intensity for 4 months and achieved more than twice the WL observed by others even in the 400-kcal/day group. Lee *et al.* (29) conducted a study in young men with obesity to show effects of extremely high exercise volume with high-energy intake on WL outcomes. More than 190 young men (aged 17–19 years) were instructed to follow military training for 20 weeks. The high-intensity training began at 10 h/week and was increased to 20 h by the 12th week. Meals were provided and no dietary or caloric restrictions prescribed. The study is limited by no calorie consumption data being collected. Nonetheless, the 20-week exercise intervention resulted in a mean WL of 12.5 kg and it was mainly from FM loss (i.e. 11.9 kg). This study suggests that at least in young men with obesity, high-dose and high-intensity exercise (without prescribed caloric restriction) can lead to a substantial WL.

To enhance our understanding of the potential dose–response relationships, it is timely to pool the data of all the interventions together and construct statistical models to identify the specific factors in AE interventions that predict WL outcomes. If this is limited by the heterogeneous methods used in different studies, a multi-centre RCT could be designed to further elucidate the issue.

Habitual activity and/or daily walking interventions without calorie restriction

Sedentary lifestyle is often assumed to be a contributing factor in obesity (30,31). The number of steps taken by an individual each day is considered as a marker of such activity. For instance, a sedentary lifestyle is defined as a daily step count that is less than 5,000 steps, whereas an active lifestyle is defined as a daily step count of more than 8,000–10,000 steps (32). Therefore, habitual increases in activity (monitored using pedometers) have long been recommended as part of a multicomponent approach to WL. In fact, at times, the recommendation to reach 10,000 steps per day has been substituted as a recommendation for adequate exercise for those engaged in WL programmes. Here, we consider the evidence in support of that recommendation. Studies are summarized in Table 3. It is important to note that this body of literature is at times confounded by the nature of the instructions to and/or actions of participants. While the intention is to simply achieve the required steps, there is variability in how this is achieved, ranging from simply parking further away or going up and down stairs as opposed to using elevators to intentional walking for sustained periods of time.

In 2012, David *et al.* (33) reported the results of a 12-week walking intervention, for postmenopausal women. The primary comparison was to determine the value of having a coach with whom the participants interacted via an interactive voice response system to receive support. All participants were told to increase their daily steps until they reached 10,000 steps per day, and they were asked to report their daily steps via the interactive voice response system. A pooled analysis conducted at the end of the intervention revealed significant reductions in BMI, BW and WC. Based on the results, the authors suggested that taking 10,000 steps per day had significant favourable effects on improving weight management. Unfortunately, the authors did not report height and weight at baseline or the percentage of weight reduction. However, because a loss of 0.93 kg even in a typically obese individual with a weight of 100 kg translates into a percentage WL of less than 1% (as compared with the 3–5% WL recommended by the AHA/TOS/ACC Guideline), the WL associated with the intervention appears minimal yet relevant.

A similar finding was reported by Musto *et al.* (34). They recruited 84 sedentary overweight women and used pedometers to measure spontaneous physical activity at baseline and after a 12-week intervention. During the intervention, the participants were given a goal to gradually increase their daily step count by 10% during each week. After they reached 10,000 steps per day, the rate of incremental

Table 3 Changes in weight, BMI, WC, % BF, FM, FFM and VO_2 max observed in recent studies with walking interventions

Reference	Sample gender (%), BMI (kg m^{-2}), age (years)	Duration (month)	Group (*n*)	Intervention		Weight (kg)	BMI (kg m^{-2})	WC (cm)	% BF	FM (kg)	FFM (kg)	VO_2 max (mL kg^{-1} min^{-1})
David *et al.* (32)	F[1], 25–40, <75	3	Walking (71)	Walking with a daily step goal to reach 10,000/day, step counts monitored feedback given weekly	Pre $\bar{x}$ ± SD	*	31.5 ± 4.1	*	*	*	*	*
					Post $\bar{x}$ ± SD	*	31.22 ± *	*	*	*	*	*
					Δ [Δ (%)]	−0.93 [*][b]	−0.28 [−0.89][b]	−1.33 [*][b]	*	*	*	*
Musto *et al.* (33)	F[2], 30.4 ± 5.5, 45.7–46.3	3	Active (43)	Walking, pedometer surveillance, step count increased by 10% per week until step count = 10,000, 3% per week increase thereafter	Pre $\bar{x}$ ± SD	81.0 ± 16.7	30.4 ± 5.5	86.7 ± 11.3	*	*	*	*
					Post $\bar{x}$ ± SD	80.3 ± 16.3	30.2 ± 5.3	86.1 ± 10.9	*	*	*	*
					Δ [Δ (%)]	−0.8 [−1.0][b,c]	−0.3 [−1.0][b,c]	−0.6 [−0.7][b]	*	*	*	*
			C (34)		Pre $\bar{x}$ ± SD	79.5 ± 12.8	29.8 ± 5.0	86.4 ± 9.4	*	*	*	*
					Post $\bar{x}$ ± SD	79.6 ± 13.3	29.9 ± 5.2	86.4 ± 10.3	*	*	*	*
					Δ [Δ (%)]	0.2 [0.3][e]	0.1 [0.3][e]	0 [0]	*	*	*	*

[1]Participants were postmenopausal.
[2]Participants were sedentary at baseline (baseline steps <5000/day).
[b]Significant difference between pre-intervention and post-intervention ($P < 0.05$).
[c]Significant difference in weight loss compared with control ($P < 0.05$).
*Cannot be derived from the available data.
% BF, body fat percentage; BMI, body mass index; C, control group; FFM, fat-free mass; FM, fat mass; VO_2 max, maximum rate of oxygen consumption; WC, waist circumference.

increase of the number of steps was reduced to 3% per week for the remaining weeks in the programme. In *post hoc* group assignment, those participants who increased their step counts to more than 3,000 steps compared with the baseline were considered as the active group, and those who increased less than 3,000 steps or defaulted were considered as the controls. At baseline, there were no differences in age, BW, BMI, daily steps, Stanford Usual Activity Questionnaire scores and resting HR between groups, but the mean calorie intake of the active group (2,017 ± 375 kcal) was significantly less than the mean baseline calorie consumption of the control group (2,186 ± 332 kcal). Compared with the baseline, the mean daily step count of the active group was significantly increased by 5,646 ± 1,328 steps, and the daily steps of the control group were also significantly, but modestly, increased by 743 ± 546 steps. The change of daily steps was significantly different between groups. Reductions were seen in mean BW, mean BMI, resting HR, WC, systolic blood pressure (SBP) and fasting glucose compared with the baseline in the active group, and the authors concluded that gradually increasing the step count in the walking programme had a mild but significant favourable effect on individuals who were overweight. Unfortunately, because the active group had a lower mean energy intake compared with the controls, the small yet significant improvements in the outcome variables may have been due to the combination of both the intervention and reduced energy intake.

Murtagh *et al.* (35) conducted a meta-analysis to examine the effect of a walking programme on the risk factors of cardiovascular disease in an inactive population. They selected 32 RCTs, with the following criteria: (i) the trial must be at least 4 weeks in duration, (ii) it must include sedentary but healthy participants, (iii) it must have at least one group receiving only a walking intervention and (iv) it must report cardiovascular disease-related risk factors both before and after the intervention. In the 32 selected references, participants were 30 to 83 years old, the mean intervention period was 18.7 weeks, the length of interventions varied from 20 to 60 min per session with frequencies ranging from 2 to 7 days/week and the intensities of physical activity (i.e. walking) varied from light to vigorous. There was a significant improvement in the aerobic fitness among the participants following walking interventions (VO_2 max $3.04\,mL\,kg^{-1}\,min^{-1}$, $P < 0.001$). The walking interventions also resulted in a significant reduction of BMI ($-0.53\,kg\,m^{-2}$, $P < 0.001$), WC (-1.51 cm, $P < 0.001$), BW (-1.37 kg, $P < 0.001$), % BF (-1.22%, $P < 0.001$), SBP (-3.58 mmHg, $P < 0.001$) and diastolic blood pressure (DBP) (-1.54 mmHg, $P = 0.02$). Overall, the meta-analysis suggested several health benefits and a modest WL associated with walking interventions. If we are to attempt to translate the WLs observed here into percentages, in a typically obese population, a mean WL of 1.37 kg would translate to a percentage weight reduction of 1.5% or less. Even though this is less than the AHA/TOS/ACC recommendations, this meta-analysis also confirmed the notion that walking alone may have a small but potentially meaningful impact on weight.

These small, yet significant, beneficial effects of walking interventions were confirmed by Hanson and Jones (36) in another meta-analysis and systematic review, which included studies published before November 2013. Inclusion criteria were participants aged >19 years, mainly group-based inclusion, outdoor walking interventions and reports of physiological or psychological outcomes. In 42 selected studies, there were 1,843 participants, the majority of whom were women, and the mean age of the participants was 58 years. Most of the studies were conducted within the USA, and 74% of the studies were conducted between 2003 and 2013. Health status of the participants, duration of interventions and exercise volumes in selected studies varied. Health conditions included arthritis, dementia, diabetes mellitus, psychiatric disorders, overweight and obesity. Durations of interventions ranged from 3 weeks to 1 year, and exercise volumes varied from self-determined low-intensity to high-intensity walking. The mean rate of adherence was 75%. Results from the meta-analysis indicated that there were significant increases in VO_2 max ($2.66\,mL\,kg^{-1}\,min^{-1}$, $P \leq 0.001$), physical functioning score (SF-36 score, 6.02 points, $P = 0.03$) and metres of walking in 6 min (79.6 m, $P \leq 0.001$). There were significant reductions in SBP (-3.72 mmHg, $P \leq 0.001$), DBP (-3.14 mmHg, $P \leq 0.001$), resting HR (-2.88 bpm, $P \leq 0.001$), % BF (-1.31%, $P = 0.001$), BMI ($-0.71\,kg\,m^{-2}$, $P = 0.003$), total cholesterol ($-0.11\,mmol\,L^{-1}$, $P = 0.03$) and depression score (-0.67, $P \leq 0.001$). Reductions in all of the earlier measures except for DBP ($P = 0.03$) and depression score ($P \leq 0.001$) were seen homogenously across all the considered studies. This meta-analysis suggests that outdoor and group walking interventions seem to be effective strategies to improve health outcomes, which included lowering BMI and % BF. We could not translate BMI reduction ($-0.71\,kg\,m^{-2}$) to a percentage reduction in order to compare with the outcomes of previously described studies and analyses. However, this reduction was greater than the BMI reductions observed in previously described studies and meta-analyses. This may be due to the inclusion of studies that were conducted for longer durations (up to 1 year) and due to the inclusion of walking interventions conducted at higher intensity.

Considering the available evidence, walking interventions that primarily focus on increasing the number of steps taken in a unit of time such as a day and/or somewhat more planned walking interventions of modest intensity appear to be producing statistically significant reductions in weight as compared with control groups, yet by only 1–1.5% of the initial weight. However, brisk walking has been used effectively in several studies described under the AE section, with subjects maintaining 60–80% of the maximum HR during exercise sessions and ultimately achieving a WL of at least 2–3%, approaching the WL targets recommended in the AHA/ACC/TOS Guidelines. As described in the previous section, the intensity of AEs seems to play an important role in causing WL. In this section, included walking studies that did not typically cite nor attend to intensity of walking were not a major concern. Thus, it would appear, given what was noted previously, that intensity may explain the smaller effect sizes in WL and BMI reduction observed in walking interventions that primarily focus on self-determined low-intensity walking and/or increasing daily step counts with regard to WL outcomes.

Resistance training interventions without calorie restriction

Generally, it is assumed that WL is accompanied by a loss of both the FM and fat-free mass (FFM) and also that increased FFM is associated with increased resting energy expenditure (37). Exercise-induced WL in general results in a lesser degree of FFM loss compared with diet-only-induced WL, and some studies have indicated that RT may play a role in preserving (or potentially increasing) FFM or during WL induced during diet + exercise combined interventions (38). There is a paucity of literature examining the impact of RT within the context of WL. However, several studies designed to test other outcomes also allow examination of this question and thus are included here. Results are summarized in Table 4.

In 2009, Kirk *et al.* (39) examined whether minimally supervised RT will increase daily energy expenditure and improve fat oxidation in a young overweight sedentary population. Sixty-three overweight participants were randomly assigned into control and RT groups, of whom only 39 participants completed the calorimetry protocols in the study. Subjects in the RT group participated in three sessions of supervised RT per week for 6 months. Each RT session was made up of three to six repetitions of a set of nine exercises to train major muscle groups. Both groups were instructed to maintain their baseline dietary intake and spontaneous activity at a constant level. Total energy and macronutrient intakes were evaluated using monthly 24-h recalls and 3-day food records. These were not significantly different compared with the baseline and were not different between the two groups. Compared with the baseline, the weight and BMI of both groups increased significantly from baseline, but there was no difference between groups. FFM was significantly increased in the RT group, whereas the FFM in the control group did not increase. Also, the FM and % BF increased significantly in the control group, while FM in the RT group did not increase significantly compared with the baseline. After the 6-month intervention, resting metabolic rate (RMR) and sleeping metabolic rate (SMR) in participants in the RT group increased significantly compared with the baseline. Post-intervention SMR in the RT group was significantly greater compared with the corresponding SMR in the control group. However, there are several notable limitations. First, it is difficult to evaluate the issue of increasing BMI in this study as the authors sampled energy intake only for 3 days/month and they used self-reported data. In addition, the subpopulation, which underwent calorimetry, was selected by convenience sampling. Thus, our interpretation of this study must be cautious. However, this study does provide some limited support for the notion that RT can increase RMR and improve body composition in overweight subjects.

Willis *et al.* (40) examined the effects of exercise on body mass and BF in subjects with dyslipidemia. Subjects were largely sedentary (i.e. did not engage in regular exercise for more than one to two times per week) and did not have a history of hypertension, diabetes mellitus or coronary artery disease. Participants were asked to maintain their lifestyle in a 4-month run-in period and then were randomly assigned into three different groups including RT, AE, and AE plus RT (AE/RT) for 8 months. Participants in the AE group were asked to perform supervised, HR-monitored exercise, and the exercise volumes were progressively increased from 65% to 80% of VO_2 max to reach about 12 miles/week in the first 8 to 10 weeks. Participants in the RT group performed supervised training, and the training volume was gradually increased to 8 to 12 repetitions per set, three sets per session, at a frequency of three sessions per week by week 5. Participants in the AE/RT group performed the same volumes of both AE and RT. All groups did not receive DIs, and WL was not indicated as a goal. Adherence rates were not significantly different across the three groups. Daily energy intake was not significantly different between groups at baseline and did not significantly change compared with the baseline. Compared with the baseline, the AE and AE/RT groups achieved a significant mean WL, and the RT group had a significant weight gain. All three groups achieved significant reductions in WC, FM and % BF and significant increases in VO_2 max. The RT and AE/RT groups had significant increases in FFM and thigh muscle area compared with the baseline and the AE group. To summarize, only the groups that included AE showed favourable changes in weight, WC and FM from baseline, and only the groups that included RT showed favourable changes in FFM and thigh muscle area. Furthermore, between-group comparison showed that the AE/RT group had a significantly greater % BF reduction compared with the AE and RT groups. However, FM, % BF, WC and VO_2 max improved as compared with the baseline for all groups, with the AE and AE/RT groups achieving significantly higher reductions of FM and % BF compared with the RT group. Finally, strength, FFM and thigh muscle were each improved in the groups with RT. While it may be tempting to conclude from this study that a programme that includes both RT and AE even in the absence of prescribed calorie restriction can produce more favourable outcomes than either alone and that an exercise programme that includes primarily RT may not achieve desired WL, design limitations preclude this conclusion. It is notable that the combined group (AE/RT) was prescribed twice the dose of exercise as that of either RT or AE alone. Thus, we can only really conjecture based on the two interventions that were absent of this limitation. Thus, AE alone appeared to be preferable to RT alone for WL.

Roberts *et al.* (41) conducted a randomized trial to examine whether RT is favourable for overweight and obese young men, related to several glucose regulation parameters. For the purpose of this review, we will only examine weight and body-composition-related outcomes. They recruited healthy sedentary young adults (performed light-intensity physical activities less than twice per week). Participants were randomly assigned into the control or RT group and were asked to maintain their spontaneous physical activity and eating patterns. The RT intervention included three 1-h sessions per week of supervised training for 12 weeks, in which training intensity was gradually increased. After 12 weeks of the intervention, there were no differences in BW, BMI and WC between groups. However, the mean BMI of the RT group was significantly increased compared with the baseline. Compared with the control group, the RT group achieved a significant increase in FFM and several measures of strength. Furthermore, the RT group had significant decreases in total and trunk FM compared with the baseline, but the changes of total and trunk FM were not significantly different compared with those of the control group. The results of this study suggested that structured RT in overweight and obese young adult men seems to improve body composition and biochemical markers related to glycaemic control and insulin sensitivity independent of changes in BMI.

Moghadasi *et al.* (42) examined whether RT would affect the level of adipocyte fatty-acid-binding protein in middle-aged men with obesity, because it is suggested that adipocyte fatty-acid-binding protein, which is expressed in cytoplasm of adipocytes and macrophages, is associated with insulin sensitivity and fat metabolism and is a predictor of type 2 diabetes mellitus. They recruited 22 sedentary middle-aged obese men (did not participant in any exercise programme for at least 6 months). Participants were randomly assigned to the control or RT group, and the controls were asked to maintain their baseline level of physical activity. Participants in the RT group were asked to perform two to four sets of 8–12 repetitions at 65–80% of one repetition maximum (i.e. the maximum force generated in one maximal contraction) for eight circuit training stations at each exercise session lasting approximately 50–60 min, at a frequency of three sessions per week. After 8 weeks of RT, no differences were observed in BW BMI and WC between groups. The RT group had significantly decreased % BF and several indicators related to glucose regulation compared with the control group. These results suggested that RT could improve body composition, but not weight, while improving biomarkers related to regulating blood sugar.

The studies summarized here are representative of the current beliefs surrounding the value of RT in weight management. RT shows consistent benefits in improving body composition, strength and certain metabolic parameters and, alone, appears not to induce meaningful WL. While our review is focused primarily on the value of RT in the absence of prescribed calorie restriction as it relates to WL, it is notable that a broader body of literature strongly suggests (i) a benefit in improving a range of cardiometabolic and other obesity-related health parameters independent of WL and (ii) that if combined with moderate calorie restriction, RT alone can in fact induce meaningful WL in overweight and obese individuals. Clark and Goon (43) published the results of a literature review on the role of RT in changing the health status of overweight and obese individuals. The authors agreed with the fact that RT *per se* does not cause a significant WL, based on the available evidence. Nevertheless, their review of the literature and a subsequent pooled analysis indicated that RT, when combined with a dietary energy deficit of 500 kcal/day, reduces weight by 4.775 ± 7.05 kg, while increasing FFM by 0.2748 ± 2.67 kg and reducing FM by 6.0948 ± 4.18 kg. The review further summarized evidence on improvements of biochemical markers indicating that RT reverses the obesity-induced undesirable changes in the blood levels of testosterone; adrenal androgens; growth hormone; insulin; catecholamines, leptin; cortisol; adiponectin; ghrelin; peroxisome proliferator-activated receptor alpha beta and gamma; interleukin 1b and tumour necrosis factor alpha;. Moreover, the authors summarized evidence suggesting that RT interventions appear to have higher compliance rates than other forms of moderate-intensity, extended-duration AE interventions.

In summary, our review suggests that overall, there is value in including RT to improve health for overweight and obese individuals even in the absence of volitional attempts to reduce daily caloric intake. However, it appears that doing so in the absence of caloric restriction may likely result in increased BMI and weight gain. Furthermore, the impact on body composition shows some inconsistencies. In the studies conducted by Willis *et al.* (40), Kirk *et al.* (39) and Roberts *et al.* (41), RT was found to increase FFM. In addition, Kirk *et al.* (39) found that RT contributes to increases in SMR and RMR. The effect of RT on the reduction of FM remains questionable as FM remained unchanged in two of three studies after RT. Thus, based on our review, the effects of RT on FM and FFM remain to be established. The body of literature involving the role of RT in obesity suffers from substantial methodological heterogeneity, which limits the ability to clearly delineate its

Table 4 Changes in weight, BMI, WC, % BF, FM, FFM and VO_2 max observed in recent studies with resistance training interventions

Reference	Sample gender (%), BMI (kg m^{-2}), age (years)	Duration (month)	Group (*n*)	Intervention		Weight (kg)	BMI (kg m^{-2})
Kirk *et al.*(38)	M (69%) + F, 27.7, 21.0	6	RT (22)	Supervised, 3 days/week, one set of nine exercises at 85–90% of one RM	Pre $\bar{x}$ ± SD	86.7 ± 13.1	27.8 ± 3.3
					Post $\bar{x}$ ± SD	89.2 ± 12.2	28.7 ± 3.3
					Δ [Δ (%)]	2.5 [2.9][b]	0.8 [2.9][b]
			C (17)		Pre $\bar{x}$ ± SD	82.2 ± 11.5	27.6 ± 2.5
					Post $\bar{x}$ ± SD	84.6 ± 12.8	28.3 ± 2.9
					Δ [Δ (%)]	2.4 [2.9][b]	0.7 [2.5][b]
Willis *et al.*(39)	M[1] + F[1] (57.1), 25–35, 18–70	8	AE (38)	65–80% VO_2 max, average 133 min/week	Pre $\bar{x}$ ± SD	88.0 ± 11.1	30.6 ± 3.2
					Post $\bar{x}$ ± SD	86.2 ± *	*
					Δ [Δ (%)]	−1.8 [−2.0][b,er*,r*]	*
			RT (44)	8–12 repetitions/set, three sets/day, 3 days/week	Pre $\bar{x}$ ± SD	88.7 ± 15.6	30.5 ± 3.4
					Post $\bar{x}$ ± SD	89.5 ± *	*
					Δ [Δ (%)]	0.8 [0.9][b,e*,r*]	*
			AE + RT (37)	AE – 65–80% VO_2 max, average 133 min/week RT – 8–12 repetitions/set, three sets/day, 3 days/week	Pre $\bar{x}$ ± SD	88.9 ± 11.5	30.5 ± 3.4
					Post $\bar{x}$ ± SD	87.3 ± *	*
					Δ [Δ (%)]	−1.6 [−1.8][b,e*,r*]	*
Roberts *et al.*(40)	M, ≥27, 18–35	3	RT (28)	Increasing intensity resistance training to reach 6–8 repetitions/set, 1 h/session, three sessions/week	Premedian	96.6	30.9
					Postmedian	97.1	31.2
					Δ [Δ (%)]	*	*
			C (8)		Premedian	98.5	33.6
					Postmedian	98.0	33.2
					Δ [Δ (%)]	*	*
Moghadasi *et al.*(41)	M, 32.7 ± 1.7, 46.2	3	RT (11)	8–12 repetitions of 65–80% of one RM, 50–60 min/day, 3 days/week	Pre $\bar{x}$ ± SD	98.5 ± 5.1	32.4 ± 1.0
					Post $\bar{x}$ ± SD	98.2 ± 4.9	32.3 ± 0.9
					Δ [Δ (%)]	−0.3 [−0.30][b*]	−0.1 [−0.3][b*]
			C (11)		Pre $\bar{x}$ ± SD	100.8 ± 9.4	33.0 ± 2.3
					Post $\bar{x}$ ± SD	100.7 ± 9.1	32.9 ± 2.2
					Δ [Δ (%)]	−0.1 [−0.1][b*]	−0.1 [−0.3][b*]

[1]Participants had dyslipidemia.
[b]Significant difference between pre-intervention and post-intervention ($P < 0.05$).
[c]Significant difference compared with the control group ($P < 0.05$).
[e]Significant difference compared with the aerobic exercise group ($P < 0.05$).
[er]Significant difference compared with the AE + RT group ($P < 0.05$).
[r]Significant difference compared with the resistance group ($P < 0.05$).
*Cannot be derived from the available data.
% BF, body fat percentage; AE, aerobic exercise intervention; BMI, body mass index; C, control group; FFM, fat-free mass; FM, fat mass; RM, repetition maximum; RT, resistance training intervention; VO_2 max, maximum rate of oxygen consumption; WC, waist circumference.

value both with and without concomitant caloric restriction. Often times, studies fail to adequately measure/account for calorie intake, concurrent changes in habitual activity, non-prescribed WL behaviours, inconsistent dose (duration and intensity) of exercise across intervention types and so forth. Incomplete data reporting and/or collection further contributes to the methodological heterogeneity between trials that largely precludes conducting meaningful meta-analysis to address these deficits in knowledge. Therefore, it is timely to conduct a comprehensive RCT, to examine the effects of RT while accounting for these limitations in the literature.

Role of physical activity on maintenance of weight loss

Following WL, people regain about one-third of the lost weight within 1 year (44). While an in-depth treatment of the role of exercise in maintaining WL is beyond the scope of the current review, we will attempt to frame some important considerations in this regard as they apply to our current approach to the literature. Within the context of determining the discrete effects of diet and exercise in obesity, we have excluded studies of specific disease states (e.g. Look AHEAD). Also, in this somewhat convoluted

Table 4 *Continued*

Reference	WC (cm)	% BF	FM (kg)	FFM (kg)	VO_2 max (mL kg^{-1} min^{-1})
Kirk	*	32.7 ± 8.4	27.2 ± 8.9	55.3 ± 8.9	*
et al. (38)	*	33.0 ± 8.0	28.2 ± 8.0	56.8 ± 9.4	*
	*	0.3 [0.9][c*]	0.9 [3.3][c*]	1.5 [2.7][b,c*]	*
	*	33.2 ± 9.1	26.0 ± 7.4	52.7 ± 10.7	*
	*	35.3 ± 7.4	28.3 ± 7.0	52.4 ± 10.3	*
	*	2.1 [6.3][b,e*]	2.3 [8.8][b,e*]	−0.3 [−0.6][e*]	*
Willis	96.1 ± 10.3	39.4 ± 7.2	34.7 ± 7.9	53.3 ± 8.7	27.3 ± 5.6
et al. (39)	95.1 ± *	38.4 ± *	33.1 ± *	53.2 ± *	30.7 ± *
	−1.0 [−1.0][b,er*,r*]	−1.0 [−2.5][b,er*,r*]	−1.6 [−4.6][b,er*,r*]	−0.1 [0.2][er*,r*]	3.43 [12.5][b,er*,r*]
	93.6 ± 9.1	38.8 ± 8.7	34.3 ± 9.1	54.4 ± 13.3	27.0 ± 6.2
	93.5 ± *	38.1 ± *	34.0 ± *	55.5 ± *	28.3 ± *
	−0.1 [−0.1][e*,er*]	−0.7 [−1.8][b,e*,er*]	−0.3 [−0.9][e*,er*]	1.1 [2.0][b,e*,er*]	1.3 [4.8][b,e*,er*]
	97.3 ± 8.9	39.2 ± 8.1	34.9 ± 8.9	54.0 ± 9.6	27.0 ± 5.8
	95.6 ± *	37.2 ± *	32.5 ± *	54.8 ± *	31.3 ± *
	−1.7 [−1.7][b,e*,r*]	−2.0 [−5.1][b,e*,r*]	−2.4 [−6.9][b,e*,r*]	0.8 [1.5][b,e*,r*]	4.3 [15.9][b,e*,r*]
Roberts	103.3	*	27.9	*	*
et al. (40)	101.4	*	26.2	*	*
	*	*	*	*	*
	106.5	*	25.0	*	*
	106.7	*	26.1	*	*
	*	*	*	*	*
Moghadasi	*	23.5 ± 3.4	*	*	*
et al. (41)	*	23.0 ± 3.6	*	*	*
	*	−0.5 [2.1][b*,c]	*	*	*
	*	27.7 ± 4.5	*	*	*
	*	27.8 ± 4.5	*	*	*
	*	0.1 [0.4][b*,e]	*	*	*

body of literature, it is often quite difficult to identify studies where the diet and exercise elements of the intervention are not inextricably interwoven, thus eliminating the ability to evaluate independent effects of these treatment elements. Finally, the WL literature is unfortunately plagued by the lack of an adequate and clearly defined definition of what is considered 'maintenance'. At times, maintenance is described as the point in time where active intervention ends and participants are sent on their way to continue their WL efforts at home unsupervised. It typically fails to note whether an individual's personal goal is in fact to 'maintain' treatment-induced 'weight loss' or to continue to lose weight, in effect participating in self-directed WL treatment. In some cases, this 'maintenance phase' occurs after only several weeks and very likely the participants' goals are not to maintain the weight they have lost, but rather to continue losing weight to some personally defined goal. At other times, the active treatment interventions may be considerably longer, and as such, the individual goals of the participants may vary from maintaining the weight lost during active treatment to continuing to lose weight. In the course of the current review, we noted that at times meta-analyses designed specifically to understand the role of exercise in 'WL' mixed together studies that also included periods where active treatment had ended.

If we were to assume we were only dealing with individuals for whom the maintenance phase is truly a period for avoiding weight regain, then the effect of exercise on weight maintenance can be discussed in two different ways. First, could exercise interventions conducted during the WL phase slow the weight regain during the maintenance phase compared with diet-only interventions? Second, does exercise during the maintenance phase assist WL maintenance? We will summarize this literature.

The association of exercise during active treatment on longer-term maintenance

It is suggested that combining diet and exercise in interventions could give rise to better WL maintenance outcomes compared with diet-only interventions after a 1-year follow-up. Curioni *et al*. (11) conducted a meta-analysis to examine if the outcomes would differ after 1 year of unsupervised follow-up after diet-only interventions and diet + exercise combined interventions. They selected studies that included DIs and diet + exercise combined interventions but excluded studies with exercise-only interventions and interventions that included pharmacological approaches. They compared the outcomes by using percentage WL, which was defined as WL after the intervention or after 1 year of follow-up/baseline BW. In the six analysed trials, diet + exercise combined interventions resulted in a 20% greater WL compared with diet-only interventions (95% CI: −0.41, 0.01; WL percentage after intervention: diet + exercise combined = 13 ± 5.5%, diet only = 10 ± 3.6%) whereas the percentage of weight maintenance (defined as WL after the follow-up/WL after intervention) during 1 year of unsupervised follow-up was similar in both types of interventions (50%). Furthermore, participants in diet + exercise combined interventions still had about 20% greater WL compared with participants in diet-only interventions (95% CI: −0.42, −0.01; %WL after 1 year of follow-up: diet + exercise combined = 6.8 ± 4.1%, diet only = 4.6 ± 2.5%). The results of this study were compatible with the results of the National Weight Control Registry (NWCR) (45), suggesting that greater initial WL, irrespective of the intervention, would lead to greater WL maintenance on follow-up. Thus, diet + exercise combined interventions seem to be effective in WL maintenance by increasing the initial WL. Still, these studies fail to adequately account for the mixed goals of study participants (combining those desiring to maintain with those who wish to continue to lose weight).

Hunter *et al*. (46) conducted a randomized trial to evaluate the effect of exercise on WL maintenance. They recruited 208 women whose BMI ranged from 27 to 30 kg m^{-2} and whose age ranged from 21 to 46 years. During the active treatment phase, all participants were asked to follow an 800-kcal typical food-based diet provided by the research group until they achieved a BMI of $<25\,\text{kg m}^{-2}$ (M = 154 ± 61 days). In addition, the participants were randomly assigned into three groups: DI + AE, DI + RT and DI only (non-exercise group). The participants had one follow-up examination after 1 year. Both the AE and RT groups were asked to attend supervised exercise training, three times per week during the WL phase, and were encouraged to keep exercising two times per week during the 1-year follow-up. The AE group was asked to perform 40 min of walking or jogging, three times per week, and the intensity was gradually increased from 67% of maximum HR for 20 min to achieve 80% of maximum HR for 40 min by the eighth week. The RT group performed a 10-repetition set of 80% of one repetition maximum, which was evaluated every 3 weeks. Participants in both exercise conditions were divided into two groups (namely adherers and non-adherers) based on the accomplishment of at least 60% of scheduled exercises during the 1 year of follow-up. Weight gain among the adherers in both the AE and RT groups was significantly less compared with the weight gain among the AE non-adherers, RT non-adherers and the non-exercise group. Weight gain seen in adherers in the AE group (3.1 kg) was significantly less than the weight gain observed in the adherers in the RT group (3.9 kg). However, adherers in both groups gained significantly less weight compared with the weight gain seen in the controls (6.4 kg). Therefore, this study suggested that adherence to a moderate volume of either AE or RT (about 80 min/week) during active treatment hindered weight regain during a 1-year weight maintenance period. One major limitation in this study is not reporting the energy intakes of the individuals during the baseline and maintenance periods. Nonetheless, data suggest that low-frequency, moderate-intensity AE and RT interventions may hinder weight regain during the weight maintenance phase.

Role of exercise during maintenance

Teixeira *et al*. (47) suggested that the behaviours (and motivations) necessary for maintaining WL may in fact be both qualitatively and quantitatively different than those required for achieving initial WL. This is very likely true of exercise. The American College of Sports Medicine position stand (48) on exercise and WL states the following: 'Cross-sectional and prospective studies indicate that after WL, weight maintenance is improved with PA >250 min/wk. However, no evidence from well-designed RCTs exists to judge the effectiveness of PA for prevention of weight regain after WL'. This represents an approximate 100 min/week above that recommended for modest WL by this same group.

In an attempt to better understand the characteristics of a subset of very successful WL maintainers, Wing and Hill(49) defined successful long-term WL maintenance as the intentional maintenance of a 10% loss of the initial BW for a period of at least 1 year, even if the post-WL BMI remains $>30\,\text{kg m}^{-2}$. They created the NWCR (48) to attempt to identify and track behaviours common to a group of self-selected individuals who join the website and who are willing to provide data on WL and related behaviour. In order to qualify, participants self-report having successfully maintained a WL of at least 30 lb for at least 1 year. Unfortunately, the value of the data obtained from the registry is frequently overstated. Thus, we will frame some limitations. First, the registry relies on self-reported physical activity and nutrition information, which is known to be unreliable (50). However, this is a limitation that impacts much of the research to date. In addition, weight and height (used to calculate BMI) are also self-reported, which also has known limitations (50). Also, of particular note are the limitations associated with the self-selected nature of the study population. Because the registry only includes those who are successful, it cannot account for the large excluded group of not successful individuals who may in fact report exactly the same behaviours as those reported by people who are included in the registry. Finally, the registry simply provides associations, like much of the literature used to support exercise recommendations for maintenance (48). Nonetheless, the registry's true value is to inform us as to what questions may be of value in designing RCTs to better understand maintenance. Some notable findings indicate that participants in the registry reported the following: (i) a total of 91% chose regular exercise as one of the maintenance strategies; (ii) a total of 49% reported that they both increased daily (habitual) physical activity and engaged in regular planned exercises to maintain their WL; (iii) average exercise volumes were 3,293 kcal/week for men and 2,545 kcal/week for women, which translates to about 1 h of moderate-intensity exercise per day.

Swift *et al*. summarize the role of physical activity in maintaining WL in their review (52). Overall, they note the lack of depth in the current literature; however, based on available evidence, they support the recommendations of the American College of Sports Medicine to target levels greater than 200 min/week.

While clearly our understanding of the role of physical activity in maintaining lost weight is far from adequate, it appears that two recommendations can be made. First, it is likely that including physical activity in addition to DI during active WL may positively affect longer-term WL outcomes. This may be a function of the physical activity itself, or equally plausibly, it may be that habits formed during active WL continue into maintenance, resulting in extended, direct impact on energy balance or any number of other as yet unidentified reasons. The current literature is insufficient to answer this question. Second, while there is a paucity of well-controlled RCT evidence to inform us, it appears that maintaining exercise above the levels suggested to maintain health and or lose weight (150 min/week) may be prudent for some individuals. The precise quantity is also indeterminable from the current literature.

Conclusions and future directions

In this broad review, we examined the effectiveness of diet + exercise combined interventions and exercise interventions without calorie restriction (including AE, low-intensity walking/habitual activity and RT interventions) on inducing WL, changes in body composition and improved cardiorespiratory fitness in the context of managing overweight and obesity. We also briefly reviewed the role of physical activity in maintaining lost weight.

Our critical review of the literature, after eliminating studies that were ill-equipped to answer the question at hand, indicated that diet + exercise combined interventions were more effective than diet-only interventions in inducing WL at 6 months. Such interventions typically result in 8–11% WL. Notably, however, moderate-intensity to high-intensity AE-only interventions without prescribed diet, conducted at a frequency of at least three to five times per week, were also effective in giving rise to approximately 2–3% loss of the initial weight within 6 months. In addition, interventions that target low-intensity walking and habitual activity that typically targets increasing daily 'step counts' also appear to produce modest WLs of 1–1.5% of the initial weight at 3–6 months. Conversely, RT alone does not appear to be effective in inducing WL. In fact, modest weight gain was most commonly reported in these studies; however, it was typically associated with concurrent increases in the more metabolically active FFM (and associated improvements in % BF and other fitness parameters). To conclude, both diet + exercise combined interventions and moderate-intensity to high-intensity AE-only interventions can assist people with obesity to achieve the 3–5% WL recommended by the AHA/ACC/TOS Guidelines (5).

Weight loss programmes vary considerably in how they present their recommendations. However, in our experience, a frequently recommended approach (particularly in public health domains) is to target increases in physical activity that focus only on increasing daily steps to 10,000. Our review suggests that this strategy may not be optimal. In fact, taken together, our findings suggest that recommendations for physical activity to achieve WL should target each of moderate-intensity AE and RT in planned prescribed exercise sessions coupled with recommendations to target 10,000 steps in addition to structured exercise for maximum benefit as this form of activity appears to contribute independently to WL. RCTs are needed to examine this proposed approach that combines all these often times compartmentalized recommendations into a cohesive, evidence-based whole. These trials should be sufficiently powered to examine each type of exercise (and also dose–response relationships) simultaneously. One of the most important problems in the literature is how to pool the data of all the exercise interventions together and identify the specific factors in exercise interventions that predict WL outcomes. However, most AE and RT interventions were using heterogeneous methods, and RT interventions often fail to account for calorie intake. Because these may limit the results of meta-analyses, a multi-centre RCT should be designed to explicate this issue.

Strong evidence for the value of exercise in maintaining lost weight is sparse, and frequent assertions that exercise is more important for maintenance than initial WL appear not to be supported by our findings. Clearly, our review of active treatment phases indicates the value of exercising during WL. The other often-touted need for extremely high levels of exercise for maintenance is yet to be confirmed in well-designed RCTs. In part, the dogma about maintenance is based on overinterpretation of associational data including those of the NWCR. This however is not meant to suggest that exercise is not an essential part of maintaining weight lost. First, our review suggests that while somewhat scarce, data do likely support the need to increase the dose of exercise during maintenance. However, these findings remain somewhat equivocal. Perhaps more important are the data that support the role of exercise during the active treatment phase in supporting greater maintenance of weight lost and improved body composition and accompanying metabolic profiles and cardiorespiratory fitness. The latter being of particular importance given that Barry *et al.* (53) and Ross *et al.* (28) in recent meta-analysis concluded that increased cardiorespiratory fitness in overweight and obese individuals reduces their risk of mortality.

Our study has some notable strengths. In examining the literature, we focused primarily on the interventions where intention-to-treat analyses were performed in order to most accurately and conservatively represent the data. We have also attempted to address the issue of heterogeneity of exercise protocols between trials in both our selection and our discussion of both meta-analyses and individual studies, which is a factor that is frequently not attended to adequately in interpreting each. In terms of limitations, differences in non-exercise physical activity and calorie intake are two potential problems in this body of literature. However, where available, we noted analyses that controlled for this factor vs. those that did not. Another issue that limits conclusions in all trials involving energy balance is the known report bias in reporting energy intake and expenditure (50). However, given that the *ad libitum* energy intake and overall energy intake determined in several trials (19,54) did not show a significant difference compared with the controls and the probability that bias is potentially distributed similarly across interventions and controls, the impact on conclusions regarding control vs. exercise groups may likely be minimal.

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