Dose-Response Effects of Exercise and Caloric Restriction on Visceral Adiposity in Overweight and Obese Adults: A Systematic Review and Meta-Analysis of Randomized Controlled Trials

Supplementary Materials

Recchia F, *et al. Br J Sports Med* 2023;0:1–9. doi: 10.1136/bjsports-2022-106304

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Table S1A Exercise intensity categorization (Reference)

Intensity	%$HR_{reserve}$ %$VO_{2reserve}$	%HR_{max}	%VO_{2max}	RPE 6-20	METs			%1-RM
					Young	Middle-aged	Older	
Very light (v. LIG)	< 30	< 57	< 37	≤ 9	< 2.4	< 2.0	< 1.6	< 30
Light (LIG)	30 – < 40	57 – < 64	37 – < 45	9 – 11	< 4.8	< 4.0	< 3.2	30 – < 50
Moderate (MOD)	40 – < 60	64 – < 76	46 – < 64	12 – 13	4.8 – < 7.2	4.0 – < 6.0	3.2 – < 4.8	50 – < 70
Vigorous (VIG)	60 – < 90	76 – < 96	64 – < 91	14 – 17	7.2 – < 10.2	6.0 – < 8.5	4.8 – < 6.8	70 – < 85
Near max to max (MAX)	≥ 90	≥ 96	≥ 91	≥ 18	≥ 10.2	≥ 8.5	≥ 6.8	≥ 85

Adopted from the American College of Sports Medicine's Guidelines for Exercise Testing and Prescription (9th Edition).
1-RM One-Repetition Maximum; METs Metabolic Equivalent of Task; RPE Rate of Perceived Exertion.

Table S1B Exercise intensity categorization (Implementation)

Study	Groups	Prescribed Intensity	Categorization
Abdelbasset et al., 2019, 2020a,b	HIIT (1)	80-85% VO_{2max} 50% VO_{2max}	**VIG**
	MICT (2)	60-70% HR_{max}	**LIG** – **MOD**
Blond et al., 2019	MOD (1) (2)	50% $VO_{2reserve}$	**MOD**
	VIG (3) (4)	70% $VO_{2reserve}$	**VIG**
Cho et al., 2011	HI (1)	70-75% VO_{2max}	**VIG**
	LI (2)	40-50% VO_{2max}	**LIG** – **MOD**
Coker et al., 2009a	EX	50% VO_{2peak}	**MOD**
Cowan et al., 2018	LILV (1)	50% VO_{2peak}	**MOD**
	LIHV (2)	50% VO_{2peak}	**MOD**
	HIHV (3)	75% VO_{2peak}	**VIG**
Hallsworth et al., 2015	HIIT	RPE 16 – 17 NA	**VIG**
Hong et al., 2014	EX	50-60% VO_{2max}	**MOD**
Irving et al., 2008, 2009	HI (1)	RPE 15 – 17 RPE 10 – 12	**LIG – VIG** (taken as **MOD**)
	LI (2)	RPE 10 – 12	**LIG – MOD**
Johnson et al., 2009	EX	50-70% VO_{2peak}	**MOD – VIG**
Jung et al., 2012	MOD (1)	3.5-5.2 METs	**LIG – MOD**
	VIG (2)	> 5.3 METs	**MOD – VIG**
Keating et al., 2015	HILV (1)	70% VO_{2peak} 50% VO_{2peak}	**VIG** **MOD**

	LIHV (2) LILV (3)	50% VO_{2peak}	**MOD**
Keating et al., 2017	RT	80-85% 1-RM	**VIG**
Lesser et al., 2016	EX	55-85% HR_{max}	**LIG – VIG** (taken as **MOD**)
Nordby et al., 2012 Bladbjerg et al., 2017	EX	65-85% $HR_{reserve}$	**VIG**
Reichkendler et al., 2013	HV (1)	> 70% VO_{2max} 50-70% VO_{2max}	**MOD – VIG**
	MV (2)	> 70% VO_{2max} 50-70% VO_{2max}	**MOD – VIG**
Ross et al., 2000 Thong et al., 2000	EX	≤ 70% VO_{2peak}	**MOD – VIG**
Ross et al., 2004	EX	80% HR_{max}	**VIG**
Saremi et al., 2010	EX	60-85% HR_{max}	**LIG – VIG** (taken as **MOD**)
Shojaee-Moradie et al., 2007	EX	60-85% VO_{2max}	**MOD – VIG**
Slentz et al., 2005	HIHV	65-80% VO_{2peak}	**VIG**
	HILV	65-80% VO_{2peak}	**VIG**
	MILV	40-55% VO_{2peak}	**LIG – MOD**
Wu et al., 2017	HI (1) (2)	65-70% VO_{2max}	**VIG**
	LI (3) (4)	50-56% VO_{2max}	**MOD**
Zhang et al., 2015	HIIT (1)	85-95% HR_{peak} 50-60% HR	**VIG**
	MICT (2)	60-70% HR_{peak}	**MOD**
Zhang et al., 2016	MOD (1)	3.0 – 6.0 METs	**LIG – MOD**
	VIG (2)	8.0 – 10.0 METs	**VIG – MAX**

Zhang et al., 2017	HIIT (1)	90% VO_{2max} Passive	**VIG**
	MICT (2)	60% VO_{2max}	**MOD**

EX exercise; **HI** high intensity; **HIIT** High-intensity interval training; **HV** high volume; **LI** low intensity; **LIG** light intensity; **LV** low volume; **MI** moderate intensity; **MICT** Moderate intensity continuous training; **MOD** moderate intensity; **MV** moderate volume; **RT** resistance training; **VIG** vigorous intensity.

Table S2A Additional study and intervention characteristics (exercise)

Study	Location	Groups[a]	Frequency	Intensity	Time	Caloric deficit
Abdelbasset et al., 2019, 2020a,b	Egypt	HIIT (1)	3 d/wk	80%-85% VO_{2max} & 50%VO_{2max}	3 x 4 min & 2 x 2 min	NR
		MICT (2)	3 d/wk	60%-70% HR_{max}	40-50 min	NR
Blond et al., 2019	Denmark	MOD (1)	5 d/wk	50% $VO_{2reserve}$	NR	370 kcal/d
		VIG (2)	5 d/wk	70% $VO_{2reserve}$	NR	370 kcal/d
Cho et al., 2011	South Korea	HI (1)	3 d/wk	70%-75% VO_{2max}	NR	400 kcal/d
		LI (2)	3 d/wk	40%-50% VO_{2max}	NR	400 kcal/d
Coker et al., 2009a	United States	AE	NR	50% VO_{2peak}	NR	2,500 kcal/wk
Coker et al., 2009b*	United States	HI (1)	4-5 d/wk	75% VO_{2peak}	NR	1,000 kcal/wk
		MI (2)	4-5 d/wk	50% VO_{2peak}	NR	1,000 kcal/wk
Cowan et al., 2018	Canada	LILV (1)	5 d/wk	50%VO_{2peak}	NR	240 kcal/d
		LIHV (2)	5 d/wk	50%VO_{2peak}	NR	480 kcal/d
		HIHV (3)	5 d/wk	75%VO_{2peak}	NR	480 kcal/d
Davidson et al., 2009*	Canada	AE	5 d/wk	60%-75% VO_{2peak}	30 min	NR
Hallsworth et al., 2015	United Kingdom	HIIT	3 d/wk	RPE 16 – 17	30-40 min	NR
Hong et al., 2014	South Korea	AE	3 d/wk	50%-60% VO_{2max}	50-70 min	400 kcal/d
Irving et al., 2008, 2009	United States	HI (1)	5 d/wk	RPE 15 – 17	NR	400 kcal/d
		LI (2)	2 d/wk	RPE 10 – 12	NR	400 kcal/d
Johnson et al., 2009	Australia	AE	3 d/wk	50%-70% VO_{2peak}	30-45 min	280 kcal/d
Jung et al., 2012	South Korea	MOD (1)	5 d/wk	3.5-5.2 METs	60 min	500 kcal/d
		VIG (2)	5 d/wk	> 5.3 METs	30 min	500 kcal/d
Keating et al., 2015	Australia	HILV (1)	3 d/wk	70% VO_{2peak}	45 min	360 kcal/d
		LIHV (2)	4 d/wk	50% VO_{2peak}	60 min	360 kcal/d

		LILV (3)	3 d/wk	50% VO_{2peak}	45 min	220 kcal/d
Keating et al., 2017	Australia	RT	3 d/wk	80%-85% 1-RM	30-60 min	NR
Koo et al., 2010	South Korea	AE	7 d/wk	NR	120 min	500 kcal/d
Lee et al., 2012*	South Korea	HI (1)	3-5 d/wk	70% VO_{2max}	NR	13.5-22.5 METs-h/wk
		LI (2)	3-5 d/wk	50% VO_{2max}	NR	13.5-22.5 METs-h/wk
Lesser et al., 2016	Canada	AE	3 d/wk	55%-85% HR_{max}	40 min	NA
Nordby et al., 2012 Bladbjerg et al., 2017	Denmark	AE	7 d/wk	65%/85% $HR_{reserve}$	NR	600 kcal/d
Pugh et al., 2014* Cuthbertson et al., 2016*	United Kingdom	AE	3-5 d/wk	30%-60% $HR_{reserve}$	30-45 min	230 kcal/d
Reichkendler et al., 2013	Denmark	HV (1)	3 d/wk	> 70% VO_{2max}	NR	600 kcal/d
		MV (2)	4 d/wk	50%-70% VO_{2max}	NR	300 kcal/d
Ross et al., 2000 Thong et al., 2000	Canada	AE	7 d/wk	≤ 70% VO_{2peak}	NR	700 kcal/d
Ross et al., 2004	Canada	AE	7 d/wk	80% HR_{max}	NR	500 kcal/d
Saremi et al., 2010	Iran	AE	5 d/wk	60%-85% HR_{max}	15-50 min	NR
Schmitz et al., 2007	United States	RT	2 d/wk	NR	45-60 min	NR
Shojaee-Moradie et al., 2007	United Kingdom	AE	3 d/wk	60%-85% VO_{2max}	20 min	200 kcal/d
Slentz et al., 2005	United States	HIHV (1)	NR	65%-80% VO_{2peak}	NR	23 kcal/kg/wk
		HILV (2)	NR	65%-80% VO_{2peak}	NR	14 kcal/kg/wk
		MILV (3)	NR	40%-55% VO_{2peak}	NR	14 kcal/kg/wk
Wu et al., 2017	South Korea & United States	HI (1)	4-5 d/wk	65%-70% VO_{2max}	NR	13.5-22.5 METs-h/wk
		LI (2)	4-5 d/wk	50%-56% VO_{2max}	NR	13.5-22.5 METs-h/wk
Zhang et al., 2015	China	HIIT (1)	4 d/wk	90% HR_{peak} & 55%HR_{peak}	4 x 4min & 3 x 3min	249 kcal/d

		MICT (2)	4 d/wk	65% HR_{peak}	33min	253 kcal/d
Zhang et al., 2016	China	MOD (1)	5 d/wk	3.0 – 6.0 METs	30 min	170 kcal/d
		VIG (2)	5 d/wk	8.0 – 10.0 METs	30 min	340 kcal/d
Zhang et al., 2017	China	HIIT (1)	3-4 d/wk	90% VO_{2max} Passive	NR	60 kcal/d
		MICT (2)	3-4 d/wk	60% VO_{2max}	NR	60 kcal/d

AE aerobic exercise; **HI** high intensity; **HIIT** high-intensity interval training; **HR_{max}** maximum heart rate; **$HR_{reserve}$** heart rate reserve; **HV** high volume; **LI** low intensity; **LV** low volume; **METs** metabolic equivalents of task; **MI/MOD** moderate intensity; **MICT** moderate-intensity continuous training; **MV** moderate volume; **NR** not reported; **RM** repetition maximum; **RPE** rating of perceived exertion; **RT** resistance training; **VIG** vigorous intensity; **VO_{2max}** maximal oxygen uptake; **VO_{2peak}** peak oxygen uptake; **$VO_{2reserve}$** oxygen uptake reserve

* NOT included in the meta-analysis due to insufficient data

[a]Intervention arms being synthesized only

Table S2B Additional study and intervention characteristics (caloric restriction)

Study	Location	Groups[a]	Diet Prescription	Caloric deficit
Bouchonville et al., 2014 Napoli et al., 2014	United States	CR	NR	500-750 kcal/d
Brennan et al., 2021	United States	CR	NR	500-1000 kcal/d
Coker et al., 2009a	United States	CR	NR	2,500 kcal/wk
Ibáñez et al., 2010 Idoate et al., 2011 García-Unciti et al., 2012	Spain	WL	NR	500 kcal/d
Kang et al., 2018	South Korea	LCD	NR	300 kcal/d
Koo et al., 2010	South Korea	CR	1200 kcal/d	550 kcal/d
Larson-Meyer et al., 2006, 2010 Redman et al., 2007, 2010	United States	CR	25% daily deficit	700 kcal/d
Lee et al., 2018	South Korea	WL	NR	300 kcal/d
Ng et al., 2007, 2009 Chan et al., 2008	Australia	WL	6,143 kJ/d	870 kcal/d
Nordby et al., 2012 Bladbjerg et al., 2017	Denmark	CR	NR	600 kcal/d
Ross et al., 2000 Thong et al., 2000	Canada	CR	NR	700 kcal/d
Ross et al., 2004	Canada	WL	NR	500 kcal/d
Schübel et al., 2018	Germany	CR	20% daily deficit	410 kcal/d
Schutte et al., 2022	The Netherlands	LNCR (1)	25% daily deficit	415 kcal/d
		HNCR (2)	25% daily deficit	415 kcal/d
Trepanowski et al., 2018	United States	CR	25% daily deficit	730 kcal/d

CR caloric restriction; **HN** High nutrient; **LCD** low-calorie diet; **LN** Low nutrient; **NR** not reported; **WL** weight loss; **WM** weight maintenance

[a]Intervention arms being synthesized only

Table S3A Summary of findings for exercise (GRADE Framework)

Effect of exercise in adults with excess adiposity			
Population: Adults (≥ 18 years old) with an elevated BMI and/or waist circumference **Setting:** Community/outpatient **Interventions:** Exercise **Comparisons:** Usual care/no intervention/health education/weight maintenance			
Outcomes	**Effect size (95% CI)**	**Participants (Studies)**	**Quality of Evidence (GRADE)***
Visceral fat (healthy)	-0.34 (-0.45 to -0.23)	921 (19)	⨁⨁⨁⨀[a]
Visceral fat (comorbidities)	-0.17 (-0.33 to -0.01)	431 (7)	⨁⨁⨁⨀[b]

*Certainty of evidence grades:
(1) ⨁⨁⨁⨁ High: further research is unlikely to change the confidence in the estimate of effect.
(2) ⨁⨁⨁⨀ Moderate: further research is likely to have an important impact on the confidence in the estimate of effect and may change the estimate.
(3) ⨁⨁⨀⨀ Low: further research is very likely to have an important impact on the confidence in the effect estimate and is likely to change the estimate.
(4) ⨁⨀⨀⨀ Very low: any estimate of effect is very uncertain.

[a]Downgraded by one level for risk of bias: most of the included studies were susceptible to at least moderate risk of bias.
[b]Downgraded by one level for heterogeneity: compared to the healthy counterparts, the heterogeneity is higher among studies of participants with comorbidities. Nonetheless, more than half of the studies were only susceptible to low risk of bias. The certainty of evidence was therefore downgraded by one level.

Table S3B Summary of findings for caloric restriction (GRADE Framework)

Effect of caloric restriction in adults with excess adiposity			
Population: Adults (≥ 18 years old) with an elevated BMI and/or waist circumference **Setting:** Community/outpatient **Interventions:** Caloric restriction **Comparisons:** Usual care/no intervention/health education/weight maintenance			
Outcomes	**Effect size (95% CI)**	**Participants (Studies)**	**Quality of Evidence (GRADE)***
Visceral fat	-0.53 (-0.71 to -0.35)	721 (15)	⨁⨁⨁⨀[a]

*Certainty of evidence grades:
(1) ⨁⨁⨁⨁ High: further research is unlikely to change the confidence in the estimate of effect.
(2) ⨁⨁⨁⨀ Moderate: further research is likely to have an important impact on the confidence in the estimate of effect and may change the estimate.
(3) ⨁⨁⨀⨀ Low: further research is very likely to have an important impact on the confidence in the effect estimate and is likely to change the estimate.
(4) ⨁⨀⨀⨀ Very low: any estimate of effect is very uncertain.

[a]Downgraded by one level for risk of bias: most of the included studies were susceptible to at least moderate risk of bias.

Table S4A Meta-regression analyses for exercise studies

Moderator	**K**	**Effect [95% CI]**	**P value**
Intervention duration	46	.00 [-.00 to .00]	.95
Age	41	.01 [.00 to .02]	.14
BMI	42	-.03 [-.07 to .00]	.05
Sex	44	-.18 [-.44 to .08]	.16
Exercise frequency (continuous)	42	-.02 [-.08 to .05]	.66

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Table S4B Meta-regression analyses for caloric restriction studies

Moderator	**K**	**Effect [95% CI]**	**P value**
Intervention duration	16	.00 [-.01 to .02]	.69
Age	15	.00 [-.02 to .02]	.79
BMI	16	.01 [-.05 to .06]	.78
Sex	15	-.37 [-.98 to .23]	.21

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Table S5A Subgroup analyses for exercise studies

Moderator	K	Effect [95% CI]	P value
Exercise frequency (categorical)			
≤ 3.5 d/wk	15	-.31 [-.48 to -.14]	< .001
> 3.5 d/wk	22	-.25 [-.40 to -.09]	= .002
Intensity			
Low	6	-.11 [-.33 to .11]	= .11
Moderate	22	-.32 [-.46 to -.17]	< .001
Vigorous	16	-.34 [-.49 to -.19]	< .001
Disease			
Healthy	33	-.34 [-.45 to -.23]	< .001
DM	6	-.21 [-.48 to .05]	= .11
METS	2	-.02 [-.49 to .45]	= .92
NAFLD	5	-.18 [-.39 to .04]	= .10
Measure			
MRI	20	-.22 [-.32 to -.11]	< .001
CT	26	-.44 [-.57 to -.30]	< .001
Supervision			
Supervised	35	-.33 [-.43 to -.22]	< .001
Unsupervised	11	-.18 [-.36 to .00]	= .05
Continent			
Asia	19	-.23 [-.40 to -.06]	= .012
USA	13	-.30 [-.46 to -.15]	= .001
Europe	9	-.45 [-.75 to -.14]	= .010
Australia	5	-.22 [-.35 to -.09]	= .009

CT Computed Tomography; DM Diabetes Mellitus; METS Metabolic Syndrome; MRI Magnetic Resonance Imaging; NAFLD Non-Alcoholic Fatty Liver Disease.

Table S5B Subgroup analyses for caloric restriction studies

Moderator	K	Effect [95% CI]	P value
Disease			
Healthy	14	-.55 [-.73 to -.36]	< .001
DM	1	-.06 [-.86 – .78]	= .86
METS	1	-.07 [-1.50 to .05]	= .05
Measure			
MRI	11	-.50 [-.73 to -.28]	= .002
CT	5	-.58 [-.91 to -.25]	< .001
Continent			
Asia	3	-.57 [-2.19 to 1.04]	= .27
USA	7	-.50 [-.61 to -.38]	< .001
Europe	5	-.50 [-.95 to -.06]	= .034
Australia	1	-.74 [-1.44 to -.04]	= .038

CT Computed Tomography; DM Diabetes Mellitus; METS Metabolic Syndrome; MRI Magnetic Resonance Imaging.

Fig. S1 PRISMA Flow chart

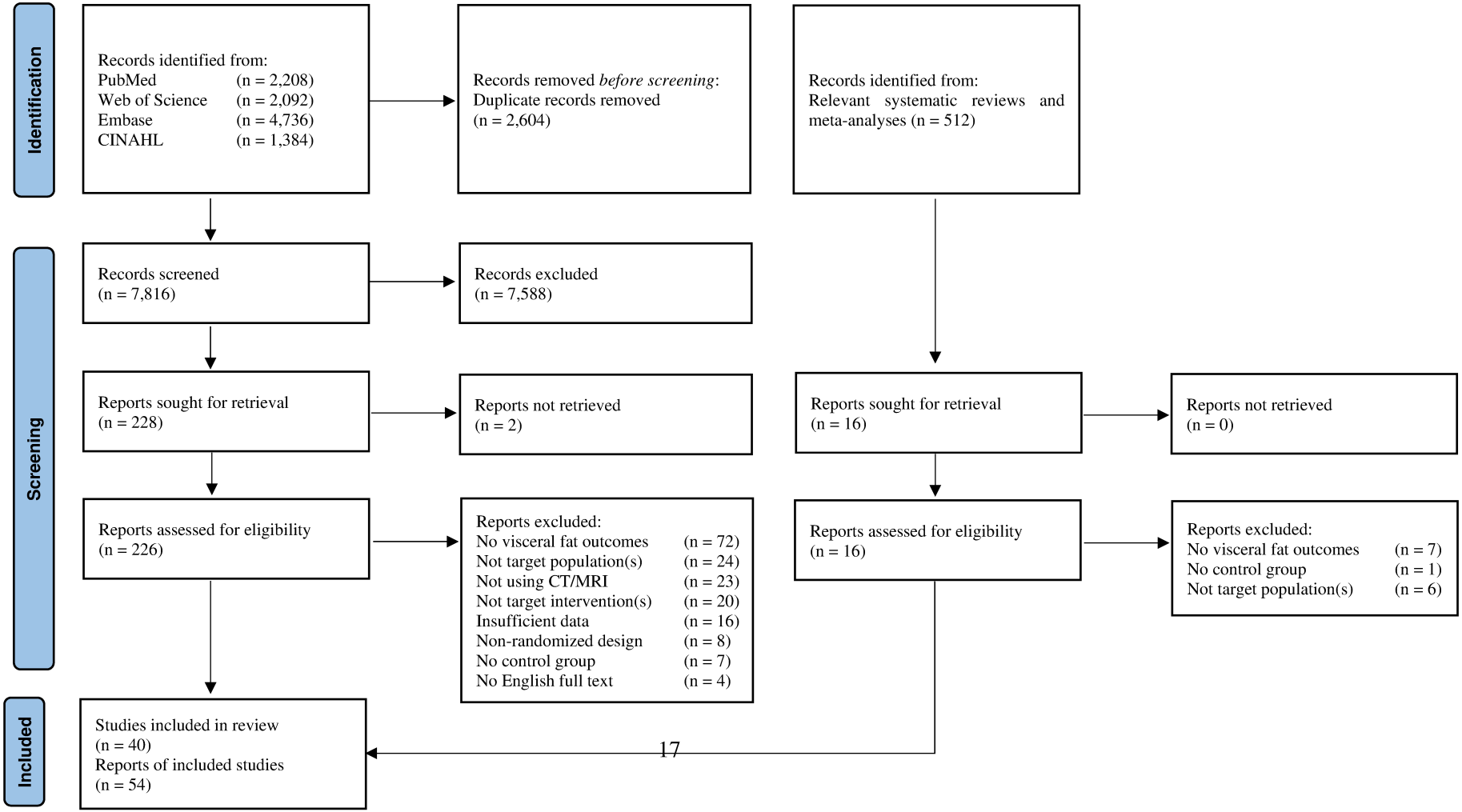


Fig. S2 Forest plot of the effect of exercise on waist circumference

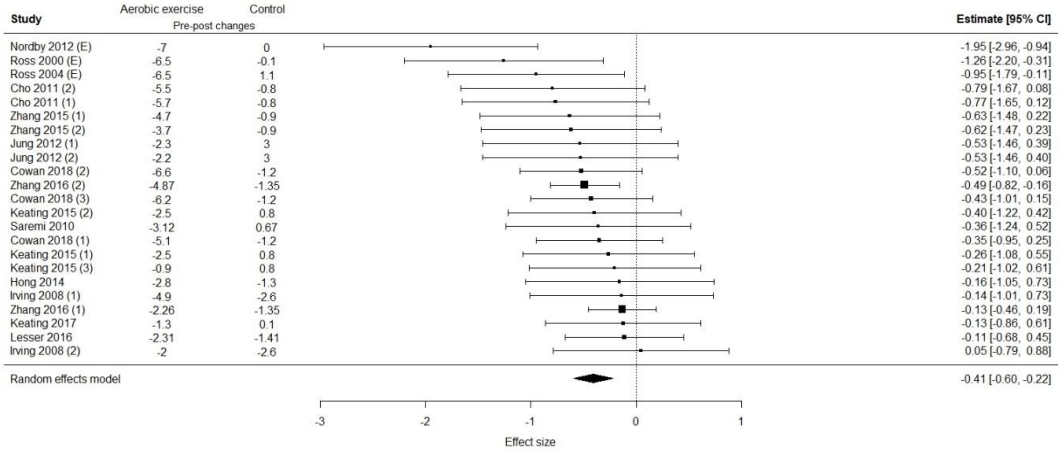


Fig. S3 Dose-response effect of exercise on waist circumference

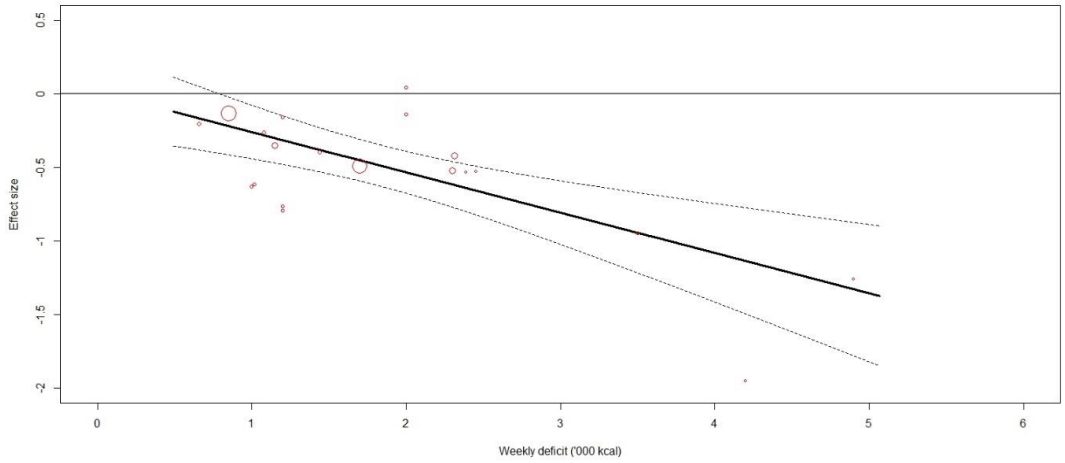


Fig. S4 Forest plot of the effect of caloric restriction on waist circumference

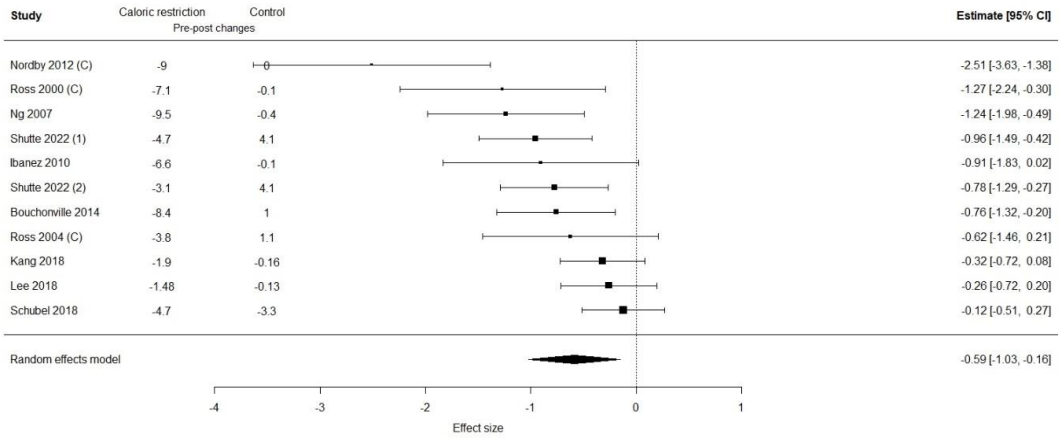


Fig. S5 Dose-response effect of caloric restriction on waist circumference

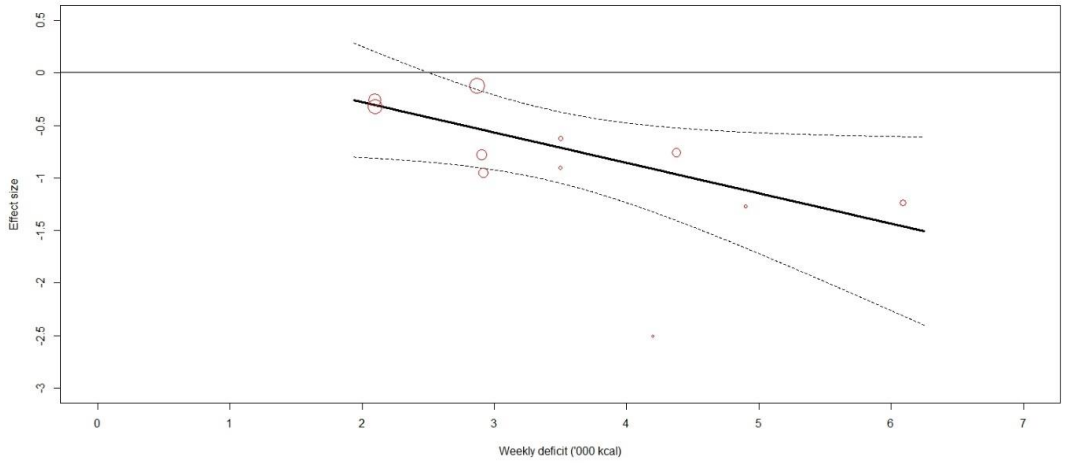


Fig. S6A Risk of Bias assessmment for exercise studies

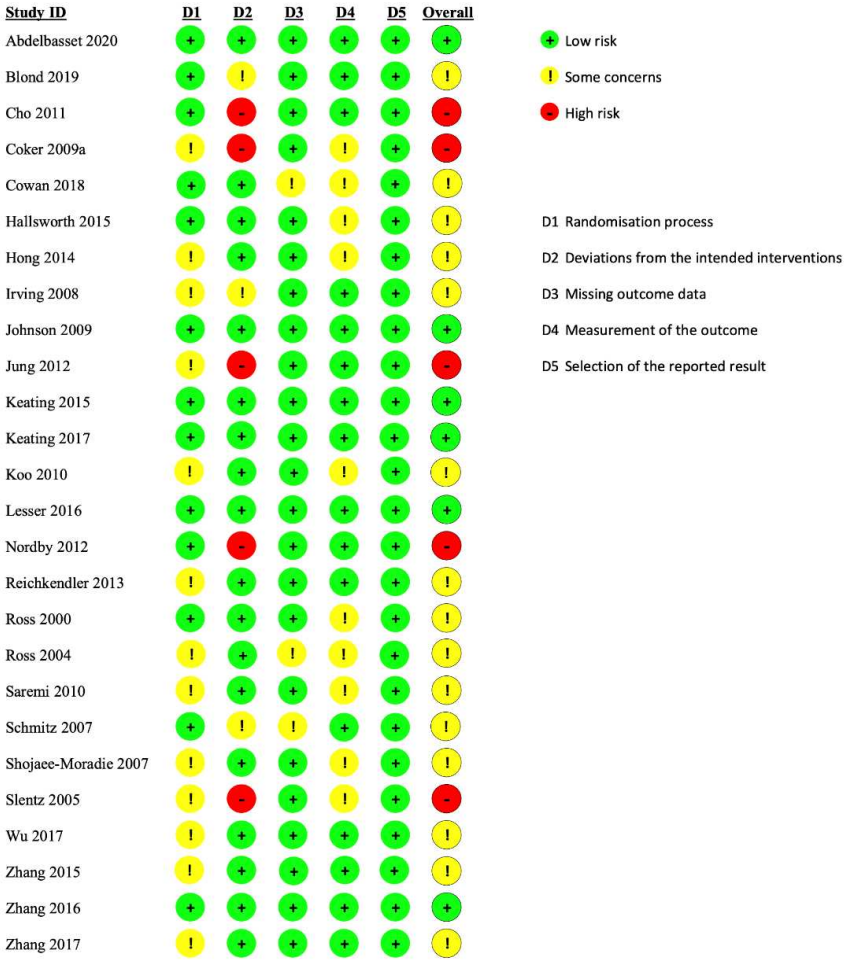
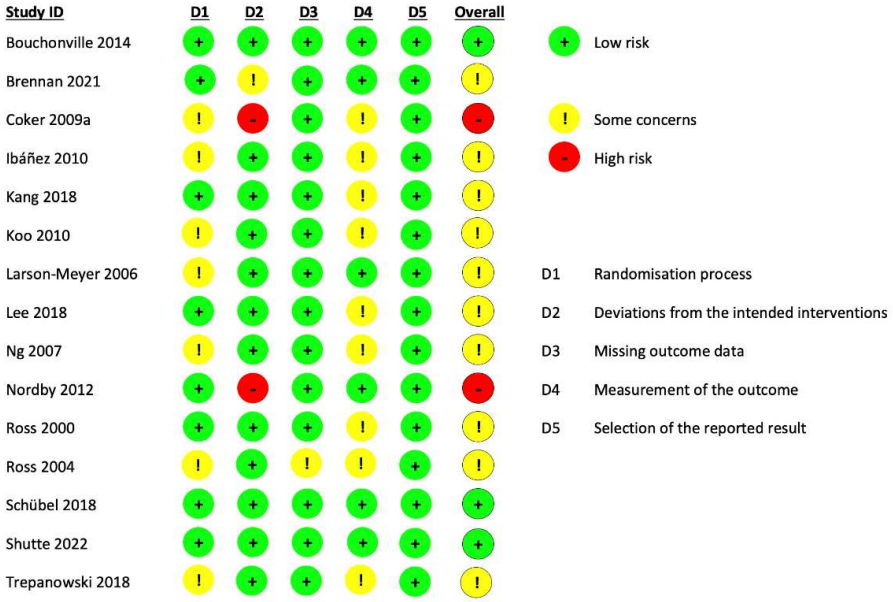


Fig. S6B Risk of Bias assessment for caloric restriction studies



Appendix S1 Search strategy

PubMed

(overweight OR obesity OR central obesity) AND (exercise OR "physical training" OR endurance training OR "aerobic training" OR "continuous training" OR resistance training OR "strength training" OR "weight training" OR "interval training" OR "intermittent training" OR "HIIT" OR caloric restriction OR calori* restrict* OR calori* reduc* OR "low calorie diet*" OR "hypocaloric diet*" OR diet, reducing[MH] OR "diet intervention*" OR "dietary intervention*" OR "energy restrict*" OR "low energy diet*" OR weight loss[MH] OR "weight reduction") AND (visceral fat OR intra abdominal fat OR abdominal fat OR adipose tissue) AND ((randomized controlled trial[PT] OR controlled clinical trial[PT] OR randomized[TIAB] OR randomised[TIAB] OR placebo[TIAB] OR randomly[TIAB] OR trial[TIAB] OR groups[TIAB]) NOT (animals[MH] NOT humans[MH]))

Web of Science

(ALL=(overweight OR obes* OR "central* obes*" OR "abdominal* obes*")) AND (ALL=(exercise OR "physical training" OR "endurance training" OR "aerobic training" OR "continuous training" OR "resistance training" OR "strength training" OR "weight training" OR "interval training" OR "intermittent training" OR "HIIT" OR "calori* restrict*" OR "calori* reduc*" OR "low calorie" OR hypocaloric OR diet$ OR "diet* intervention*" OR "diet* restrict*" OR "energy restrict*" OR "energy reduc*" OR "weight loss" OR "weight reduction")) AND (ALL=("CON" OR control* OR "usual care" OR "conventional care" OR "standard care" OR "no intervention" OR "health education")) AND ((ALL=(visceral OR abdominal OR intraabdominal)) AND (ALL=(fat OR "adipose tissue" OR adiposity OR lipid$))) AND (TI=(randomized OR randomised OR randomly OR placebo OR trial OR groups) OR AB=(randomized OR randomised OR randomly OR placebo OR trial OR groups))

Embase

((exp overweight/ or overweight or exp obesity/ or obes* or ((abdominal* or central*) adj obes*)) and (exercise or ((physical or endurance or aerobic or continuous or resistance or strength or weight or interval or intermittent) adj training) or HIIT or (calori* adj (restrict* or reduc*)) or low calor* diet* or hypocaloric diet* or (diet* adj

(intervention* or restrict* or therapy)) or energy restrict* or low energy diet* or (weight adj (loss or reduction))) and ((visceral fat or intraabdominal fat or abdominal fat or adipose tissue))).mp. and ((randomized controlled trial/ or controlled clinical trial/ or controlled study/ or (randomized or randomised or placebo or randomly or trial or groups).ti,ab.) not ((animal/ or nonhuman/) not human/))

CINAHL

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(overweight OR obes* OR (MH "obesity+") OR "central* obes*" OR "abdominal* obes*") AND (exercise OR (MH "exercise+") OR "physical training" OR "endurance training" OR "aerobic training" OR "continuous training" OR "resistance training" OR "strength training" OR "weight training" OR "interval training" OR "intermittent training" OR "HIIT" OR (calori* W1 (restrict* OR reduc*)) OR "low calorie diet*" OR "hypocaloric diet*" OR (MH "diet, reducing") OR (MH "restricted diet") OR "diet* restrict*" OR "diet* intervention*" OR "energy restrict*" OR "low energy diet*" OR (weight W1 (loss OR reduction))) AND (((visceral OR intraabdominal OR abdominal) W1 fat) OR adipose tissue) AND ((PT randomized controlled trial OR (MH "randomized controlled trial") OR PT clinical trial OR (MH "clinical trial") OR TI (randomi#ed OR placebo OR randomly OR trial OR groups) OR AB (randomi#ed OR placebo OR randomly OR trial OR groups)) NOT ((MH "animals") NOT (MH "human")))

Appendix S2 Reference list

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