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Joint associations of device-measured physical activity and abdominal obesity with incident cardiovascular disease: a prospective cohort study

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ABSTRACT

Objective To examine the joint associations between physical activity and abdominal obesity with the risk of cardiovascular disease (CVD) events.

Methods We included 70 830 UK Biobank participants (mean age±SD=61.6 ± 7.9 years; 56.4% women) with physical activity measured by wrist-worn accelerometers and without major chronic diseases. Participants were jointly categorised into six groups based on their physical activity level (tertiles of total volume and specific intensity levels) and presence or absence of abdominal obesity based on measured waist circumference. Associations with incident CVD (fatal and non-fatal events) were determined using proportional subdistribution hazard models with multivariable adjustment.

Results After excluding events during the first 2 years of follow-up, participants were followed for a median of 6.8 years, during which 2795 CVD events were recorded. Compared with the low abdominal adiposity and highest tertile of physical activity, abdominal obesity was associated with higher risk of incident CVD, especially in those with low levels of vigorous-intensity physical activity (HR 1.42, 95% CI 1.22 to 1.64). Approximately 500 min per week of moderate-to-vigorous intensity and approximately 30–35 min of vigorous-intensity physical activity offset the association of abdominal obesity and the risk of having a CVD event.

Conclusion Physical activity equivalent to approximately 30–35 min of vigorous intensity per week appears to offset the association between abdominal obesity and incident CVD. About 15 times more physical activity of at least moderate intensity is needed to achieve similar results.

WHAT IS ALREADY KNOWN ON THIS TOPIC

⇒ Abdominal obesity is associated with a higher risk of developing and dying from cardiovascular disease (CVD). Whether physical activity can reduce or fully offset this association is unclear.

WHAT THIS STUDY ADDS

⇒ We found that approximately 500 min of moderate-to-vigorous intensity physical activity or 30–35 min of vigorous-intensity physical activity per week, measured by wrist-worn accelerometers, fully offset the association of abdominal obesity with incident CVD.

HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE OR POLICY

⇒ Encouraging people to participate in vigorous-intensity physical activity (eg, climbing stairs at a fast pace) for short periods on most days of the week appears to be a promising strategy to counteract the effects of abdominal obesity on CVD outcomes in middle-aged adults.

INTRODUCTION

Cardiovascular diseases (CVDs) are the leading causes of deaths globally but are to a large degree preventable through modifiable risk factors such as smoking, alcohol consumption, poor diets, obesity and physical inactivity.[1]

Obesity is associated with higher risk of CVD, however, susceptibility to obesity-related CVD depends largely on body fat distribution.[2] Further, individuals with higher abdominal adiposity (ie, abdominal obesity) are at higher risk of CVD morbidity and mortality independently of total adiposity.[2–4] This association is largely mediated by impaired glucose and lipid metabolisms, which are often seen with increasing ectopic fat deposition.[5 6] Lifestyle behaviours, such as physical activity, reduce the risk of CVD via the same metabolic pathways.[7] It is, therefore, plausible that higher levels of physical activity may counteract the deleterious association between abdominal adiposity and CVD.

Accelerometer-measured physical activity captures sporadic and incidental periods of physical activity, which cannot be measured by self-report instruments.[8] It provides valid information on light-intensity physical activity (LPA) which may be beneficial for cardiometabolic health and longevity.[9] At the other end of the intensity spectrum, recent research suggests vigorous-intensity physical activity (VPA) is particularly relevant for reducing the risk for incident CVD.[10 11] However, whether different intensities of physical activity modify the association between abdominal and total adiposity and the risk for incident CVD remains unclear.

Using accelerometer-measured physical activity in a large prospective cohort of adults from the UK, we aimed to examine the joint and stratified association between abdominal adiposity and different intensities of physical activity with incident CVD. As a secondary aim, we repeated the analysis replacing abdominal adiposity with total adiposity.

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METHODS

This study followed the Strengthening the Reporting of Observational Studies in Epidemiology reporting guidelines (online supplemental table 1). The statistical analysis and presentation is consistent with the CHecklist for statistical Assessment of Medical Papers statement.[12]

Data source and study population

We used data from the UK Biobank (application number 29717), a cohort of more than 500 000 participants (5.5% response rate), aged 37–73 years, recruited across the UK, who provided written informed consent. Baseline data collection, conducted between 2006 and 2010 acros 22 assessment centres, included questionnaires, physical measurements and biological sampling, and were linked to electronic registries. Between 2013 and 2015, physical activity was measured by accelerometers in a subsample of participants (n=103 613).[13]

Exposures

Adiposity

Trained clinical staff performed all anthropometric measurements at baseline following standardised protocols.[13] We determined abdominal adiposity using two proxies. First, we classified participants as having abdominal obesity based on the WHO's waist circumference (WC) cut-offs (≥88 cm for women and ≥102 cm for men).[14] Second, to account for the high correlation between WC and the body mass index (BMI, weight(kg)/height (m^2)),[6] we derived a measure of abdominal adiposity that is statistically independent of total adiposity (BMI) by regressing WC on BMI. Using the residuals from this regression, we categorised participants into low, medium and high 'WC-for-BMI' groups, mirroring the sex-specific distribution of normal weight, overweight and obesity based on BMI.[15] Finally, we used the BMI as a proxy of total adiposity. Additional descriptive information on the creation of these measures of adiposity is included in online supplemental table 2.

Physical activity

Participants wore an Axivity AX3 accelerometer (Axivity, York, UK) on their dominant wrist for 24 hours during seven consecutive days. Data were collected at a sampling rate of 100 Hz and a dynamic range of ±8 g. Individual participant data were extracted from 5 s epoch time series. Exclusions criteria included <72 hours of wear time, missing data in the included 1-hour periods, implausible acceleration values (average vector magnitude acceleration >100 mg) or uncalibrated data.[16] Total physical activity was extracted from measured average vector magnitude in mg. Time spent in LPA and moderate-to-vigorous physical activity (MVPA) was determined through a machine-learning approach.[16 17] The validation sample for this approach had insufficient VPA for the algorithm to identify a useful characterisation pattern. Therefore, time spent in VPA was estimated from the average proportion of time spent in accelerations above 400 mg.[18] Participants were categorised into tertiles (low, medium, high) for each activity measure (further details in online supplemental table 2).

Incident CVD

We defined incident CVD events as the first non-fatal cardiovascular event (International Statistical Classification of Diseases and Related health Problems 10th edition (ICD-10) codes I20–I25, I50 and I60–I64) from hospital inpatient records, primary or secondary diagnoses, in addition to death by cardiovascular event (primary) (ICD-10 codes I00–I99),[19] obtained from national registries. Events occurring after finishing the accelerometer measurement were considered incident. Participants were followed to incident CVD, death, withdrawal from the study, or 30 September 2021 for England, 31 July 2021 for Scotland or 31 March 2016 for Wales, whichever occurred first.

Covariates

We identified confounders a priori based on a directed acyclic graph.[20] Detailed information on covariates is shown in online supplemental table 2. Self-reported sociodemographic covariates included ethnicity, education, living with partner and employment status. The Townsend Index was used as a marker of area-level socioeconomic status.[21] Self-reported lifestyle covariates included a dietary quality index, alcohol intake and smoking history. History of depression, hypertension and statins medication were derived from a combination of questionnaire data and verbal interview. To identify undiagnosed hypertensive patients, clinical blood pressure measurements were considered alongside self-reported data. Type 2 diabetes cases were identified using a previously developed algorithm.[22]

Analytical sample

To reduce the risk of reverse causality, participants with major chronic diseases at baseline (eg, neurodegenerative, immunological or systemic diseases), underweight (BMI <18.5 kg/m^2), unable to walk, with mobility limitations or with a history of cancer or CVD before the accelerometer assessment were excluded (online supplemental table 2). Following these criteria, a total of 22 451 participants were excluded (online supplemental figure 2). Of the remaining participants, 68 090 had complete data on exposures, outcomes and covariates. We retrieved missing data on covariates for an additional 2740 participants by performing multiple imputation using chained equations with 20 datasets generated.

Statistical analyses

Descriptive statistics included mean and SD for normally distributed continuous variables, median and range for skewed continuous variables, and percentages for categorical data.

First, we examined the independent associations of abdominal obesity and physical activity with incident CVD using the lowest WC and highest physical activity groups as the reference, respectively. Then we examined the joint associations of abdominal obesity (two categories based on WHO cut-off points and three based on 'WC-for-BMI' residuals) and physical activity tertiles (resulting in six and nine distinct categories, respectively), with incident CVD. The group with the lowest level of adiposity and highest level of physical activity was used as the reference. In addition, we examined the joint associations between total adiposity (three categories of BMI) and physical activity (resulting in nine BMI-physical activity categories) with incident CVD.

Subdistribution HRs with 95% CIs for incident CVD were calculated using Fine-Gray models to account for non-CVD deaths as a competing event. Models were left-truncated to start the follow-up time 2 years after the accelerometer assessments (2013–2015). Age was used as the underlying timescale, and models were adjusted for covariates at baseline (2006–2010), sequentially. We employed models 1, 1b and 1c for independent associations analyses, while models 1–3 were used for joint and stratified associations analyses. Model 1 was adjusted for age at accelerometer assessment (as timescale) and sex. Models 1b and

Table 1 Descriptive characteristics of the included participants by sex and group of waist circumference

	Women (n=39 963)		Men (n=30 867)	
	Low waist circumference	Abdominal obesity	Low waist circumference	Abdominal obesity
Age at accelerometer assessment (mean (SD))	60.9 (7.8)	62.2 (7.5)	61.7 (8.1)	62.9 (7.6)
Physical activity (median, (range))				
Total volume (average acceleration, mg)	29.1 (7.7–97.1)	25.6 (5.9–67.5)	28.1 (8.2–97.2)	24.4 (5.9–89.5)
LPA (min/week)	2287.3 (28.0–5799.5)	2130.1 (47.0–5702.6)	1910.7 (68.0–5409.5)	1773.8 (143.6–4855.9)
MVPA (min/week)	233.0 (0.0–2509.2)	148.0 (0.0–2229.2)	332.0 (0.0–2999.7)	226.0 (0.0–2388.3)
VPA (min/week)	6.0 (0.0–734.2)	2.5 (0.0–468.5)	10.5 (0.0–756.7)	4.5 (0.0–480.0)
BMI categories (n; %)				
Normal weight (18.5–24.9 kg/m^2)	18 864; 65.3	447; 4.0	9656; 40.8	24; 0.3
Overweight (25–29.9 kg/m^2)	9402; 32.6	4674; 42.1	12 929; 54.6	2458; 34.2
Obese (≥30.0 kg/m^2)	603; 2.1	5973; 53.8	1089; 4.6	4711; 65.5
Ethnicity (n; %)				
White	27 876; 96.8	10 630; 96.2	22 832; 96.8	6984; 97.5
Asian	334; 1.2	96; 0.9	341; 1.4	68; 0.9
Black	218; 0.8	178; 1.6	198; 0.8	53; 0.7
Others/mixed	365; 1.3	151; 1.4	225; 1.0	60; 0.8
Townsend Index (mean (SD))	−1.8 (2.8)	−1.5 (2.9)	−1.9 (2.8)	−1.7 (2.8)
Education (n; %)				
No qualifications	1851; 6.5	963; 8.8	1527; 6.5	669; 9.4
Not college/university degree	13 714; 47.9	5842; 53.2	10 276; 43.8	3676; 51.7
College/university degree	13 036; 45.6	4172; 38.0	11 655; 49.7	2764; 38.9
Living with partner (n; %)	21 461; 74.5	7801; 70.5	19 338; 81.9	5790; 80.7
Employment status (n; %)				
Unemployed (not in employment)	2122; 7.4	724; 6.6	675; 2.9	244; 3.4
Employed	18 793; 65.6	6839; 62.0	16 333; 69.4	4778; 66.8
Retired	7737; 27.0	3467; 31.4	6526; 27.7	2133; 29.8
Diet pattern (n; %)				
Not meeting any targets	3509; 12.3	1619; 14.9	5369; 23.1	1939; 27.6
Meeting one target	10 957; 38.5	4377; 40.2	9729; 41.9	3006; 42.9
Meeting 2–3 targets	13 994; 49.2	4883; 44.9	8147; 35.0	2069; 29.5
Alcohol consumption (n; %)				
Never	948; 3.3	434; 3.9	402; 1.7	127; 1.8
Former	618; 2.1	285; 2.6	532; 2.2	147; 2.0
Current, <3 times/week	13 834; 48.0	6195; 55.9	8886; 37.6	2946; 41.0
Current, ≥3 times/week	13 443; 46.6	4168; 37.6	13 837; 58.5	3967; 55.2
Smoking status (n; %)				
Never	18 492; 64.2	6510; 58.9	13 627; 57.7	3306; 46.1
Previous	8862; 30.8	3880; 35.1	8201; 34.7	3295; 45.9
Current	1450; 5.0	669; 6.0	1789; 7.6	572; 8.0
History of depression (n; %)	1252; 4.3	755; 6.8	648; 2.7	284; 3.9
Type 2 diabetes (n; %)	208; 0.7	481; 4.3	583; 2.5	673; 9.4
Hypertension (n; %)	10 214; 35.4	6361; 57.3	12 020; 50.8	5181; 72.0
Statin user (n; %)	1406; 4.9	1253; 11.3	2659; 11.2	1584; 22.0

Abdominal obesity was defined based on the WHO's cut-offs as ≥88 cm for women and ≥102 cm for men. Number varies from 68 090 (healthy diet pattern) to 70 830 because of missing data.
BMI, body mass index; LPA, light-intensity physical activity; MVPA, Moderate-to vigorous-intensity physical activity; VPA, vigorous-intensity physical activity.

2 were adjusted as model 1 plus ethnicity, education, living with partner, employment, Townsend Index, diet quality, alcohol intake, smoking and depression. Models 1b for WC and BMI exposures were also adjusted for MVPA. Models 1b and 2 were adjusted as model 1 plus ethnicity, education, living with partner, employment, Townsend Index, diet quality, alcohol intake, smoking and depression. Model 1b for WC and BMI exposures was also adjusted for MVPA. Models 1b and 2 for WC based on WHO cut-offs were additionally adjusted for BMI in continuous form.[6] We considered model 2 as the main model. Prevalent type 2 diabetes, hypertension and use of statins medication were considered mediators in the causal pathway from abdominal obesity and/or physical activity to CVD and we did not adjust for them in the main model. However, these could be conceptually considered as confounders or mediators. To address this, we created models 1c and 3, which were adjusted as models 1b and 2, respectively, but included type 2 diabetes, hypertension and statins medication as confounders in an alternative scenario (online supplemental figure 1). Proportional hazards assumption was verified using log-log plots, and interactions between adiposity and physical activity variables were assessed through likelihood-ratio tests.

Table 2 Independent associations between physical activity, adiposity categories and risk of incident cardiovascular disease

			HRs (95% CI)		
	n participants	n events	Model 1	Model 1b	Model 1c
Adiposity measures					
Waist circumference categories (clinical cut-off)					
Low (<88 cm in women, <102 cm in men)	52 543	1819	1 (reference)	1 (reference)	1 (reference)
High (≥88 cm in women, ≥102 cm in men)	18 287	976	1.51 (1.40 to 1.63)	1.13 (1.01 to 1.26)	1.11 (0.99 to 1.23)
Waist circumference for body mass index (BMI) residuals*					
Low	28 993	894	1 (reference)	1 (reference)	1 (reference)
Medium	29 486	1261	1.06 (0.97 to 1.16)	1.05 (0.96 to 1.15)	1.03 (0.95 to 1.13)
High	12 351	640	1.21 (1.09 to 1.34)	1.16 (1.04 to 1.29)	1.13 (1.01 to 1.25)
BMI, categories					
Normal weight (18.5–24.9 kg/m^2)	28 991	824	1 (reference)	1 (reference)	1 (reference)
Overweight (25–29.9 kg/m^2)	29 463	1275	1.25 (1.15 to 1.37)	1.20 (1.09 to 1.31)	1.12 (1.02 to 1.23)
Obese (≥30.0 kg/m^2)	12 376	696	1.79 (1.62 to 1.98)	1.60 (1.43 to 1.77)	1.37 (1.23 to 1.53)
Physical activity measures					
Total physical activity tertiles of mg (median, range)					
High (35.9, 31.0–97.2)	23 586	660	1 (reference)	1 (reference)	1 (reference)
Medium (27.7, 24.7–31.0)	23 622	851	1.07 (0.97 to 1.19)	1.02 (0.92 to 1.13)	1.01 (0.91 to 1.12)
Low (21.4, 5.9–24.7)	23 622	1284	1.33 (1.21 to 1.47)	1.16 (1.05 to 1.29)	1.13 (1.02 to 1.25)
Light-intensity physical activity tertiles of min/week (median, range)					
High (2794.3, 2390.4–5799.5)	23 605	790	1 (reference)	1 (reference)	1 (reference)
Medium (2089.1, 1808.1–2390.3)	23 615	916	1.03 (0.93 to 1.13)	1.01 (0.91 to 1.10)	1.00 (0.91 to 1.10)
Low (1489.0, 28.0–1808.0)	23 610	1089	1.11 (1.01 to 1.22)	1.04 (0.95 to 1.15)	1.03 (0.95 to 1.13)
MVPA tertiles of min/week (median, range)					
High (511.9, 349.2–2999.7)	23 579	825	1 (reference)	1 (reference)	1 (reference)
Medium (247.1, 164.1–349.1)	23 628	894	1.17 (1.06 to 1.28)	1.11 (1.01 to 1.22)	1.09 (0.99 to 1.20)
Low (87.5, 0.0–164.0)	23 623	1076	1.43 (1.31 to 1.57)	1.23 (1.12 to 1.36)	1.20 (1.09 to 1.32)
Vigorous-intensity physical activity tertiles of min/week (median, range)					
High (31.7, 13.1–756.7)	23 369	680	1 (reference)	1 (reference)	1 (reference)
Medium (6.1, 2.8–13.0)	23 827	914	1.14 (1.03 to 1.26)	1.08 (0.97 to 1.19)	1.06 (0.96 to 1.17)
Low (1.0, 0.0–2.7)	23 634	1201	1.42 (1.29 to 1.57)	1.25 (1.13 to 1.39)	1.21 (1.10 to 1.34)

Model 1 was adjusted for age (used as timescale in the model) and sex. Model 1b was adjusted as Model 1 plus ethnicity, education, living with partner, employment, Townsend Index, diet quality, alcohol intake, smoking, depression. Waist circumference and BMI models were adjusted for MVPA. Waist circumference was adjusted for BMI (continuous). Model 1c was adjusted as model 1b plus type 2 diabetes, hypertension and statins medication.
*We regressed waist circumference on BMI and used the residuals to create an index of central adiposity independent of total adiposity. Residuals were used to categorise the participants as having low, medium and high waist circumference-for-BMI based on the sex-specific distribution of normal weight, overweight and obese BMI categories.
MVPA, Moderate-to vigorous-intensity physical activity.

Several supporting and sensitivity analyses were performed. First, we examined the associations between abdominal obesity and incident CVD stratified by tertiles of physical activity. Second, we repeated the joint associations analysis between abdominal obesity, physical activity and CVD stratified by sex. Third, we repeated the analysis based on WHO cut-offs without adjustment for the BMI. Finally, we also repeated the primary analysis left-truncating the models to exclude the first 5 years of follow-up. The analyses were performed using Stata V.17 statistical software (StataCorp).

Patient and public involvement

There was no patient or public involvement in the planning, conceptualisation, research design, analysis, interpretation or composition of the findings. Results will be disseminated via institutional websites, press releases and the UK Biobank participant resource.

Equity, diversity and inclusion statement

Our research team comprises six men and one woman from various countries in Europe and Australia. The study population is diverse in terms of age, gender, demographics and comorbidities. However, the predominantly white composition of the cohort resulted in underrepresentation of other ethnic groups. Individuals from lower socioeconomic backgrounds and marginalised communities may also have lower representation. Methodological constraints required excluding individuals with specific comorbidities and mobility limitations from analyses.

RESULTS

We included 70 830 participants (56% women) with a mean (SD) age at the time of accelerometer assessment of 61.6 (7.9) years. Median follow-up time was 6.8 years during which 2795 CVD events occurred (2558 non-fatal and 237 fatal). Descriptive characteristics of the participants across WC categories are provided in table 1. Online supplemental table 3 presents a summary of the weekly physical activity levels (median and range) per activity tertiles and WC categories.

Abdominal obesity and low physical activity were independently associated with higher risk of incident CVD. Adjusting for BMI, abdominal obesity was associated with a 13% higher risk of CVD (HR 1.13, 95% CI 1.01 to 1.26). The HRs (95% CI) for high versus low physical activity ranged from 1.04 (0.95 to 1.15) for LPA to 1.25 (1.13 to 1.39) for VPA (table 2).

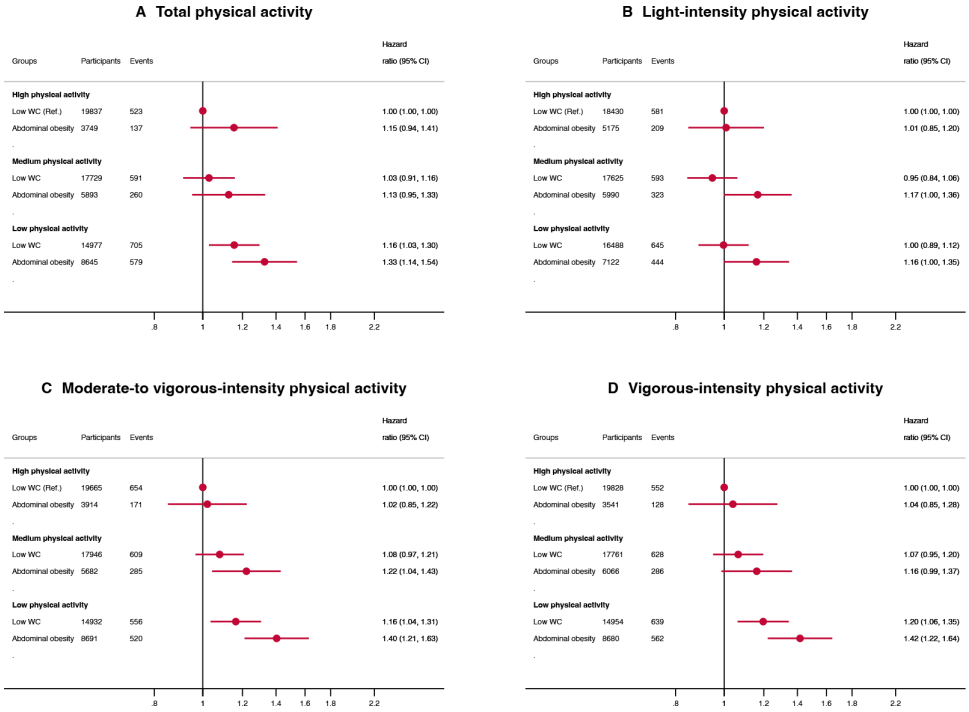

Figure 1 Joint associations between waist circumference (WC) categories from clinical cut-offs, physical activity tertiles and incident cardiovascular disease. Ref: reference. Figure shows weekly volumes of (A) total physical activity, (B) light-intensity, (C) moderate-to-vigorous intensity and (D) vigorous-intensity physical activity. Median (range) of physical activity levels for high, medium and low tertiles were, for total physical activity, 35.9 (31.0–97.2), 27.7 (24.7–31.0) and 21.4 (5.9–24.7) mg, respectively. For light-intensity min/week, 2794.3 (2390.4–5799.5), 2089.1 (1808.1–2390.3) and 1489.0 (28.0–1808.0). For moderate-to-vigorous intensity min/week, 511.9 (349.2–2999.7), 247.1 (164.1–349.1) and 87.5 (0.0–164.0). For vigorous-intensity min/week, 31.7 (13.1–756.7), 6.1 (2.8–13.0) and 1.0 (0.0–2.7). Results are from main model, adjusted for age (as timescale), sex, body mass index, ethnicity, education, living with partner, employment, Townsend Index, diet quality, alcohol intake, smoking and depression.

Joint associations between abdominal adiposity and physical activity with CVD

The highest risk of incident CVD was consistently observed in those with abdominal obesity and low physical activity, with HRs (95% CI) of 1.33 (1.14 to 1.54) for abdominal obesity and low total activity and 1.42 (1.22 to 1.64) for abdominal obesity and low VPA (figure 1). In contrast, high LPA (median=2090 min/week), high MVPA (median=512 min/week) and high VPA (median=32 min/week) mitigated the association between abdominal obesity and CVD (HRs (95% CI): 1.01 (0.85 to 1.20), 1.02 (0.85 to 1.22) and 1.04 (0.85 to 1.28), respectively). A high level of total physical activity did not completely offset the association with abdominal obesity.

The magnitude of the associations diminished after adjustment for type 2 diabetes, hypertension and statins medication as potential mediators, but the association pattern was unchanged (online supplemental figure 3).

Analysis of joint physical activity and WC-for-BMI categories supported the findings based on WHO cut-off points (figure 2). The highest risk was observed in the group with high WC and low MVPA (HR 1.64; 95% CI 1.39 to 1.94). Compared with the high physical activity and low WC-for-BMI, having medium or low levels of total physical activity, MVPA and VPA was associated with higher risk for incident CVD irrespective of abdominal adiposity. Having a higher WC-for-BMI was not associated with increased risk of CVD in those with high levels of MVPA (median=512 min/week) and VPA (median=32 min/week). Model 3 exhibited similar patterns, although less pronounced associations.

Joint associations between general adiposity and physical activity with CVD

A clear dose–response association between BMI and risk of CVD was found in all strata of physical activity in joint associations between physical activity and general adiposity as measured by BMI (online supplemental figure 4). High levels of physical activity attenuated but did not offset the association from having overweight or obesity. Being normal weight was associated with higher risk in those with low levels of total physical activity (HR 1.21; 95% CI 1.02 to 1.43) and low VPA (HR 1.24; 95% CI 1.06 to 1.47). Obesity combined with low MVPA was associated with the highest risk (HR 2.03; 95% CI 1.75 to 2.36).

Supporting and sensitivity analyses

Results from the analyses stratified by physical activity levels aligned with joint associations analyses, indicating that high levels of total physical activity, LPA, MVPA and VPA mitigated the risk associated with abdominal obesity and high WC-for-BMI (online supplemental tables 4 and 5). Whereas medium levels of VPA also offset the association in people with abdominal obesity and high WC-for-BMI, individuals with medium MVPA and LPA remained at 17%–27% higher risk. The patterns for the joint associations between WC and physical activity with incident CVD were similar in men and women. However, the effect sizes appeared greater in magnitude in women compared with men (online supplemental tables 6 and 7). Repeating the analysis of WHO cut-offs without adjustment for BMI accentuated associations and high levels of physical activity no longer offset the association between abdominal obesity and CVD (online

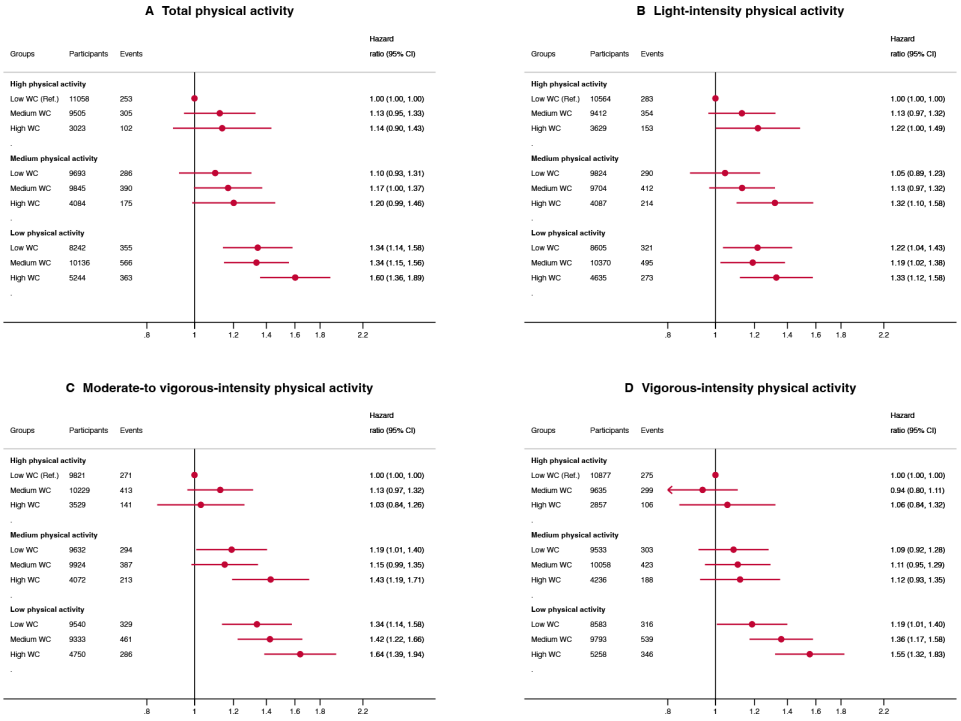

Figure 2 Joint associations between categories of waist circumference (WC)-for-body mass index residuals, physical activity tertiles and incident cardiovascular disease. Ref: reference. Figure shows tertiles of weekly volumes of (A) total physical activity, (B) light-intensity, (C) moderate-to-vigorous intensity and (D) vigorous-intensity physical activity. Median (range) of physical activity levels for high, medium and low tertiles were, for total physical activity, 35.9 (31.0–97.2), 27.7 (24.7–31.0) and 21.4 (5.9–24.7) mg, respectively. For light-intensity min/week, 2794.3 (2390.4–5799.5), 2089.1 (1808.1–2390.3) and 1489.0 (28.0–1808.0). For moderate-to-vigorous intensity min/week, 511.9 (349.2–2999.7), 247.1 (164.1–349.1) and 87.5 (0.0–164.0). For vigorous-intensity min/week, 31.7 (13.1–756.7), 6.1 (2.8–13.0) and 1.0 (0.0–2.7). Results are from main model, adjusted for age (as timescale), sex, body mass index, ethnicity, education, living with partner, employment, Townsend Index, diet quality, alcohol intake, smoking and depression.

supplemental figure 5). The sensitivity analysis excluding the first 5 years of follow-up showed similar patterns but generally attenuated associations between higher WC and risk of CVD (online supplemental figure 6).

DISCUSSION

Our results suggest that physical activity of any intensity can mitigate or even offset the association between abdominal obesity and incident CVD. Approximately 30–35 min per week of VPA appear to effectively offset the association of abdominal obesity with incident CVD.

Although high levels of LPA appear to attenuate the risk, the magnitude of associations were markedly stronger for MVPA and, particularly, for VPA. Indeed, as much as approximately 500 min per week of MVPA appear needed to fully offset the association with incident CVD.

Our results extend previous observations examining associations between VPA and risk for incident CVD[10 11] by modelling these associations in combination with proxies of abdominal adiposity. The observation that relatively small amounts of VPA offset the association was consistent both when analysing abdominal adiposity using WHO's WC cut-offs and when using WC-for-BMI residuals. We also found that being categorised in the lowest tertile of any physical activity intensity was associated with an increased risk of incident CVD, even when abdominal adiposity was low. Encouraging people with low levels of physical activity to engage in small amounts of VPA may be more appealing compared with large amounts of MVPA to reduce the risk of incident CVD.

We observed that high levels of physical activity were beneficial regardless of BMI strata. However, higher general adiposity, particularly obesity (BMI > 30 kg/m^2), was associated with higher risk of incident CVD irrespective of physical activity. This finding corroborates previous observations from self-reported physical activity data and CVD mortality in women.[23] However, recent evidence suggests that high levels of self-reported physical activity may eliminate the risk of CVD mortality in people with grade I obesity (BMI 30–35 kg/m^2), but not in those with grade II (≥35 kg/m^2).[15] Insufficient statistical power prevented us from analysing associations by obesity grades. Further investigation is needed to determine the extent to which physical activity can mitigate CVD risk across different levels of obesity.

Measurements of WC do not distinguish between subcutaneous and visceral adipose tissue, both metabolically active.[24] During physical activity, subcutaneous adipose tissue in the upper body exhibits high lipolytic rates,[25] while the lower body contributes minimally,[26] and fatty acids used by active muscles mainly originate from subcutaneous abdominal fat.[27] The BMI includes lower-body subcutaneous fat tissue that may act as a metabolic buffer and protect other tissues from lipotoxicity caused by excess lipids and ectopic fat.[28] Moreover, individual variation in visceral adipose tissue exists for individuals with similar BMI, potentially explaining the variability in CVD risk profiles.[2] Thus, it is plausible that physical activity may more effectively mitigate the association between abdominal adiposity and incident CVD compared with total adiposity, particularly when the latter is assessed by BMI. This may also clarify the stronger associations observed between joint WC-physical

activity categories and CVD without BMI adjustment (online supplemental figure 5) compared with the analysis with BMI adjustment (figure 1).

Our results may inform future physical activity recommendations. Current recommendations, primarily based on self-reported physical activity, suggest that 150–300 min of MVPA or 75–150 min of VPA or a combination of both is associated with substantial health benefits. This recommendation considers the same health benefits for half the amount of VPA compared with MVPA. Our results, as well as those from others,[11 29] challenge this concept. We found that approximately 15 times more MVPA was needed to mitigate the association between abdominal adiposity with incident CVD compared with VPA. This difference may be explained by the higher intensity physical activity leading to improvements in cardiorespiratory fitness, a strong marker of cardiovascular health that has been shown to modify the association between obesity and mortality, also known as the fat-but-fit paradox.[30–32] Previous studies have demonstrated that small bouts of VPA can improve cardiorespiratory fitness and have positive cardiovascular effects that may be greater than those from moderate-intensity activity.[33–36] Altogether, our results challenge the notion that substituting half the amount of MVPA with VPA maintains equal health benefits. Future guidelines may prioritise promoting the achievement of small amounts of VPA as a more feasible and time-effective strategy to counteract the CVD risk from abdominal obesity.

Our study's main strength lies in the inclusion of a large sample with WC and BMI measurements performed by clinical staff, reducing self-report bias.We categorised both central (WC) and total adiposity (BMI) based on WHO cut-offs, easily and routinely assessed by clinicians, enabling direct implementation of our findings in clinical practice. To investigate the independent associations of WC with CVD, we adjusted for BMI to isolate the specific contribution of abdominal adiposity to CVD risk.[6] Furthermore, we performed additional analyses using a variable based on WC-for-BMI residuals that confirmed the robustness of our findings. We measured physical activity by wrist-worn accelerometers, which is more accurate than self-report. However, physical activity levels derived from wrist-worn accelerometers are substantially higher than that from waist worn accelerometers.[37] Thus, absolute levels of time spent in moderate and vigorous-intensity and their associations with clinical outcomes are not directly comparable between studies employing different monitor placements.

Limitations

Limitations of our study include the use of WC and the BMI as proxy measures of abdominal and total adiposity, respectively. Also, we used a single baseline assessment of adiposity and covariates, as well as a single accelerometer measurement that was performed about 5 years later. In subsamples of 16 230 and 15 854 participants with repeated WC and BMI assessments in 2014, we observed relatively stable adiposity measures, with 84% remaining in the same WC category and 78% in the same BMI category compared with their baseline measurements. However, we were unable to adjust for potential changes in exposures and covariates. The single measurement of physical activity also limits inference on individual variability of physical activity over time. To mitigate the risk of reverse causation, we excluded participants with prevalent diseases, mobility limitations and events occurring within the initial 2 years of follow-up (5 years in the sensitivity analysis). However, this may not completely eliminate this bias.[38] We also performed multivariate adjustment for numerous potential confounders, but residual bias from unmeasured or insufficiently measured confounders, such as smoking volume, intensity or duration, may still be present. Additionally, UK Biobank is not representative of its source population and there is evidence of healthy volunteer selection bias,[39] which may be accentuated in the subgroup with accelerometer measurements.[10]

Implications for clinical practice and health policy

People living with obesity face difficulties in attaining and maintaining weight loss and in physical activity participation.[40] Our results imply that public health messaging should focus on achieving small amounts of VPA for reducing the risk of incident CVD, instead of only focusing on 'a number on a scale'. This may be especially attractive for those with limited time or motivation for more structured exercise.[36]

Future directions

Future studies should use more precise measures of adiposity, such as DXA scans or MRI, to further explore how physical activity, preferably long-term patterns, can reduce the detrimental effect of excess adipose tissue on CVD risk. Studying the role of intramuscular fat and lean mass tissue's quality and volume in these associations could also provide valuable insights.[41] Additional research may want to include accelerometers attached to other body parts (eg, waist, thigh) to determine potential differences in the amount of physical activity needed to mitigate the risk for incident CVD associated with adiposity compared with the results from wrist-worn devices.

CONCLUSION

Physical activity equivalent to approximately 30–35 min of vigorous intensity per week, measured by wrist-worn accelerometers, appears to offset the association between abdominal obesity and incident CVD. A considerably greater amount of physical activity of at least moderate intensity, approximately 500 min per week, is needed to achieve similar results.

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