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ORIGINAL ARTICLE

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Trends in cardiovascular disease risk factors by BMI category among adults in England, 2003-2018

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Abstract

Objective: This study aimed to estimate trends in cardiovascular disease risk factors by BMI category among adults in England (n = 115,860).

Methods: Risk factors included cigarette smoking, hypertension, total diabetes, and raised total cholesterol. Risk factor prevalence was computed in the following four 4-year time periods: 2003-2006; 2007-2010; 2011-2014; and 2015-2018. Change was computed as the difference between the first and last time periods, expressed in percentage points (PP).

Results: Hypertension remained at a stable level among men with normal weight but decreased among men with obesity (−4.1 PP; 95% CI: −7.1 to −1.0). Total diabetes remained at a stable level among adults with normal weight but increased among adults with obesity (men: 3.5 PP, 95% CI: 1.2 to 5.7; women: 3.6 PP, 95% CI: 1.8 to 5.4). Raised total cholesterol decreased in all BMI groups but fell more sharply among women with obesity (−21 PP; 95% CI: −25 to −17) versus their counterparts with normal weight (−16 PP; 95% CI: −18 to −14).

Conclusions: Greater reductions in hypertension and raised total cholesterol among adults with overweight and obesity partially reflect improvements in screening, treatment, and control among those at highest cardiovascular risk. Higher levels of risk factor prevalence among adults with overweight and obesity, in parallel with rising diabetes, highlight the importance of national prevention efforts to combat the public health impact of excess adiposity.

INTRODUCTION

Individual-level epidemiologic studies have documented the higher rates of cardiovascular disease (CVD) outcomes associated independently with modifiable risk factors (1,2). For example, excess body weight accounted for approximately 4 million deaths worldwide in 2015, and CVD accounted for nearly 70% of deaths related to high BMI, of which more than 60% occurred among persons with obesity (3). At the population level, halting the rises in diabetes and obesity and reducing levels of other CVD risk factors such as current tobacco use, harmful alcohol consumption, insufficient physical activity (PA), intake of salt/sodium, and high blood pressure (BP) are major World Health Organization global targets for reducing overall mortality from the four main noncommunicable diseases by 25% in 2025, relative to 2010 levels (4).

Obesity prevalence among adults has markedly increased in England over the past 25 years, rising from 16% in 1994 to 28% in 2018 (5), with contributory factors that include increases in the availability and affordability of energy-dense foods (3) and environmental barriers to PA. At the same time, prevention efforts via greater chronic disease management may have led to population subgroups at higher risk being screened and tested more frequently (6), potentially improving CVD risk factor profiles through lifestyle advice and/or pharmacological treatment of high levels of BP, cholesterol, and blood glucose.

Monitoring equity in risk factor reduction requires establishing whether any favorable trends at the population level have been achieved equally within high- and low-risk subgroups, including BMI groups (6-8). Risk factor trends at the population level in England have been investigated previously, including studies that have assessed secular changes at the upper tail of the BMI distribution (9). Stability or favorable/unfavorable change in risk factor prevalence at the population level potentially mask divergent trends by BMI group. However, to our knowledge, no studies to date have examined trends in both the prevalence and management of CVD risk factors by BMI category in England. Using data from annual repeated cross-sectional surveys of adults spanning 16 years (Health Survey for England [HSE] 2003-2018), we examined change over time in the prevalence of six key CVD risk factors (4): smoking, physical inactivity, harmful alcohol consumption, hypertension, diabetes, and raised total cholesterol, all examined by BMI category.

Study Importance

What is already known?

- Previous studies in England have highlighted the associations between obesity and higher risk of cardiovascular disease.

What does this study add?

- Changes in key cardiovascular disease risk factors by BMI category showed heterogeneity. Relative to adults with normal weight, levels of hypertension and raised total cholesterol declined faster among adults with obesity, but levels of total diabetes increased.

How might these results change the direction of research or the focus of clinical practice?

- Policy makers and health care professionals need to address underlying mechanisms for rising diabetes prevalence among adults with obesity.

METHODS

The HSE is a series of annual surveys designed to measure health and health-related behaviors. Details of the survey methods have been published elsewhere (10). Briefly, new nationally representative samples of people living in private households were drawn annually using multistage stratified probability sampling. All adults (aged 16 years or older) at each selected household were eligible. Data were collected at two home visits. First, an interviewer administered questionnaires on sociodemographic variables, lifestyle behaviors, general health, and self-reported morbidity and took height and weight measurements. Second, a nurse visited and asked further questions, including questions regarding current prescribed medication, and collected BP as well as additional anthropometric measurements and nonfasting blood samples.

Data on height, weight, smoking, and alcohol consumption were collected annually. BP collection took place annually except for 2004, and blood samples for cholesterol were taken in 2003, 2006, and annually from 2011. Information on self-reported diagnosed diabetes and measurement of glycated hemoglobin (HbA_{1c}) (as a marker for undiagnosed diabetes) was collected in 2006 and annually from 2009. We used comparable self-reported PA data collected in 2008, 2012, and 2016, and alcohol data from 2007 were used to include new questions on wine consumption (11).

Response rates declined over the study period; estimated response rates were 66% in 2003 and 54% in 2018 (interview), 77% in 2003 and 51% in 2018 (nurse visit), and 58% in 2003 and 38% in 2018 (blood samples). Ethical approval was obtained from a National Health Service research ethics committee prior to starting each survey. Participants gave verbal consent to be interviewed, visited by a nurse, and have BP and anthropometric measurements taken, and they provided written consent for blood sampling. No specific approval was required for the present analyses of anonymized data.

Definitions of key variables

Height and weight measurements were taken by trained interviewers using standardized protocols. Height was measured using portable stadiometers with a sliding head plate, a base plate, and connecting rods marked with a measuring scale. One measurement was taken with the head positioned in the Frankfort plane. Digital scales were used for weight measurement. A single measurement was recorded, and participants who were pregnant, unable to stand, or unsteady on their feet were not weighed. BMI was calculated as weight in kilograms divided by height in meters squared, and the World Health Organization classification was used to group participants into four mutually exclusive categories: underweight (<18.5), normal weight (18.5-24.9), overweight (25.0-29.9), and obesity (≥30.0) (12). Separate estimates are presented for class I obesity (30.0-34.9) and classes II and III combined (hereafter referred to as class II-III obesity: BMI ≥ 35.0).

All risk factors were dichotomized. Self-reported cigarette smoking status was categorized as non- (never and ex-regular smokers) and current smokers. Participants were classified as physically inactive if they achieved <30 minutes of moderate-to-vigorous PA per week. Details of the PA questionnaire used in the HSE series have been described elsewhere (13). This definition of inactivity corresponds with that used by Public Health England and Sport England.

Participants who had consumed alcohol in the last week were asked questions regarding the amounts of different types of alcohol consumed on the day they drank the most. We defined excess drinking as drinking over the recommended daily limits on the heaviest drinking day (4 and 3 units for men and women, respectively) (11).

At the nurse visit, three BP readings were taken in a seated position at 1-minute intervals using an appropriately sized cuff after 5 minutes of rest, following standardized protocols by Omron digital monitors (Omron HEM-907; Omron Healthcare Co., Ltd., Kyoto, Japan). Participants who had exercised, eaten, drunk alcohol, or smoked in the 30 minutes before measurements were excluded from analyses. The mean of the second and third BP readings were used. Survey-defined hypertension was defined as systolic BP ≥ 140 mm Hg, diastolic BP ≥ 90 mm Hg, or having reported taking medication prescribed for high BP. We defined and separately analyzed three indicators of hypertension management (diagnosed, treated, and controlled) using the subset of participants classified as hypertensive as the denominator. Diagnosed hypertension was defined as a self-report of having been diagnosed as having high BP by a doctor or nurse. Only those aware of ever having high BP were asked this question; all diagnosed cases were, therefore, aware. Over the study period, two out of three participants with survey-defined hypertension reported ever having high BP. Treated hypertension was defined as a self-report of taking prescribed medication for high BP. Controlled hypertension was defined as having BP levels below recommended target levels (≤140/90 mm Hg) (14).

Participants who reported that their doctor had diagnosed them as having diabetes were classified as having doctor-diagnosed diabetes. HbA_{1c} was measured from EDTA-blood samples and determined by high-performance liquid chromatography (HPLC) using an automated analyzer. Those who did not report diagnosed diabetes were classified as having undiagnosed diabetes if HbA_{1c} was ≥ 6.5% (prior to HSE 2012) or ≥ 48 mmol/mol (HSE 2012-2018). Total diabetes included both doctor-diagnosed and undiagnosed participants (15). Blood samples were taken for serum total cholesterol. Raised total cholesterol was defined as ≥ 5 mmol/L regardless of lipid-lowering medication use, reflecting National Institute for Health and Care Excellence guidelines (16). Adjustments to the measured values of HbA_{1c} and total cholesterol were applied to account for changes in laboratory equipment.

Statistical analysis

Analyses were limited to participants aged 16 years or older (n = 137,645) with valid height and weight data (n = 115,860). Analytic sample sizes varied by CVD risk factor because information was not available in certain HSE years and because of missing data. All analyses were based on complete cases (those with no missing data in the BMI and relevant CVD risk factor variables), and analytic sample sizes were as follows: smoking (n = 115,472), PA (n = 26,051), alcohol consumption (n = 83,969), BP (n = 71,948), diabetes (n = 47,818), and total cholesterol (n = 43,340). The numbers of participants with missing data (for relevant survey years) were as follows: current smoking status (n = 388), PA (n = 155), alcohol consumption (n = 470), BP (n = 43,912), diabetes (n = 42,943), and total cholesterol (n = 36,473). The higher amount of missing data for BP, diabetes, and total cholesterol can be mainly attributed to the fact that not all interviewed persons completed the nurse visit and/or blood sample components of the survey.

We chose a priori to stratify analyses by sex. Available data from four consecutive annual surveys were aggregated into four non-overlapping survey periods (2003-2006, 2007-2010, 2011-2014, and 2015-2018) to boost sample sizes and, therefore, increase the precision of estimates. Risk factor prevalence was estimated by time period for all adults (i.e., all BMI groups combined) and by BMI category (normal weight, overweight, obesity, class I obesity, and class II-III obesity); estimates are not presented for the underweight category because of the low prevalence (2%). Estimates were directly age-standardized (pooled HSE data as the standard population). The absolute change in prevalence was computed as the difference between the first and last time periods, expressed in percentage points (PP). Wald tests were used to test the null hypothesis of no change in prevalence between the two estimates. The same procedure was used to compare the difference in prevalence between the first and last time periods in the overweight and obesity categories versus the normal-weight group. Analyses were repeated on adults with survey-defined hypertension (n = 23,216) to estimate the change in prevalence of diagnosed, treated, and controlled hypertension. Sample sizes were too small to estimate the change in levels of diagnosed diabetes among participants with total diabetes. Therefore, changes in diagnosed and undiagnosed diabetes by BMI category were estimated using all adults as the denominator.

All analyses accounted for the complex survey design, incorporating the appropriate weights that accounted for greater nonparticipation at each successive stage (interview, nurse visit, and blood sample collection) and the geographical clustering of participants in primary sampling units. Statistical significance was set at $p < 0.05$ for two-tailed tests, with no adjustment for multiple comparisons. Ninety-five percent confidence intervals (CI) are used to convey precision. Data set preparation and analysis were performed in SPSS Statistics version 24.0 (IBM Corp., Armonk, New York) and in Stata version 15.1 (StataCorp LLC, College Station, Texas), respectively. HSE data sets, including the most recent survey (17), are available via the UK Data Service (www.ukdataservice.ac.uk) and are subject to an end user license agreement; all reproducible code has been made openly accessible via GitHub (https://github.com/shauns11/RiskFactorsByBMI.git; GitHub Inc., San Francisco, California).

RESULTS

Table 1 shows the characteristics of the analytic sample (n = 115,860 adults with valid height and weight measurements) by 4-year survey period. The proportion of participants aged 75 years or over increased from 7.0% in 2003-2006 to 10.4% in 2015-2018, and the

TABLE 1 Characteristics of the analytic sample by 4-year survey period

	All	2003-2006	2007-2010	2011-2014	2015-2018
	n (%)	*n* (%)	*n* (%)	*n* (%)	*n* (%)
Sample size	115,860 (100)	31,421 (100)	29,708 (100)	28,204 (100)	26,527 (100)
Male	52,667 (50)	14,418 (50)	13,558 (50)	12,772 (50)	11,919 (50)
Age group (y)					
16-34	28,802 (31)	8,222 (31)	7,555 (31)	6,886 (31)	6,139 (30)
35-54	41,273 (36)	11,541 (36)	10,626 (36)	10,051 (35)	9,055 (34)
55-74	35,138 (26)	9,148 (25)	8,838 (25)	8,565 (26)	8,587 (27)
75+	10,647 (8)	2,510 (7)	2,689 (7)	2,702 (8)	2,746 (8)
Degree or equivalent	26,496 (24)	5,747 (19)	6,110 (22)	7,071 (26)	7,568 (30)
White	104,262 (88)	28,894 (91)	26,915 (89)	25,130 (87)	23,323 (86)
BMI (kg/m^2), mean (SD)	27.1 (5.3)	26.9 (5.1)	27.1 (5.2)	27.2 (5.4)	27.5 (5.7)
Weight (kg), mean (SD)	77.2 (17.1)	76.3 (16.5)	77.0 (16.8)	77.4 (17.2)	78.3 (18.0)
Height (m), mean (SD)	1.7 (0.1)	1.7 (0.1)	1.7 (0.1)	1.7 (0.1)	1.7 (0.1)
BMI category					
Underweight	1,776 (2)	472 (2)	450 (2)	428 (2)	426 (2)
Normal weight	40,339 (36)	11,374 (37)	10,423 (37)	9,712 (36)	8,830 (35)
Overweight	43,526 (37)	12,014 (38)	11,205 (37)	10,651 (37)	9,656 (36)
Obesity	30,219 (25)	7,561 (23)	7,630 (25)	7,413 (25)	7,615 (27)
Class I	20,373 (17)	5,228 (16)	5,222 (17)	4,938 (17)	4,925 (18)
Class II-III	9,846 (8)	2,273 (7)	2,408 (8)	2,475 (8)	2,690 (9)

Note: Analytic sample is based on participants with valid height and weight data. Normal weight: BMI 18.5 to 24.9; overweight: BMI 25 to 29.9; obesity: BMI ≥ 30; class I obesity: 30 to 34.9; class II-III obesity: BMI ≥ 35. Estimates are weighted.

proportion with a degree or higher qualification increased from 19% in 2003-2006 to 30% in 2015-2018. BMI increased on average by 0.5, reflecting an increase in mean weight of 1.9 kg.

CVD risk factor prevalence by survey period and BMI category is shown in Table 2 (men) and Table 3 (women). Figure 1 shows the absolute change in prevalence between the first and last time periods, expressed in PP.

Current cigarette smoking

Current cigarette smoking prevalence decreased among all adults in both sexes from 2003-2006 to 2015-2018 (men: −6.5 PP, 95% CI: −7.7 to −5.3; women: −7.8 PP, 95% CI: −8.9 to −6.8). Smoking prevalence varied by BMI category within each time period among men (highest among those with normal weight) but showed no variation among women. Whereas current cigarette smoking prevalence decreased between the first and last time periods among all BMI groups, it fell more sharply for men with normal weight (−8.1 PP; 95% CI: −10.3 to −5.8) versus men with obesity (−3.8 PP; 95% CI: −6.2 to −1.4) (Figure 1).

Physical inactivity

Levels of physical inactivity (<30 minutes of moderate-to-vigorous PA per week) were higher among adults with obesity versus those with normal weight in each survey (2008, 2012, and 2016), especially among women. Inactivity prevalence remained at a stable level among all adults (~18% and ~24% for men and women, respectively). However, stability in prevalence among all adults masked divergent trends by BMI category among women: inactivity prevalence decreased among those with normal weight (−2.8 PP; 95% CI: −5.3 to −0.3) but marginally increased among those with overweight (3.0 PP; 95% CI: −0.4 to 6.3).

Excess alcohol consumption

Levels of drinking above recommended daily alcohol limits decreased in both sexes from 2007-2010 to 2015-2018 (men: −6.8 PP, 95% CI: −8.2 to −5.3; women: −4.7 PP, 95% CI: −5.9 to −3.5). In each time period, levels of drinking above recommended daily limits in men were higher in the overweight group than the normal-weight group, and levels of drinking above recommended daily limits in women were higher among those with normal weight versus those with obesity. Prevalence decreased over time among all BMI groups for both sexes (Figure 1) but change over time (relative to those with normal weight) did not vary by BMI (p > 0.170).

Survey-defined hypertension and indicators of management

Hypertension prevalence (defined as BP ≥ 140/90 mm Hg or taking medication prescribed for high BP) decreased from 2003-2006 to

TABLE 2 Age-standardized risk factor prevalence by BMI group and 4-year survey period in men

	2003-2006	2007-2010	2011-2014	2015-2018	PP change		PP change vs. normal weight	
Risk factor by BMI group	% (95% CI)	% (95% CI)	% (95% CI)	% (95% CI)	% (95% CI)	*p* value	% (95% CI)	*p* value
Current smoking								
All	25.5 (24.7 to 26.3)	23.1 (22.3 to 23.9)	22.4 (21.5 to 23.3)	19.0 (18.1 to 19.9)	−6.5 (−7.7 to −5.3)	<0.001	- - -	- - -
Normal weight	32.2 (30.7 to 33.7)	29.1 (27.6 to 30.7)	27.2 (25.6 to 28.8)	24.2 (22.4 to 25.9)	−8.1 (−10.3 to −5.8)	<0.001	- - -	- - -
Overweight	24.6 (23.4 to 25.8)	20.6 (19.5 to 21.8)	21.1 (19.8 to 22.4)	17.6 (16.2 to 19.0)	−7.0 (−8.9 to −5.2)	<0.001	1.0 (−1.8 to 3.8)	0.481
Obesity	20.6 (18.9 to 22.2)	21.2 (19.4 to 23.0)	21.2 (19.4 to 23.1)	16.7 (15.0 to 18.5)	−3.8 (−6.2 to −1.4)	0.002	4.2 (1.0 to 7.4)	0.010
Class I	21.5 (19.5 to 23.5)	21.8 (19.6 to 23.9)	21.4 (19.2 to 23.6)	16.9 (14.9 to 19.0)	−4.6 (−7.5 to −1.7)	0.002	3.5 (−0.1 to 7.1)	0.055
Class II-III	18.2 (15.1 to 21.2)	19.3 (16.0 to 22.6)	20.8 (17.6 to 24.0)	16.4 (13.4 to 19.4)	−1.8 (−6.1 to 2.5)	0.407	6.3 (1.4 to 11.1)	0.011
Inactivity								
All	- - -	18.2 (17.1 to 19.2)	18.1 (16.6 to 19.6)	18.6 (17.0 to 20.1)	0.4 (−1.5 to 2.3)	0.658	- - -	- - -
Normal weight	- - -	17.0 (15.0 to 18.9)	17.3 (14.4 to 20.1)	16.9 (14.1 to 19.7)	−0.1 (−3.5 to 3.4)	0.967	- - -	- - -
Overweight	- - -	16.3 (14.7 to 17.9)	16.0 (14.0 to 18.1)	17.4 (14.8 to 19.9)	1.1 (−1.9 to 4.0)	0.487	1.1 (−3.4 to 5.6)	0.621
Obesity	- - -	22.8 (20.3 to 25.2)	22.1 (19.0 to 25.1)	23.7 (20.0 to 27.4)	0.9 (−3.5 to 5.4)	0.682	1.0 (−4.5 to 6.5)	0.722
Class I	- - -	21.7 (18.8 to 24.7)	19.5 (16.3 to 22.6)	19.9 (16.6 to 23.1)	−1.9 (−6.3 to 2.5)	0.402	−1.8 (−7.3 to 3.7)	0.518
Class II-III	- - -	26.0 (21.9 to 30.1)	27.9 (21.5 to 34.3)	33.5 (25.3 to 41.7)	7.5 (−1.7 to 16.6)	0.111	7.5 (−2.3 to 17.3)	0.132
Alcohol above daily limits								
All	- - -	42.2 (41.2 to 43.2)	38.4 (37.4 to 39.4)	35.5 (34.4 to 36.5)	−6.8 (−8.2 to −5.3)	<0.001	- - -	
Normal weight	- - -	39.0 (37.3 to 40.6)	35.7 (34.0 to 37.4)	33.8 (32.0 to 35.6)	−5.2 (−7.6 to −2.7)	<0.001	- - -	
Overweight	- - -	44.4 (42.9 to 45.9)	40.1 (38.5 to 41.6)	37.2 (35.6 to 38.8)	−7.2 (−9.4 to −5.0)	<0.001	−2.0 (−5.2 to 1.1)	0.205
Obesity	- - -	42.2 (40.2 to 44.2)	38.7 (36.7 to 40.8)	34.5 (32.4 to 36.6)	−7.7 (−10.6 to −4.7)	<0.001	−2.5 (−6.2 to 1.2)	0.188
Class I	- - -	43.3 (41.0 to 45.6)	40.1 (37.6 to 42.7)	36.5 (33.9 to 39.0)	−6.8 (−10.3 to −3.4)	<0.001	−1.7 (−5.8 to 2.4)	0.425
Class II-III	- - -	38.7 (34.7 to 42.8)	35.8 (32.1 to 39.5)	29.4 (25.6 to 33.2)	−9.3 (−14.9 to −3.8)	0.001	−4.2 (−10.2 to 1.9)	0.176
Hypertension								
All	31.2 (30.3 to 32.1)	31.5 (30.6 to 32.4)	30.4 (29.4 to 31.5)	28.1 (27.1 to 29.2)	−3.0 (−4.4 to −1.7)	<0.001	- - -	
Normal weight	21.2 (19.7 to 22.7)	23.2 (21.6 to 24.9)	19.6 (18.0 to 21.3)	19.7 (17.9 to 21.5)	−1.5 (−3.9 to 0.8)	0.199	- - -	
Overweight	30.5 (29.1 to 31.9)	29.8 (28.4 to 31.1)	30.3 (28.7 to 31.9)	26.0 (24.4 to 27.5)	−4.5 (−6.6 to −2.5)	<0.001	−3.0 (−6.1 to 0.1)	0.056
Obesity	43.5 (41.4 to 45.5)	42.9 (40.7 to 45.2)	42.7 (40.2 to 45.1)	39.4 (37.1 to 41.6)	−4.1 (−7.1 to −1.0)	0.009	−2.5 (−6.3 to 1.2)	0.187
Class I	42.4 (40.0 to 44.8)	40.3 (37.8 to 42.8)	40.4 (37.6 to 43.3)	35.8 (33.2 to 38.4)	−6.6 (−10.1 to −3.1)	<0.001	−5.0 (−9.2 to −0.9)	0.016
Class II-III	47.2 (43.2 to 51.2)	50.8 (46.4 to 55.2)	48.5 (43.8 to 53.3)	48.4 (43.4 to 53.5)	1.2 (−5.2 to 7.6)	0.712	2.7 (−4.1 to 9.5)	0.428

(Continues)

TABLE 2 (Continued)

Risk factor by BMI group	2003-2006 % (95% CI)	2007-2010 % (95% CI)	2011-2014 % (95% CI)	2015-2018 % (95% CI)	PP change % (95% CI)	*p* value	PP change vs. normal weight % (95% CI)	*p* value
Raised total cholesterol								
All	62.0 (60.7 to 63.2)	- - -	51.1 (49.8 to 52.4)	45.7 (44.3 to 47.0)	−16 (−18 to −14)	<0.001	- - -	
Normal weight	55.8 (53.6 to 58.1)	- - -	45.9 (43.6 to 48.2)	41.3 (38.8 to 43.7)	−15 (−18 to −11)	<0.001	- - -	
Overweight	65.4 (63.5 to 67.3)	- - -	56.0 (53.8 to 58.2)	48.9 (46.8 to 51.0)	−16 (−19 to −14)	<0.001	−1.9 (−6.2 to 2.5)	0.398
Obesity	68.6 (65.4 to 71.7)	- - -	56.6 (53.5 to 59.8)	49.0 (46.0 to 52.1)	−20 (−24 to −15)	<0.001	−5.0 (−10.6 to 0.7)	0.084
Class I	70.3 (66.9 to 73.7)	- - -	57.3 (53.7 to 60.9)	49.5 (45.9 to 53.2)	−21 (−26 to −16)	<0.001	−6.2 (−12.3 to 0.0)	0.049
Class II-III	61.2 (54.6 to 67.8)	- - -	53.9 (47.8 to 59.9)	49.3 (42.9 to 55.8)	−12 (−21 to −3)	0.012	2.7 (−7.1 to 12.6)	0.583

Note: Estimates age-standardized to the pooled HSE data; - - - denotes comparable data not available. Normal weight: BMI 18.5 to 24.9; overweight: BMI 25 to 29.9; obesity: BMI ≥ 30; class I obesity: BMI 30 to 34.9; class II-III obesity: BMI ≥ 35. Estimates for total diabetes are shown in Table 5. *p* values obtained using Wald tests.

2015-2018 (men: −3.0 PP, 95% CI: −4.4 to −1.7; women: −2.9 PP, 95% CI: −4.0 to −1.8). Hypertension prevalence showed a strong graded association in both sexes in each time period, being highest among adults with obesity. Hypertension prevalence decreased among all BMI groups for both sexes (by 3 to 4 PP), although there was no statistically significant change among men with normal weight (−1.5 PP; 95% CI: −3.9 to 0.8; $p = 0.199$).

Among participants with hypertension, levels of diagnosed, treated, and controlled hypertension by survey period and BMI category are shown in Table 4; Figure 2 shows the change in prevalence between the first and last time periods. The pattern of change (relative to those with normal weight) was similar by BMI for both sexes ($p > 0.100$), and the proportion of hypertension that was diagnosed remained at a similar level, whereas proportions of hypertension that were treated and controlled improved during the study period.

Total diabetes, including diagnosed and undiagnosed

Estimates of total diabetes, including diagnosed and undiagnosed (elevated HbA_{1c}), are shown in Table 5 (Figure 3 shows the change in prevalence between the first and last time periods). Total diabetes increased from 2003-2006 to 2015-2018 (men: 2.3 PP, 95% CI: 1.3 to 3.2; women: 2.0 PP, 95% CI: 1.3 to 2.7). As with hypertension, total diabetes showed a strong graded association in both sexes in each time period, being highest among adults with obesity. The secular increase in total diabetes among all adults masked divergent trends by BMI category. Among men, total diabetes prevalence remained stable among adults with normal weight (1.1 PP; 95% CI: −0.4 to 2.6) but increased among adults with overweight (1.5 PP; 95% CI: 0.2 to 2.7) and obesity (3.5 PP; 95% CI: 1.2 to 5.7). A similar finding was observed for women.

Based on all adults as the denominator, levels of diagnosed diabetes increased among adults with overweight (men: 1.2 PP, 95% CI: 0.1 to 2.3; women: 1.7 PP, 95% CI: 0.6 to 2.7) and among women with obesity (2.6 PP; 95% CI: 1.0 to 4.2). Levels of undiagnosed diabetes increased only among adults with obesity (men: 1.8 PP, 95% CI: 0.2 to 3.4; women: 1.0 PP, 95% CI: 0.1 to 1.9). Relative to their counterparts with normal weight, levels of diagnosed diabetes increased among adults with overweight and obesity in women, but not in men.

Raised total cholesterol

Levels of raised total cholesterol (≥ 5 mmol/L) decreased from 2003-2006 to 2015-2018 (men: −16 PP, 95% CI: −18 to −14; women: −16 PP, 95% CI: −18 to −15). Cross-sectionally, raised total cholesterol prevalence was highest among adults with overweight and obesity. Raised total cholesterol prevalence decreased among all BMI groups but fell more sharply among women with obesity (−21 PP; 95% CI: −25 to −17) versus their counterparts with normal weight (−16 PP; 95% CI: −18 to −14).

TABLE 3 Age-standardized risk factor prevalence by BMI group and 4-year survey period in women

Risk factor by BMI group	2003-2006	2007-2010	2011-2014	2015-2018	PP change		PP change vs. normal weight	
	% (95% CI)	% (95% CI)	% (95% CI)	% (95% CI)	% (95% CI)	*p* value	% (95% CI)	*p* value
Current smoking								
All	23.4 (22.7 to 24.2)	20.1 (19.4 to 20.8)	17.8 (17.1 to 18.5)	15.6 (14.9 to 16.3)	−7.8 (−8.9 to −6.8)	<0.001	- - -	- - -
Normal weight	25.1 (24.0 to 26.2)	20.8 (19.7 to 21.9)	18.1 (17.0 to 19.2)	16.0 (14.9 to 17.2)	−9.1 (−10.7 to −7.5)	<0.001	- - -	- - -
Overweight	22.5 (21.3 to 23.7)	20.0 (18.8 to 21.2)	17.8 (16.6 to 19.0)	15.3 (14.1 to 16.5)	−7.2 (−8.9 to −5.5)	<0.001	1.9 (−0.4 to 4.1)	0.099
Obesity	22.9 (21.4 to 24.3)	20.8 (19.3 to 22.2)	18.0 (16.6 to 19.4)	15.6 (14.3 to 16.8)	−7.3 (−9.2 to −5.4)	<0.001	1.7 (−0.7 to 4.2)	0.162
Class I	23.3 (21.5 to 25.2)	20.1 (18.3 to 21.9)	17.6 (15.8 to 19.3)	15.6 (13.9 to 17.2)	−7.8 (−10.2 to −5.3)	<0.001	1.3 (−1.6 to 4.2)	0.375
Class II-III	22.3 (20.0 to 24.6)	21.9 (19.6 to 24.2)	18.6 (16.5 to 20.8)	15.3 (13.4 to 17.3)	−7.0 (−10.0 to −3.9)	<0.001	2.1 (−1.3 to 5.5)	0.223
Inactivity								
All	- - -	23.6 (22.5 to 24.6)	24.4 (22.8 to 25.9)	23.2 (21.6 to 24.8)	−0.4 (−2.3 to 1.5)	0.710	- - -	- - -
Normal weight	- - -	20.5 (19.0 to 22.0)	19.3 (17.0 to 21.6)	17.7 (15.7 to 19.7)	−2.8 (−5.3 to −0.3)	0.027	- - -	- - -
Overweight	- - -	20.2 (18.5 to 21.8)	23.3 (20.7 to 25.8)	23.2 (20.3 to 26.0)	3.0 (−0.4 to 6.3)	0.080	5.8 (1.8 to 9.8)	0.004
Obesity	- - -	31.5 (29.1 to 33.8)	31.3 (28.0 to 34.5)	31.2 (27.6 to 34.7)	−0.3 (−4.5 to 3.9)	0.887	2.5 (−2.3 to 7.3)	0.308
Class I	- - -	28.5 (25.8 to 31.3)	30.3 (26.1 to 34.5)	28.7 (24.2 to 33.1)	0.1 (−5.1 to 5.3)	0.960	2.9 (−2.7 to 8.6)	0.309
Class II-III	- - -	36.7 (32.6 to 40.8)	33.1 (28.3 to 37.9)	34.6 (29.3 to 39.9)	−2.1 (−8.8 to 4.6)	0.539	0.7 (−6.4 to 7.8)	0.844
Alcohol above daily limits								
All	- - -	32.4 (31.5 to 33.2)	28.6 (27.7 to 29.4)	27.7 (26.8 to 28.6)	−4.7 (−5.9 to −3.5)	<0.001	- - -	- - -
Normal weight	- - -	34.3 (33.1 to 35.5)	30.5 (29.2 to 31.7)	30.7 (29.4 to 32.0)	−3.5 (−5.3 to −1.8)	<0.001	- - -	- - -
Overweight	- - -	34.0 (32.5 to 35.4)	30.3 (28.9 to 31.8)	29.2 (27.7 to 30.7)	−4.8 (−6.9 to −2.7)	<0.001	−1.2 (−3.9 to 1.4)	0.361
Obesity	- - -	27.6 (26.0 to 29.1)	23.8 (22.3 to 25.3)	23.1 (21.6 to 24.6)	−4.5 (−6.7 to −2.4)	<0.001	−1.0 (−3.7 to 1.8)	0.491
Class I	- - -	27.9 (26.0 to 29.8)	25.3 (23.4 to 27.3)	24.3 (22.4 to 26.3)	−3.5 (−6.2 to −0.8)	0.010	0.0 (−3.2 to 3.2)	0.998
Class II-III	- - -	27.3 (24.8 to 29.7)	21.4 (19.1 to 23.7)	21.3 (19.0 to 23.5)	−6.0 (−9.3 to −2.7)	<0.001	−2.5 (−6.2 to 1.3)	0.201
Hypertension								
All	27.1 (26.4 to 27.8)	27.8 (27.0 to 28.5)	25.7 (24.9 to 26.4)	24.2 (23.4 to 25.0)	−2.9 (−4.0 to −1.8)	<0.001	- - -	- - -
Normal weight	20.9 (19.7 to 22.0)	19.7 (18.5 to 20.8)	18.3 (17.1 to 19.4)	16.5 (15.4 to 17.6)	−4.3 (−5.9 to −2.7)	<0.001	- - -	- - -
Overweight	26.3 (25.1 to 27.4)	26.2 (25.0 to 27.4)	24.7 (23.5 to 25.9)	23.2 (21.9 to 24.5)	−3.1 (−4.8 to −1.4)	<0.001	1.2 (−1.1 to 3.6)	0.305
Obesity	37.6 (35.9 to 39.3)	40.7 (39.0 to 42.5)	36.6 (35.0 to 38.2)	34.3 (32.5 to 36.1)	−3.3 (−5.8 to −0.8)	0.009	1.0 (−1.9 to 4.0)	0.491
Class I	34.3 (32.3 to 36.2)	35.5 (33.6 to 37.4)	34.2 (32.3 to 36.2)	30.0 (27.9 to 32.0)	−4.3 (−7.1 to −1.5)	0.003	0.0 (−3.2 to 3.3)	0.987
Class II-III	43.4 (40.4 to 46.3)	50.3 (47.0 to 53.6)	40.5 (37.7 to 43.3)	40.7 (37.6 to 43.9)	−2.6 (−7.0 to 1.7)	0.232	1.7 (−2.9 to 6.3)	0.471

(Continues)

TABLE 3 (Continued)

Risk factor by BMI group	2003-2006	2007-2010	2011-2014	2015-2018	PP change		PP change vs. normal weight	
	% (95% CI)	% (95% CI)	% (95% CI)	% (95% CI)	% (95% CI)	*p* value	% (95% CI)	*p* value
Raised total cholesterol								
All	64.7 (63.6 to 65.7)	- - -	52.5 (51.3 to 53.6)	48.2 (47.0 to 49.4)	−16 (−18 to −15)	<0.001	- - -	- - -
Normal weight	62.3 (60.7 to 63.9)	- - -	51.1 (49.4 to 52.8)	46.2 (44.5 to 47.9)	−16 (−18 to −14)	<0.001	- - -	- - -
Overweight	66.0 (63.9 to 68.0)	- - -	54.2 (52.3 to 56.1)	50.9 (48.4 to 53.3)	−15 (−18 to −12)	<0.001	0.9 (−3.0 to 4.9)	0.635
Obesity	71.1 (68.6 to 73.7)	- - -	55.8 (53.1 to 58.5)	50.1 (47.4 to 52.7)	−21 (−25 to −17)	<0.001	−5.0 (−9.3 to −0.6)	0.025
Class I	72.0 (68.9 to 75.0)	- - -	57.7 (54.3 to 61.2)	50.0 (47.0 to 53.0)	−22 (−26 to −18)	<0.001	−5.8 (−10.8 to −0.9)	0.021
Class II-III	69.8 (65.5 to 74.0)	- - -	52.3 (48.2 to 56.5)	49.4 (45.1 to 53.8)	−20 (−26 to −14)	<0.001	−4.3 (−10.8 to 2.3)	0.200

Note: Estimates age-standardized to the pooled HSE data; - - - denotes comparable data not available. Normal weight: BMI 18.5 to 24.9; overweight: BMI 25 to 29.9; obesity: BMI ≥ 30; class I obesity: BMI 30 to 34.9; class II-III obesity: BMI ≥ 35. Estimates for total diabetes are shown in Table 5. *p* values obtained using Wald tests.

DISCUSSION

Using data spanning 16 years (2003-2018), we examined change over time in the prevalence of six key CVD risk factors by BMI category. Although levels of physical inactivity and consumption of alcohol above daily limits (on the heaviest drinking day) were stable and decreased in all BMI groups, respectively, a number of risk factors showed divergent trends. First, although current cigarette smoking prevalence decreased among all BMI groups, it declined more slowly among men with obesity. Second, hypertension prevalence decreased among all BMI groups for both sexes except among men with normal weight. Third, among both sexes, total diabetes prevalence remained stable among adults with normal weight but increased among adults with overweight and obesity. Fourth, raised total cholesterol prevalence decreased among all BMI groups for both sexes but fell more sharply among women with obesity.

Comparisons with other studies

Among adults with overweight and obesity, our findings of 1) decreases in hypertension and raised cholesterol and 2) increases in diabetes agree with similar analyses of the United States National Health and Nutrition Examination Survey. Among adults aged 20 to 74 years with overweight and obesity, Gregg and colleagues, using 1960-2000 data, found 1) decreasing levels of high BP and current smoking, 2) a stable level of total diabetes, and 3) an increase in diagnosed diabetes (7). Increases in treated hypertension were larger among adults with overweight and obesity than for lean (BMI < 25) adults (7). Among adults with obesity, Saydah and colleagues, using 1999-2010 data, found 1) stable levels of self-reported smoking, total diabetes, undiagnosed diabetes, and hypertension and 2) a decrease in untreated hypertension (6). Guo and Garvey, using 1999-2014 data, reported a significant increase in mean HbA1c among adults with obesity, whereas mean BP and lipid metrics improved (18).

Population-level trends in CVD risk factor prevalence

In agreement with the population-level trends presented herein, previous studies using HSE data have shown decreases in current cigarette smoking (19), hypertension (19), and raised total cholesterol (19), as well as stability in PA (13,20) and increases in total diabetes (19) and obesity (5). Multiple policies have been enacted in England over the study period that have likely affected these trends. These included attempts to standardize and improve the management of chronic diseases in primary care settings (e.g., financially incentivized screening and treatment of hypertension and dyslipidemia with lifestyle advice and/or medications) (21) and published National Institute for Health and Care Excellence guidelines that recommended targeted screening to identify undiagnosed diabetes in asymptomatic populations (22). National health promotional

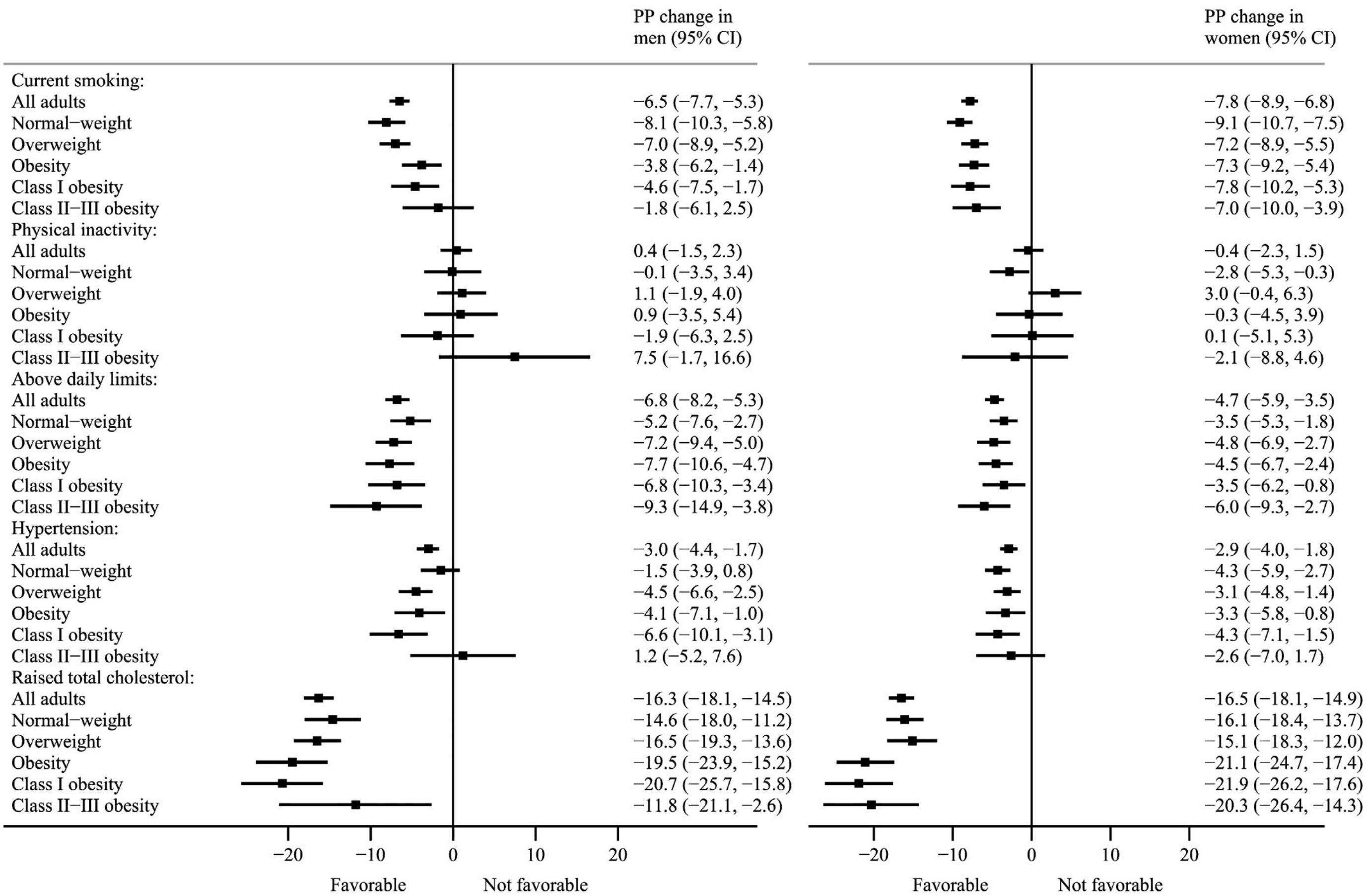

FIGURE 1 Absolute change in CVD risk factor prevalence (2003-2006 to 2015-2018) by BMI category and sex. CVD, cardiovascular disease; PP, percentage points

activities included a widely marketed mass media "This Girl Can" campaign to increase PA (23). Voluntary targets for industry were set by governments, such as reducing the salt content of processed foods (24). Whole-population based strategies included tobacco control policies such as smoke-free legislation, higher taxation, a higher minimum age of sale of cigarettes, licensing of nicotine replacement therapy for harm reduction, and introduction of plain packaging (25).

Despite these policies, the population-level trends in CVD risk factors show both favorable and unfavorable changes. The decline in current cigarette smoking prevalence has been linked to the tobacco control policies listed above (26). The recent fall in survey-defined hypertension is typically attributed to decreased salt intake in foods (24) and improved detection, treatment, and control of high BP, although levels of management remain suboptimal (27). Although levels of glycemic control have improved across all social groups (28), the rise in total diabetes reflects both improved case ascertainment and increases in incidence associated with rising obesity (through numerous pathophysiological mechanisms that increase the risk of type II diabetes among adults with obesity) (29). Longer survival for those with diabetes is also a potential contributory factor (30). The increased uptake and efficacy of lipid-lowering medications such as statins for the primary prevention of CVD within UK primary care during the study period (31) may be a key driver of the reduction in raised total cholesterol prevalence.

Divergent trends in CVD risk factor prevalence by BMI category

A number of factors have likely contributed to the divergent trends in risk factors by BMI category. Larger reductions in the prevalence of survey-defined hypertension and raised total cholesterol among adults with overweight and obesity may reflect, at least partially, the results of the aforementioned targeted efforts to improve chronic disease management in primary care settings (6,7). In terms of CVD risk profile, diagnosing existing cases of diabetes is generally beneficial, particularly for BP and lipid modification as well as glycemic control, resulting in a stalling or reduction of risk factor progression despite advancing disease (15). Worldwide reductions in raised levels of BP and cholesterol through improved treatment and/or changes in other risks have contributed to the fall in CVD rates worldwide despite increases in BMI (3).

In contrast, the slower fall in cigarette smoking prevalence among men with obesity, albeit from a lower prevalence in the first

TABLE 4 Levels of diagnosed, treated, and controlled hypertension by BMI group, gender, and 4-year survey period

Hypertension management indicator by BMI category	2003-2006	2007-2010	2011-2014	2015-2018	PP change		PP change vs. normal weight	
	% (95% CI)	% (95% CI)	% (95% CI)	% (95% CI)	% (95% CI)	*p* value	% (95% CI)	*p* value
Men								
Diagnosed								
All	55.3 (53.1 to 57.6)	57.0 (54.1 to 59.9)	58.0 (55.8 to 60.1)	59.0 (56.9 to 61.0)	3.6 (0.6 to 6.6)	0.018	- - -	- - -
Normal weight	46.3 (40.5 to 52.0)	39.8 (32.3 to 47.3)	51.1 (45.6 to 56.7)	49.3 (44.1 to 54.6)	3.1 (−4.7 to 10.9)	0.437	- - -	- - -
Overweight	55.4 (52.3 to 58.4)	56.1 (51.8 to 60.4)	54.8 (51.5 to 58.1)	57.7 (54.5 to 60.9)	2.3 (−2.1 to 6.8)	0.300	−0.7 (−9.7 to 8.2)	0.871
Obesity	60.5 (56.7 to 64.2)	65.3 (60.8 to 69.8)	63.6 (60.3 to 66.9)	63.8 (60.8 to 66.9)	3.4 (−1.4 to 8.2)	0.169	0.3 (−8.9 to 9.5)	0.950
Class I	57.6 (53.5 to 61.8)	63.3 (58.2 to 68.5)	61.7 (57.6 to 65.7)	62.0 (58.2 to 65.8)	4.4 (−1.3 to 10.0)	0.131	1.3 (−8.4 to 11.0)	0.798
Class II-III	69.9 (62.6 to 77.3)	74.0 (66.0 to 82.0)	67.5 (61.8 to 73.2)	67.3 (62.2 to 72.4)	−2.6 (−11.6 to 6.3)	0.561	−5.7 (−17.5 to 6.0)	0.339
Treated								
All	40.0 (38.4 to 41.7)	46.9 (45.1 to 48.6)	48.8 (46.9 to 50.6)	50.4 (48.5 to 52.4)	10.4 (7.9 to 13.0)	<0.001	- - -	- - -
Normal weight	33.6 (29.6 to 37.7)	39.9 (35.5 to 44.3)	40.1 (35.3 to 44.9)	41.2 (36.2 to 46.2)	7.6 (1.1 to 14.0)	0.021	- - -	- - -
Overweight	38.5 (36.2 to 40.8)	44.7 (42.2 to 47.2)	45.6 (43.0 to 48.3)	47.3 (44.2 to 50.4)	8.8 (4.9 to 12.7)	<0.001	1.2 (−6.4 to 8.8)	0.755
Obesity	45.6 (42.8 to 48.3)	51.8 (49.1 to 54.6)	55.6 (52.8 to 58.5)	56.9 (54.0 to 59.8)	11.3 (7.4 to 15.3)	<0.001	3.7 (−3.8 to 11.3)	0.329
Class I	43.0 (40.0 to 46.1)	49.6 (46.5 to 52.8)	53.2 (49.8 to 56.6)	52.4 (48.9 to 55.9)	9.4 (4.8 to 14.0)	<0.001	1.8 (−6.2 to 9.8)	0.658
Class II-III	53.6 (47.8 to 59.4)	57.7 (52.3 to 63.1)	61.3 (56.5 to 66.0)	65.3 (60.9 to 69.8)	11.7 (4.5 to 19.0)	0.002	4.1 (−5.4 to 13.7)	0.394
Controlled								
All	20.0 (18.6 to 21.4)	27.4 (25.8 to 29.0)	30.3 (28.6 to 32.1)	32.9 (31.0 to 34.8)	12.9 (10.6 to 15.3)	<0.001	- - -	- - -
Normal weight	15.9 (12.4 to 19.4)	24.6 (20.7 to 28.6)	25.9 (21.6 to 30.3)	27.0 (22.4 to 31.6)	11.1 (5.3 to 16.8)	<0.001	- - -	- - -
Overweight	19.0 (17.0 to 20.9)	26.6 (24.3 to 28.9)	28.4 (25.9 to 30.9)	30.3 (27.4 to 33.1)	11.3 (7.8 to 14.8)	<0.001	0.2 (−6.6 to 7.0)	0.955
Obesity	23.3 (20.8 to 25.8)	29.3 (26.7 to 31.9)	34.3 (31.4 to 37.1)	37.4 (34.6 to 40.3)	14.1 (10.3 to 17.9)	<0.001	3.1 (−3.9 to 10.0)	0.390
Class I	22.6 (19.9 to 25.4)	28.0 (25.0 to 31.0)	33.1 (29.7 to 36.4)	34.4 (31.0 to 37.7)	11.8 (7.4 to 16.1)	<0.001	0.7 (−6.6 to 8.0)	0.855
Class II-III	26.3 (20.4 to 32.2)	32.7 (27.3 to 38.1)	37.2 (31.9 to 42.5)	43.0 (37.7 to 48.3)	16.7 (8.8 to 24.6)	<0.001	5.6 (−4.2 to 15.4)	0.262
Women								
Diagnosed								
All	60.5 (58.2 to 62.9)	65.3 (62.3 to 68.3)	65.9 (63.8 to 68.0)	63.5 (61.5 to 65.4)	3.0 (−0.1 to 6.0)	0.056	- - -	- - -
Normal weight	53.3 (48.6 to 58.1)	56.1 (49.7 to 62.5)	57.1 (52.3 to 62.0)	57.5 (53.2 to 61.9)	4.2 (−2.2 to 10.6)	0.202	- - -	- - -
Overweight	58.4 (54.8 to 62.1)	62.3 (57.2 to 67.4)	66.6 (63.0 to 70.2)	61.1 (57.6 to 64.5)	2.6 (−2.5 to 7.7)	0.313	−1.6 (−9.6 to 6.5)	0.702
Obesity	68.3 (64.8 to 71.8)	72.3 (68.2 to 76.4)	71.0 (68.0 to 74.0)	68.5 (65.6 to 71.4)	0.2 (−4.4 to 4.7)	0.936	−4.0 (−11.7 to 3.8)	0.313
Class I	66.3 (61.9 to 70.8)	71.9 (66.8 to 77.1)	70.3 (66.5 to 74.1)	67.5 (63.6 to 71.3)	1.1 (−4.7 to 7.0)	0.704	−3.0 (−11.7 to 5.6)	0.493
Class II-III	73.2 (67.4 to 79.0)	72.1 (65.4 to 78.8)	72.8 (68.2 to 77.5)	69.4 (65.0 to 73.8)	−3.8 (−11.1 to 3.5)	0.307	−8.0 (−17.5 to 1.6)	0.102

(Continues)

TABLE 4 (Continued)

Hypertension management indicator by BMI category	2003-2006	2007-2010	2011-2014	2015-2018	PP change		PP change vs. normal weight	
	% (95% CI)	% (95% CI)	% (95% CI)	% (95% CI)	% (95% CI)	*p* value	% (95% CI)	*p* value
Treated								
All	49.9 (48.1 to 51.8)	56.9 (55.1 to 58.7)	58.8 (57.1 to 60.6)	58.2 (56.3 to 60.1)	8.2 (5.6 to 10.9)	<0.001	- - -	- - -
Normal weight	40.5 (36.9 to 44.0)	46.6 (42.9 to 50.3)	51.2 (47.3 to 55.2)	49.4 (45.1 to 53.6)	8.9 (3.4 to 14.4)	0.002	- - -	- - -
Overweight	47.9 (45.0 to 50.8)	54.6 (51.6 to 57.6)	59.4 (56.3 to 62.4)	57.1 (53.7 to 60.6)	9.2 (4.7 to 13.8)	<0.001	0.4 (−6.7 to 7.5)	0.918
Obesity	58.4 (55.6 to 61.2)	64.5 (62.0 to 67.1)	63.6 (61.0 to 66.2)	64.1 (61.4 to 66.9)	5.8 (1.8 to 9.7)	0.004	−3.1 (−9.8 to 3.6)	0.363
Class I	56.1 (52.6 to 59.6)	61.9 (58.5 to 65.2)	62.1 (58.7 to 65.5)	60.2 (56.5 to 63.9)	4.1 (−1.0 to 9.2)	0.116	−4.8 (−12.3 to 2.7)	0.210
Class II-III	63.2 (58.4 to 67.9)	68.5 (64.4 to 72.6)	66.5 (62.5 to 70.5)	68.2 (64.0 to 72.4)	5.0 (−1.3 to 11.4)	0.122	−3.8 (−12.1 to 4.4)	0.361
Controlled								
All	24.9 (23.3 to 26.4)	31.7 (29.9 to 33.4)	36.6 (34.8 to 38.5)	35.8 (33.9 to 37.7)	10.9 (8.5 to 13.4)	<0.001	- - -	- - -
Normal weight	20.0 (17.0 to 23.0)	27.1 (23.7 to 30.5)	30.4 (26.6 to 34.2)	32.4 (28.3 to 36.5)	12.4 (7.4 to 17.5)	<0.001	- - -	- - -
Overweight	23.9 (21.5 to 26.4)	30.6 (27.8 to 33.4)	38.6 (35.4 to 41.7)	35.3 (32.0 to 38.6)	11.3 (7.2 to 15.5)	<0.001	−1.1 (−7.6 to 5.4)	0.744
Obesity	28.9 (26.2 to 31.6)	35.2 (32.5 to 38.0)	39.4 (36.5 to 42.3)	38.3 (35.3 to 41.3)	9.4 (5.4 to 13.4)	<0.001	−3.0 (−9.5 to 3.4)	0.361
Class I	28.2 (25.0 to 31.3)	32.1 (28.6 to 35.5)	38.6 (35.0 to 42.2)	35.6 (31.6 to 39.5)	7.4 (2.4 to 12.4)	0.004	−5.0 (−12.2 to 2.1)	0.167
Class II-III	31.1 (26.1 to 36.2)	39.7 (35.0 to 44.4)	40.9 (35.9 to 45.9)	41.4 (36.7 to 46.1)	10.3 (3.4 to 17.2)	0.004	−2.1 (−10.7 to 6.5)	0.627

Note: Hypertension defined as BP ≥ 140/90 mm Hg or reported taking medication prescribed for high BP. - - - denotes comparable data not available. Estimates age-standardized to the pooled HSE data (persons with hypertension). Normal weight: BMI 18.5 to 24.9; overweight: BMI 25 to 29.9; obesity: BMI ≥ 30; class I obesity: BMI 30 to 34.9; class II-III obesity: BMI ≥ 35. *p* values obtained using Wald tests.

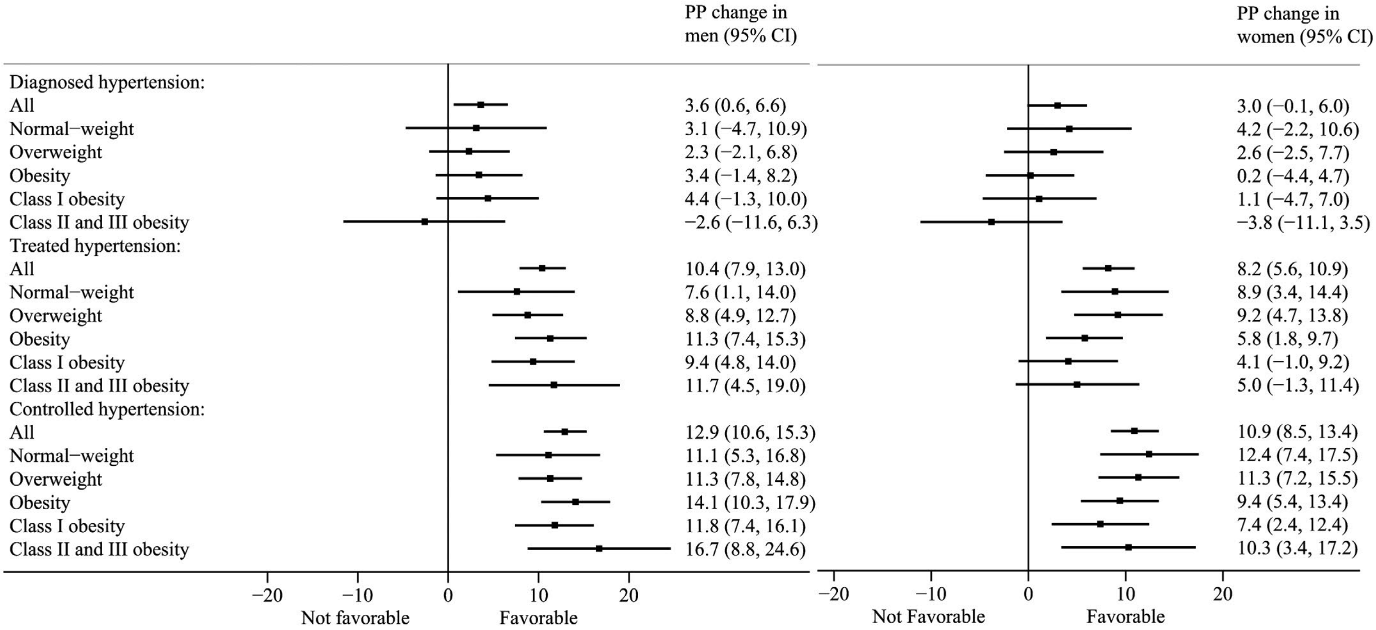

FIGURE 2 Absolute change in diagnosed, treated, and controlled hypertension (2003-2006 to 2015-2018) by BMI category and sex. PP, percentage points

survey period (2003-2006), and the marginal increase in inactivity prevalence among women with overweight, may, to some extent, reflect influences of living in obesogenic environments (32): i.e., neighborhoods with higher socioeconomic deprivation, geographic barriers to PA, and lower air quality that may influence adiposity levels over and above other individual characteristics (33). Reverse causality, i.e., a reluctance of smokers to tolerate post-cessation weight gain (34) and the fact that higher adiposity in itself is a risk factor for smoking (35) which makes it more difficult to quit, is also a potential contributory factor for the slower decline in current smoking levels among men with obesity.

Strengths and limitations

The main strengths of our study include the use of repeated nationally representative health examination surveys that objectively measured anthropometry, BP, cholesterol, and HbA1c using standardized protocols over the 16-year study period, thereby eliminating self-report bias for these factors (36). Stratifying results by sex enabled us to identify differences in the patterns of change over time; our use of direct standardization removed the potential confounding influence of age.

The present study has a number of limitations. Our study is descriptive; therefore, it does not directly address the underlying causes of the recent divergent trends in CVD risk factors by BMI. Use of repeated cross-sectional surveys with new samples drawn annually precludes assessment of within-individual change in BMI or risk factors. Data on smoking, alcohol consumption, PA, and diagnosed diabetes relied on self-reported information and may be subject to recall and social-desirability bias. Despite the pooling of annual data to improve precision, limitations of sample size meant that we could not examine trends in risk factors by BMI within different minority ethnic groups or examine trends in diagnosed diabetes among those with total diabetes. Response rates to the HSE have declined over time, creating the potential for increased bias in the most recent survey years, although the overall survey response rate, in and of itself, is not a good indicator of the level of nonresponse bias (37). In the present study, participants who were interviewed but excluded from the analytic sample because of missing anthropometry data were significantly older, less educated, and less likely to report very good/good general health; this proportion has also increased over time, from 12% in 2003 to 18% in 2018 (data not shown). As expected, there was a lower response rate to the nurse visit and blood sample collection, which resulted in fewer people who were interviewed at the first stage with information on hypertension and diabetes. We used nonresponse weights available with the data, including specially designed weights to account for some of the bias in the propensity to respond at the later stages, to minimize the impact of response bias on our findings; nevertheless, our findings may underestimate the differences in risk factor prevalence by BMI and overestimate the magnitude of favorable trends. Finally, changes in clinical guidelines for reducing high levels of BP, total cholesterol, and HbA1c can make the long-term interpretation of trends difficult, as adults would be more likely to be treated at lower levels of CVD risk in the most recent surveys (7). However, the elevated levels of BP (≥ 140/90 mm Hg) (14), total cholesterol (≥ 5 mmol/L), and HbA1c (≥ 48 mmol/mol) (38) used were based on guidelines relevant for the whole study period.

TABLE 5 Levels of total diabetes, including diagnosed and undiagnosed diabetes, by BMI group, gender, and 4-year survey period

Diabetes by BMI category	2003-2006	2007-2010	2011-2014	2015-2018	PP change		PP change vs. normal weight	
	% (95% CI)	% (95% CI)	% (95% CI)	% (95% CI)	% (95% CI)	*p* value	% (95% CI)	*p* value
Men								
Total diabetes								
All	5.9 (5.3 to 6.5)	7.4 (6.4 to 8.4)	8.0 (7.4 to 8.7)	8.1 (7.4 to 8.9)	2.3 (1.3 to 3.2)	<0.001	- - -	- - -
Normal weight	3.1 (2.2 to 4.0)	2.7 (1.4 to 4.0)	4.4 (3.4 to 5.4)	4.2 (2.9 to 5.4)	1.1 (−0.4 to 2.6)	0.158	- - -	- - -
Overweight	5.1 (4.2 to 5.9)	6.1 (4.9 to 7.4)	5.7 (4.9 to 6.5)	6.5 (5.6 to 7.5)	1.5 (0.2 to 2.7)	0.023	0.4 (−1.5 to 2.2)	0.700
Obesity	10.4 (8.9 to 11.9)	12.8 (10.5 to 15.0)	14.9 (13.2 to 16.6)	13.9 (12.2 to 15.6)	3.5 (1.2 to 5.7)	0.003	2.4 (−0.2 to 5.0)	0.076
Class I	8.4 (6.9 to 10.0)	11.2 (8.7 to 13.8)	12.3 (10.4 to 14.2)	11.4 (9.6 to 13.3)	3.0 (0.6 to 5.5)	0.015	1.9 (−0.8 to 4.7)	0.170
Class II-III	17.5 (13.4 to 21.5)	18.3 (13.2 to 23.5)	22.6 (18.9 to 26.4)	20.4 (16.7 to 24.1)	3.0 (−2.5 to 8.4)	0.291	1.8 (−3.8 to 7.5)	0.524
Diagnosed								
All	4.2 (3.7 to 4.7)	5.5 (4.6 to 6.3)	5.9 (5.3 to 6.4)	5.9 (5.3 to 6.5)	1.7 (0.9 to 2.5)	<0.001	- - -	- - -
Normal weight	2.3 (1.5 to 3.1)	2.2 (1.0 to 3.3)	3.7 (2.8 to 4.6)	3.7 (2.4 to 4.9)	1.4 (−0.1 to 2.8)	0.063	- - -	- - -
Overweight	3.6 (2.8 to 4.4)	4.4 (3.3 to 5.4)	4.2 (3.6 to 4.9)	4.8 (4.0 to 5.6)	1.2 (0.1 to 2.3)	0.039	−0.2 (−2.0 to 1.6)	0.825
Obesity	7.5 (6.1 to 8.8)	9.3 (7.4 to 11.3)	10.3 (8.9 to 11.6)	9.2 (8.0 to 10.3)	1.7 (−0.1 to 3.5)	0.062	0.3 (−2.0 to 2.6)	0.790
Class I	5.7 (4.4 to 7.1)	8.0 (5.9 to 10.1)	8.3 (6.8 to 9.8)	7.5 (6.3 to 8.8)	1.8 (0.0 to 3.7)	0.053	0.4 (−1.9 to 2.8)	0.713
Class II-III	14.0 (10.2 to 17.7)	14.2 (9.5 to 18.9)	16.3 (13.3 to 19.4)	13.6 (10.9 to 16.4)	−0.3 (−4.9 to 4.3)	0.899	−1.7 (−6.5 to 3.2)	0.497
Undiagnosed								
All	1.7 (1.3 to 2.0)	2.0 (1.4 to 2.5)	2.1 (1.8 to 2.5)	2.2 (1.9 to 2.6)	0.6 (0.1 to 1.1)	0.021	- - -	- - -
Normal weight	0.8 (0.3 to 1.3)	0.6 (0.0 to 1.2)	0.7 (0.4 to 1.1)	0.5 (0.2 to 0.9)	−0.3 (−0.8 to 0.3)	0.350	- - -	- - -
Overweight	1.5 (1.1 to 1.9)	1.8 (1.0 to 2.5)	1.5 (1.1 to 1.9)	1.8 (1.2 to 2.3)	0.3 (−0.4,1.0)	0.383	0.6 (−0.3 to 1.4)	0.183
Obesity	2.9 (2.1 to 3.8)	3.4 (2.1 to 4.8)	4.6 (3.5 to 5.8)	4.7 (3.4 to 6.0)	1.8 (0.2 to 3.4)	0.029	2.0 (0.3 to 3.7)	0.019
Class I	2.7 (1.8 to 3.6)	3.3 (1.7 to 4.8)	4.0 (2.7 to 5.4)	3.9 (2.4 to 5.4)	1.2 (−0.5 to 2.9)	0.174	1.5 (−0.4 to 3.3)	0.115
Class II-III	3.5 (1.5 to 5.5)	4.2 (1.3 to 7.0)	6.3 (3.7 to 8.8)	6.8 (3.9 to 9.6)	3.2 (−0.2 to 6.7)	0.067	3.5 (0.0 to 7.1)	0.050
Women								
Total diabetes								
All	4.0 (3.5 to 4.5)	5.4 (4.6 to 6.3)	5.9 (5.4 to 6.5)	6.0 (5.4 to 6.5)	2.0 (1.3 to 2.7)	<0.001	- - -	- - -
Normal weight	2.6 (1.9 to 3.3)	2.0 (1.2 to 2.9)	2.2 (1.7 to 2.8)	2.4 (1.8 to 2.9)	−0.2 (−1.1 to 0.7)	0.648	- - -	- - -
Overweight	3.3 (2.7 to 4.0)	4.1 (2.9 to 5.2)	4.8 (4.0 to 5.5)	5.2 (4.3 to 6.2)	1.9 (0.8 to 3.1)	0.001	2.1 (0.7 to 3.6)	0.004
Obesity	7.3 (6.0 to 8.6)	11.6 (8.9 to 14.3)	12.0 (10.4 to 13.5)	10.9 (9.6 to 12.2)	3.6 (1.8 to 5.4)	<0.001	3.8 (1.8 to 5.8)	<0.001
Class I	5.8 (4.5 to 7.1)	7.4 (5.4 to 9.4)	10.1 (8.5 to 11.8)	8.4 (6.9 to 9.8)	2.5 (0.6 to 4.5)	0.010	2.8 (0.7 to 4.8)	0.010
Class II-III	9.8 (7.2 to 12.5)	17.8 (12.7 to 23.0)	15.3 (12.2 to 18.4)	14.9 (12.6 to 17.1)	5.0 (1.5 to 8.5)	0.005	5.2 (1.6 to 8.8)	0.004

(Continues)

TABLE 5 (Continued)

Diabetes by BMI category	2003-2006	2007-2010	2011-2014	2015-2018	PP change		PP change vs. normal weight	
	% (95% CI)	% (95% CI)	% (95% CI)	% (95% CI)	% (95% CI)	*p* value	% (95% CI)	*p* value
Diagnosed								
All	3.1 (2.6 to 3.5)	3.6 (3.0 to 4.3)	4.1 (3.6 to 4.6)	4.5 (4.0 to 5.0)	1.5 (0.8 to 2.1)	<0.001	- - -	- - -
Normal weight	2.1 (1.4 to 2.7)	1.2 (0.6 to 1.9)	1.2 (0.8 to 1.6)	1.7 (1.2 to 2.2)	−0.4 (−1.2 to 0.4)	0.367	- - -	- - -
Overweight	2.5 (1.9 to 3.1)	2.5 (1.7 to 3.4)	3.3 (2.7 to 4.0)	4.2 (3.3 to 5.1)	1.7 (0.6 to 2.7)	0.002	2.1 (0.8 to 3.4)	0.002
Obesity	5.5 (4.3 to 6.6)	7.6 (5.9 to 9.3)	8.5 (7.2 to 9.9)	8.1 (7.0 to 9.2)	2.6 (1.0 to 4.2)	0.001	3.0 (1.2 to 4.7)	0.001
Class I	4.2 (3.1 to 5.3)	5.6 (3.8 to 7.4)	6.9 (5.5 to 8.4)	5.7 (4.5 to 7.0)	1.5 (−0.1 to 3.2)	0.073	1.9 (0.1 to 3.7)	0.041
Class II-III	7.7 (5.3 to 10.1)	10.6 (7.5 to 13.7)	11.4 (8.6 to 14.3)	11.8 (9.7 to 13.9)	4.2 (1.0 to 7.3)	0.010	4.5 (1.3 to 7.8)	0.006
Undiagnosed								
All	0.9 (0.7 to 1.2)	1.8 (1.3 to 2.3)	1.8 (1.5 to 2.1)	1.5 (1.2 to 1.7)	0.5 (0.2 to 0.9)	0.002	- - -	- - -
Normal weight	0.5 (0.2 to 0.8)	0.8 (0.3 to 1.3)	1.0 (0.7 to 1.4)	0.7 (0.3 to 1.0)	0.2 (−0.3 to 0.6)	0.505	- - -	- - -
Overweight	0.8 (0.5 to 1.1)	1.5 (0.8 to 2.3)	1.4 (1.0 to 1.8)	1.1 (0.7 to 1.4)	0.2 (−0.2 to 0.7)	0.332	0.1 (−0.6 to 0.8)	0.811
Obesity	1.8 (1.2 to 2.5)	4.0 (1.8 to 6.2)	3.4 (2.6 to 4.2)	2.8 (2.2 to 3.5)	1.0 (0.1 to 1.9)	0.025	0.9 (−0.2 to 1.9)	0.097
Class I	1.6 (0.9 to 2.4)	1.8 (0.8 to 2.8)	3.2 (2.3 to 4.2)	2.6 (1.8 to 3.4)	1.0 (−0.1 to 2.1)	0.068	0.8 (−0.3 to 2.0)	0.160
Class II-III	2.2 (0.9 to 3.4)	7.2 (2.8 to 11.6)	3.9 (2.5 to 5.3)	3.0 (2.0 to 4.0)	0.9 (−0.7 to 2.5)	0.285	0.7 (−1.0 to 2.4)	0.403

Note: Undiagnosed diabetes: no reported diagnosed diabetes and $HbA_{1c} \geq 6.5\%$ (prior to HSE 2012) or ≥ 48 mmol/mol (HSE 2012-2018). - - - denotes comparable data not available. Estimates age-standardized to the pooled HSE data. Normal weight: BMI 18.5 to 25; overweight: BMI 25 to 30; obesity: BMI ≥ 30; class I obesity: BMI 30 to 34.9; class II-III obesity: BMI ≥ 35. *p* values obtained using Wald tests.

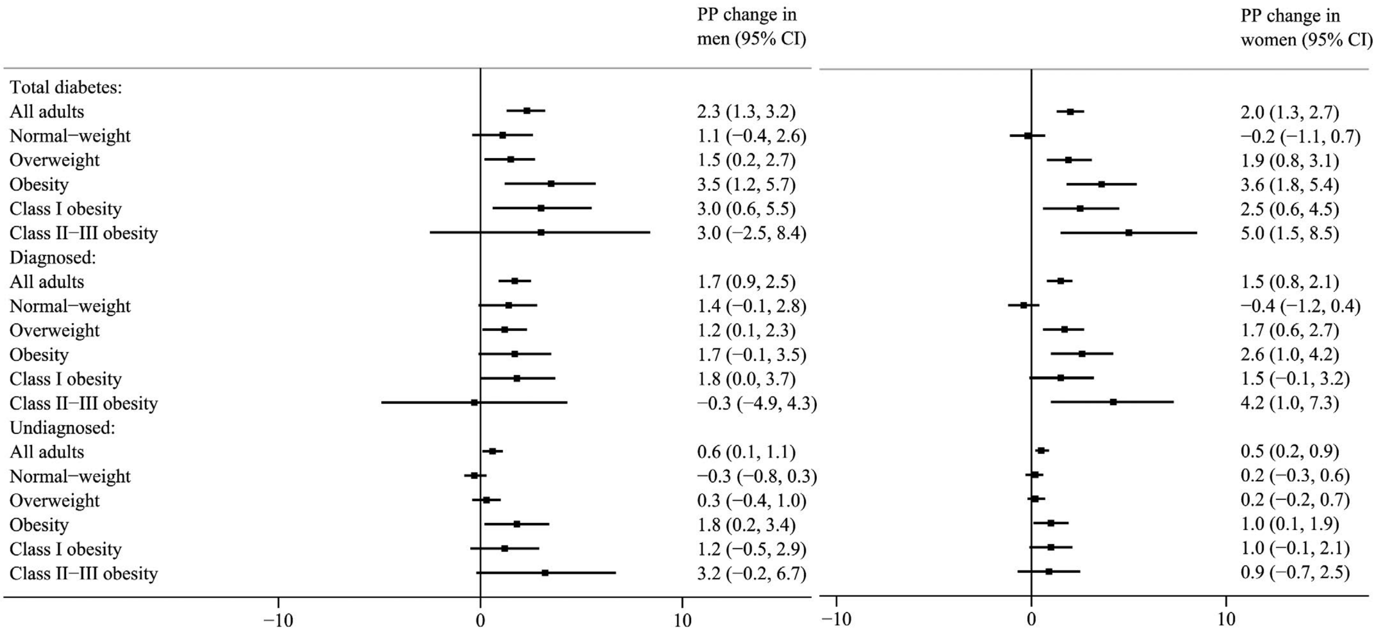

FIGURE 3 Absolute change in total diabetes (2003-2006 to 2015-2018), including diagnosed and undiagnosed, by BMI category and sex. PP, percentage points

CONCLUSION

Relative to adults with normal weight, greater reductions in hypertension and raised total cholesterol among adults with overweight and obesity reflect, at least partially, improvements in screening and treatment in those at highest cardiovascular risk. Higher levels of risk factor prevalence among adults with overweight and obesity, in parallel with secular increases in diabetes, highlight the importance of national prevention efforts to combat the public health impact of excess adiposity.

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CONFLICT OF INTEREST

The authors declared no conflict of interest.

AUTHOR CONTRIBUTIONS

SS and JSM conceptualized the study. SS was responsible for generating the data sets, conducting the analyses, interpreting the results, and drafting the manuscript. SS, LNF, and JSM critically revised the manuscript. All authors have read and approved the manuscript.

ETHICS APPROVAL

The procedures used in the Health Survey for England (HSE) to obtain informed consent from survey participants are very closely scrutinized by a National Health Service ethics committee each year. Approval was obtained from the following research ethics committees (REC): HSE 2003, 2005, 2006 and 2007: London Multi-Centre REC; HSE 2008: Oxford A REC 07/H0604/102; HSE 2009: Oxford B REC 08/H0605/103; HSE 2010: Oxford B REC 09/H0605/73; HSE 2011 and 2012: Oxford A REC 10/H0604/56; HSE 2013 and 2014: Oxford A REC 12/sc/0317; HSE 2015: West London NRES Committee 14/LO/0862; HSE 2016, 2017 and 2018: Nottingham REC 15/EE/0299. This study is a secondary analysis of previously collected data; therefore, additional ethical approval was not required.

DATA AVAILABILITY STATEMENT

The HSE data sets generated and analyzed during the current study are available via the UK Data Service (UKDS, https://ukdataservice.ac.uk/) and are subject to their end user license agreement. Statistical code to enable replication of our results (using the data sets deposited at the UKDS) has been made openly accessible via GitHub (https://github.com/shauns11/RiskFactorsByBMI.git). Citations for the HSE data sets are provided at the end of this manuscript.

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