

Age- and sex-specific effects of obesity, metabolic syndrome and its components on back pain: The English Longitudinal Study of Ageing

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Abstract

Objectives We aimed to investigate age- and sex-specific effects of obesity, metabolic syndrome (MetS) and its components on back pain in middle-aged and older English individuals.

Methods We used data from the English Longitudinal Study of Ageing, wave 2 (2004-2005). Body mass index (BMI) expressed the obesity, while MetS was defined according to revised Adult Treatment Panel (ATP) III criteria. We assessed associations between obesity, MetS and its components with presence and severity of back pain and provided estimates per strata, middle-aged (50-64 years) and older (65-79 years), women and men.

Results The study sample included 3328 participants, 1021 and 835 middle-aged women and men and 773 and 699 older women and men, respectively. We found that BMI (OR=1.07, 95% CI 1.05-1.09), MetS (OR=1.47, 95% CI 1.22-1.77), high waist circumference (WC), high triglycerides (TG), and high fasting blood glucose were associated with the presence of back pain. Effects of BMI were consistent across the strata. However, MetS was associated with back pain only in women, middle-aged (OR=1.59, 95% CI 1.14-2.21) and older (OR=1.43, 95% CI 1.01-2.05). The MetS component driving this association was high WC, supported by high TG in older women. Higher BMI, presence of MetS, high blood pressure and TG were associated with back pain severity.

Conclusions We found that obesity was associated with the presence and severity of back pain, irrespective of age and sex. However, we found women-specific effects of MetS driven by high WC, indicating that metabolic dysregulation contributes to back pain pathophysiology in women.

Keywords: back pain, body mass index, metabolic syndrome, waist circumference, sex differences.

1. Introduction

Obesity is a global problem and a multi-dimensional risk factor for numerous health conditions, from metabolic to mechanical [1, 2]. A cluster of metabolic abnormalities – excess body fat around the waist, increased blood pressure, lipid and glucose levels – known as metabolic syndrome (MetS) [3] is a well-recognised cardiovascular risk factor that further impacts all parts of the human body [4-6]. The mechanical effects of obesity due to increased loading have been associated with musculoskeletal diseases [7]. Of these, back pain has alarming prevalence, impact on socio-economic systems and individual's quality of life [8, 9]. While obesity has been a common denominator of both MetS and back pain, the relationship between these two assuming the cardiovascular contribution to back pain pathophysiology requires better understanding.

Previous few reports on MetS and back pain association pointed to age and sex differences [10, 11]. The study in middle-aged Japanese participants found that MetS was significantly associated with back pain in women [11]. Another Japanese study in middle-aged and older participants investigated MetS as the outcome predicted by back pain and observed a trend in the association, again only in women [10]. Recently, we reported the lack of indirect effects of body weight and fat mass via inflammatory and metabolic parameters on back pain in middle-aged English women [12]. However, direct effects of metabolic parameters included in MetS can account for different underlying conditions or clustering, not only the activity of adipose tissue. These direct effects of MetS on back pain in European population are lacking.

Therefore, we used the English population-based cohort to assess the association of obesity, MetS and its components with back pain. We considered overall and central obesity, MetS, each component and the number of positive MetS components. Given the previous reports, we used stratification and provided age- (middle-aged and older) and sex-specific results.

2. Methods

2.1. Study design and study sample

We utilised data from the prospective cohort - the English Longitudinal Study of Ageing (ELSA). The cohort has started in 2002 with biannual follow-ups (waves), including English adults aged 50 years and older. It has been accepted as a nationally representative sample of people living in private households of the UK [13-15]. All waves included main interviews (face-to-face or telephone) that collected demographics, health, and behaviour measures. However, clinical and laboratory examinations were done in alternative waves (2,4,6 and 8) during the nurse visits. We used cross-sectional data from wave 2 (2004-2005) when all information of interest - back pain, anthropometric and metabolic data - were collected. The Multi-centre Research and Ethics Committee approved the ELSA study. All the participants have given written informed consent for participation.

2.2. Anthropometric parameters and obesity

As anthropometric parameters, we used waist circumference (WC), weight and height measures. During the measurements, participants were in a standing position with arms alongside the body and relaxed abdomen, head in the Frankfort plane, barefoot and without bulky clothing. WC was measured using a flexible tape placed at the midpoint between the last rib and iliac crest at the end of the expiration [16]. A portable Tanita electronic scale with a precision of 0.1 kg was used for weight assessment. Height was measured to the nearest 1mm by a portable stadiometer [17, 18]. We calculated waist-to-height ratio (WHtR) using WC and height measurements and body mass index (BMI) using weight and height measurements (kg/m^2).

For analyses, we used continuous BMI and binary high WHtR (>0.6) [19] as measures of overall and central/abdominal obesity. We categorised BMI according to World Health Organisation into: normal-weight ($<25 \text{ kg/m}^2$), overweight ($25\text{-}30 \text{ kg/m}^2$) and obese ($>30 \text{ kg/m}^2$) for additional analyses.

2.3. Metabolic parameters and metabolic syndrome

As metabolic parameters, we used systolic and diastolic blood pressures (SBP and DBP), fasting serum triglycerides (TG), high-density lipoprotein cholesterol (HDL), blood glucose

(FBG), and glycated haemoglobin (HbA1c) [20]. SBP and DBP were measured in a sitting position using the blood pressure monitor (Omron HEM-907, OMRON Healthcare, UK) [21]. Blood samples were taken from all the participants at the nurse visit unless participants refused it, had a history of convulsions, bleeding disorders or taking anticoagulants [18]. Participants below 80 years were asked to fast before the nurse visit unless they were diagnosed with diabetes or taking antidiabetic medications or insulin and those who seemed frail. Eligible participants were considered to have fasted if they had the last meal day before or did not have food or drink except water on the day or had a light meal or drink a minimum of five hours earlier on the day of the nurse visit [15]. Blood was taken into plain tubes for TG and HDL, fluoride oxalate tubes for FBG and ethylenediaminetetraacetic acid tubes for HbA1c. HDL was assessed using DAX Oxidase assay, TG using an enzymatic method, FBG using Hexokinase method, (Olympus Chemistry Analyser AU640, OLYMPUS Corporation, UK) and HbA1c using a Tosoh G7 High-Performance Liquid Chromatography analyser (Tosoh, Japan) [18]. Metabolic parameters were used as continuous variables for descriptive purposes.

Binary variables of metabolic parameters and metabolic syndrome (MetS) were defined according to revised National Cholesterol Education Program Adult Treatment Panel (ATP) III criteria [3, 20]. These were: high WC ($\geq 88\text{cm}$ for women, $\geq 102\text{cm}$ for men); high BP ($\geq 130/85\text{mmHg}$ or treatment for previously diagnosed hypertension); high serum TG ($\geq 1.7\text{mmol/L}$); low serum HDL ($< 1.03\text{mmol/L}$ for men, $< 1.3\text{mmol/L}$ for women); high serum FBG ($\geq 5.6\text{mmol/L}$ or treatment for previously diagnosed type 2 diabetes). The ATP III criteria consider the use of antilipemic drugs when defining hyperlipidaemia. However, the ELSA study did not have data on antilipemic drugs, so only serum TG and HDL values were included in the definition here. The presence of three or more of these components defined MetS [20]. We also used the number of MetS components, a categorical variable (0-5) calculated by summing the number of positive MetS components. We combined the groups positive for 4 and 5 MetS components due to small frequencies [22]. Also, we combined obesity ($\text{BMI} \geq 30\text{kg/m}^2$) and MetS (\geq three positive components) into a categorical outcome with four

groups: not obese without MetS, not obese with MetS, obese without MetS, and obese with MetS.

2.4. Outcomes

The primary outcome was the binary variable presence of back pain. Participants were asked, “Are you often troubled with pain?” [15]. Then, the next question addressed the severity of pain in specific parts of the body when walking on a flat surface, i.e., “How would you rate pain in your back if you were walking on a flat surface? Where 0 is no pain, and 10 is severe excruciating pain, as bad as you can imagine”. From this original scale, we derived a binary variable with zero being no back pain and any intensity (≥ 1) defining the presence of back pain. As the secondary outcome, we used the severity of back pain when present, i.e., on a scale of 1-10.

2.5. Covariates

We used self-reported age, sex, smoking habits, physical activity, depression symptoms as confounding variables, and additionally, diagnosed health conditions for descriptive purposes. Smoking habits defined the status – smoking or not. Physical activity was based on self-reported participation in vigorous-, moderate- and low-intensity physical activities at work and in free time, as described previously [23]. We assessed depressive symptoms in the past week using the 8-item Centre for Epidemiologic Studies-Depression Scale (CES-D), scaled as 0-8, where a higher number represents worse symptomatology [24, 25]. Diagnosed health conditions included self-reported but previously diagnosed by a doctor, cardiovascular diseases, and diabetes. These conditions and BMI have been multicollinear with MetS and its components, thus not included as confounding variables [26].

2.6. Statistical analysis

We provided descriptive statistics of our study sample, the mean and standard deviation or median and interquartile range for continuous variables and frequencies for categorical variables. We stratified the sample – middle-aged (50 to 64 years) vs older (65 to 79 years),

women vs men. We compared participants between strata using t-test and χ^2 -test. In our primary analyses, we used binary logistic regression to assess the associations of obesity, MetS and each MetS component with the presence of back pain (Model 1) and when controlling for confounding variables (Model 2). Also, to explore the dose-response effect, we assessed the relationship between the number of MetS components (1,2,3, and 4-5 referenced to none) and the presence of back pain. In the secondary analyses, we employed linear regression to explore the association of obesity and MetS with the severity of back pain in participants with back pain. All the analyses were conducted in the total sample and primary analyses in stratified samples, consistently in the same step-by-step manner. We interpreted results from Model 2 as the main findings.

Furthermore, we conducted several additional analyses. We assessed the effects of BMI categories and combined effects of obesity and MetS (not obese with MetS, obese without MetS, and obese with MetS referenced to not obese without MetS) with the presence of back pain in the total sample using adjusted binary logistic regression (Model 2). We tested the interaction between physical activity and depression with BMI and MetS to test whether the effects of obesity and MetS depended on the level of physical activity or depression. We performed a non-response analysis comparing our sample with excluded participants due to missing values in the exposure or outcome variables using the independent samples t-test for continuous variables and χ^2 -test for categorical variables. We examined multicollinearity between obesity-related parameters – BMI and components of MetS – using partial correlation analysis when controlling for age and sex.

We analysed data using IBM SPSS® Statistics 25.0 (IBM, Chicago, Illinois, United States).

3. Results

3.1. Study samples descriptions

The ELSA wave 2 research nurse visit included 7666 participants. Participants with missing data in single or multiple exposures or outcome variables were excluded (N=4338). Most of

the excluded individuals (N=3945, 90.9%) did not have fasting glucose levels due to the study's eligibility for fasting described above. Thus, the study sample included 3328 participants. Figure 1 shows the study flow chart and details on missing values per variable. Descriptive statistics of the main sample are shown in Table 1 and 2. Participants were on average 64 years old (SD=7.3), 54% were women, 13% reported current smoking habits, three-quarters moderate or high physical activity, and low depression symptoms (mean=1.32, SD=1.80). The prevalence of back pain was 20.2% (N=673), and the average severity in those who reported it was 5.01 (SD=2.36). The average sample BMI was 27.88 (SD=4.71), and the prevalence of MetS was 35%. The most prevalent MetS component was high BP (62%), followed by high WC (50%) and high TG (37%).

When the sample stratified, there were 1021 and 835 middle-aged women and men and 773 and 699 older women and men, respectively. Comparison between strata – different age groups of the same sex and different sex of same age group – are in Appendix Tables A1 and A2. Briefly, back pain was more prevalent in women than men in both age groups, and an increasing age trend was observed in women but not men. Interestingly, the average severity in those who reported back pain did not differ between strata. There was no difference in overall obesity (BMI) between strata either. However, central obesity (high WHtR) had an increasing age trend in both sexes, and it was more prevalent in men than women in both age groups. The same pattern of MetS prevalence was observed. The most prevalent MetS component in both age groups of men was high BP, followed by high WC and TG. In middle-aged women, the most common MetS component was high WC, then high BP and TG, while in older women high BP became the most frequent. In both women and men, high BP had significant increasing age prevalence, while it was not the case with high WC or TG. Opposite to WHtR pattern, high WC was more prevalent in women than men in both age groups.

3.2. Associations between obesity and MetS with back pain

We found that increased BMI (overall obesity) and high WHtR (central obesity) were significantly associated with increased odds of having back pain in the total sample (Table 3).

When the sample was stratified, we found that the overall obesity association was consistent across all age and sex strata. However, the central obesity association was driven by significant associations in middle-aged women and older men. Further, MetS and its components – high WC, TG and FBG – were associated with increased odds of back pain in the total sample. Stratifying the sample, we found the specific age and sex associations that drove these overall observations. Namely, MetS and high WC were significantly associated with increased back pain odds in women, middle-aged and older, and high TG only in older women, while high FBG in middle-aged men. We did not observe any significant associations between high BP or low HDL and back pain. We did not find a dose-response association between the number of MetS components and the presence of back pain either.

3.3. Association between obesity and MetS with the severity of back pain

We found that higher BMI and MetS presence were significantly associated with higher severity of back pain (Table 4). Two MetS components – high BP and TG – were associated with the severity of back pain. We did not observe effects of high WHtR, WC, FBG or low HDL on the severity of back pain. Also, we did not find a significant dose-response association between the number of MetS components and the severity of back pain.

3.4. Additional analyses

Compared to normal-weight participants, overweight (OR=1.38, 95% CI 1.09-1.76) and obese (OR=2.10, 95% CI 1.64, 2.70) had higher odds of having back pain. When we explored the combined effects of obesity and MetS on back pain, we found that back pain prevalence per group was 15.5% and 20.7% in not obese without and with MetS, respectively, and 24.3% and 32.3% in obese without and with MetS, respectively. Also, we found that obese without MetS (OR=1.48, 95% CI 1.12-1.96) and obese with MetS (OR=2.10, 95% CI 1.65-2.67) had significantly increased odds of having back pain compared to not obese without MetS (Appendix Table A3). Further, we did not find a significant interaction between physical activity and depression with BMI or MetS.

We conducted the non-response analyses comparing characteristics of our sample participants with those excluded due to missing values in exposure and outcome variables (Appendix Table A4). Compared to our sample participants, the excluded ELSA participants were on average five years older, reported smoking more often (16 vs 13%), more sedentary and low physical activity, higher CES-D score (1.71 (SD=1.98) vs 1.32 (SD=1.80)) and more diagnosed health conditions. The prevalence of back pain was higher (23.3 vs 20.2%) and severity among those with back pain was higher (5.32 (SD=2.34) vs 5.01 (SD=2.36)) in the excluded ones. There was no difference in BMI.

Further, we assessed the collinearity between BMI and MetS components using partial correlation when adjusted for age and sex (Appendix Table A5). BMI significantly correlated with all MetS components – strongly ($r > 0.70$) with WC, moderately ($0.30 < r < 0.70$) with HDL, and weakly ($r < 0.30$) with SBP, DBP, TG, and FBG. Most MetS components weakly correlated with each other. A strong correlation was observed between SBP and DBP, and moderate correlations between WC and HDL and TG and HDL.

4. Discussion

In this English population-based study, we found that obesity, overall and central, MetS and its high WC, TG and FBG components were associated with back pain. We investigated the age- and sex-specificity of these effects and found that overall obesity (BMI) effects on back pain were universal, as observed in women and men, middle-aged and older. However, central obesity (WHtR) was associated with back pain in the age- and sex-specific manner – in middle-aged women and older men. MetS and high WC were sex-specifically associated with back pain, only in women, middle-aged and older. High TG effects on back pain were observed in older women, while high FBG in middle-aged men. Given the specific effects of MetS components, there was no dose-response association between the number of positive components and back pain. Finally, among participants who reported experiencing back pain, higher BMI, presence of MetS, high BP and TG were associated with more severe pain.

This study utilised data from a large UK population-representative sample, assessed age- and sex-specific effects, and accounted for essential biopsychosocial confounding. Still, there are some limitations to be considered. Firstly, laboratory measures were not available for all ELSA participants, and we excluded participants to whom MetS could not be defined. Excluded participants were older and had more diagnosed health conditions associated with ageing. However, our study investigated age-specific effects compensating for the exclusions by showing estimates in the older. Secondly, we did not have data on antilipemic medication use, and our high TG and low HDL variables were based only on serum levels; thus, these results could be shifted toward zero and should be interpreted with caution. Thirdly, the back pain outcome was not the clinically defined chronic pain (duration), but the pain of public health importance affecting walking/activity and consequently the quality of life of ageing individuals. Finally, although we accounted for the effect of important confounding, residual confounding cannot be ruled out.

The overall obesity, assessed by BMI, has a common mechanism irrespective of age and sex on back pain. In a recent mechanistic study in middle-aged English women, we explored direct and indirect effects of body weight and BMI on back pain and found only direct loading effects [12]. Here, we reproduced these findings and extended them to men and the older group. Systematised evidence, without stratification, is also consistent with our studies. [2, 27, 28]. Therefore, increased mechanical loading is likely the prominent universal mechanism underlying the association between BMI and back pain. The higher weight increases the torque and compression loads on the spine and surrounding structures when interacting with the physical environment during standing, sitting, and lifting [29, 30]. It increases the accidental sprains and strains that may result in back pain [7]. Additionally, when back pain is experienced, a higher BMI is related to more severe pain. Thus, weight management should be prioritised for musculoskeletal health. We also showed that a BMI of 27 could be the weight reduction goal concerning musculoskeletal pain overall, including back pain [31].

Further, central obesity defined by WHtR was associated with back pain in middle-aged women and older men. We considered WHtR a measure linking BMI and MetS, as central fat

distribution can drive mechanical and metabolic effects [32, 33]. However, its effect was observed only in groups with the strongest BMI (older men) or MetS (middle-aged women) effects. It indicates that concerning back pain, WHtR does not add substantially more evidence than BMI or MetS alone, and overall obesity measure (BMI) has prominence for estimating the presence and severity of back pain.

MetS was associated with back pain in a sex-specific manner, only in women, and high WC as its component was the key contributor to the observed association. We found that MetS without obesity did not increase back pain risk. However, when we compared obese participants, we found that obese with MetS had a 42% higher risk of back pain than obese without MetS, and age and sex-stratification allowed more information on the involved MetS component. The previous Japanese study in middle-aged participants found that MetS and high WC were related to back pain [11]. We confirmed that this association was also observed in English middle-aged women and added the evidence on the same association in older women. Some studies investigated WC alone, not as a MetS component, and back pain observed sex-based differences too [34, 35]. WC is the most time stable MetS component, and it is not affected by medications daily, possibly explaining why its effect was the strongest driver of the MetS effect on back pain. Also, it accounts for visceral fat that has been an accurate predictor of cardiovascular health in women [36]. In our mechanistic study, we did not find indirect effects of body weight or BMI via BP, TG, HDL and FBG in middle-aged women [12]. Here, we also added a lack of direct effects of these metabolic parameters in this group. The effect of high TG was observed only in older women. It could be due to the loss of oestrogen protective effects on the cardiovascular system that become pronounced in late life [37, 38]. We did find that BP and TG were related to back pain severity in participants who experienced back pain, indicating that poorer cardio-metabolic health is making pain worse. Finally, in middle-aged men, we did not observe the effect of MetS on back pain, but we did find the effect of high FBG. It indicates that FBG could have a different mechanism on back pain, possibly via loss of muscle mass and strength or nerve damage [39]. However, future well-designed studies should explore the mechanism of WC, TG and FBG effects on back

pain in more depth, in an age- and sex-dependent manner. It could lead to better prevention and treatment optimisation of back pain and better quality of life.

In this study, we showed that overall obesity was associated with the presence and severity of back pain, irrespective of age and sex. Furthermore, we found that MetS was associated with back pain in a sex-specific manner, only in women. The MetS component driving the effect was high WC in middle-aged and older women, supported by high TG in older women. In participants with back pain, MetS, high BP and TG also contributed to more severe pain. Thus, while obesity has a prominent mechanical effect on back pain in men and women, its coexisting metabolic dysregulation contributes to back pain pathophysiology in women only.

Disclosure of interest

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Author contributions

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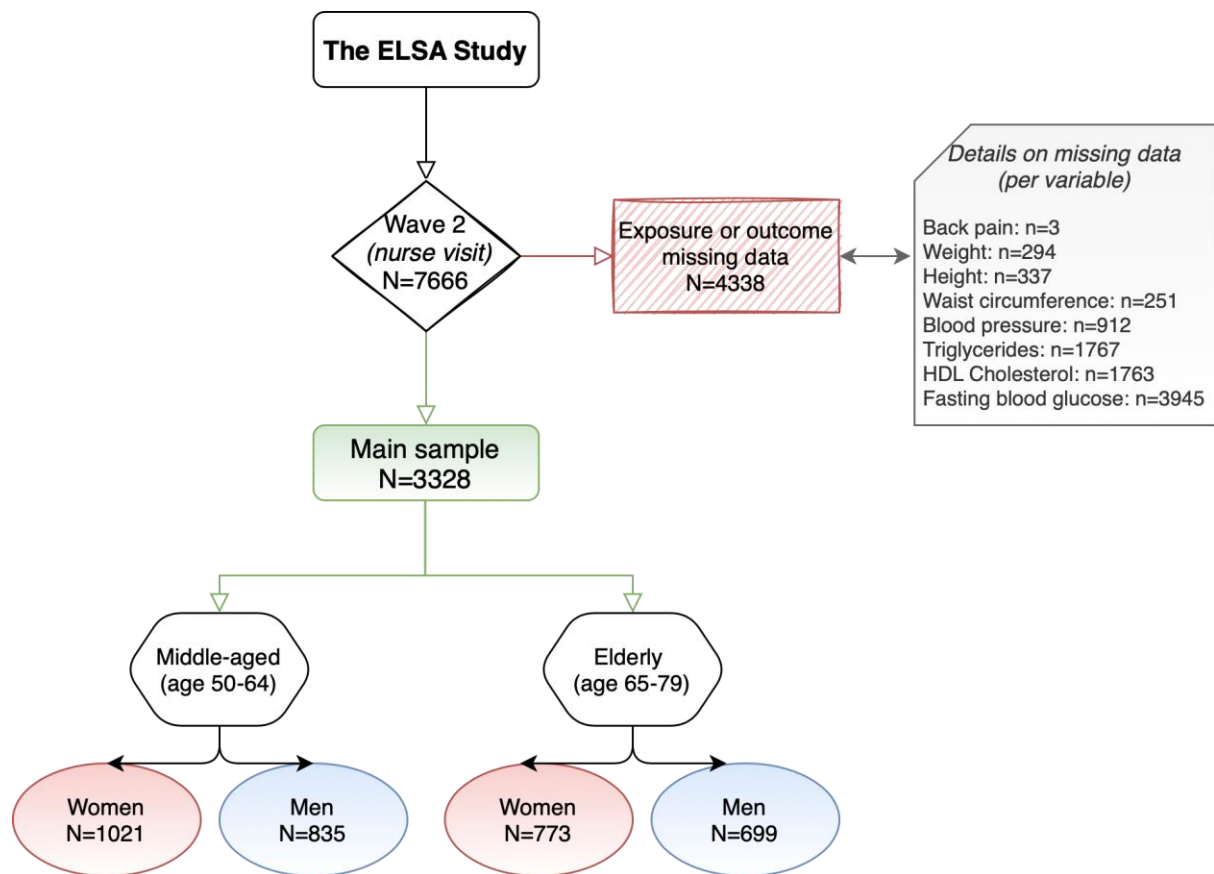


Figure 1 The study flowchart.

Table 1 Descriptive statistics of the study sample

Variable	Main sample (n=3328)
Age (years), mean (SD)	63.84 (7.30)
Women, %	53.9
Smoking habits, % ^a	
Currently smoking	12.6
Physical activity, % ^a	
Sedentary	1.6
Low	19.9
Moderate	55.8
High	22.7
Depression score (0-8), mean (SD)	1.32 (1.80)
Diagnosed health conditions, %	
Angina	8.2
Myocardial infarction	4.7
Congestive heart failure	0.5
Heart murmur	3.9
Arrhythmia	6.0
Diabetes	7.5
Stroke	2.9
Treatment, %	
Antihypertensives	14.6
Antidiabetics	6.5
Back pain, %	
Yes	20.2
Back pain severity (1-10), mean (SD) ^b	5.01 (2.36)

SD - standard deviation.

^a In the main sample, there were 7 and 1 missing values in smoking habits and physical activity, respectively.

^b Back pain severity refers only to 673 participants (20.2%) who reported back pain, excluding 0 value of no pain.

Table 2 Obesity and metabolic syndrome in the study sample

Variable	Main sample (n=3328)
Weight (kg), mean (SD)	77.26 (15.10)
Height (m), mean (SD)	1.66 (0.09)
Waist circumference (cm), mean (SD)	95.31 (13.01)
Waist-to-height ratio, mean (SD)	0.57 (0.07)
Body mass index (kg/m ²), mean (SD)	27.88 (4.71)
WHO Body mass index categories, %	
Normal-weight	27.5
Overweight	44.6
Obese	27.9
Metabolic factors, mean (SD) ^a	
Systolic blood pressure (mmHg)	134.09 (18.10)
Diastolic blood pressure (mmHg)	76.20 (10.53)
Triglycerides (mmol/L)	1.64 (0.98)
HDL cholesterol (mmol/L)	1.54 (0.38)
Fasting blood glucose (mmol/L)	5.02 (0.90)
HbA1c (%)	5.60 (0.78)
Components of MetS, % ^c	
High waist circumference	49.6
High blood pressure	61.7
High triglycerides	36.6
Low HDL cholesterol	12.4
High fasting glucose	19.0
High HbA1c, % ^d	8.6
High Waist-to-height ratio, % ^d	33.1
MetS, %	
Number of components	
0	8.9
1	23.6
2	32.9
3	23.7
4	8.4
5	2.5
Yes (presence of 3 or more)	34.6
Obesity and MetS, %	
Not Obese without MetS	53.2
Not obese with MetS	18.9
Obese without MetS	12.2
Obese with MetS	15.7

SD - standard deviation; HDL – high-density lipoprotein; HbA1c – haemoglobin A1C; MetS – metabolic syndrome; BMI – body mass index; WHO – World Health Organisation.

^a In the main sample, there were 36, 36, 177, 54 missing values in systolic blood pressure, diastolic blood pressure, fasting blood glucose and HbA1c, respectively.

^b WHO body mass index categories were defined as: normal-weight (BMI < 25 kg/m² – including also underweight <18.5 kg/m² due to small frequency, i.e., 0.6%), overweight (BMI ≥ 25.0 to < 30.0 kg/m²) and obese (BMI ≥ 30.0 kg/m²).

^c High waist circumference: ≥ 88cm for women and ≥102cm for men; hypertension: ≥ 130/85 mmHg or using antihypertensive medication; high triglycerides: ≥ 1.7 mmol/L; low HDL cholesterol: <1.0 mmol/L for men and < 1.3 mmol/L for women; high fasting glucose: ≥ 5.6 mmol/L or using anti-diabetic medication for diagnosed diabetes.

^d High HbA1c: ≥ 6.5%, and high waist-to-height ratio: ≥ 0.6.

Table 3 Associations of obesity and metabolic syndrome with back pain

		Total Sample	Middle-aged (50 – 64 years)		Older (65 - 79 years)	
		(n=3328)	Men (n=835)	Women (n=1021)	Men (n=699)	Women (n=773)
Variable ^a	Models	OR (95% CI)	OR (95% CI)	OR (95% CI)	OR (95% CI)	OR (95% CI)
Obesity						
BMI	1	1.09 (1.07, 1.11)	1.08 (1.03, 1.12)	1.08 (1.05, 1.11)	1.12 (1.07, 1.18)	1.09 (1.06, 1.13)
	2	1.07 (1.05, 1.09)	1.06 (1.02, 1.11)	1.07 (1.04, 1.10)	1.10 (1.05, 1.16)	1.07 (1.03, 1.10)
High WHtR	1	2.00 (1.68, 2.38)	1.94 (1.33, 2.81)	2.24 (1.63, 3.07)	2.74 (1.82, 4.12)	1.71 (1.23, 2.39)
	2	1.64 (1.36, 1.98)	1.49 (0.99, 2.24)	1.88 (1.34, 2.64)	2.18 (1.42, 3.36)	1.31 (0.92, 1.88)
MetS						
Presence of MetS	1	1.70 (1.43, 2.02)	1.56 (1.08, 2.26)	1.82 (1.33, 2.48)	1.69 (1.13, 2.52)	1.87 (1.34, 2.61)
	2	1.47 (1.22, 1.77)	1.32 (0.89, 1.97)	1.59 (1.14, 2.21)	1.45 (0.95, 2.21)	1.43 (1.01, 2.05)
High waist circumference	1	1.81 (1.52, 2.15)	1.57 (1.09, 2.26)	1.80 (1.32, 2.45)	1.64 (1.11, 2.42)	1.96 (1.41, 2.74)
	2	1.44 (1.20, 1.73)	1.29 (0.87, 1.92)	1.58 (1.14, 2.19)	1.43 (0.95, 2.16)	1.46 (1.03, 2.08)
High blood pressure	1	1.22 (1.02, 1.45)	1.34 (0.91, 1.97)	1.32 (0.98, 1.79)	1.10 (0.71, 1.72)	1.04 (0.73, 1.49)
	2	1.12 (0.93, 1.36)	1.15 (0.76, 1.74)	1.16 (0.84, 1.60)	1.15 (0.72, 1.84)	1.02 (0.70, 1.49)
High triglycerides	1	1.35 (1.14, 1.61)	1.41 (0.98, 2.04)	1.27 (0.93, 1.74)	1.33 (0.89, 1.99)	1.60 (1.15, 2.23)
	2	1.21 (1.01, 1.45)	1.27 (0.85, 1.90)	1.05 (0.75, 1.48)	1.13 (0.74, 1.73)	1.49 (1.05, 2.12)
Low HDL cholesterol	1	1.59 (1.26, 2.01)	1.14 (0.64, 2.03)	1.96 (1.28, 2.98)	1.82 (1.11, 2.99)	1.41 (0.90, 2.21)
	2	1.28 (1.00, 1.66)	0.85 (0.45, 1.62)	1.52 (0.96, 1.38)	1.43 (0.84, 2.45)	1.21 (0.75, 1.96)
High fasting glucose	1	1.56 (1.27, 1.90)	2.20 (1.46, 3.32)	1.52 (1.01, 2.30)	1.48 (0.97, 2.28)	1.41 (0.96, 2.08)
	2	1.28 (1.03, 1.60)	1.70 (1.09, 2.66)	1.12 (0.72, 1.76)	1.22 (0.77, 1.93)	1.15 (0.76, 1.74)
Number of MetS components						
1	1	0.93 (0.64, 1.37)	0.63 (0.27, 1.46)	0.84 (0.47, 1.48)	0.91 (0.31, 2.62)	1.73 (0.71, 4.20)
2		1.50 (1.05, 2.14)	1.60 (0.77, 3.34)	1.32 (0.77, 2.26)	1.21 (0.44, 3.33)	2.14 (0.92, 4.96)
3		1.94 (1.36, 2.79)	1.71 (0.82, 3.60)	2.19 (1.25, 3.84)	1.44 (0.52, 3.95)	3.06 (1.31, 7.17)
4		2.33 (1.57, 3.46)	2.33 (1.02, 5.32)	1.98 (1.01, 3.88)	2.34 (0.83, 6.62)	3.34 (1.36, 8.22)
1		0.80 (0.54, 1.19)	0.44 (0.18, 1.05)	0.77 (0.42, 1.40)	0.77 (0.25, 2.35)	1.40 (0.56, 3.48)
2		1.21 (0.83, 1.75)	1.19 (0.56, 2.53)	1.06 (0.60, 1.87)	1.11 (0.39, 3.20)	1.67 (0.70, 3.95)
3		1.52 (1.04, 2.22)	1.05 (0.48, 2.28)	1.78 (0.98, 3.23)	1.18 (0.41, 3.41)	2.30 (0.96, 5.49)
4		1.52 (0.99, 2.31)	1.26 (0.52, 3.03)	1.11 (0.53, 2.31)	1.57 (0.52, 4.70)	2.17 (0.85, 5.50)

BMI – body mass index; WHtR – waist-to-height ratio; MetS - metabolic syndrome; HDL – high-density lipoprotein; OR - odds ratio; CI - confidence interval.

^a High waist-to-height ratio: ≥ 0.6 ; MetS: three or more positive components defined further as high waist circumference: ≥ 88 cm for women and ≥ 102 cm for men; hypertension: $\geq 130/85$ mmHg or using antihypertensive medication; high triglycerides: ≥ 1.7 mmol/L; low HDL cholesterol: <1.0 mmol/L for men and < 1.3 mmol/L for women; high fasting glucose: ≥ 5.6 mmol/L or using anti-diabetic medication for diagnosed diabetes.

Models were constructed using logistic regression, having back pain when walking on a flat surface reference to no back pain. The odds ratio shows the increased odds of back pain for every BMI unit increase, and the high WHtR, the presence of MetS or MetS component referenced to the low WHtR, absence of MetS or the MetS component. Bold results were statistically significant. Model 1 was unadjusted.

Model 2 was adjusted for age, sex, smoking status, physical activity, and depression score in the total sample and adjusted for age, smoking status, physical activity and depression score in the stratified samples.

Table 4 Associations of obesity and metabolic syndrome with severity of back pain

Participants with back pain (severity 1-10) (n=673)		
<i>Variable^a</i>	<i>Models</i>	<i>Beta (95% CI)</i>
Obesity		
BMI	1	0.06 (0.02, 0.09)
	2	0.05 (0.02, 0.08)
High WHtR	1	0.31 (-0.05, 0.67)
	2	0.22 (-0.14, 0.57)
MetS		
Presence of MetS	1	0.72 (0.37, 1.08)
	2	0.64 (0.29, 0.99)
High waist circumference	1	0.29 (-0.08, 0.66)
	2	0.16 (-0.20, 0.52)
High blood pressure	1	0.43 (0.05, 0.80)
	2	0.38 (0.01, 0.75)
High triglycerides	1	0.60 (0.24, 0.96)
	2	0.55 (0.20, 0.90)
Low HDL cholesterol	1	0.25 (-0.23, 0.73)
	2	0.19 (-0.28, 0.65)
High fasting glucose	1	0.38 (-0.03, 0.79)
	2	0.24 (-0.18, 0.65)
Number of MetS components		
1	1	0.40 (-0.43, 1.22)
2		0.46 (-0.30, 1.22)
3		1.13 (0.36, 1.90)
4		1.08 (0.25, 1.90)
1	2	0.24 (-0.56, 1.04)
2		0.29 (-0.45, 1.03)
3		0.94 (0.19, 1.69)
4		0.77 (-0.05, 1.58)

BMI – body mass index; WHtR – waist-to-height ratio; MetS – metabolic syndrome; HDL – high-density lipoprotein; CI – confidence interval.

^a High waist-to-height ratio: ≥ 0.6 ; MetS: three or more positive components defined further as high waist circumference: ≥ 88 cm for women and ≥ 102 cm for men; hypertension: $\geq 130/85$ mmHg or using antihypertensive medication; high triglycerides: ≥ 1.7 mmol/L; low HDL cholesterol: <1.0 mmol/L for men and < 1.3 mmol/L for women; high fasting glucose: ≥ 5.6 mmol/L or using anti-diabetic medication for diagnosed diabetes.

Models were constructed using linear regression with the severity of back pain when walking on a flat surface as the continuous outcome. Betas represent an increase or decrease in the severity of back pain for every BMI unit increase, and the high WHtR, the presence of MetS or its components compared to the low WHtR, the absence of MetS or its components. Bold results were statistically significant.

Model 1 was unadjusted.

Model 2 was adjusted for age, sex, smoking status, physical activity, and depression score.

Highlights

- Body mass index is associated with back pain in middle-aged and older women and men
- Metabolic syndrome is associated with back pain only in women
- High waist circumference drives the effect of metabolic syndrome in women
- Metabolic syndrome contributes to the severity of back pain

Table A1 Descriptive statistics and comparisons of stratified samples – different age groups of the same sex

Variable	Men		<i>P-value</i> ^a	Women		<i>P-value</i> ^a
	Middle-aged (Age 50 – 64 years) (n=835)	Elderly (Age 65 – 79 years) (n=699)		Middle-aged (Age 50 – 64 years) (n=1021)	Elderly (Age 65 – 79 years) (n=773)	
Smoking habits, % ^b						
Currently smoking	15.6	10.3	<0.01	14.5	8.8	<0.01
Physical activity, % ^b			<0.01			<0.01
Sedentary	1.1	2.3		1.0	2.3	
Low	15.0	19.5		19.1	26.7	
Moderate	53.2	56.8		57.4	55.6	
High	30.8	21.5		22.5	15.4	
Depression score (0-8), mean (SD)	1.11 (1.71)	0.95 (1.50)	0.07	1.55 (1.90)	1.58 (1.94)	0.71
Diagnosed health conditions, %						
Angina	6.7	14.7	<0.01	3.5	10.1	<0.01
Myocardial infarction	4.7	9.9	<0.01	1.3	4.4	<0.01
Congestive heart failure	0.4	0.6	0.71	0.1	1.2	<0.01
Heart murmur	2.3	3.1	0.34	5.0	4.8	0.91
Arrhythmia	4.7	7.6	<0.05	4.6	7.9	<0.01
Diabetes	5.9	12.7	<0.01	5.0	8.0	<0.05
Stroke	2.0	5.3	<0.01	1.1	4.0	<0.01
Treatment, %						
Antihypertensives	11.0	17.6	<0.01	10.9	20.6	<0.01
Antidiabetics	5.6	10.7	<0.01	4.4	6.5	0.06
Back pain, %						
Yes	16.3	16.9	0.78	21.3	26.1	<0.05
Back pain severity (1-10), mean (SD) ^c	4.84 (2.53)	4.91 (2.50)	0.83	5.05 (2.41)	5.15 (2.10)	0.66
Body mass index (kg/m ²), mean (SD)	28.01 (4.31)	27.68 (3.88)	0.12	28.03 (5.34)	27.70 (4.93)	0.18
WHO Body mass index categories, %			0.66			0.82
Normal-weight	22.4	24.0		30.6	32.0	
Overweight	50.8	50.8		39.7	38.8	
Obese	26.8	25.2		29.8	29.2	
Components of MetS, %						
High waist circumference	42.9	45.9	0.24	53.4	55.1	0.47
High blood pressure	59.6	71.2	<0.01	50.1	70.8	<0.01

High triglycerides	42.8	38.3	0.08	31.8	34.7	0.22
Low HDL cholesterol	10.7	14.9	<0.05	11.5	13.3	0.24
High fasting glucose	19.6	26.3	<0.01	13.0	19.7	<0.01
High HbA1c ^b	8.4	13.9	<0.01	5.6	8.2	<0.05
High WHtR	33.3	42.2	<0.01	26.7	33.0	<0.01
MetS, %						
Number of components			<0.01			<0.01
0	9.7	5.4		12.1	6.9	
1	23.6	21.3		28.2	19.5	
2	30.7	31.3		33.4	36.1	
3	25.9	27.2		18.4	25.2	
4	7.9	11.7		5.5	10.0	
5	2.3	3.0		2.4	2.3	
Yes (presence of 3 or more)	36.0	41.9	<0.05	26.2	37.5	<0.01
Obesity and MetS, %			<0.05			<0.01
Not obese without MetS	53.9	48.4		58.2	50.1	
Not obese with MetS	19.3	26.5		12.0	20.7	
Obese without MetS	10.1	9.7		15.6	12.4	
Obese with MetS	16.8	15.5		14.2	16.8	

SD – standard deviation; WHO – World Health Organisation; MetS – metabolic syndrome; HDL – high-density lipoprotein; HbA1c – haemoglobin A1C; WHtR – waist-to-height ratio.

^a P-values were derived from independent samples t-test for continuous variables and χ^2 -test for categorical variables.

^b Number of observations varied due to missing values; in middle-aged men, there were 2 and 12 missing values in current smoking and high HbA1c, respectively; in elderly men, there were 14 missing values in high HbA1c; in middle-aged women, there were 2 and 15 missing values in current smoking and high HbA1c, respectively; in elderly women, there were 3, 1 and 9 missing values in current smoking, physical activity and high HbA1c, respectively.

^c Back pain severity refers only to participants who reported back pain, excluding 0 value of no pain. There were 136 middle-aged and 118 elderly men, and 217 middle-aged and 202 elderly women with back pain.

Table A2 Descriptive statistics and comparisons of stratified samples – different sex of the same age group

Variable	Middle-aged (age 50 – 64 years)		<i>P</i> -value ^a	Elderly (Age 65 – 79 years)		<i>P</i> -value ^a
	Men (n=835)	Women (n=1021)		Men (n=699)	Women (n=773)	
Smoking habits, % ^b						
Currently smoking	15.6	14.5	0.56	10.3	8.8	0.37
Physical activity, % ^b			<0.01			<0.01
Sedentary	1.1	1.0		2.3	2.3	
Low	15.0	19.1		19.5	26.7	
Moderate	53.2	57.4		56.8	55.6	
High	30.8	22.5		21.5	15.4	
Depression score (0-8), mean (SD)	1.11 (1.71)	1.55 (1.90)	<0.01	0.95 (1.50)	1.58 (1.94)	<0.01
Diagnosed health conditions, %						
Angina	6.7	3.5	<0.01	14.7	10.1	<0.05
Myocardial infarction	4.7	1.3	<0.01	9.9	4.4	<0.01
Congestive heart failure	0.4	0.1	0.33	0.6	1.2	0.27
Heart murmur	2.3	5.0	<0.01	3.1	4.8	0.11
Arrhythmia	4.7	4.6	1.00	7.6	7.9	0.85
Diabetes	5.9	5.0	0.41	12.7	8.0	<0.01
Stroke	2.0	1.1	0.12	5.3	4.0	0.26
Treatment, %						
Antihypertensives	11.0	10.9	0.94	17.6	20.6	0.16
Antidiabetics	5.6	4.4	0.24	10.7	6.5	<0.01
Back pain, %						
Yes	16.3	21.3	<0.05	16.9	26.1	<0.01
Back pain severity (1-10), mean (SD) ^c	4.84 (2.53)	5.05 (2.41)	0.43	4.91 (2.50)	5.15 (2.10)	0.36
Body mass index (kg/m ²), mean (SD)	28.01 (4.31)	28.03 (5.34)	0.92	27.68 (3.88)	27.70 (4.93)	0.93
WHO Body mass index categories, %			<0.01			<0.01
Normal-weight	22.4	30.6		24.0	32.0	
Overweight	50.8	39.7		50.8	38.8	
Obese	26.8	29.8		25.2	29.2	
Components of MetS, %						
High waist circumference	42.9	53.4	<0.01	45.9	55.1	<0.01
High blood pressure	59.6	50.1	<0.01	71.2	70.8	0.86
High triglycerides	42.8	31.8	<0.01	38.3	34.7	0.16

Low HDL cholesterol	10.7	11.5	0.60	14.9	13.3	0.41
High fasting glucose	19.6	13.0	<0.01	26.3	19.7	<0.01
High HbA1c	8.4	5.6	<0.05	13.9	8.2	<0.01
High WHtR	33.3	26.7	<0.05	42.2	33.0	<0.01
MetS, %						
Number of components			<0.01			0.26
0	9.7	12.1		5.4	6.9	
1	23.6	28.2		21.3	19.5	
2	30.7	33.4		31.3	36.1	
3	25.9	18.4		27.2	25.2	
4	7.9	5.5		11.7	10.0	
5	2.3	2.4		3.0	2.3	
Yes (presence of 3 or more)	36.0	26.2	<0.01	41.9	37.5	0.09
Obesity and MetS, %			<0.01			<0.05
Not obese without MetS	53.9	58.2		48.4	50.1	
Not obese with MetS	19.3	12.0		26.5	20.7	
Obese without MetS	10.1	15.6		9.7	12.4	
Obese with MetS	16.8	14.2		15.5	16.8	

SD – standard deviation; WHO – World Health Organisation; MetS – metabolic syndrome; HDL – high-density lipoprotein; HbA1c – haemoglobin A1C; WHtR – waist-to-height ratio.

^a P-values were derived from independent samples t-test for continuous variables and χ^2 -test for categorical variables

^b Number of observations varied due to missing values; in middle-aged men, there were 2 and 12 missing values in current smoking and high HbA1c, respectively; in elderly men there were 14 missing values in high HbA1c; in middle-aged women, there were 2 and 15 missing values in current smoking and high HbA1c, respectively; in elderly women, there were 3, 1 and 9 missing values in current smoking, physical activity and high HbA1c, respectively,

^c Back pain severity refers only to participants who reported back pain, excluding 0 value of no pain. There were 136 middle-aged men and 217 women, and 118 elderly men and 202 women with back pain.

Table A3 Associations of combined effects of obesity and metabolic syndrome with back pain

Variable categories	n	Presence of back pain, %	Severity of back pain ^a Mean, (SD)	Models	Total sample (n=3328)		
					OR (95% CI)	OR (95% CI)	OR (95% CI)
Not obese without MetS	1769	15.5	4.60 (2.30)	1	reference	0.70 (0.56, 0.89)	0.57 (0.44, 0.74)
				2		0.81 (0.63, 1.03)	0.68 (0.51, 0.89)
Not obese with MetS	629	20.7	5.42 (2.42)	1	1.42 (1.13, 1.80)	reference	0.81 (0.60, 1.10)
				2	1.24 (0.97, 1.58)		0.84 (0.61, 1.15)
Obese without MetS	407	24.3	4.94 (2.27)	1	1.75 (1.35, 2.27)	1.23 (0.91, 1.66)	reference
				2	1.48 (1.12, 1.96)	1.20 (0.87, 1.65)	
Obese with MetS	523	32.3	5.41 (2.37)	1	2.61 (2.08, 3.26)	1.83 (1.40, 2.39)	1.49 (1.11, 1.99)
				2	2.10 (1.65, 2.67)	1.70 (1.28, 2.25)	1.42 (1.04, 1.93)

MetS – metabolic syndrome; n – number of participants; SD – standard deviation; OR – odds ratio; CI – confidence interval.

^a Severity of back pain refers only to participants who reported back pain, excluding 0 value of no pain.

Models were constructed using logistic regression, having back pain when walking on a flat surface reference to no back pain as outcome. The odds ratio shows the increased odds of back pain for the specified combined obesity and MetS groups when referenced to the indicated group. Bold results were statistically significant.

Model 1 was unadjusted.

Model 2 was adjusted for age, sex, smoking status, physical activity, and depression score.

Table A4 Non-response analyses due to missing values

<i>Variable</i>	<i>Main sample (n=3328)</i>	<i>Excluded (n=4338)</i>	<i>P-value^a</i>
Age (years), mean (SD)	63.84 (7.30)	68.65 (10.58)	<0.01
Women, %	53.9	55.8	0.54
Smoking habits, % ^b			
Currently smoking	12.6	16.0	<0.01
Physical activity, % ^b			<0.01
Sedentary	1.6	8.6	
Low	19.9	27.9	
Moderate	55.8	47.5	
High	22.7	16.0	
Depression score (0-8), mean (SD) ^b	1.32 (1.80)	1.71 (1.98)	<0.01
Diagnosed health conditions, %			
Angina	8.2	12.7	<0.01
Myocardial infarction	4.7	7.7	<0.01
Congestive heart failure	0.5	1.2	<0.01
Heart murmur	3.9	6.4	<0.01
Arrhythmia	6.0	10.7	<0.01
Diabetes	7.5	7.9	0.64
Stroke	2.9	6.3	<0.01
Back pain, % ^b			
Yes	20.2	23.3	<0.01
Back pain severity (1-10), mean (SD) ^c	5.01 (2.36)	5.32 (2.34)	<0.01
Body mass index (kg/m ²), mean (SD) ^b	27.88 (4.71)	27.97 (5.03)	0.44

SD – standard deviation.

^a P-values were derived from independent samples t-test for continuous variables and χ^2 -test for categorical variables comparing the main sample with excluded participants.^b Number of observations varied due to missing values; in the included sample, there were 7 and 1 missing values in smoking habits and physical activity, respectively; in the excluded sample, there were 13, 5, 2, 3 and 442 missing values in smoking habits, physical activity, depression score, back pain and BMI, respectively.^c Back pain severity refers only to participants who reported back pain, excluding 0 value of no pain. There were 673 and 1344 participants with back pain in included and excluded sample, respectively.

Table A5 Partial correlation between variables of obesity and metabolic syndrome

<i>Variable</i>	BMI	WC	SBP	DBP	TG	HDL	FBG
BMI							
r_s	1.00	0.88	0.18	0.23	0.23	-0.30	0.14
p-value		<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
n		3119	3119	3119	3119	3119	3119
WC							
r_s		1.00	0.16	0.20	0.27	-0.32	0.16
p-value			<0.01	<0.01	<0.01	<0.01	<0.01
n			3119	3119	3119	3119	3119
SBP							
r_s			1.00	0.70	0.11	0.04	0.06
p-value				<0.01	<0.01	0.063	<0.01
n				3119	3119	3119	3119
DBP							
r_s				1.00	0.11	0.04	0.03
p-value					<0.01	<0.05	0.144
n					3119	3119	3119
TG							
r_s					1.00	-0.32	0.14
p-value						<0.01	<0.01
n						3119	3119
HDL							
r_s						1.00	-0.12
p-value							<0.01
n							3119
FBG							
r_s							1.00
p-value							
n							

BMI – body mass index; WC – waist circumference; SBP – systolic blood pressure; DBP – diastolic blood pressure; TG – triglycerides; HDL – high density lipoprotein; FBG – fasting blood glucose; r_s – partial correlation coefficient controlling for age and sex; n – number of observations.