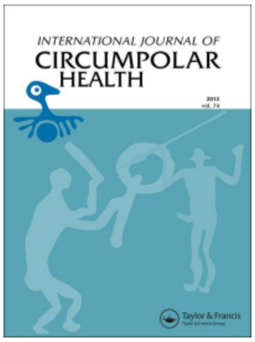


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ORIGINAL RESEARCH ARTICLE



# Assessing the prevalence of obesity in a Russian adult population by six indices and their associations with hypertension, diabetes mellitus and hypercholesterolaemia

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**ABSTRACT**

The anthropometric index that best predicts cardiometabolic risk remains inconclusive. This study therefore assessed the prevalence of obesity using six indices and compared their associations with obesity-related cardiometabolic disorders. We determined obesity prevalence according to body mass index, waist circumference, waist-to-hip ratio, waist-to-height ratio (WHtR), body fat percentage and fat mass index (FMI) using data from the Know Your Heart study ($n = 4495$, 35–69 years). The areas under the receiver operating characteristic curves (AUCs) provided predictive values of each index for detecting the presence of hypertension, hypercholesterolaemia and diabetes. Age-standardised obesity prevalence significantly varied according to anthropometric index: from 17.2% (FMI) to 75.8% (WHtR) among men and from 23.6% (FMI) to 65.0% (WHtR) among women. WHtR had the strongest association with hypertension (AUC = 0.784; $p < 0.001$) and with a combination of disorders (AUC = 0.779; $p < 0.001$) in women. In women, WHtR also had the largest AUCs for hypercholesterolaemia, in men – for hypertension, diabetes and a combination of disorders, although not all the differences from other obesity indices were significant. WHtR exhibited the closest association between hypertension and a combination of disorders in women and was non-inferior compared to other indices in men.

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**KEYWORDS**
Obesity prevalence; anthropometric index; waist-to-height ratio; fat mass index; cardiometabolic disorder; Russia

## Background

Globally, excessive fat mass accumulation in the general population is a growing health threat as it predisposes to non-communicable diseases, such as metabolic and cardiovascular diseases (CVD) [1–3]. The Russian Federation is a country with high incidence and mortality from CVD (30.5 per 1000 population and 640.3 per 100 000 population in 2021, respectively) [4]. It is therefore a troublesome development that body shape phenotypes have changed significantly in European populations over the last several decades, consistent with the emergence of the obesity epidemic [5,6]. Thus, reliable and easy-to-measure obesity indicators are needed in practice not only for detection of obesity but also for screening people with increased risks of obesity-related cardiometabolic disorders [7].

Anthropometric indices used in clinical practice today measure obesity in different ways. The body mass index (BMI), the function of weight and height, is the most common method to assess general obesity at the population level [8–10]. However, if obesity is defined based on BMI alone, one cannot distinguish between high levels of lean mass versus fat body mass [8,11–13]. Other measures of obesity rest on the assessment of fat accumulation in the abdominal region, reflecting abdominal or central obesity, i.e. visceral adiposity [14]. These measures include waist circumference (WC), waist-to-hip ratio (WHR), waist-to-height ratio (WHtR), body roundness index and a body shape index [11,15,16]. Other measurements of obesity could reflect body fatness in a more accurate way [8,10,13]. Imaging techniques, such as computed tomography and magnetic resonance imaging, are the most

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precise methods for quantifying muscle and fat mass and estimating visceral and total adipose tissue [17,18]. Body fat percentage (BFP) and fat mass index (FMI) are obtained from bioelectrical impedance analysis (BIA), the simplest and least expensive method for assessing body composition and measuring body fat [8]. However, these measurements are not included in the standard clinical examination protocols as they require special equipment and additional time.

The estimated obesity prevalence varies depending on the method used to determine the amount of adipose tissue. BMI is most commonly used to assess the prevalence of obesity in epidemiological studies. However, since the end of the twentieth century, there has been a shift towards accumulation of abdominal fat in European countries [5,19]. Prevalence of abdominal obesity measured by WC is higher compared to that of general obesity assessed by BMI both in Europe (47.2% vs 23%) and in the Russian Federation (55% vs 23.1%) [19–21]. The direct comparisons of abdominal obesity are complicated due to the different WC thresholds used in these studies. Data on obesity according to other metrics in Europe are limited [15,22]. Population-based assessments of obesity prevalence based on WHR, WHtR, BFP and FMI indices have not been reported for Russia to date.

Obesity is not only a CVD risk factor but is also associated with other major CVD risk factors (e.g. type 2 diabetes mellitus (diabetes), hypertension and dyslipidemia), which could be the consequence of obesity-related metabolic abnormalities [3,12,23–28]. Thus, early detection of obesity and its related complications is a key for the prevention of adverse cardiovascular outcomes.

Basically, general and abdominal obesity have different associations with metabolic CVD risk factors. Accumulation of adipose tissue in the abdominal region is closer related to the development of obesity-related disorders, CVD outcomes and even all-cause mortality compared to general obesity as defined using BMI [11,23,24,26]. Diabetes, hypertension and hypercholesterolaemia in combination with abdominal obesity constitute a cluster of criteria for the metabolic syndrome [3,29]. These conditions, also called cardiometabolic disorders, are highly prevalent in obese and overweight people and, when occurring simultaneously, accelerate the early onset of CVD [23,25].

To predict risks of developing non-communicable diseases, such as CVD, the World Health Organization (WHO) recommends using indicators of abdominal obesity in addition to BMI, as abdominal fat accumulation could be observed even in those with normal BMI [30]. However, to date, there is no consensus of the value of WC, WHR and WHtR indices of abdominal obesity for better prediction of cardiometabolic disorders [31]. WHtR is a promising index that allows the same cut-off across age and gender and therefore could be a superior tool to identify obesity-related cardiometabolic risks [15,31–33]. Since obesity itself could be prevented and contextualises the development of other diseases, comparing the relationship between different anthropometric indices and cardiometabolic disorders is essential for the prevention and early detection of obesity-related diseases [34]. To date, there are limited data on associations of the anthropometric indices of general obesity, abdominal obesity and obesity according to fat mass with cardiometabolic disorders [8,10,35,36]. The aim of this study was to assess the prevalence of obesity using six indices and compare their associations with hypertension, hypercholesterolaemia and diabetes in a Russian adult population.

## Methods

### *Study design and participants*

The Know Your Heart study (KYH) is a cross-sectional study that was conducted in the Russian Federation in 2015–2018. A random population-based sample of 5089 men and women aged 35–69 years was selected from the population of two Russian cities: Arkhangelsk and Novosibirsk, as described earlier [37]. The participants were interviewed in their homes about their health, as well as socio-demographic and lifestyle characteristics. The respondents were then invited to undergo a health check at a polyclinic. The health check included an interview, anthropometry and physical, laboratory and body impedance examinations. Our analysis was based on 2352 and 2143 participants, from Arkhangelsk and Novosibirsk, respectively.

### *Anthropometric measurements*

Anthropometry was done by trained personnel according to a standard protocol. The participants were wearing light clothes and without shoes during all anthropometric measurements. Height was measured with a Seca® 217 portable stadiometer (Seca limited). Body weight, total fat mass and BFP were measured with a TANITA BC 418 body composition analyser (TANITA, Europe GmbH). WC was measured twice at the narrowest part of the trunk. Hip circumference (HC) was measured twice at the widest part of the hips [37].

BMI was calculated as weight in kilograms divided by the square of height in metres and was classified as follows: underweight (BMI <18.5 kg/m$^2$), normal weight (BMI 18.5–24.9 kg/m$^2$), overweight (25.0–29.9 kg/m$^2$) and obesity (BMI ≥30 kg/m$^2$) [38]. We applied the definition of high disease risk (comparable to BMI ≥ 30 kg/m$^2$) for WC >102 cm for men and >88 cm for women [30]. WHR was calculated as the mean of two WC measurements divided by the mean of two HC measurements. According to WHR, obesity was defined as >0.9 for men and >0.85 for women [30]. We calculated WHtR as the mean of two WC measurements divided by height, both in centimetres (cm). Obesity was defined as WHtR >0.5 for both sexes [39].

A BFP ≥25% for men and ≥35% for women was considered obesity [9]. FMI was calculated as the total fat mass in kg divided by the height squared in metres. Obesity, according to FMI, was defined as FMI >9 kg/m$^2$ in men and >13 kg/m$^2$ in women [40,41].

### Clinical parameters

Systolic and diastolic blood pressure was measured on the brachial artery using an OMRON 705 IT automatic blood pressure monitor (OMRON Healthcare). Three measurements were performed at two-minute intervals; the mean of the second and third measurements was used for the analysis.

As the health check was performed throughout the day, participants were asked to fast for at least 4 h prior to attending the polyclinic. Levels of total cholesterol (mmol/L) and low-density lipoprotein cholesterol (LDL, mmol/L) were assessed in serum using enzymatic colour tests (AU 680; Chemistry System Beckman Coulter). Levels of glycated haemoglobin (HbA1c, %) were measured using immuno-turbidimetric tests (AU 680; Chemistry System Beckman Coulter) [37].

### Medication use

The commercial name, dosage, indication and frequency of use of up to seven medicines were recorded during the health check. The names of the medicines were coded according to the WHO Anatomical Therapeutic Chemical (ATC) classification system version 2016 as follows: antidiabetic medication (ATC class A10); antihypertensive medication (ATC classes C02, C03, C07, C08 or C09); lipid-lowering medication (ATC class C10) [42,43].

### Cardiometabolic disorders

Hypertension was defined as systolic blood pressure >140 mmHg and/or diastolic blood pressure >90 mmHg at the health check and/or self-reported daily use of antihypertensive medication. Hypercholesterolemia was defined as total cholesterol ≥5.2 mmol/L and/or LDL cholesterol of >3.0 mmol/L and/or self-reported daily use of lipid-lowering medication. Diabetes was defined as HbA1C ≥6.5% and/or self-reported daily use of antidiabetics.

### Statistical analysis

Continuous variables were presented as means (M) with standard deviations (SD); categorical variables as absolute numbers (Abs) and proportions (%). Proportions of participants with obesity according to different indices were sex- and age-stratified. Sex-specific obesity prevalence estimates were age-standardised to the European Standard Population 2013 (ESP2013) with 5-year bands and presented with 95% confidence intervals (CI) [44]. We performed comparisons of men and women on continuous variables with a two-sample t-test. Pearson's chi-squared test was used for between-group comparisons of categorical variables. We applied receiver operating characteristic (ROC) analysis and calculated the area under the ROC-curve (AUC) to evaluate and compare the predictive value of the studied obesity indices for the presence of cardiometabolic disorders (hypertension, diabetes, hypercholesterolaemia and a combination of at least two disorders) in men and women. A test was considered perfect if AUC was equal to 1.0, whereas an AUC equal to 0.5 indicated that the predictive value is no better than chance [45]. The AUCs were presented with 95% CIs, and the lower confidence limit above 0.5 was indicating a significant predictive value [45]. We compared the AUCs for six indices simultaneously by using the DeLong test with the level of significance $p < 0.05$ [46]. Subsequently, we conducted multiple pairwise comparisons with the Bonferroni correction and the level of significance $p < 0.003$. The Liu method for empirical estimation of the optimal cutpoint for a diagnostic test (maximising the product of sensitivity and specificity) was applied to identify optimal cut-off values in the adiposity indices to distinguish between participants with and those without cardiometabolic disorders [47,48]. Respective sensitivity and specificity values were reported. Finally, we examined associations of cardiometabolic disorders with the presence of obesity defined according to six indices by calculating age-adjusted prevalence ratios (PRs) with 95% CI. Statistical analysis was performed using the Stata version 17 (StataCorp, College Station, Texas, USA).

## Results

### Characteristics of the study subjects

All obesity indices were significantly different between sexes, except the WHtR (Table 1). Mean values of BMI, BFP and FMI were higher in women, while WC and WHR were higher in men. When comparing cardiometabolic disorders, the proportion of those with hypertension was larger in men (63.3% vs 53.4%), while diabetes was more prevalent in women (9.1% vs 7.4%). The majority of all participants (84.1%) had hypercholesterolaemia with no sex differences.

### Obesity prevalence

The estimated proportions of participants with obesity varied depending on the index applied. In men, obesity ranged from 18.4% if defined by FMI to 77.9% when defined by WHtR (Table 1). There were higher proportions of women with obesity compared to men if obesity was defined by BMI, WC, BFP or FMI, in contrast to WHR or WHtR.

After standardisation to ESP2013, between-sex differences in obesity prevalence by each of the six parameters did not change (Figure 1). However, in both sexes, the proportions decreased by 1–3% compared to the respective non-standardised ones. The difference between the prevalence of abdominal obesity according to WHtR and WHR was 24% in women, in contrast to 2.5% in men.

Men had higher proportions of WHtR and WHR obesity in all age groups with a gap between these two indices and all other metrics of obesity (Figure 2). The proportions of participants with obesity according to WHtR and BFP were higher in women independently of age. The proportions of obese, according to all parameters, increased with age in both sexes except obesity according to BMI in males. In contrast to men, women exhibited a steep increase in all indices in the age group of 40–45 years and upwards.

### Differences in diagnosing obesity based on BMI versus other indices

When the participants were classified by the conventional BMI categories (Figure 3), those without overweight or obesity according to BMI (<25.0 kg/m$^2$) had proportions categorised as obese according to other indices, except for FMI. These proportions ranged from 2.4% according to WC to 16.2% according WHtR in women and from 0.18% according to WC to 40.0% according to WHR in men. Of those who were classified as overweight based on BMI (25.0–29.9 kg/m$^2$), obesity was identified in 45.4–87.0% of women and in 20.7–94.6% of men according to the used indices of abdominal obesity and BFP. The highest proportions of obese among those who were classified as overweight according to BMI were found in both sexes if applying WHtR. The lowest proportions were registered for FMI (0.8% in women and 2.4% in men). Of those with obesity as defined by BMI (≥30.0 kg/m$^2$), the largest share of the surveyed women had obesity according to WHtR, BFP

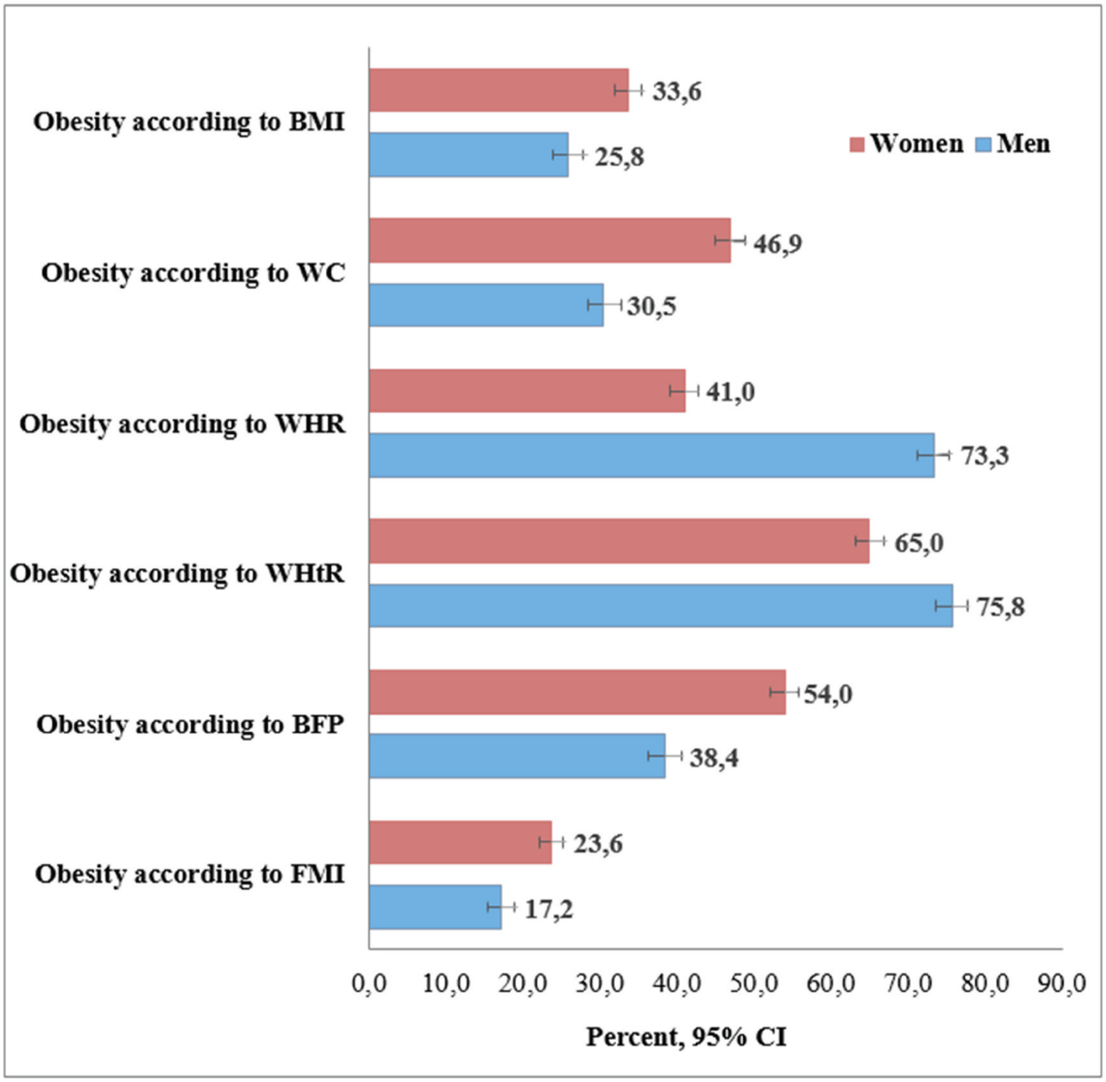
**Table 1.** Anthropometric and clinical characteristics of the studied population by sex.

| Characteristic | Women N = 2611 | Men N = 1884 | p |
|---|---|---|---|
| Age, years (Mean, SD) | 53.82 (9.72) | 54.15 (9.58) | 0.264 |
| **Anthropometric parameters** | Mean (SD) | | |
| BMI, kg/m$^2$ | 28.60 (6.17) | 27.62 (4.78) | <0.001 |
| WC, cm | 89.85 (14.28) | 96.88 (12.53) | <0.001 |
| WHR, ratio | 0.84 (0.075) | 0.95 (0.068) | <0.001 |
| WHtR, ratio | 0.56 (0.092) | 0.55 (0.072) | 0.194 |
| BFP, % | 36.02 (7.58) | 23.19 (6.94) | <0.001 |
| FMI, kg/m$^2$ | 10.70 (4.36) | 6.67 (2.99) | <0.001 |
| **Proportions of participants with obesity** | Absolute (%) | | |
| BMI ≥30.0 kg/m$^2$ | 953 (36.5) | 499 (26.5) | <0.001 |
| WC ≥102 cm for men and ≥ 88 for women | 1333 (51.1) | 606 (32.2) | <0.001 |
| WHR >0.9 for men and > 0.85 for women | 1172 (44.9) | 1415 (75.1) | <0.001 |
| WHtR ≥0.5 | 1815 (69.5) | 1467 (77.9) | <0.001 |
| BFP >25% for men and >35% for women | 1493 (57.7) | 771 (41.3) | <0.001 |
| FMI >9 kg/m$^2$ for men and >13 kg/m$^2$ for women | 670 (25.9) | 344 (18.4) | <0.001 |
| **Cardiometabolic disorders** | Absolute (%) | | |
| Hypertension | 1289 (53.4) | 1100 (63.3) | <0.001 |
| Hypercholesterolemia | 2162 (84.1) | 1560 (84.2) | 0.931 |
| Diabetes | 231 (9.1) | 135 (7.4) | 0.041 |

BMI – body mass index. WC – waist circumference. WHR – waist-to-hip ratio. WHtR – waist-to-height ratio. BFP – body fat percentage. FMI – fat mass index.

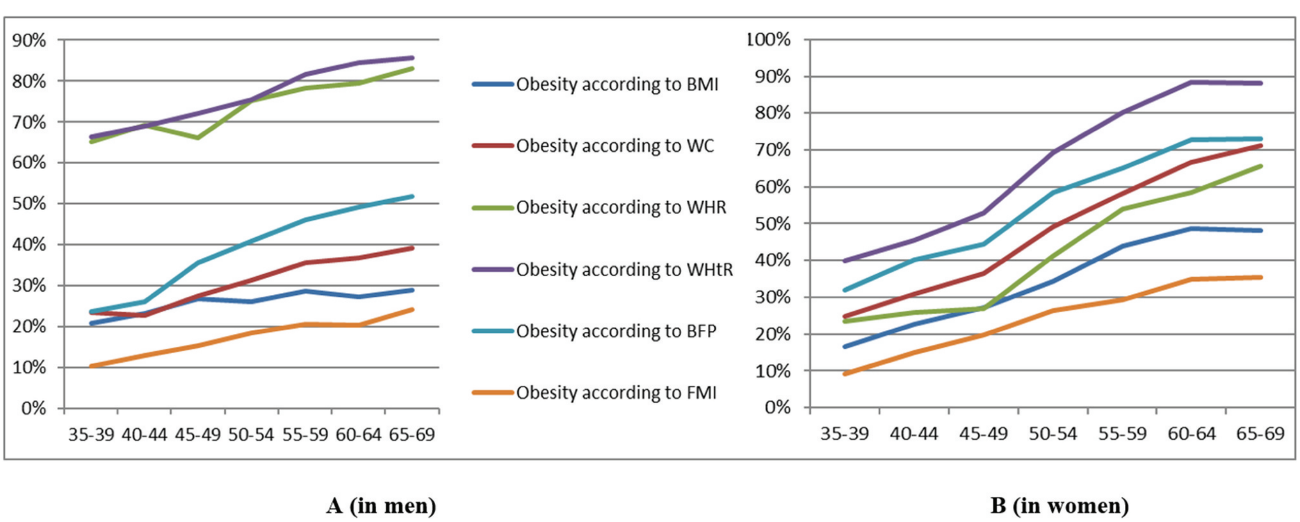
Hypertension was defined as systolic blood pressure >140 mmHg and/or diastolic blood pressure >90 mmHg at the medical examination (average of the 2nd and 3rd measurements) and/or self-reported daily use of antihypertensive medication. Hypercholesterolemia was defined as total cholesterol ≥5.2 mmol/L and/or LDL cholesterol of >3.0 mmol/L and/or self-reported daily use of lipid-lowering medication. Diabetes was defined as HbA1C ≥ 6.5% and/or self-reported daily use of antidiabetics.

Missing data: anthropometric parameters − 594 (11.7%), body fat − 38 (0.8%).



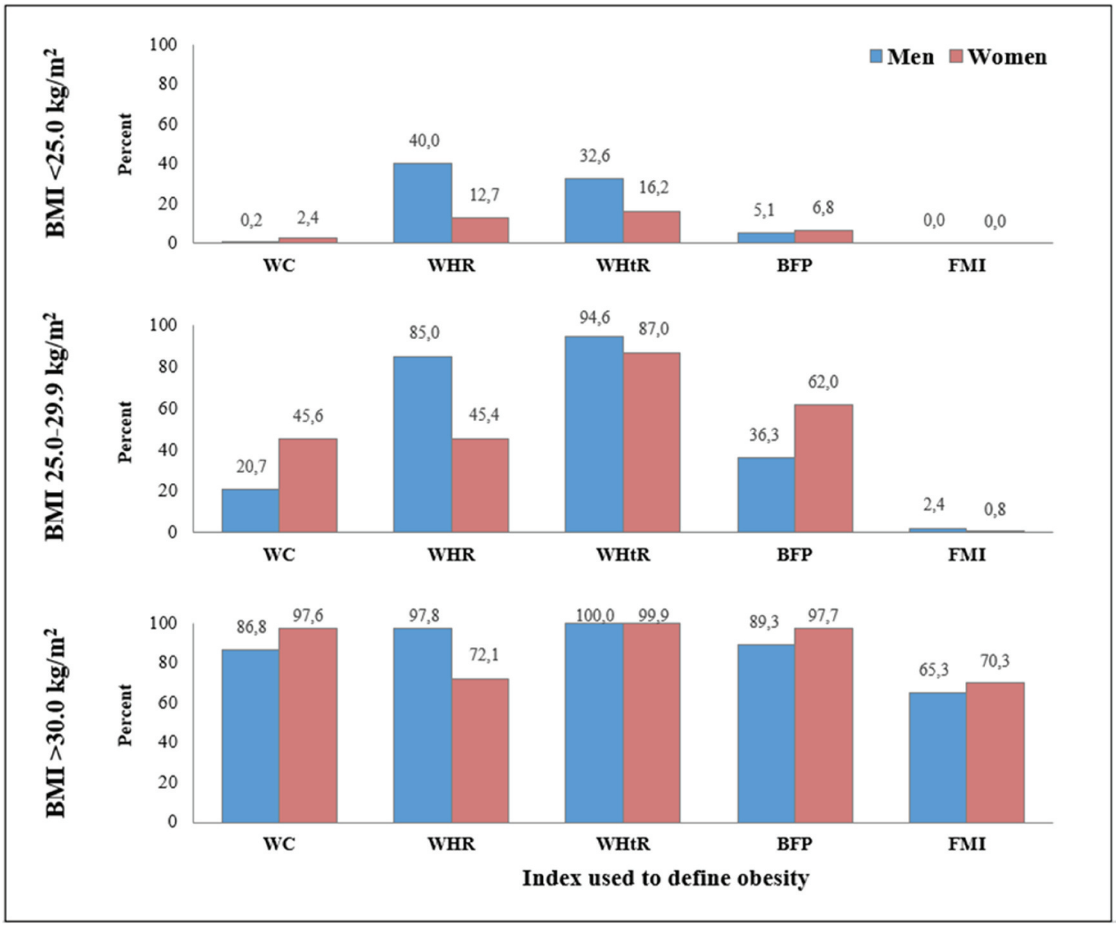

BMI – body mass index. WC – waist circumference. WHR – waist-to-hip ratio. WHtR – waist-to-height ratio. BFP – body fat percentage. FMI – fat mass index.

**Figure 1.** Age-standardised prevalence of obesity according to BMI, WC, WHR, WHtR, BFP and FMI by sex.




BMI – body mass index. WC – waist circumference. WHR – waist-to-hip ratio. WHtR – waist-to-height ratio. BFP – body fat percentage. FMI – fat mass index

**Figure 2.** Obesity proportions according to BMI, WC, WHR, WHtR, BFP and FMI by age and sex.




BMI – body mass index. WC – waist circumference. WHR – waist-to-hip ratio. WHtR – waist-to-height ratio. BFP – body fat percentage. FMI – fat mass index.

**Figure 3.** Obesity presence according to WC, WHR, WHtR, BFP and FMI by BMI categories and sex.

and WC, and a major part of the surveyed men were obese according to WHtR and WHR. FMI demonstrated the lowest obesity proportion in both sexes (70.3% in women and 65.3% in men).

### *Associations of the six obesity indices with cardiometabolic disorders*

The AUCs between each cardiometabolic disorder and obesity index are shown in Table 2. While all obesity metrics had a reasonable predictive capacity in detecting the presence of all analysed disorders, the AUCs between the six indices were significantly different for all risk factors both in women and in men. Among women, the discriminatory power of WHtR for hypertension (78.4%) and a combination of disorders (77.9%) after pairwise comparisons were significantly different from all other indices. WHtR for hypercholesterolaemia (65.2%) was significantly higher compared to BMI (62.5%) and WC (63.7%) in women. Among men, the discriminatory power of WHtR for hypertension (68.2%) was significantly higher compared to BMI (64.5%) and WC (65.6%). At the same time, the discriminatory power of WHtR for diabetes (78.3%) was higher compared to BMI (75.6%) and BFP (74.8%). Furthermore, the discriminatory power of WHtR for a combination of disorders (67.6%) was higher compared to BMI (64.4%) and WC (65.4%) in men.

The optimal empirically defined cut-off points of the six indices that best balanced sensitivity and specificity for cardiometabolic disorders, in women and men, are shown in Table 3. All these cut-off values were the lowest for hypercholesterolaemia and the highest for diabetes in both sexes. The calculated cut-offs for all cardiometabolic disorders were lower than conventionally used for BMI in both sexes (except for diabetes in women) and for FMI, WC and BFP (except for diabetes) in men.

Regardless of the index used, the prevalence of hypertension, hypercholesterolaemia and diabetes were higher in participants with obesity (Table 4). The only exception was obesity according to FMI,

**Table 2.** AUC for obesity indices relative to cardiometabolic disorders in women and men.

| | Hypertension | Hypercholesterolemia | Diabetes | At least 2 of 3 disorders |
|---|---|---|---|---|
| Obesity index | *n* = 2389 | *n* = 3687 | *n* = 366 | *n* = 2106 |
| **Women** | | | | |
| BMI | 0.749 (0.729; 0.768)[b,d,e] | 0.625 (0.594; 0.655)[d] | 0.732 (0.701; 0.763)[b,c,d,e] | 0.739 (0.719; 0.759)[b,d] |
| WC | 0.766 (0.747; 0.785)[a,d,e,f] | 0.637 (0.607; 0.667)[d] | 0.775 (0.746; 0.804)[a,e,f] | 0.762 (0.742; 0.781)[a,d,e,f] |
| WHR | 0.748 (0.728; 0.767)[d] | 0.633 (0.603; 0.662) | **0.791 (0.763; 0.820)**[a,e,f] | 0.749 (0.729; 0.768)[d] |
| WHtR | **0.784 (0.766; 0.802)**[a,b,c,e,f] | **0.652 (0.622; 0.683)**[a,b,f] | 0.786 (0.758; 0.814)[a,e,f] | **0.779 (0.761; 0.798)**[a,b,c,e,f] |
| BFP | 0.730 (0.710; 0.750)[a,b,d,f] | 0.633 (0.603; 0.663) | 0.696 (0.664; 0.728)[a,b,c,d,f] | 0.727 (0.706; 0.747)[b,d,f] |
| FMI | 0.746 (0.726; 0.765)[b,d,e] | 0.632 (0.601; 0.662)[d] | 0.724 (0.693; 0.755)[b,c,d,e] | 0.739 (0.719; 0.759)[b,d,e] |
| *p*-value* | <0.001 | <0.001 | <0.001 | <0.001 |
| **Men** | | | | |
| BMI | 0.645 (0.618; 0.672)[d,f] | 0.611 (0.573; 0.648) | 0.756 (0.711; 0.801)[d] | 0.644 (0.617; 0.670)[d,f] |
| WC | 0.656 (0.630; 0.682)[d] | 0.606 (0.568; 0.644) | 0.774 (0.731; 0.817) | 0.654 (0.627; 0.680)[d] |
| WHR | 0.666 (0.640; 0.692) | 0.594 (0.557; 0.631) | 0.758 (0.715; 0.800) | 0.664 (0.638; 0.690) |
| WHtR | **0.682 (0.656; 0.708)**[a,b] | 0.613 (0.575; 0.651) | **0.783 (0.741; 0.825)**[a,f] | **0.676 (0.650; 0.701)**[a,b] |
| BFP | 0.669 (0.643; 0.696) | 0.628 (0.590; 0.665) | 0.748 (0.703; 0.793)[d] | 0.668 (0.642; 0.694) |
| FMI | 0.667 (0.640; 0.693)[a] | **0.624 (0.586; 0.662)** | 0.758 (0.713; 0.803) | 0.665 (0.639; 0.691)[a] |
| *p*-value* | <0.001 | 0.009 | <0.001 | <0.001 |

Data are shown as AUCs (95% confidence interval). The highest AUC value for a cardiometabolic disorder is shown in bold.

*DeLong test was used for simultaneous comparisons of the six indices. At the next step, multiple pairwise comparisons were made with the Bonferroni correction and the level of significance $p < 0.003$, and [a]In the table denotes significant difference between the corresponding index with BMI, [b]Difference with WC, [c]Difference with WHR, [d]Difference with WHtR, [e]Difference with BFP, [f]Difference with FMI.

AUC – area under curve, BMI – body mass index. WC – waist circumference. WHR – waist-to-hip ratio. WHtR – waist-to-height ratio. BFP – body fat percentage. FMI – fat mass index.

Hypertension was defined as systolic blood pressure >140 mmHg and/or diastolic blood pressure >90 mmHg at the medical examination (average of the 2nd and 3rd measurements) and/or self-reported daily use of antihypertensive medication. Hypercholesterolaemia was defined as total cholesterol ≥5.2 mmol/L and/or LDL cholesterol of >3.0 mmol/L and/or self-reported daily use of lipid-lowering medication. Diabetes was defined as HbA1C ≥ 6.5% and/or self-reported daily use of antidiabetics. A combination of at least two disorders was defined as simultaneous presence of at least any two of the three cardiometabolic disorders (hypertension, hypercholesterolaemia or diabetes).

where the association did not reach statistical significance for hypercholesterolaemia in either sex. Obesity exhibited closer associations with diabetes, as prevalence ratios of diabetes in obese people were higher compared to hypertension and hypercholesterolaemia for all indices and in both sexes. Being obese, according to WHTR, is associated with a 6.2-fold increase in the probability of having diabetes among women and 4.4-fold increase among men. Obesity, according to WHtR, had a significantly closer association with hypertension (PR 2.16) compared to other indices in women.

Obesity according to all six indices was associated with simultaneous presence of at least two cardiometabolic disorders (Table 4). However, among women, the prevalence ratio of at least two disorders was significantly higher for obesity according to WHtR (PR 2.24) compared to all other metrics. Among men, the difference in the prevalence of at least two disorders was not significant only between WHtR (PR 1.70) and WHR (PR 1.51).

## Discussion

In our study, the prevalence of obesity varied substantially depending on the measure used. In men, it ranged from 17.2% according to FMI to 75.8% according to WHtR. In women, it ranged from 23.6% to 65.0% according to FMI and WHtR, respectively. Compared to FMI, the prevalence of obesity defined by WHtR was 4.4-fold higher in men and 2.8-fold higher in women. Out of the six indices studied, WHtR had the strongest associations with hypertension and a combination of at least two cardiometabolic disorders in women.

### *Prevalence of obesity according to different indices*

Obesity prevalence depends on both the population and the measure used. In Europe, obesity prevalence varies from 19.7% in Denmark to 27.8% in the United Kingdom if assessed using BMI (≥30 kg/m$^2$) and from 25.9% in France to 73.9% in Romania if based on WC measurements (combined data of >94 or 102 cm for men and >80 or 88 cm for women) [1,19,49–51]. Women have higher prevalence of obesity according to both indices [20]. In our study, the prevalence of obesity according to BMI and WC (33.6% and 46.9% in women and 25.8% and 30.5% in men) were comparable to the Bulgarian, Czech, Hungarian and Portuguese populations, higher than in other European and Asian studies, especially in women, but lower compared to the U.S. data [1,7,52–57].

According to the Russian multi-centre Epidemiology of Cardiovascular Diseases and their Risk Factors in Regions of the Russian Federation (ESSE-RF) study

**Table 3.** Empirically defined optimal cut-off points for the six indices to predict cardiometabolic disorders.

| | | Predicted cardiometabolic disorder | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Hypertension | | | Hypercholesterolaemia | | | Diabetes | | | At least 2 of 3 disorders | | |
| | | *n* = 2389 | | | *n* = 3687 | | | *n* = 366 | | | *n* = 2106 | | |
| Index | Conventional cut-off | Optimal cut-off | Sensitivity, % | Specificity, % | Optimal cut-off | Sensitivity, % | Specificity, % | Optimal cut-off | Sensitivity, % | Specificity, % | Optimal cut-off | Sensitivity, % | Specificity, % |
| **Women** | | | | | | | | | | | | | |
| BMI, kg/m$^2$ | 30.0 | 27.25 | 71 | 68 | 26.11 | 64 | 57 | 30.12 | 69 | 68 | 27.25 | 72 | 66 |
| WC, cm | 88.0 | 88.28 | 69 | 72 | 84.83 | 63 | 58 | 94.68 | 74 | 69 | 88.28 | 69 | 70 |
| WHR, ratio | 0.85 | 0.82 | 77 | 62 | 0.82 | 61 | 59 | 0.87 | 74 | 72 | 0.84 | 70 | 68 |
| WHtR, ratio | 0.5 | 0.54 | 73 | 70 | 0.51 | 71 | 55 | 0.59 | 73 | 69 | 0.55 | 71 | 72 |
| BFP, % | 35.0 | 35.75 | 71 | 66 | 33.75 | 67 | 55 | 37.85 | 72 | 59 | 36.25 | 69 | 66 |
| FMI, kg/m$^2$ | 13.0 | 9.53 | 73 | 66 | 8.78 | 67 | 56 | 11.29 | 74 | 63 | 9.53 | 74 | 64 |
| **Men** | | | | | | | | | | | | | |
| BMI, kg/m$^2$ | 30.0 | 27.08 | 59 | 64 | 26.51 | 59 | 57 | 28.94 | 72 | 68 | 27.08 | 60 | 61 |
| WC, cm | 102.0 | 96.18 | 59 | 66 | 93.38 | 62 | 56 | 103.38 | 67 | 76 | 96.18 | 60 | 64 |
| WHR, ratio | 0.9 | 0.94 | 61 | 65 | 0.92 | 69 | 48 | 0.97 | 72 | 67 | 0.94 | 63 | 62 |
| WHtR, ratio | 0.5 | 0.55 | 62 | 66 | 0.53 | 67 | 53 | 0.58 | 74 | 70 | 0.55 | 63 | 62 |
| BFP, % | 25.0 | 22.75 | 64 | 62 | 21.55 | 64 | 57 | 27.15 | 63 | 75 | 23.15 | 62 | 62 |
| FMI, kg/m$^2$ | 9.0 | 5.74 | 68 | 57 | 5.70 | 63 | 56 | 7.45 | 72 | 68 | 5.74 | 70 | 54 |

Data are Cut-off, Sensitivity (%), Specificity (%).

BMI – body mass index. WC – waist circumference. WHR – waist-to-hip ratio. WHtR – waist-to-height ratio. BFP – body fat percentage. FMI – fat mass index.

Hypertension was defined as systolic blood pressure >140 mmHg and/or diastolic blood pressure >90 mmHg at the medical examination (average of the 2nd and the 3rd measurements) and/or self-reported daily use of antihypertensive medication. Hypercholesterolaemia was defined as total cholesterol ≥5.2 mmol/L and/or LDL cholesterol of >3.0 mmol/L and/or self-reported daily use of lipid-lowering medication. Diabetes was defined as HbA1C ≥6.5% and/or self-reported daily use of antidiabetics. A combination of at least two disorders was defined as simultaneous presence of any two of the three cardiometabolic disorders (hypertension, hypercholesterolaemia or diabetes).

**Table 4.** Age-adjusted prevalence ratios of cardiometabolic disorders in the presence of obesity measured with six indices.

| | Hypertension | Hypercholesterolaemia | Diabetes | At least 2 of 3 disorders |
|---|---|---|---|---|
| | *n* = 2389<br>PR (95% CI) | *n* = 3687<br>PR (95% CI) | *n* = 366<br>PR (95% CI) | *n* = 2106<br>PR (95% CI) |
| **Women** | | | | |
| BMI ≥30.0 kg/m$^2$ | 1.52 (1.43; 1.62) | 1.04 (1.01; 1.08) | 2.83 (2.18; 3.67) | 1.54 (1.44; 1.65) |
| WC ≥88 cm | 1.70 (1.57; 1.83) | 1.05 (1.02; 1.09) | 3.99 (2.76; 5.76) | 1.71 (1.57; 1.86) |
| WHR >0.85 | 1.48 (1.39; 1.59) | 1.05 (1.01; 1.08) | 4.10 (2.94; 5.71) | 1.54 (1.43; 1.66) |
| WHtR ≥0.5 | 2.16 (1.90; 2.46) | 1.11 (1.07; 1.16) | 6.15 (3.09; 12.23) | 2.24 (1.94; 2.57) |
| BFP >35% | 1.64 (1.51; 1.79) | 1.07 (1.03; 1.10) | 2.18 (1.59; 2.99) | 1.66 (1.51; 1.82) |
| FMI >13 kg/m$^2$ | 1.42 (1.34; 1.50) | 1.02 (0.99; 1.05) | 2.29 (1.80; 2.90) | 1.42 (1.33; 1.52) |
| **Men** | | | | |
| BMI ≥30.0 kg/m$^2$ | 1.27 (1.19; 1.35) | 1.07 (1.02; 1.11) | 4.05 (2.92; 5.61) | 1.34 (1.24; 1.45) |
| WC ≥102 cm | 1.31 (1.23; 1.39) | 1.05 (1.01; 1.09) | 4.29 (3.02; 6.08) | 1.36 (1.26; 1.47) |
| WHR >0.9 | 1.35 (1.22; 1.49) | 1.14 (1.08; 1.21) | 4.61 (2.22; 9.60) | 1.51 (1.33; 1.71) |
| WHtR ≥0.5 | 1.45 (1.29; 1.62) | 1.22 (1.14; 1.30) | 4.36 (1.99; 9.52) | 1.70 (1.47; 1.97) |
| BFP >25% | 1.27 (1.19; 1.36) | 1.11 (1.06; 1.15) | 3.24 (2.25; 4.68) | 1.36 (1.25; 1.47) |
| FMI >9 kg/m$^2$ | 1.25 (1.17; 1.34) | 1.05 (0.997; 1.10) | 4.33 (3.17; 5.91) | 1.32 (1.22; 1.44) |

PR – prevalence ratio. BP – blood pressure. BMI – body mass index. WC – waist circumference. WHR – waist-to-hip ratio. WHtR – waist-to-height ratio. BFP – body fat percentage. FMI – fat mass index. CI – confidence interval.

Hypertension was defined as systolic blood pressure >140 mmHg and/or diastolic blood pressure >90 mmHg at the medical examination (average of the 2nd and the 3rd measurements) and/or self-reported daily use of antihypertensive medication. Hypercholesterolaemia was defined as total cholesterol ≥5.2 mmol/L and/or LDL cholesterol of >3.0 mmol/L and/or self-reported daily use of lipid-lowering medication. Diabetes was defined as HbA1C ≥ 6.5% and/or self-reported daily use of antidiabetics. A combination of at least two disorders was defined as simultaneous presence of any two of the three cardiometabolic disorders (hypertension, hypercholesterolaemia or diabetes).

(2014–2015), the prevalence of BMI-based and WC-based obesity in population of 25–64 years was 27.5% and 44.0% in men vs 31.4% and 61.8% in women, respectively [21,58]. Our study population was, on average, older and showed a higher prevalence of BMI-based obesity in women (33.6%), but lower WC-based obesity prevalence in both sexes (30.5% in men, 46.9% in women). However, the lower prevalence of abdominal obesity could not be concluded because of the higher threshold for WC-based obesity (102/88 cm for men/women) used in our study compared to ESSE-RF (94/80 cm for men/women) [21]. These findings are in line with an earlier Russian population study with participants aged 45–69 years. There, the prevalence of BMI-based obesity was 21% in men and 47% in women [59]. In the study based on Siberian population of Russia aged 45–64, the prevalence of abdominal obesity by WC (94/80 cm) according to the Health, Alcohol and Psychosocial factors In Eastern Europe (HAPIEE) project was 46% in men and 79% in women [28]. An earlier study in the Siberian part of Russia demonstrated that WC-based obesity defined by 94 cm for men and 80 cm for women was 49% in men and 81% in women, respectively, while the corresponding estimates would be 24% and 58%, if 102 and 88 cm thresholds for men and women had been used [60]. Such difference in the cut-offs originates from changes in obesity-related health risk estimates, which are of practical importance but complicate the use of the WC index in routine practice and for comparisons between studies [30].

The direct relationship between obesity prevalence and age is well known [30,61,62]. We also found that the prevalence of obesity according to each of the studied indices was positively associated with age, except for BMI in males, reflecting potential deficiencies of this tool.

We observed sex differences in obesity prevalence regardless of the index used. These findings are in line with previous studies showing a higher obesity prevalence in women according to BMI, BFP and FMI [9,52,58,63]. However, the anteriority of men or women in the prevalence of abdominal obesity depends on the anthropometric index used. In our study, obesity prevalence was higher in women compared to men if assessed by WC, but lower when using WHR or WHtR. This is in agreement with several previous studies [19,49,63,64], but others came up with different conclusions [22,55]. De facto, taking into account hip circumference leads to a decrease in the prevalence of obesity in women. Women are more likely to accumulate adipose tissue in the lower body, which is considered safer in terms of metabolic disorders [11].

To our knowledge, there were no population-based studies reporting WHR, WHtR or BIA measures in Russia. The results of the Swedish Malmö Diet and Cancer (MDC) cohort study showed prevalence of obesity according to WHR ranging between 16.6% and 22.0% in men and 42.0% and 48.3% in women aged 45–73 years; whereas according to BFP, it was between 19.8% and 21.8% in men and 36.8–43.4% in women [22]. These prevalences were lower compared to our data, although different thresholds were used for both indices (>1.00 for men and >0.80 for women for WHR obesity and ≥25% for men and ≥33% for women for BFP obesity). Mean WHtRs in our study population (0.56 in women and 0.55 in men) were lower than in Portugal for both sexes [52], but higher than in Korean or Taiwanese adults [54,65]. The WHtR-based obesity prevalence in our study was lower compared to the US (75.8% vs 83.1% and 65.0% vs 72.9% in men and women, respectively), but higher compared to adults in the United Kingdom, Sweden or Nepal [7,15,66]. The mean FMI in our population (10.7 kg/m$^2$ in women and 6.67 kg/m$^2$ in men) was higher than in Korean adults [65]. The prevalence of FMI-defined obesity was lower compared to the US but higher compared to Swedish adults [9,22].

In men, there is a gap between the prevalence of obesity assessed using WHR or WHtR and the prevalence estimates based on other indices. This could be explained by the predisposition to the upper body but not the lower body, fat accumulation among men [11]. A rising global trend in abdominal obesity prevalence has been observed since the 1990s, and this trend has been more drastic in men and young adults [19]. Therefore, simultaneous accounting for waist and hip circumferences leads to a significant increase in the prevalence of obesity among men.

As obesity prevalence varies depending on the measure used, direct comparisons of studies using different anthropometric indices are problematic. It is preferable to obtain data based on the same obesity measurement tools in separate populations. In addition, studies of relationships between different obesity indices allow a better understanding of adiposity-related features of specific ethnic groups. For example, for the same BFP, Caucasians have a higher BMI compared to American Blacks and Polynesians [67]. Having presented assessments of obesity prevalence in a Russian population sample based on six indices, including age- and sex-stratified prevalence estimates, we believe our study provides a comprehensive material for domestic and international comparisons.

### Abdominal obesity in those with BMI <30 kg/m$^2$

When using BMI, one relies on the assumption that the distribution of adipose tissue is homogenous [9]. However, obesity is a heterogeneous condition due to the variability in regional body fat deposition. Furthermore, the BMI value has limitations to correctly assess adiposity in those with increased body fat and normal BMI or with low lean mass and high body fat [8,11–13].

In our study, obesity prevalence, according to WHtR, was the highest in women and in men. Moreover, 87.0% of women and 94.6% of men who were overweight according to BMI had obesity according to WHtR. If assessing BMI-based obesity only, one would underestimate excess abdominal fat distribution, especially in overweight people [9]. Thus, WHtR could detect more obesity cases than other indices, reflecting its superiority compared to the other metrics. Early detection of obesity, especially in abdominal region, is critical for early strategies to prevent obesity-related consequences.

Our study may have several practical implications. First, BMI should not be the only method of screening for obesity, but additionally an index of abdominal obesity should be used for screening and early intervention [30]. Second, for routine practice, the WHtR index is an attractive anthropometric measure with a single threshold >0.5 for both sexes, in all ages and in all ethnicities [68,69]. On the other hand, WHO thresholds for WHtR (>0.5) may not be appropriate for every population [10], thus specific cut-offs should be found for different settings [68]. In our setting, the empirically estimated cut-offs of WHtR with highest sensitivity and specificity for detecting hypercholesterolaemia (0.51 vs 0.53 for women and men) are the closest to the standard cut-off, while the empirical cut-offs for other conditions were higher. Therefore, a standard cut-off value for WHtR (>0.5) is plausible for early detection and prevention of cardiometabolic disorders in the study population. This standard cut-off value for WHtR will reasonably work with an easy-to-understand public health message "keep your waist circumference to less than half your height" [69,70].

The empirically defined optimal cut-off points for BMI in men (26.51–28.94 kg/m$^2$) and in women (26.11–27.25 kg/m$^2$), except for diabetes, were lower than the standard ones (BMI ≥30 kg/m$^2$ for both sexes). Among men, the calculated cut-offs for FMI (5.45–5.74 kg/m$^2$) and for WC (93.38–96.18 cm) and for BFP (21.55–23.15%), both except for diabetes, were also lower than the standard ones (FMI ≥9 kg/m$^2$, WC ≥102 cm and BFP ≥25%). For this reason, relying on the standard definitions of obesity based on BMI, BFP and FMI, one underestimates the risk of cardiometabolic disorders in the studied population. Therefore, recommended cut-offs for these indices are not always appropriate and are not fully suitable in our setting.

### Obesity and cardiometabolic disorders

The prevalence of cardiometabolic disorders in our study was higher compared with data from another

Russian study. In the ESSE-RF study, the prevalence of hypertension was 49.1% and 39.9%, the prevalence of hypercholesterolaemia (total cholesterol ≥5 mmol/l) was 58.1% and 57.9%, and the prevalence of diabetes was 3.8% and 5.4% in men and women, respectively [71,72]. This could be connected with the younger age of ESSE-RF participants (25–64 years) and differences in the definitions of these conditions [71,72].

Previous studies show that indices of obesity are associated with cardiometabolic disorders and can predict CVD [10,12,19,66,68,73]. Although numerous studies and meta-analyses demonstrate a strong link between visceral and ectopic fat and the development of obesity-related metabolic conditions [11–13,74], a consensus on the best anthropometric predictor of cardiometabolic abnormalities remains to be achieved [66,68]. We found that all indices were associated with hypertension, diabetes and hypercholesterolaemia, although the AUCs for the latter were the lowest compared to other conditions and the prevalence of hypercholesterolaemia did not differ significantly in both sexes regardless of the obesity status defined according to FMI.

In our study, WHtR was the strongest indicator of hypertension (AUC 0.784) and a combination of at least two disorders (AUC 0.779) in women compared to all other indices. In men, WHtR had a significantly higher predictive value for hypertension and for having two of the three studied cardiometabolic disorders compared to BMI and WC, but it was non-inferior compared to WHR, BFP and FMI. Indices based on BIA, a more sophisticated method to assess fat accumulation, had no advantage over anthropometric indices in relation to cardiometabolic disorders and thus in the ability to predict them. Although these indices accurately detect true fat mass, they do not differentiate between regional fat distribution and subcutaneous or visceral fat, thus having questionable advantages compared with simpler WC-based obesity measurements [75].

WHtR also showed a better performance compared to other indices in different studies. Among Taiwanese adults, WHtR had a stronger association with hypertension compared to BMI and was non-inferior compared to WC [54]. In a screening of Brazilian female population aged 20–49 years, WHtR had a higher discriminatory power to detect hypertension, compared to BMI, WC, WHR, BFP and C index (based on WC, weight and height) [76]. In the Korean adult population, the WHtR had the highest AUCs for components of metabolic syndrome, including elevated blood pressure, fasting glucose level, triglyceride level and reduced high-density lipoprotein cholesterol level compared to BMI, lean mass, fat mass, trunk fat mass and bone mineral content [65]. Using WHtR ≥0.5 helps to identify more people with metabolic syndrome components compared to obesity defined by BMI and WC simultaneously [15]. In several studies, WHtR was also found to be a better predictor of cardiometabolic disorders and CVD compared to other obesity indices [69,70,77], but not in the others [68,78–80]. These contradictions may be related to the different cut-offs for anthropometric indices to predict metabolic abnormalities in different populations.

In our study, using standard cut-off points, we identified a significantly higher prevalence of cardiometabolic conditions among participants with obesity defined according to each of the six studied indices, except for FMI. Participants with obesity defined as WHtR greater than 0.5 were 1.11–6.15 times more likely to have hypertension, hypercholesterolaemia or diabetes, compared with those with WHtR below 0.5. These PRs were higher than for other indices used, and the finding agrees with several other studies in different countries [66,68,81].

In addition to assessing the deposition of fat in the abdominal region, the possible explanation of the comparative superiority of WHtR can be the fact that, this index also takes into account the individual height. WC or WHR do not account for the variation in body height, although the proportion of abdominal fat assessed by these indices may differ according to different height [7]. WHtR is more useful than WC or WHR because it assumes that a certain amount of abdominal fat is acceptable for a certain height [33]. If height is not accounted for, one may face a finding that individuals with the lowest height tertile have 30% higher prevalence of metabolic syndrome than subjects with the highest height tertile despite the WC. This effect was observed in both the high WC group (WC >102 cm in males and >88 cm in females) and the low WC group but not if grouped by high or low WHtR [82]. It was also shown that people with normal WC but elevated WHtR were more likely to have hypertension, diabetes and CVD [7], reflecting a higher sensitivity of WHtR in terms of detecting cardiometabolic abnormalities. Finally, the threshold for abdominal obesity on the WHtR scale is placed rather low, which, on the one hand, results in increased prevalence estimates, but on the other, it denotes cardiometabolic risk among subjects who are not classified as obese using other anthropometric indices [54], which seems a valuable advantage to be relied upon in early prevention.

### *Strengths and limitations*

This is the first population-based study that examines the prevalence of obesity in the Russian adult population using six indices. One strength of the study is that it has described the associations of six metrics with obesity-related cardiometabolic disorders, thus shedding new light on the pros and cons of using different indices in screening for metabolic abnormalities. Another strength of the study is that all anthropometric measurements were made by trained staff, without self-reported data, which could be prone to bias [83]. Two indices (BFP and FMI) were measured using special equipment (BIA), which is uncommon in large-scale epidemiological studies. The third strength is that the definitions of the studied cardiometabolic disorders (hypertension, hypercholesterolaemia and diabetes) were based on the combined data of self-report and clinical and laboratory examination, which makes them reasonably reliable.

The study also has some limitations. First, the data on medications were self-reported and thus could be biased due to the inaccurate reports and subsequent misclassification of the treatment received. However, participants were asked to show the prescribed medications and indicate their commercial names, doses and frequency of use, which must have reduced the reporting bias. In addition, the bias was unlikely substantial as the self-reported data on daily intake of medicines for hypertension, diabetes and hypercholesterolaemia were shown to be in good agreement with medical documentation [84]. Second, blood samples were collected without full fasting that could affect the studied measurements of blood lipids. Triglyceride levels are most affected by the recent food intake, while total cholesterol and LDL cholesterol are considerably reduced in 4-h period [85]. For this reason, we could not include hypertriglyceridaemia into our analysis although it is an important obesity-associated cardiometabolic disorder. Third, the findings of a cross-sectional study are not a conclusive evidence of a causal relation between obesity and cardiometabolic disorders, although it may be reasonably assumed that pathophysiological pathways most commonly go from gaining weight to hypertension, hypercholesterolaemia and diabetes, rather than vice versa. Finally, the study included a Caucasian population, residents of two Russian urban settings [37]. Generalisability of the findings may therefore be limited to populations with similar sociodemographic characteristics and/or ethnic composition.

## Conclusion

In men, the prevalence of obesity ranged from 17.2% according to FMI to 75.8% according to WHtR. In women, it ranged from 23.6% to 65.0%, respectively. This reflects its strong dependence on the tool used. Using BMI only, we underestimate excess abdominal fat distribution, especially in those overweight. Therefore, indices of abdominal obesity should be used in parallel with BMI for early detection of abdominal obesity and prevention of its consequences. WHtR, an easily determined anthropometric index, was identified as the most useful tool for obesity screening and early prevention of hypertension and combinations of cardiometabolic disorders in women. It also demonstrated superiority compared to BMI and WC but non-inferiority compared to WHR, BFP and FMI in relation to the above-mentioned disorders in men.

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## Disclosure statement

No potential conflict of interest was reported by the author(s).

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## Authors' contributions

Conceptualisation, K.K., A.V.K., S.M.; Data curation, K.K., A.V.K. Methodology, K.K., A.V.K., A.K., S.M.; Project administration A.V. K.; Formal analysis, K.K., A.V.K.; Visualisation, K.K., A.V.K.; Interpretation of data, K.K., A.V.K., A.K.; Writing – original draft preparation, K.K.; Writing – review and editing, A.V.K., A.K., I.D., S.M.; Supervision, A.V.K., A.K., I.D. All authors have read and agreed to the published version of the manuscript.

## Data availability statement

Researchers may apply for access to KYH data. See data access regulations and instructions at https://metadata.knowyourheart.science. All data requests will be guided by the protection of personal information, the confidentiality agreement with the participants and participants' informed consent.

## Ethical approval and informed consent

The authors declare that all procedures that contributed to this work comply with the ethical standards of the WMA Declaration of Helsinki. All participants signed an informed consent form. Ethical approval for the study was received from the ethics committees of the London School of Hygiene and Tropical Medicine (approval number 8808), Novosibirsk State Medical University (approval number 75; 21 May 2015), the Institute of Preventive Medicine, Novosibirsk (approval received 26 December 2014) and the Northern State Medical University, Arkhangelsk (approval number 01/01–15; 27 January 2015).

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