BMI is dead; long live waist-circumference indices: But which index should we choose to predict cardio-metabolic risk?

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Abstract

Background and Aims: There is growing evidence that Body Mass Index (BMI) is unfit for purpose. Waist circumference (WC) indices appear to be the preferred alternative, although it is not clear which WC index is optimal at predicting cardio-metabolic risk (CMR) and associated health outcomes.

Methods and Results: We obtained a stratified random probability sample of 53,390 participants from the Health Survey for England (HSE), 2008-2018. The four available CMR factors were; high-density lipoproteins (HDL) cholesterol, glycated haemoglobin (HbA1c), systolic (SBP) and diastolic blood pressure (DBP). Strength of association between the four cardio-metabolic risk factors and competing anthropometric indicators of weight status [BMI, Waist-to-height ratio (WHTR), unadjusted WC, and a new WC index independent of height, WHT·5R=WC/height$^{0.5}$] was assessed separately, using simple correlations and ANCOVAs, and together (combined) using MANCOVA, controlling for age, sex and ethnicity. Centile curves for the new index WHT·5R=WC/height$^{0.5}$were also provided.

Conclusions: Waist-circumference indices were superior to BMI when explaining/predicting our CMR factors, before and after controlling for age, sex and ethnicity. No single WC index was consistently superior. Results suggest that WHTR is the strongest predictor of HbA1c, confirming that shorter individuals are at great risk of diabetes. The most appropriate WC index associated with blood pressure was WHT·5R for DBP, or unadjusted WC for SBP. Given HDL cholesterol is independent of height, the best predictor of HDL was WHT.5R. Clearly, "no one size fits all!". MANCOVA identified WHT·5R to be the best single WC index associated with a composite of all four CMR factors.

Keywords: Obesity; Anthropometry; Metabolic Health; Diabetes; Disease Risk

Introduction

Body mass index (BMI) has long been used as *the* primary anthropometric index for monitoring weight status in clinical and public health settings despite its limitations being historically well established (1) and its use described as unethical (2) due to its flaws as a measure of weight status. A body of research has also demonstrated that anthropometric indices involving waist circumference (WC) rather than BMI, are better associated with non-communicable diseases such as cardio-metabolic risk (CMR) (3-6), but there is still considerable debate as to which WC index is likely to be the best to replace BMI. The use of WC indices provides an anthropometric measure which is more reflective of central adiposity and visceral fat than BMI (3), although there is evidence that WC differs by ethnicity (4).

Research by Ashwell et al (3) suggests that the waist-to-height ratio (WHTR) is the strongest predictor of cardio-metabolic risk (CMR) in adults. Nevill et al. (5) show that a new ratio, waist divided by height$^{0.5}$ (WHT·5R), is not only independent of stature (using allometric scaling) but also a stronger predictor of CMR compared with a wide range of other anthropometric indices including BMI, waist-to-hip ratio (WHR), and waist-to-height ratio (WHTR). The likely explanations as to why WHT·5R is a better predictor of CMR are twofold. Firstly, waist girth is likely to be the most sensitive dimension to detect changes in adiposity, certainly better than BMI, as BMI reflects changes in muscle mass and adiposity. Secondly, using height$^{0.5}$ to normalize or scale waist girth for individuals of different body size is more suitable, since WHT·5R is both theoretically (7) and empirically (5) independent of stature but also height$^{0.5}$ is unaffected by changes in adiposity, unlike hip girth that is used to normalise WHR. Clearly, unadjusted WC will penalize taller subjects (for obvious reasons i.e., taller people will have on average greater WC but not necessarily have any greater cardio-metabolic risk). In contrast, WHTR will penalize shorter individuals (the correlation between WHTR and height is negative, i.e., height over scales WC). The only WC-by-height ratio that will not penalize taller or shorter individuals (i.e., it removes the effect of height from WC completely) is WHT·5R=WC/(Height$^{0.5}$) (5) i.e., it correctly scales WC for differences in height.

It is possible however that for some CMR variables it might be appropriate to penalize shorter or taller individuals. For example, shorter stature has been linked to higher risk of diabetes in several studies, e.g., (8), even suggesting that height could be used to predict the risk for the condition. It has been reported that insulin sensitivity and beta cell function are better in taller people (8). Short stature is related to an increased risk of myocardial infarction, heart failure and stroke (9); (10), in addition to higher cardiovascular risk, a risk that might in part be mediated by cardio-metabolic risk factors relevant to type 2 diabetes — for example blood pressure,

blood fats and inflammation. For this reason, adopting WHTR rather than WC or WHT·5R might be more appropriate for predicting some indicators of CMR, such as glycated haemoglobin (HbA1c).

Conversely, taller height in adulthood has been strongly associated with lower life expectancy (11) with studies suggesting that taller stature is associated with increased mortality from cancer (9), (10). Larger organ size in taller individuals has been cited as one reason for increased cancer mortality due to increased likelihood of developing cancerous cells although lifestyle factors including nutrition status and obesity are acknowledged contributors to cancer (12), hence why anthropometric measures relating to body size are increasingly recommended in predicting cancer risk (13). Stature is important when considering anthropometric indices that are best used to predict health or disease risk as, unlike body mass, it represents the interaction between an individual's genetic endowments and early life environments (14). However, the most appropriate way to scale for waist circumference when using anthropometric indices to predict health status remains equivocal. As stated above, if we do not divide waist circumference by stature we penalize taller individuals, but if we divide waist circumference by unadjusted stature we penalize shorter individuals. There remains little consensus on which anthropometric index is best associated with CMR as measures such as WC or WHTR likely overscale or underscale depending on the population they are employed with. A more nuanced examination of how best to scale waist circumference for stature is needed to better inform clinicians and researchers in their decision making. Whilst there are a considerable number of studies employing waist based indices to screen for health risk, or to 'predict' risk related to cardiovascular and other diseases (2,3,5,7,13), no study to date has examined which waist based index might best be associated with key CMR variables in the same sample. Without such an investigation the lack of clarity regarding which anthropometric index might best be related to CMR variables will remain. The current study addresses this issue by comparing the association between competing anthropometric indices and CMR variables in the same sample of participants.

Hence, the purpose of the current study is to compare the strength of the associations between the four competing anthropometric indices (BMI, WHTR, WHT·5R, and WC) with a number of key CMR variables to inform both clinicians and researchers alike which WC index is the most appropriate to adopt that may well depend on which CMR factor is being assessed.

Methods

Participants

A stratified random probability sample of 53390 participants (90% Caucasian, 6% South Asian, 1·6% Black, 1·8% mixed ethnicity, 0·6% other ethnicity) from private households in England was obtained from pooled data from ten years of the Health Survey for England (HSE) 2008-2018 (15). Each survey year consists of a new sample of participants. Although it is very unlikely that participants would be selected for inclusion in more than one HSE, they are not precluded. The HSE survey combines questionnaire-based answers with anthropometric measurements and the analysis of blood samples, captured as part of the nurse visit. Each dataset contributing to the pooled cohort is a random, nationally representative sample of the adult general population and is not selected specifically on health grounds. Of note, although the HSE does provide some information regarding participant health status (e.g., prior diagnosis of diabetes, heart disease, or hypertension) and current medication, the data provided is not consistent across each year's survey and the exact nature of current medication is not provided in such a way to distinguish between participants. Of the current sample 11.3% of the participants were taking prescribed drugs that lower blood pressure (including beta blockers, Ace inhibitors, calcium blockers and other unnamed drugs that have this affect). 8.1% of the overall sample were taking prescribed medication for lowering cholesterol and some other issues associated with heart disease (lipid lowering cholesterol/fibrinogen). 3% of the overall sample were taking prescribed medication for diabetes. 14% of the overall sample were taking some form of prescribed cardiovascular medication (including some detailed above). The percentage of individuals in the data who were on medication for BP, cholesterol, diabetes other diagnosed cardiovascular problems are representative of the general population and so were included in the analysis without adjustment. Internationally, the HSE is regarded as a robust data set for population health surveys (16) which provides reliable estimates of undiagnosed conditions in the way this data can — hence its use in the present study. Demographic information collected included sex, age group and ethnic group (see Table 1 for descriptive statistics).

Procedures

Anthropometry

Anthropometric measures included height, weight, and waist circumference (WC). Trained interviewers, who were required to pass an accreditation test before working on the study, assessed height and weight. Professionally

qualified nurses who were also proficient at taking blood samples measured WC. In addition, they attended a two-day training session at which they received equipment training and were briefed on the specific requirements of the survey with respect to measuring blood pressure, taking waist and hip measurements and taking blood.

Only valid height and weight measurements were included in the analysis. These are where the interviewer taking measurements recorded 'no problems experienced, reliable height measurement obtained' for height and 'no problems experienced, reliable weight measurement obtained' for weight. Height measurements were considered invalid if the participant stooped during measurement, wore religious headgear, a wig, sported a hairstyle that caused measurement issues, wore shoes during measurement or failed to stand still. Weight measurements were considered invalid if the participant weighed more than 200 kg, or the interviewer was unsatisfied with the weight recorded where, for example, the surface used was uneven.

WC was measured by a nurse and taken from the midpoint between the lower rib and the upper margin of the iliac crest (hip bone). WC measurements were taken twice, using the same tape and recorded to the nearest millimetre, the mean of the two valid measurements were used in the analysis.

Assessment of Cardiometabolic Risk

The four available cardio-metabolic risk factors were; high-density lipoproteins (HDL) cholesterol, glycated haemoglobin (HbA1c), systolic (SBP) and diastolic (DBP) blood pressure. Nurses took blood pressure using an Omron HEM 907 monitor. Cases were excluded from the analysis if blood pressure measurements were considered invalid. Those who had smoked, drunk, eaten, or exercised within 30 minutes of having their blood pressure taken were excluded from analysis given these factors can affect blood pressure.

Nurses collected blood samples and deposited them into two tubes. HDL cholesterol was analysed from blood deposited in a 6ml plain tube (no anticoagulant) and HbA1c analysed from a 4ml EDTA (ethylene diamine tetra-acetic acid) tube. The order of priority for collecting samples was first the 6ml plain tube, followed by the 4ml EDTA tube. After collection, the tubes were posted to the Blood Sciences Department at the RVI, which acted as the co-ordinating department for transport of samples to the individual departments undertaking the analyses. The Royal Victoria Infirmary (RVI), Newcastle upon Tyne Hospitals NHS Foundation Trust, analysed the blood samples.

Statistical Methods

To explore and compare the strength of the association between the four cardio-metabolic risk factors and the four anthropometric indicators of weight status (BMI, Waist-to-height ratio, Waist-to-height$^{0.5}$ and WC), we conducted three types of analyses. The first (1), we used simple correlations between the four cardio-metabolic risk factors and the four anthropometric indicators of weight status (BMI, Waist-to-height ratio, Waist-to-height$^{0.5}$ and WC). Secondly (2), recognizing that these simple correlations will ignore the confounding effects of age, sex and ethnicity, a second set of analyses were performed, using 3-way ANCOVAs (incorporating 'age group', 'sex' and ethnicity as fixed factors) to explore the strength of the 4 anthropometric indicators as separate covariates on the four cardio-metabolic risk factor dependent variables. Thirdly (3), four MANOVA's were performed (adopting the four cardiometabolic risk factor variables as a multivariate dependent variable) with 'age group', 'sex' and 'ethnicity' as fixed factors, to explore the strength of the four anthropometric indicators as separate covariates. This three-stage process for analysis was employed to provide a more comprehensive statistical appraisal of the different anthropometric indices on CMR risk. Pearson's correlations provide an indication of the magnitude of association between individual CMR risk factors and the different anthropometric indices without control for confounders (i.e., pure relationship). The use of ANCOVA as our second stage approach enables the assessment of the association between individual CMR risk factors and the different anthropometric indices whilst controlling for confounders. The use of MANOVA as the third stage approach enables consideration of all the CMR variables as one multivariate variable (i.e., a collective value for CMR risk) whilst also accounting for confounders. Using such an approach enables a robust appraisal of the association between the different anthropometric indices and CMR risk, by accounting for confounders with each individual CMR risk factor and also when all the CMR risk factors are considered collectively as one multivariate variable.

Centile curves

We fitted centile curves for the Waist-to-Height $^{0.5}$ (WHT$^{\cdot}$5R) by age and gender, using a series of models collectively known as Generalized Additive Model for Location, Scale and Shape (GAMLSS) (17). Using this approach, we were able to fit different response distributions and different nonparametric smoothing functions (cubic splines, P-splines, and local polynomial regression). The response distributions fitted included the Box-Cox-t, Box-Cox Cole and Green, Box-Cox Power Exponential and normal response distributions, using a log link for mu(μ) in all but the normal distribution. We selected the best fitting models using Generalised Akaike Information Criterion values (18), which ranks models according to their relative importance. The Box-Cox-t (μ, σ, ν, τ) power transformation produced the best fit for males and the Box-Cox Power Exponential (μ, σ, ν, τ) for

females. Both distributions are four-parameter distributions, which include location (μ) the median of the distribution, scale, sigma (σ), approximately the coefficient of variation, *nu* (ν) which controls for skewness (the transformation to symmetry), and *tau* (τ) the kurtosis of the distribution (16).

Results

Mean ± SD for height, mass, BMI, WHTR, WHT·5R and WC are presented in Table 1.

Table 1 Here

The unadjusted correlations (number of observations N) between the four CMR factors and the four anthropometric ratios BMI, WHTR, WHT·5R and WC are given in Table 2. The higher the correlation, the superior the association. The strongest predictor of high-density lipoproteins (HDL) cholesterol was WC (r=-0·373), for glycated haemoglobin (HbA1c) it was WHTR (r=0·324), for systolic (SBP) it was WC (r=0·356) and for diastolic blood pressure (DBP) it was WC (r=0·309).

Table 2 Here

Some of the stronger associations are illustrated in Figure 1a, 1b and 1c.

Figure 1a,1b,1c Here*

Clearly the confounding effect of age, sex and ethnicity are ignored in the Pearson's correlations and graphs. To overcome this limitation, 4 separate ANCOVA's were performed on each of the 4 CMR factors using BMI, WHTR, WHT.5R and WC as separate/individual covariates. A summary of the ANCOVA results are given in Table 3. The higher the F-value associated with each covariate, the superior the association. The strongest predictor of high-density lipoproteins (HDL) cholesterol was WHT.5R (F=4954·3), for glycated haemoglobin (HbA1c) it was WHTR (F=2048·3), for systolic (SBP) it was WC (F=1883·6) and for diastolic blood pressure (DBP) it was WHT.5R (F=3151·0). The ANCOVA main effects of ethnicity for the four CMR factors are also reported in supplementary Figures S1, S2, S3 and S4 respectively.

Table 3 Here

Four MANOVA's (adopting the four cardiometabolic risk factor variables as a single multivariate dependent variable) were performed with 'age group', 'sex' and 'ethnicity' as fixed factors, to explore the strength of association between the combined CMR factor dependent variable and the four anthropometric indicators, incorporated as separate covariates. Table 4 reports the contributions (Willk's Lambda and F ratios) of the four covariates. The higher the F-value associated with each covariate (together with the lower the Willk's Lambda), the superior the association. The strongest predictor of the four CRF factors combined was WHT.5R (F=2216·3) with a Willk's Lambda = 0·794.

Table 4 Here

The centile curves for WHT·5R by age are given for males and females separately in Figures 2a and 2b respectively. These centile curves provide a straightforward interpretation with a valuable level of precision. For example, in the case of an individual's WHT·5R slope and age, if their estimate is on the 60th centile, it means that for every 100 individuals of the same age, 60 would have a lower WHT·5R slope and 40 a higher WHT·5R slope.

Figure 2a and 2b Here

Discussion

Our initial results confirm that the three waist-circumference indices (WHTR, WHT·5R and WC) are consistently superior to BMI when explaining/predicting our four CMR factors in a large sample of English adults, both before and after controlling for the key confounders of age, sex and ethnicity. However, no single WC index was consistently superior at predicting the four CMR factors, see Tables 2 and 3. Our results highlight the fact that no one single WC index is consistently superior to BMI, i.e., no 'one size fits all'.

Nevill et al. (4) identified (using allometric scaling) that for WC to be independent of height, WC should be divided by $HT^{0.5}$ (WHT·5R). The authors then go on to assume that in order for WC to predict a range of CMR factors accurately, WC *should* be independent of HT and, by doing so, WHT·5R would not penalize taller of shorter individuals in the process. This assumption appears premature. There are a number of CMR variables in the literature, such as glycated haemoglobin (HbA1c), where shorter individuals are at greater CMR risk (8) and thus, it could be argued that they should justifiably be penalized.

Our results confirm these observations. Tables 2 and 3 provide strong evidence that the WC-by-height index, WHTR, is not only the strongest predictor of glycated haemoglobin (HbA1c), but it also *correctly* penalizes shorter individuals as described by Nevill et al. (4) and anticipated by (7). Further inspection of the remaining CMR variables in tables 2 and 3 suggest that either WHT·5R or possibly WC are the strongest predictors. The literature also supports these observations. Although in some mammals (e.g., Giraffes), being taller is associated with higher blood pressure (19) there is little or no evidence to support this assumption in humans. As such, given that blood pressure appears to be independently associated with height in humans, unsurprisingly the most appropriate waist circumference index associated with blood pressure should be the WC independent of height ratio, WHT·5R. As far as we can ascertain from the literature, HDL cholesterol is independent of height/stature. This observation would also support our findings reported in Tables 2 and 3, that the best predictor of HDL is the WC index independent of height, WHT·5R.

Given that our results have confirmed that no WC index is able to consistently predict all CMR factors, caution should be used when recommending a single WC index to replace BMI, that is no “one size fits all”. However, if we had to recommend a single WC index to predict the combination of CMR factors, based on the MANOVA analysis reported in Table 4, we would have to recommend WHT·5R. Research has previously identified the attractiveness of WHT.5R in predicting a single CMR composite score derived from log transformed z-scores of: Triglycerides + average blood pressure ((diastolic + systolic)/2) + glucose + HDL (*-1).

The results of the present study demonstrate that if taller individuals are at greater CMR risk, then unadjusted WC is likely to be the best predictor, as was the case with systolic blood pressure in the present study. Conversely, if shorter individuals are likely to be at greater CMR risk, then dividing WC by height (WHTR) appears to be more appropriate, as was the case with HbA1c in the current study. Where there is little or no evidence of taller or shorter individuals being at greater CMR risk, then WHT·5R is the most appropriate anthropometric index to adopt, as was the case with HDL cholesterol in the present study. There are implications

of these findings are that clinicians need to be better educated that BMI performs poorly in this context and there is no one index that that is consistently associated with resting blood pressure, HbA1c and HDL cholesterol. Therefore, clinicians should be mindful that the different anthropometric indices that should be used, depending on the clinical outcome of interest. When we combined all our CMR factors as a single (dependent variable) measure of CMR using MANOVA, WHT·5R performed the best out of all the anthropometric indices. For this reason, we have included the centile curves for WHT.5R, recorded in the units ($m.m^{-0.5}$), to enable readers to compare both individual and group differences within the UK population.

Consequently, our research further highlights the inadequacy of BMI as an anthropometric proxy for weight status. Higher waist circumference is a marker of increased visceral fatness, which is causally related to cardiovascular and metabolic diseases (20). Thus, including a measure of waist circumference alongside stature will better represent disease risk than stature and total body mass, as is the case with BMI. Our results support this assertion and align with recent consensus statues from the IAS and ICCR working group on visceral obesity, that anthropometric indices for obesity/weight status must include a measure of waist circumference (21). While stature and waist circumference have been associated with CMR both independently and when combined in WHTR, it is key to highlight that WHT.5R is an anthropometric measure of weight status which is also independent of stature.

We are aware that our results are limited to just four CMR measures, those of HDL cholesterol, glycated haemoglobin (HbA1c), systolic and diastolic blood pressure. Further work verifying our findings are required to confirm the pattern of these associations using other measures of cardio-metabolic health. Another limitation of the study is that our results were also based on secondary data analysis from the HSE and while the HSE is a robust data set, analysis can only be based on those measures collected as part of that survey. Although the present results are based on data from over fifty thousand participants, it should be noted that by far the majority of this sample (90%) are Caucasian. The results of the current study should therefore be considered representative of this ethnic group. Prior work has noted that WC differs due to ethnic group (3). Future work should therefore seek to examine if the results of the present study are similar for samples from different ethnic groups. For completeness we also examined any ethnic differences in our CMR outcome variables (See supplementary figures S1-S4). This confirmed there was some ethnic variation in CMR variables but the error bars for Caucasians are considerably smaller than for any other ethnic group, reflecting the fact that the sample was so much larger in number than for other ethnic groups. As a consequence any conclusions regarding ethnic differences in CMR factors in the current

data set should be made with caution. While the increases in explaining variance may be considered relatively small, it is important to recognise in statistical terms that any improvement in identifying CMR in vulnerable patients will be valuable, irrespective of the magnitude of improvement. In practical terms, such an improvement will translate to improving the evidence base for clinical decision making.

In conclusion, although superior to BMI, no single anthropometric WC index was found to be consistently superior at predicting our four CMR factors, i.e., no 'one size fits all'. Clinicians, researchers and those in public health need to understand when either WHTR, WHT·5R or unadjusted WC is the most appropriate measure to use when predicting different CMR factors. When shorter subjects are likely to be at greater CMR risk, WHTR is probably the most suitable anthropometric index to use. When taller subjects are likely to be at greater CMR risk, then unadjusted WC is likely to be appropriate. If nether taller nor shorter individuals are likely to be at greater CMR risk, WC independent of height, WHT·5R, is probably the correct anthropometric index to use. If we had to recommend just one WC index associated with the combination of CMR factors used in the current study, we would recommend WHT·5R. These new insights will help decision making related to how body shape influences clinical health outcomes related to CMR in adults.

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Table 1. Descriptive data (Mean ± SD) for height, mass, BMI, WHTR, WHT·5R and WC by age group and sex

Sex	Age	N	Height	SD	Mass	SD	BMI	SD	WHTR	SD	WHT·5R	SD	WC	SD
Male	16-29	3543	177·5	7·0	78·8	16·7	25·0	4·9	0·49	0·07	0·66	0·10	87·7	12·9
	30-39	3616	177·4	7·2	85·0	15·3	27·0	4·5	0·54	0·07	0·71	0·09	95·2	12·0
	40-49	4359	176·1	6·8	87·4	15·7	28·2	4·6	0·56	0·07	0·75	0·09	99·1	12·2
	50-59	4344	174·9	7·0	87·5	15·3	28·6	4·6	0·58	0·07	0·77	0·09	101·6	12·1
	60-69	3255	173·9	6·9	86·7	15·4	28·7	4·7	0·59	0·07	0·78	0·09	102·9	12·2
	70-79	3218	171·8	6·8	83·4	13·5	28·2	4·1	0·60	0·07	0·79	0·09	103·1	11·4
	80-89	1201	169·5	6·8	79·1	12·1	27·5	3·9	0·60	0·06	0·78	0·08	101·9	10·6
	90+	87	166·4	6·9	74·2	12·7	26·7	3·7	0·60	0·06	0·77	0·08	99·2	10·6
	Total	23623	175·0	7·3	84·7	15·6	27·6	4·7	0·56	0·08	0·74	0·10	98·5	13·2
Female	16-29	4552	163·9	6·6	67·9	16·1	25·3	5·7	0·50	0·08	0·63	0·10	81·3	13·3
	30-39	5037	163·5	6·6	71·6	16·2	26·8	5·9	0·53	0·08	0·67	0·11	85·9	13·6
	40-49	5913	162·8	6·6	72·9	15·8	27·5	5·8	0·54	0·09	0·69	0·11	88·3	13·5
	50-59	5413	162·0	6·4	73·8	15·6	28·1	5·8	0·56	0·09	0·72	0·11	91·0	14·0
	60-69	3717	160·5	6·3	72·4	15·2	28·1	5·8	0·58	0·09	0·73	0·11	92·2	13·8
	70-79	3575	158·4	6·3	70·8	13·5	28·2	5·3	0·59	0·08	0·74	0·10	93·0	12·5
	80-89	1415	155·0	6·0	65·6	12·1	27·3	4·9	0·59	0·08	0·73	0·09	91·4	11·7
	90+	145	152·1	6·8	57·5	10·2	24·8	4·2	0·57	0·07	0·71	0·09	87·3	10·7
	Total	29767	161·7	6·9	71·3	15·5	27·3	5·8	0·55	0·09	0·70	0·11	88·5	13·9

Height (cm), Body Mass (kg), BMI ($kg \cdot m^{-2}$), WHTR ($m \cdot m^{-1}$), WHT·5R ($m \cdot m^{-0.5}$) and WC (cm); SD=Standard Deviation. Sample of 53390 participants (90% Caucasian, 6% South Asian, 1·6% Black, 1·8% mixed ethnicity, 0·6% other ethnicity)

Table 2. Pearson's correlations for the four CMR factors and the four anthropometric indices

		BMI	WHTR	WHT·5R	WC
HDL cholesterol	**Pearson Correlation**	-0·29	-0·294	-0·341	-0·373
	N	36660	37279	37279	37279
Glycated hemoglobin (HbA1C**)**	**Pearson Correlation**	0·235	0·324	0·312	0·288
	N	40348	41015	41015	41015
SBP	**Pearson Correlation**	0·268	0·337	0·353	0·356
	N	57857	58848	58848	58848
DBP	**Pearson Correlation**	0·308	0·294	0·307	0·309
	N	57852	58844	58844	58844

BMI ($kg \cdot m^{-2}$), WHTR ($m \cdot m^{-1}$) and WHT·5R ($m \cdot m^{-0.5}$) and WC(m). Sample of 53390 participants (90% Caucasian, 6% South Asian, 1·6% Black, 1·8% mixed ethnicity, 0·6% other ethnicity)

Table 3. The contributions (F ratios, R^2, R^2adj) of the four anthropometric covariates (BMI, WHTR, WHT·5R and WC) when predicting the four cardio-metabolic risk factor (HDL, HbA1c, SBP and DBP) using ANCOVAs having controlled for 'age group', 'sex' and 'ethnic group' as fixed factors.

Dependent Variable	Covariate	F ratio	R^2	Adj R^2
HDL	BMI	4077·6	0·234	0·23
	WHTR	4897·9	0·248	0·244
	WHT·5R	4954·3	0·249	0·245
	WC	4768·7	0·245	0·242
HbA1c	BMI	1490·1	0·17	0·167
	WHTR	2048·3	0·18	0·176
	WHT·5R	2007·1	0·179	0·175
	WC	1872·9	0·176	0·173
SBP	BMI	1856·4	0·258	0·255
	WHTR	1784·9	0·256	0·253
	WHT·5R	1873·5	0·257	0·255
	WC	1883·6	0·257	0·255
DBP	BMI	3028·0	0·171	0·168
	WHTR	3117·2	0·171	0·168
	WHT·5R	3151·0	0·171	0·169
	WC	3042·6	0·17	0·167

Sample of 53390 participants (90% Caucasian, 6% South Asian, 1·6% Black, 1·8% mixed ethnicity, 0·6% other ethnicity)

Table 4. The contributions of the four anthropometric covariates to predict the cardiometabolic MANOVA (combined dependent variable of HDL, HbA1c, Systolic and Diastolic blood pressure) having controlled for 'age group', 'ethnicity' and 'sex' as fixed factors.

Anthropometric variable	Wilks' Lambda	F ratio
BMI	0·820	1844·9
WHTR	0·795	2199·7
WHT·5R	0·794	2216·3
WC	0·802	2112·9

Sample of 53390 participants (90% Caucasian, 6% South Asian, 1·6% Black, 1·8% mixed ethnicity, 0·6% other ethnicity)

Figure captions

Figure 1a. The relationship between HDL cholesterol and waist circumference (Whole Sample r=-0.373, Males r=-.255, Females r =-.313)

Figure 1b. The relationship between glycated haemoglobin (HbA1C) and the waist-by-height ratio (WTHR), (Whole Sample r=0.324, Males r=.314, Females r=.333)

Figure 1c. The relationship between systolic blood pressure (mmHg) and waist circumference (cm) (Whole Sample r=0.356, Males r=.328, Females, r=.312)

Figures 2a and 2b. The centile curves for WHT·5R ($m.m^{-0.5}$) by age for males (a) and females (b)

Figure 1a. The relationship between HDL cholesterol and waist circumference (Whole sample r=-0.373, Males r=-.255, Females r=-.313)

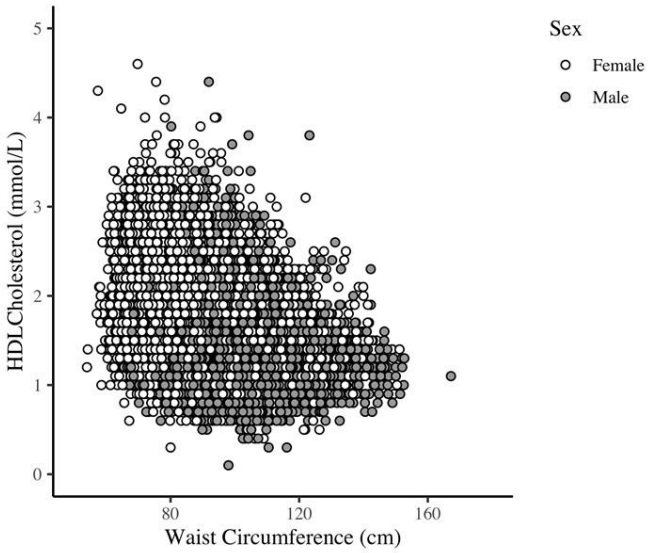

Figure 1b The relationship between glycated hemoglobin (HbA1C) and the waist-by-height ratio (WTHR), (Whole sample r=0.324, Males r=.314, Females r=.333)

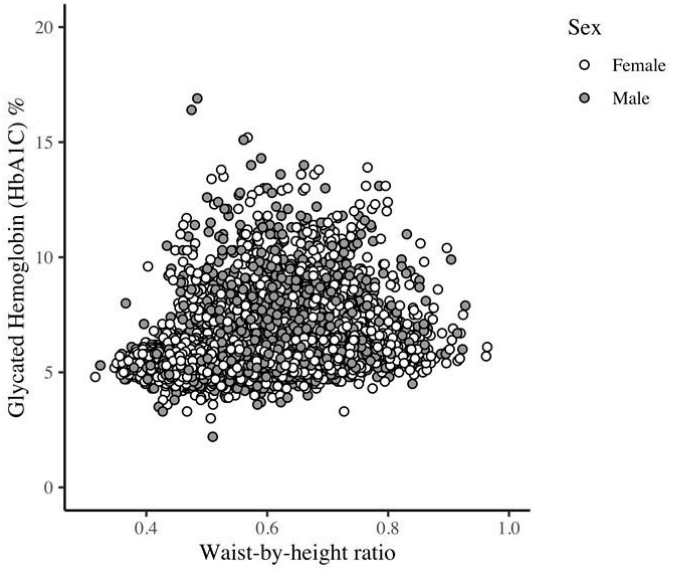

Figure 1c The relationship between systolic blood pressure (mmHg) and waist circumference (cm) (Whole sample r=0.356, Males r=.328, Females r =.312)

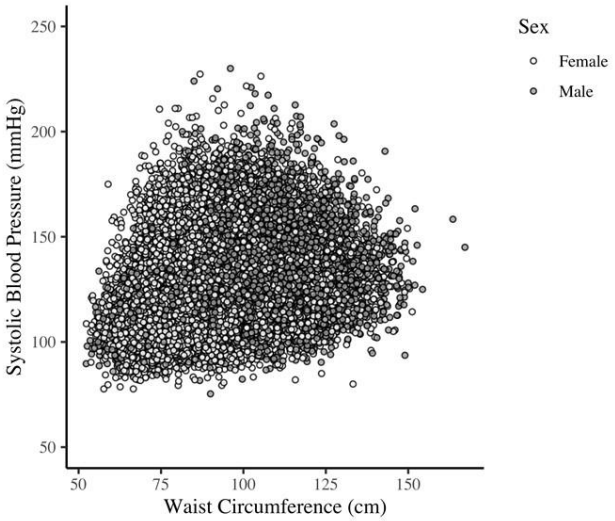

Figure 2a. Centile curves for WHT·5R ($m.m^{-0.5}$) by age for males

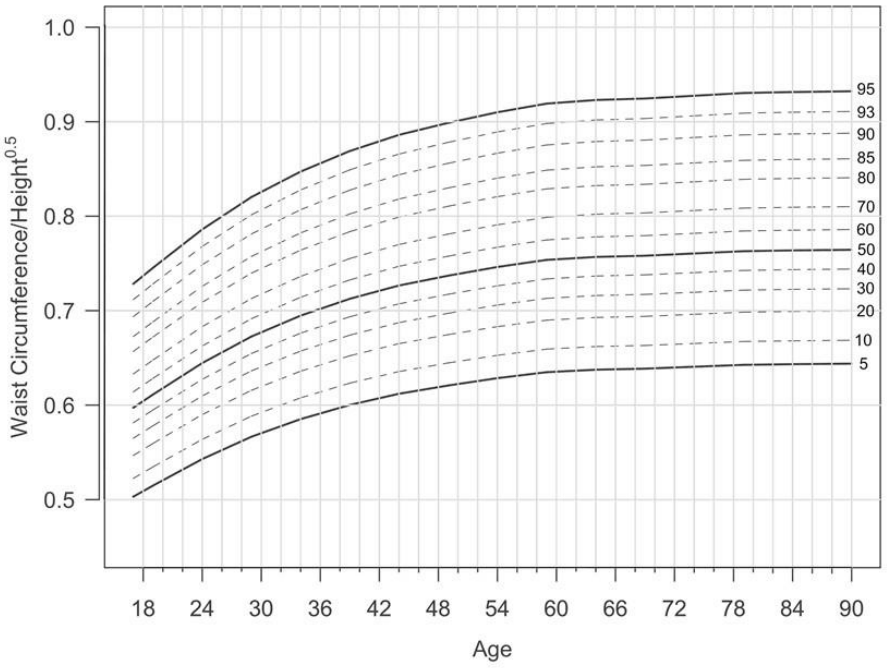

Figure 2b. Centile curves for WHT·5R ($m.m^{-0.5}$) by age for females