A simple cut-off for waist-to-height ratio (0·5) can act as an indicator for cardiometabolic risk: recent data from adults in the Health Survey for England

Sigrid Gibson[1]* and Margaret Ashwell[2,3]

[1]*Sig-Nurture Ltd, Beaulieu, Hampshire SO42 7WB, UK*
[2]*Ashwell Associates, Ashwell, Hertfordshire SG7 5PZ, UK*
[3]*Cass Business School, City University, London EC1Y 8TZ, UK*

Abstract

The National Institute for Health and Care Excellence (NICE) has acknowledged the value of waist-to-height ratio (WHtR) as an indicator for 'early health risk'. We used recent UK data to explore whether classification based on WHtR identifies more adults at cardiometabolic risk than the 'matrix' based on BMI and waist circumference, currently used for screening. Data from the Health Survey for England (4112 adults aged 18+ years) were used to identify cardiometabolic risk, indicated by raised glycated Hb, dyslipidaemia and hypertension. HbA1c, total/HDL-cholesterol and systolic blood pressure (BP) were more strongly associated with WHtR than the 'matrix'. In logistic regression models for HbA1c ≥ 48 mmol/mol, total/HDL-cholesterol > 4 and hypertension (BP > 140/90 mmHg or on medication), WHtR had a higher predictive value than the 'matrix'. AUC was significantly greater for WHtR than the 'matrix' for raised HbA1c and hypertension. Of adults with raised HbA1c, 15 % would be judged as 'no increased risk' using the 'matrix' in contrast to 3 % using WHtR < 0·5. For hypertension, comparative values were 23 and 9 %, and for total/HDL-cholesterol > 4, 26 and 13 %. Nearly one-third of the 'no increased risk' group in the 'matrix' had WHtR ≥ 0·5 and hence could be underdiagnosed for cardiometabolic risk. WHtR has the potential to be a better indicator of cardiometabolic risks associated with central obesity than the current NICE 'matrix'. The cut-off WHtR 0·5 in early screening translates to a simple message, 'your waist should be less than half your height', that allows individuals to be aware of their health risks.

Key words: Waist-to-height ratio: Obesity: BMI: National Institute for Health and Care Excellence: Cardiometabolic risk

Waist-to-height ratio (WHtR) is a proxy for central (visceral) adipose tissue[1–4]. It has recently received attention as an indicator of 'early health risk'. Several systematic reviews and meta-analyses of data in adults of all ages[5–8] and in children and adolescents[9,10] have supported the superiority of WHtR over the use of BMI and waist circumference (WC) in predicting early health risk. More than 20 years ago, a boundary value of WHtR 0·5 was first suggested as a risk assessment tool and this translates into the simple message 'keep your waist to less than half your height'[1,11–13]. Studies in many populations have supported the premise that WHtR is a simple and effective anthropometric index to identify health risks in adults of all ages[6,7,14–25] and in children and adolescents[26–29]. Not only does WHtR have a close relationship with morbidity, but also it has a clearer relationship with mortality compared with BMI[13,30].

In relation to screening, two very large prospective studies in USA have shown that WHtR is better than BMI in predicting diabetes risk[31] in all adult age groups. Similar findings have been found in Korea[32]. Further, prospective data from the Avon Longitudinal Study of Parents and Children (ALSPAC) in the UK have shown that WHtR in children aged 7–9 years predicts adolescent cardiometabolic risk better than BMI[33]. In a comprehensive narrative review, Yoo[34] concluded that 'additional use of WHtR with BMI or WC may be helpful because WHtR considers both height and central obesity. WHtR may be preferred because of its simplicity and because it does not require sex- and age-dependent cut-offs'. In 2006, the National Institute for Health and Care Excellence (NICE) tried to overcome the limitation of BMI by suggesting that WC is measured alongside BMI[35]. Public Health England then built on this suggestion to produce a comprehensive cross-classification 'matrix' to categorise risk[36]. For simplicity and clarity, we will refer to this as the 'matrix' (see Box 1). NICE has recently published a surveillance document on obesity which includes a section on the 'Identification and classification of overweight and obesity'[37]. In relation to its previous clinical guidance on obesity (CG189), this notes new evidence

Box 1. Categorisation by BMI and waist circumference (WC) – the 'matrix'

BMI classification	Waist circumference		
	Low	**High**	**Very high**
Normal weight	No increased risk	No increased risk	Increased risk
Overweight (25 to less than 30kg/m^2)	No increased risk	Increased risk	High risk
Obesity I (30 to less than 35kg/m^2)	Increased risk	High risk	Very high risk
Obesity II (35 to less than 40kg/m^2)	Very high risk	Very high risk	Very high risk
Obesity III (40kg/m^2 or more)	Very high risk	Very high risk	Very high risk

Categories for WC within the 'matrix' are: Low (men <94 cm, women <80 cm), High (men 94–102 cm, women 80–88 cm); Very high (men >102 cm, women >88 cm).

and expert feedback indicating the superior discriminatory value of WHtR as an alternative measure of adiposity. We have previously used data from the UK National Diet and Nutrition Survey to show that, within the adult UK population, the use of a simple boundary value for WHtR (0·5) identifies more people at 'early health risk' than does the 'matrix', which is based on a combination of BMI and WC[38]. We have now used more recent data (2016) from the Health Survey for England (HSE)[39] to assist NICE by comparing the risk estimated by the 'matrix' with that estimated by WHtR.

Methods

Survey design and participants

The HSE 2016 sample comprised of a core general population sample of 9558 addresses selected at random in 531 postcode sectors, issued over 12 months from January to December 2016. Fieldwork was completed in March 2017. Where an address was found to have multiple dwelling units, one dwelling unit was selected at random. A total of 8011 adults (aged 16 years and over) and 2056 co-residing children were interviewed (household response rate 59 %), and about two-thirds of adults had a nurse visit for measurements of height and weight, blood pressure (BP) and waist and hip circumference. Nurses obtained written consent for sampling and sending results to general practitioners. Weight (in bare feet and minimal clothes) was measured to the nearest 100 g using calibrated scales. Height was measured with a portable stadiometer with the head in horizontal Frankfort plane. WC was measured with a standard tape measure to the nearest millimetre at the midpoint between the lower rib and the upper margin of the iliac crest. The measurement was taken twice, with a third taken if they differed by more than 3 cm. The mean of the two closest valid measurements was used in the analysis. Participants were excluded from waist measurements if they reported that they were pregnant, had a colostomy or ileostomy or were unable to stand. All those with measurements considered unreliable by the nurse, for example, due to excessive clothing or movement, were also excluded from the analysis. Adults were also asked to provide non-fasting blood samples for the analysis of total cholesterol and HDL-cholesterol and

glycated Hb. Systolic BP (SBP) and diastolic BP were measured using a standard method (Omron; mean of three measurements). Full details of the HSE sampling design and procedures, response and weighting are given at https://files.digital.nhs./publication/m/3/hse2016-methods-text.pdfuk.

Statistical methods

Data and documentation were obtained from the UK Data Archive. Our analysis was based on adults aged 18 years and over with valid measurements for the combination of weight, height and WC. HbA1c, HDL-cholesterol, total/HDL-cholesterol, SBP and diastolic BP were used to represent cardiovascular risk factors; for high risk cut-offs, we used HbA1c of 48 mmol/mol and over; HDL-cholesterol < 1 mmol/l, total/HDL-cholesterol > 4 and for hypertension, we used the diagnostic criterion of SBP > 140 mmHg or diastolic BP over 90 mmHg or on antihypertensive medication. ANOVA was used to compare mean levels of risk factors across the tiers of anthropometric risk in separate models for WHtR and for the 'matrix'. Logistic regression was used to assess the power of WHtR or 'matrix' to predict people at high risk; the area under the receiver operating characteristic curve was used to assess discrimination. Data were weighted to adjust for unequal selection and non-response to the nurse visit; percentages are based on weighted sample n of 4112. $P < 0·05$ (two-sided) was taken to indicate statistical significance.

Classification of respondents by anthropometric indicators ('matrix' of BMI and waist circumference and waist-to-height ratio)

The 'matrix' of WC and BMI (produced by Public Health England and NICE) categorises health risk as: 'no increased risk', 'increased risk', 'high risk' and 'very high risk', as shown in Box 1[36]. Underweight adults are unclassified, but for the purpose of the present study, they were counted as 'no increased risk'.

To make the data manageable for analysis, we combined the 'matrix' categories of 'increased risk' and 'high risk' to obtain three tiers: Tier 0 'no increased risk' (including underweight), Tier 1 'increased'/'high risk' and Tier 2 'very high risk'. WHtR

was also classified into three tiers: Tier 0 'no increased risk' (WHtR < 0·5), Tier 1 'increased risk' (WHtR ≥ 0·5 and <0·6) and Tier 2 'very high risk' (WHtR ≥ 0·6). The boundary value for Tier 1 (WHtR = 0·5) was suggested more than 20 years ago and is now used routinely to indicate the first level of risk for WHtR because of the wealth of data which has accrued to support it. The boundary value for Tier 2 (WHtR 0·6) is a pragmatic decision justified by many studies which show there is a linear association between WHtR and cardiometabolic risk factors.

Results

Table 1 shows participant characteristics, according to their classification under the WHtR criteria and matrix criteria. Both showed that higher risk adults were more likely to be older and on lower income. However, WHtR classified more women in the low risk tier (Tier 0), whereas the matrix showed no sex differential.

Classification of participants by anthropometric indicators

Table 1 shows that the 'matrix' categorised 43 % of the adults sampled as Tier 0 ('no increased risk'), 33 % as Tier 1 ('increased risk' or 'high risk') and 24 % as Tier 2 or 'very high risk'. By contrast, WHtR categorised the same population as 30 % 'no increased risk' (Tier 0), 44 % 'increased risk' (Tier 1) and 26 % as 'very high risk' (Tier 2). Compared with the 'matrix', WHtR put more participants in Tier 1 (44 v. 33 %) and fewer in Tier 0 (30 v. 43 %). This is because the 'matrix' underplays risk in normal BMI people with a moderately high WC (Box 1), many of whom have high WHtR.

Cross-classification of participants by anthropometric indicators

The cross tabulation in Table 1 shows that 32 % of the adult group who were judged to be at 'no increased risk' according to the 'matrix' had WHtR equal to or greater than 0·5. Conversely, 31 % judged at increased risk (Tier 1) according to WHtR were classified as Tier 0 ('no increased risk') by the 'matrix'. This cross classification is illustrated graphically in Fig. 1.

Waist-to-height ratio is a better indicator of cardiometabolic risk factors than the 'matrix'

Table 2 shows the mean values with their standard errors of the cardiometabolic risk factors by risk tier. WHtR was a stronger predictor than the 'matrix' in models for HbA1c and SBP, as indicated by higher F values in ANOVA (Table 2). Mean values of HbA1c between highest and lowest risk tiers differed by 7·2 mmol/mol for WHtR compared with 5·2 mmol/mol for the 'matrix'; the difference in SBP was 12 mmHg for WHtR compared with 9 mmHg for the 'matrix' (Table 2). For total and HDL-cholesterol and diastolic BP, there was little difference between the indicators. Results are shown without adjustment for covariates, in order to compare the anthropometric indicators as they might be used in primary assessment. However, adjustment for age and sex slightly attenuated the effect sizes for both WHtR and the 'matrix' to a similar extent (data not shown).

Logistic regression was used to assess how well each of the two anthropometric indicators predicted raised HbA1c (≥48 mmol/mol), low HDL-cholesterol (<1 mmol/l), high total/HDL-cholesterol (>4) and overall hypertension (BP > 140/90 mmHg or on medication).

Table 3 shows that WHtR had a higher predictive value than the 'matrix' for raised HbA1c, high total/HDL-cholesterol and hypertension, based on the percentage of variance explained (14–16 % for WHtR v. 6–12 % for matrix) and higher OR. For low HDL-cholesterol, both classifications explained about 6 % of the variance.

These findings were confirmed in a receiver operating characteristic analysis based on all five categories of the 'matrix' v. three categories for WHtR. The AUC was greater with WHtR than with the 'matrix', for raised HbA1c (0·75 v. 0·69) and hypertension (0·68 v. 0·65). AUC were nearly identical on both indicators for low HDL (0·66) and total/HDL-cholesterol (0·65) (see Table 4).

Underestimation of cardiometabolic risk is greater using the 'matrix' than waist-to-height ratio

Fig. 2 shows that Tier 0 of the 'matrix' (no increased risk) was most likely to underestimate the actual risk. One in seven adults (15 %) with raised HbA1c would have been judged as at 'no increased risk' using the 'matrix', compared with only 3 % using WHtR < 0·5. Similarly, for hypertension (BP > 140/90), 23 % of those with hypertension would have been judged as 'no increased risk', compared with 9 % missed using WHtR. For low HDL-cholesterol and high total/HDL-cholesterol, about twice as many were missed using the 'matrix' than using WHtR.

Discussion

Principal findings

Among adults surveyed in the HSE 2016, important cardiometabolic risk factors representing glycaemia, dyslipidaemia and hypertension were more strongly associated with anthropometric classification using the simple cut-off for WHtR than with the 'matrix'. Prevalence data showed that nearly one-third of the 'no increased risk' group in the NICE 'matrix' had WHtR ≥ 0·5 and could therefore be under-diagnosed for cardiometabolic risk.

Comparison with analyses of previous UK data

These findings support previous studies[38,41,42] where we showed that men and women with a BMI in the 'healthy' range but WHtR ≥ 0·5 had increased levels of cardiometabolic risk factors, not only when compared with participants with 'healthy' BMI and WHtR < 0·5, but also when compared with overweight participants (BMI > 25 kg/m²) with low WHtR < 0·5. In the present study, we suggest that the 'matrix' underperforms compared with WHtR because it considers individuals with moderately high WC (80–88 cm for women, 94–102 cm for men) not to be at risk unless they are also overweight.

Normal weight central obesity

Our results support other data showing that normal weight central obesity (NWCO) is linked with cardiometabolic risk. NWCO

Table 1. Participant numbers and characteristics in the Health Survey for England sample*
(Total number and percentage in each group)

	WHtR			'Matrix'			Total weighted count	%
	Tier 0: <0·5	Tier 1: 0·5 < 0·6	Tier 2: 0·6+	Tier 0: no increased risk	Tier 1: increased risk/high risk	Tier 2: very high risk		
n	1240	1801	1072	1755	1377	980	4112	
% in each WHtR/'matrix' category	30 %	44 %	26 %	43 %	33 %	24 %		100 %
Sex								
Male	42 %	56 %	51 %	52 %	50 %	48 %	2067	50
Female	58 %	44 %	49 %	48 %	50 %	52 %	2046	50
Age group (*n* 4112) (years)								
18–24	25 %	6 %	2 %	18 %	6 %	3 %	436	11
25–34	27 %	16 %	9 %	24 %	12 %	13 %	720	18
35–44	19 %	18 %	14 %	19 %	15 %	17 %	709	17
45–54	15 %	20 %	21 %	15 %	21 %	21 %	763	19
55–64	8 %	17 %	20 %	10 %	18 %	19 %	619	15
65–74	5 %	14 %	19 %	8 %	16 %	16 %	513	12
75+	2 %	9 %	15 %	6 %	12 %	9 %	351	9
Income group (*n* 3262)								
Lowest tertile (≤£19 044)	25 %	29 %	37 %	27 %	30 %	36 %	984	30
Middle tertile (>£19 044–£36 229)	29 %	31 %	36 %	29 %	32 %	34 %	1026	31
Highest tertile (>£36 229)	46 %	40 %	27 %	44 %	38 %	30 %	1252	38
Socio-economic group (individual) (*n* 4047)								
Managerial and professional	40 %	38 %	30 %	40 %	36 %	31 %	1632	36
Intermediate occupations	24 %	26 %	24 %	24 %	25 %	26 %	980	25
Routine and manual occupations	29 %	34 %	46 %	31 %	37 %	41 %	1367	35
Other	7 %	3 %	1 %	6 %	3 %	2 %	130	4
Ethnicity (*n* 4112)								
White	86 %	87 %	88 %	85 %	88 %	89 %	3567	87
Black	4 %	3 %	3 %	4 %	2 %	4 %	139	3
Asian	7 %	8 %	6 %	8 %	8 %	5 %	297	7
Mixed	3 %	1 %	2 %	2 %	1 %	1 %	71	2
Other	1 %	1 %	1 %	1 %	1 %	1 %	32	1
'Matrix' classification (*n* 4112)								
Tier 0: no increased risk	96 %	31 %	0 %	100 %	0 %	0 %	1755	43
Tier 1: increased risk/high risk	4 %	59 %	25 %	0 %	100 %	0 %	1377	33
Tier 2: very high risk	0 %	10 %	75 %	0 %	0 %	100 %	980	24
WHtR classification (*n* 4112)								
Tier 0: <0·5	100 %	0 %	0 %	68 %	4 %	0 %	1240	30
Tier 1: 0·5 < 0·6	0 %	100 %	0 %	32 %	77 %	18 %	1801	44
Tier 2: 0·6+	0 %	0 %	100 %	0 %	20 %	82 %	1072	26
BMI (kg/m²) (*n* 4112)								
Under 18·5	5 %	0 %	0 %	4 %	0 %	0 %	63	2
18·5 and below 25	80 %	26 %	1 %	80 %	5 %	0 %	1471	36
25 and below 30	15 %	61 %	23 %	17 %	90 %	0 %	1527	37
30 and below 40	0 %	13 %	67 %	0 %	5 %	90 %	954	23
Over 40	0 %	0 %	9 %	0 %	0 %	10 %	98	2
HDL-cholesterol (mmol/l) (*n* 3183)								
≥1	97 %	92 %	84 %	96 %	91 %	84 %	2914	92
<1	3 %	8 %	16 %	4 %	9 %	16 %	270	8
TC:HDL > 4 (*n* 3182)								
≤4	86 %	63 %	53 %	81 %	62 %	51 %	2148	68
>4	14 %	37 %	47 %	20 %	38 %	49 %	1034	33
HbA1c (mmol/mol) (*n* 3139)								
<48	99 %	95 %	82 %	98 %	92 %	86 %	2922	93
48+	1 %	5 %	18 %	2 %	8 %	14 %	217	7
HbA1c and medication (*n* 3139)								
<48 no medication	99 %	94 %	81 %	98 %	92 %	84 %	2902	92
48+ or on medication	1 %	6 %	19 %	2 %	8 %	16 %	237	8
High BP (mmHg) (*n* 3545)								
<140/90	94 %	80 %	71 %	89 %	79 %	72 %	2887	81
140/90 and above	6 %	20 %	29 %	11 %	21 %	28 %	658	19
High BP (mmHg) or BP medication (*n* 3545)								
<140/90 no medication	92 %	70 %	52 %	85 %	67 %	56 %	2549	72
140/90 and above or medication	8 %	30 %	48 %	15 %	33 %	44 %	996	28

WHtR, waist-to-height ratio; TC, total cholesterol; BP, blood pressure.
* Adults aged 18 years and over including classification by WHtR and the 'matrix' tiers. Column percentages have been rounded to the nearest integer.
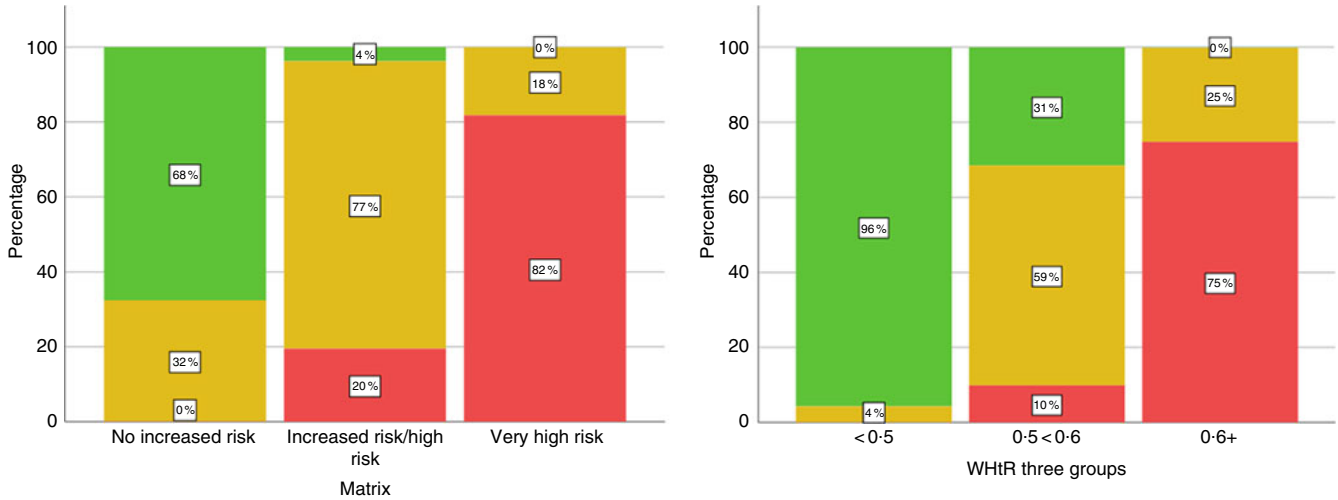
Fig 1. Cross-classification of subjects by waist-to-height ratio (WHtR) and the 'matrix'. Matrix = 'matrix' based on BMI and waist circumference. 'No increased risk' includes unclassified (underweight) adults. Percentages refer to the proportion of individuals in each group (x-axis). Total 4112, data are weighted. Numbers in Matrix categories: no increased risk = 1755; increased risk/high risk = 1379; very high risk = 980. Numbers in WHtR groups: <0·5 = 1240; 0·5 < 0·6 = 1801; 0·6+ = 1072.

is usually defined on the basis of BMI and WC measurements. Participants with NWCO show increased morbidity in relation to cardiometabolic risk greater than those in normal weight people without central obesity[43,44]. Further, their mortality is also increased as shown in several studies[45,46]. Others diagnose NWCO from BMI and WHtR and have shown that it can be associated with increase morbidity[47–50] and increased mortality[51,52]. The extent of NWCO in UK has previously been estimated as nearly one-third of the adult population, based on those in normal BMI range with WHtR > 0·5[42]. Results of the present study show that even when WC is taken into account, more than 30 % of the participants in the 'no increased risk' category (based on the 'matrix') have WHtR > 0·5.

We are only aware of one other country where risk identified by WHtR has been compared with 'matrix' based on BMI and WC. The New Zealand Ministry of Health showed from their National Survey data that WHtR 0·5 classified more people, particularly men, as being at 'early increased risk' compared with the 'matrix'. WHtR is a measure that is reported on by the Ministry of Health in its annual reports[53].

Practicality of measuring waist circumference

In general, WC is measured at one of the two places: either halfway between the iliac crest and the lower rib (WHO method) or at the umbilical level, just above the right iliac crest at the mid-axillary line. However, measurements of WHtR by either protocol similarly estimated current and prospective cardiometabolic risk biomarkers among youth with recently diagnosed diabetes[54].

Implications for screening

There is good evidence from around the world that screening for WHtR could prevent the metabolic implications of misdiagnosis by BMI alone in children[15,55], adolescents[56,57] and adults[6,13,58]. Further, recent reports from the US Army[59] and

US Air Force[60] have recommended screening of body fat and cardio fitness in military personnel using WHtR instead of other anthropometric measures.

Very simple screening based on waist-to-height ratio 0·5: the 'String Test'

Although many authors have produced specific WHtR boundary values for populations[24,27,61,62], many suggest that the simple boundary value of 0·5 can be used to indicate increased risk and used universally for primary screening[29]. Since it was first advocated in 2006[63], the simple message 'Keep your waist to less than half your height' has been recommended often[20,34,64–66]. More recently, the 'Ashwell® String Test'[67], which can broadly assess if the WHtR is below 0·5, even without a tape measure, has been suggested. This simple method is currently Government policy in Thailand[18].

Central obesity is increasing; screening is needed

Many studies have shown that the prevalence of high WC in adults has increased over time. In England, mean WC has risen from 93 to 98 cm in men and from 82 to 89 cm in women from 1993 to 2017[36]. WC has increased more rapidly than BMI in adolescents[68], and future predictions are that this gap will widen further[69] reflecting the increase in central, rather than total, obesity. Studies in China and Australia have shown there to be an acceleration in the prevalence of NWCO even without a corresponding increase in BMI[22,70,71]. The time has surely come to include routine screening for central obesity.

In terms of cost-effectiveness, measuring BMI requires weighing scales as well as stadiometer for measuring height. WHtR only requires a tape measure, making use of WHtR more cost-effective. For the simplest dichotomous assessment (WHtR above 0·5), a piece of string is sufficient[67].

Table 2. HbA1c, HDL-cholesterol and systolic blood pressure (SBP), by risk tier of anthropometric indicators: waist-to-height ratio (WHtR) and the 'matrix'
(Mean values with their standard errors)

	Risk tier			ANOVA statistics		
	0*	1†	2‡	F	P	Effect size§
HbA1c (mmol/mol) (n 3139)						
WHtR						
Mean	35·7	38·3	42·9	180	0·0001	0·099
SE	0·14	0·19	0·43			
'Matrix'						
Mean	36·6	39·1	41·8	104	0·0001	0·060
SE	0·15	0·24	0·44			
HDL-cholesterol‖ (mmol/l) (n 3183)						
WHtR						
Mean	1·7	1·5	1·3	172	0·0001	0·093
SE	0·02	0·01	0·01			
'Matrix'						
Mean	1·6	1·5	1·3	150	0·0001	0·083
SE	0·01	0·01	0·02			
TC‖ (mmol/l) (n 3182)						
WHtR						
Mean	4·9	5·3	5·2	50	0·0001	0·029
SE	0·03	0·03	0·04			
'Matrix'						
Mean	5·0	5·3	5·3	34	0·0001	0·020
SE	0·03	0·03	0·04			
TC:HDL ratio‖ (n 3182)						
WHtR						
Mean	3·1	3·8	4·2	223	0·0001	0·139
SE	0·04	0·03	0·05			
'Matrix'						
Mean	3·2	3·9	4·3	192	0·0001	0·122
SE	0·03	0·04	0·05			
SBP (mmHg) (n 3545)						
WHtR						
Mean	118	127	130	191	0·0001	0·093
SE	0·4	0·4	0·5			
'Matrix'						
Mean	121	127	130	112	0·0001	0·057
SE	0·4	0·5	0·5			
DBP (mmHg) (n 3545)						
WHtR						
Mean	69	74	76	102	0·0001	0·052
SE	0·3	0·3	0·4			
'Matrix'						
Mean	70	74	77	108	0·0001	0·055
SE	0·3	0·3	0·4			

TC, total cholesterol; DBP, diastolic blood pressure.
* Risk tier 0 = WHtR < 0·5 or 'no increased risk' in 'matrix'.
† Risk tier 1 = WHtR 0·5 < 0·6 or 'increased/high risk' in 'matrix'.
‡ Risk tier 2 = WHtR 0·6+ or 'very high risk' in 'matrix'.
§ Partial Eta squared or proportion of variance explained (0·1 = 10 %).
‖ Includes adults on lipid-lowering medication.

Strengths and limitations of our study

Strengths
- The use of the WHtR addresses a current dilemma of how to best identify 'early health risk' with a very simple, low-cost, anthropometric measure. This UK study provides further evidence for NICE to consider regarding alternative measures of adiposity.
- HSE is designed to be nationally representative of the population in England. The method includes assessment for a range of cardiovascular risk factors, including blood lipids and BP, which were investigated in our study.

Table 3. Logistic regression models showing odds of high level of risk factors, as predicted by waist-to-height ratio (WHtR) or the 'matrix'*
(Odds ratios and 95 % confidence intervals)

Risk factor	Indicator	Risk tier 0	Risk tier 1	Risk tier 2	R^2†
HbA1c ≥ 48 mmol/mol	WHtR				
	OR	1	7·0	27·5	0·151
	95 % CI		3·2–15·1	12·9–58·5	
	'Matrix'				
	OR	1	3·4	6·9	0·085
	95 % CI		2·2–5·1	4·6–10·4	
HDL-cholesterol < 1 mmol/l	WHtR				
	OR	1	2·8	5·8	0·063
	95 % CI		1·9–4·2	3·9–8·8	
	'Matrix'				
	OR	1	2·2	4·5	0·062
	95 % CI		1·6–3·1	3·3–6·3	
Total:HDL-cholesterol > 4	WHtR				
	OR	1	3·9	7·0	0·142
	95 % CI		3·2–4·9	5·5–9·0	
	'Matrix'				
	OR	1	2·9	4·6	0·114
	95 %CI		2·4–3·5	3·7–5·7	
BP > 140/90 mmHg, or medication	WHtR				
	OR	1	4·5	9·8	0·158
	95 % CI		3·5–5·8	7·6–12·6	
	'Matrix'				
	OR	1	2·8	4·4	0·098
	95 % CI		2·3–3·3	3·6–5·4	

BP, blood pressure.
* Percentage of adults at risk: HbA1c 48 mol/mol and over (7·4 %) (total n 3139); HDL-cholesterol < 1 mmol/L (8·5 %) (total n 3183); total:HDL-cholesterol >4 (33 %) (total n 3182) BP > 140/90 mmHg or on medication (28·1 %) (total n 3544).
† R^2 (Nagelkerke) = proportion of variance explained by the indicator.

Table 4. AUC (receiver operating characteristic analysis) for models based on waist-to-height ratio (WHtR) and the 'matrix'
(Mean values, with lower and upper 95 % confidence limits)

	AUC	Lower	Upper	Difference in AUC	P (Z test paired)*
HbA1c ≥ 48 mmol/mol					
WHtR (three groups)	0·75	0·72	0·77	0·05	0·0008
'Matrix' (five groups†)	0·69	0·66	0·72		
BP > 140/90 or on medication					
WHtR (three groups)	0·68	0·67	0·70	0·03	0·0002
'Matrix' (five groups)	0·65	0·63	0·67		
HDL < 1 mmol/l					
WHtR (three groups)	0·66	0·63	0·69	−0·002	0·92
'Matrix' (five groups)	0·66	0·63	0·70		
Total:HDL > 4					
WHtR (three groups)	0·65	0·63	0·67	−0·003	0·76
'Matrix' (five groups)	0·65	0·63	0·67		

* All five categories of the matrix were used in receiver operating characteristic analysis ('not applicable'/underweight, 'no increased risk', 'increased risk', 'high risk' and 'very high risk').
† Calculated according to the method of Hanley et al.[40] for comparing AUC on the same subjects.

The anthropometric data are highly reliable (measured not self-reported).
- There are no studies comparing the predictive value of the 'matrix' v. other anthropometric indicators. This paper highlights a potential problem with the existing 'matrix' (i.e. underestimating risk in normal BMI adults with
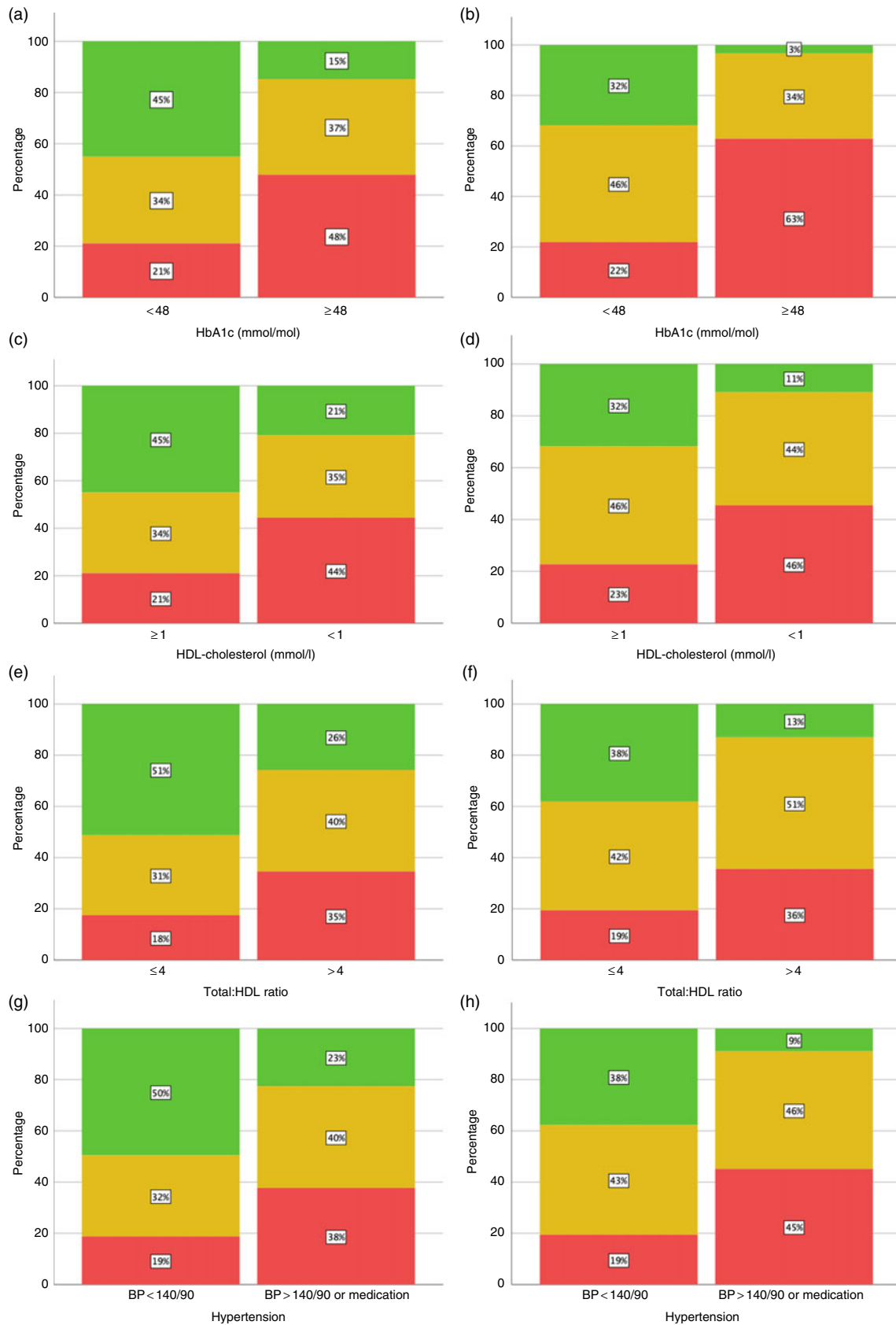
Fig. 2. Proportion of subjects at normal and high risk for cardiometabolic risk factors (HbA1c, HDL-cholesterol, total/HDL-cholesterol and hypertension). Classification by categories of anthropometric index ('matrix' and waist-to-height ratio (WHtR)). (a) HbA1c by 'matrix' (n 3139). (b) HbA1c by WHtR (n 3139). (c) HDL-cholesterol by 'matrix' (n 3183). (d) HDL-cholesterol by WHtR (n 3183). (e) Total/HDL-cholesterol by 'matrix' (3182). (f) Total/HDL-cholesterol by WHtR (n 3182). (g) Hypertension by 'matrix' (n 3545). (h) Hypertension by WHtR (n 3545). Matrix: ▇, no increased risk; ▇, increased risk/high risk; ▇, very high risk. WHtR three groups: ▇, <0·5; ▇, 0·5 < 0·6; ▇, 0·6+. BP, blood pressure (mmHg).

moderate raised WC) and provides evidence that WHtR would provide better accuracy and simplicity.

- The predictive value of WHtR is backed by systematic reviews and meta-analyses in many different populations. Prospective studies are also supportive.
- WC measurement is not difficult to do and could be done by the subject.
- The simple cut-off WHtR > 0·5 may be particularly valuable as an indicator of 'early health risk', even in adults in the normal BMI range.

Limitations

- Causality between anthropometric indicators and risk factors cannot be inferred from observational data. Body weight and body shape are plausible causes or mediators of higher levels of risk factors, but other genetic or environmental factors may affect both anthropometric indices and risk markers in tandem.
- The sample is restricted to households in England in 2016. Other datasets could be used to test the reproducibility and generalisability of our conclusions.
- WC measurement may be a sensitive issue for some people and may be less precise than height or weight. However, it is a proven risk indicator, hence its inclusion in guidelines for assessment and monitoring of obesity.
- Further studies need to address the efficiency of using WHtR as an alternative to the 'matrix' in primary care, and its value as a public health message for all ages.

Conclusions

Although BMI, WC and WHtR are, by their very nature, strongly correlated[72,73], the more important question is which anthropometric proxy measure is the simplest and most accurate in helping to indicate early cardiometabolic risk?

WHtR is a simple primary screening risk assessment tool that identifies more people at 'early health risk' than the current method of assessing risk, the 'matrix', which uses a combination of BMI and WC. We recommend that the 'matrix' be amended to show that having a high WC even in the 'healthy' range of BMI, carries 'increased' risk. Further, we believe that serious consideration should be given to the use of the simple cut-off WHtR 0·5 to replace the 'matrix'.

Of course, any anthropometric measure is only the first step in identifying people at 'early health risk'. More complex scores (e.g. for diabetes) include further risk factors such as sex, age, ethnicity, socio-economic status and family history. Further screening for clinical risk factors should follow for those deemed at risk by these simpler measures.

Our results lend support to the opinion that clinicians should look beyond BMI. Although assessing for total fat mass with BMI to identify patients at greater cardiovascular risk is a good start, it is not sufficient[74]. It is therefore timely that, in UK, NICE intends to investigate the potential use of WHtR[37].

Data sharing statement

All unpublished results from the study are available on request from the authors.

References

1. Ashwell M, Cole TJ & Dixon AK (1996) Ratio of waist circumference to height is strong predictor of intra-abdominal fat. *BMJ* **313**, 559–560.
2. Roriz AK, Passos LC, de Oliveira CC, *et al.* (2014) Evaluation of the accuracy of anthropometric clinical indicators of visceral fat in adults and elderly. *PLOS ONE* **9**, e103499.
3. Martin-Calvo N, Moreno-Galarraga L & Martinez-Gonzalez MA (2016) Association between body mass index, waist-to-height ratio and adiposity in children: a systematic review and meta-analysis. *Nutrients* **8**, E512.
4. Swainson MG, Batterham AM, Tsakirides C, *et al.* (2017) Prediction of whole-body fat percentage and visceral adipose tissue mass from five anthropometric variables. *PLOS ONE* **12**, e0177175.
5. Lee CM, Huxley RR, Wildman RP, *et al.* (2008) Indices of abdominal obesity are better discriminators of cardiovascular risk factors than BMI: a meta-analysis. *J Clin Epidemiol* **61**, 646–653.
6. Ashwell M, Gunn P & Gibson S (2012) Waist-to-height ratio is a better screening tool than waist circumference and BMI for adult cardiometabolic risk factors: systematic review and meta-analysis. *Obes Rev* **13**, 275–286.
7. Savva SC, Lamnisos D & Kafatos AG (2013) Predicting cardiometabolic risk: waist-to-height ratio or BMI. A meta-analysis. *Diabetes Metab Syndr Obes* **6**, 403–419.
8. Correa MM, Thume E, De Oliveira ER, *et al.* (2016) Performance of the waist-to-height ratio in identifying obesity and predicting non-communicable diseases in the elderly population: a systematic literature review. *Arch Gerontol Geriatr* **65**, 174–182.
9. Lo K, Wong M, Khalechelvam P, *et al.* (2016) Waist-to-height ratio, body mass index and waist circumference for screening paediatric cardio-metabolic risk factors: a meta-analysis. *Obes Rev* **17**, 1258–1275.
10. Ochoa Sangrador C & Ochoa-Brezmes J (2018) Waist-to-height ratio as a risk marker for metabolic syndrome in childhood. A meta-analysis. *Pediatr Obes* **13**, 421–432.
11. Hsieh SD & Yoshinaga H (1995) Waist/height ratio as a simple and useful predictor of coronary heart disease risk factors in women. *Intern Med* **34**, 1147–1152.
12. Ashwell M & Hsieh SD (2005) Six reasons why the waist-to-height ratio is a rapid and effective global indicator for health risks of obesity and how its use could simplify the international public health message on obesity. *Int J Food Sci Nutr* **56**, 303–307.
13. Ashwell M & Gibson S (2014) A proposal for a primary screening tool: 'Keep your waist circumference to less than half your height'. *BMC Med* **12**, 207.
14. Park SH, Choi SJ, Lee KS, *et al.* (2009) Waist circumference and waist-to-height ratio as predictors of cardiovascular disease risk in Korean adults. *Circ J* **73**, 1643–1650.

15. Khoury M, Manlhiot C & McCrindle BW (2013) Role of the waist/height ratio in the cardiometabolic risk assessment of children classified by body mass index. *J Am Coll Cardiol* **62**, 742–751.

16. Jayawardana R, Ranasinghe P, Sheriff MH, *et al.* (2013) Waist to height ratio: a better anthropometric marker of diabetes and cardio-metabolic risks in South Asian adults. *Diabetes Res Clin Pract* **99**, 292–299.

17. Rodea-Montero ER, Evia-Viscarra ML & Apolinar-Jimenez E (2014) Waist-to-height ratio is a better anthropometric index than waist circumference and BMI in predicting metabolic syndrome among obese Mexican adolescents. *Int J Endocrinol* **2014**, 195407.

18. Thaikruea L & Yavichai S (2015) Proposed waist circumference measurement for waist-to-height ratio as a cardiovascular disease risk indicator: self-assessment feasibility. *Jacobs J Obes* **1**, 1–7.

19. Liu XL, Yin FZ, Ma CP, *et al.* (2015) Waist-to-height ratio as a screening measure for identifying adolescents with hypertriglyceridemic waist phenotype. *J Pediatr Endocrinol Metab* **28**, 1079–1083.

20. Kazlauskaite R, Avery-Mamer EF, Li H, *et al.* (2017) Race/ethnic comparisons of waist-to-height ratio for cardiometabolic screening: the study of women's health across the nation. *Am J Hum Biol* **29**, e22909.

21. Radholm K, Chalmers J, Ohkuma T, *et al.* (2018) Use of the waist-to-height ratio to predict cardiovascular risk in patients with diabetes: results from the ADVANCE-ON study. *Diabetes Obes Metab* **20**, 1903–1910.

22. Song P, Li X, Bu Y, *et al.* (2019) Temporal trends in normal weight central obesity and its associations with cardiometabolic risk among Chinese adults. *Sci Rep* **9**, 5411.

23. Hou X, Chen S, Hu G, *et al.* (2019) Stronger associations of waist circumference and waist-to-height ratio with diabetes than BMI in Chinese adults. *Diabetes Res Clin Pract* **147**, 9–18.

24. Dong J, Wang SS, Chu X, *et al.* (2019) Optimal cut-off point of waist to height ratio in Beijing and its association with clusters of metabolic risk factors. *Curr Med Sci* **39**, 330–336.

25. Kawamoto R, Kikuchi A, Akase T, *et al.* (2019) Usefulness of waist-to-height ratio in screening incident metabolic syndrome among Japanese community-dwelling elderly individuals. *PLOS ONE* **14**, e0216069.

26. Choi DH, Hur YI, Kang JH, *et al.* (2017) Usefulness of the waist circumference-to-height ratio in screening for obesity and metabolic syndrome among Korean children and adolescents: Korea National Health and Nutrition Examination Survey, 2010–2014. *Nutrients* **9**, 256.

27. Jiang Y, Dou YL, Xiong F, *et al.* (2018) Waist-to-height ratio remains an accurate and practical way of identifying cardiometabolic risks in children and adolescents. *Acta Paediatr* **107**, 1629–1634.

28. Alvim RO, Zaniqueli D, Neves FS, *et al.* (2019) Waist-to-height ratio is as reliable as biochemical markers to discriminate pediatric insulin resistance. *J Pediatr* **95**, 428–434.

29. Ejtahed HS, Kelishadi R, Qorbani M, *et al.* (2019) Utility of waist circumference-to-height ratio as a screening tool for generalized and central obesity among Iranian children and adolescents: the CASPIAN-V study. *Pediatr Diabetes* **20**, 530–537.

30. Schneider HJ, Friedrich N, Klotsche J, *et al.* (2010) The predictive value of different measures of obesity for incident cardiovascular events and mortality. *J Clin Endocrinol Metab* **95**, 1777–1785.

31. Lee DH, Keum N, Hu FB, *et al.* (2018) Comparison of the association of predicted fat mass, body mass index, and other obesity indicators with type 2 diabetes risk: two large prospective studies in US men and women. *Eur J Epidemiol* **33**, 1113–1123.

32. Son YJ, Kim J, Park HJ, *et al.* (2016) Association of waist-height ratio with diabetes risk: a 4-year longitudinal retrospective study. *Endocrinol Metab* **31**, 127–133.

33. Graves L, Garnett SP, Cowell CT, *et al.* (2014) Waist-to-height ratio and cardiometabolic risk factors in adolescence: findings from a prospective birth cohort. *Pediatr Obes* **9**, 327–338.

34. Yoo EG (2016) Waist-to-height ratio as a screening tool for obesity and cardiometabolic risk. *Korean J Pediatr* **59**, 425–431.

35. National Institute for Health and Clinical Excellence (2006) *NICE Clinical Guideline 43: Obesity: Guidance on the Prevention, Identification, Assessment and Management of Overweight and Obesity in Adults and Children*. London: National Institute for Health and Clinical Excellence.

36. Public Health England (2019) Patterns and Trends in Adult Obesity. Slide 19 in Adult Obesity Slide Set. https://app.box.com/s/og3q86aqejc99okxe9xyvpfvo21xai21/file/256370456621/2019

37. National Institute for Health and Clinical Excellence (2018) Surveillance Proposal Consultation Document 2018. https://www.nice.org.uk/guidance/ph46/documents/surveillance-review-proposal

38. Ashwell M & Gibson S (2016) Waist-to-height ratio as an indicator of 'early health risk': simpler and more predictive than using a 'matrix' based on BMI and waist circumference. *BMJ Open* **6**, e010159.

39. NHS Digital (2017) Health Survey for England 2016. https://digitalnhsuk/pubs/hse2016

40. Hanley JA & McNeil BJ (1983) A method of comparing the areas under receiver operating characteristic curves derived from the same cases. *Radiology* **148**, 839–843.

41. Gibson S & Ashwell M (2015) Non-overweight 'apples' have higher cardiometabolic risk factors than overweight 'pears': waist-to-height ratio is a better screening tool than BMI for blood levels of cholesterol and glycated haemoglobin. *Obes Facts* **8**, 139.

42. Ashwell M & Gibson S (2019) Nearly one third of adults in the 'healthy' BMI range are at early cardiometabolic risk according to their waist-to-height ratio. *Proc Nutr Soc* **78**, E29.

43. Batsis JA, Zbehlik AJ, Scherer EA, *et al.* (2015) Normal weight with central obesity, physical activity, and functional decline: data from the osteoarthritis initiative. *J Am Geriatr Soc* **63**, 1552–1560.

44. Owolabi EO, Ter Goon D & Adeniyi OV (2017) Central obesity and normal-weight central obesity among adults attending healthcare facilities in Buffalo City Metropolitan Municipality, South Africa: a cross-sectional study. *J Health Popul Nutr* **36**, 54.

45. Sharma S, Batsis JA, Coutinho T, *et al.* (2016) Normal-weight central obesity and mortality risk in older adults with coronary artery disease. *Mayo Clin Proc* **91**, 343–351.

46. Hamer M, O'Donovan G, Stensel D, *et al.* (2017) Normal-weight central obesity and risk for mortality. *Ann Intern Med* **166**, 917–918.

47. Thaikruea L & Thammasarot J (2016) Prevalence of normal weight central obesity among Thai healthcare providers and their association with CVD risk: a cross-sectional study. *Sci Rep* **6**, 37100.

48. Song WF, Zhong XN, Luo R, *et al.* (2010) Utility of waist-to-height ratio in detecting central obesity and related adverse cardiovascular risk among normal weight adults. *Zhonghua Yu Fang Yi Xue Za Zhi* **44**, 1102–1105.

49. Srinivasan SR, Wang R, Chen W, *et al.* (2009) Utility of waist-to-height ratio in detecting central obesity and related adverse

cardiovascular risk profile among normal weight younger adults (from the Bogalusa Heart Study). *Am J Cardiol* **104**, 721–724.

50. Liu PJ, Ma F, Lou HP, *et al.* (2017) Normal-weight central obesity is associated with metabolic disorders in Chinese postmenopausal women. *Asia Pac J Clin Nutr* **26**, 692–697.

51. Coutinho T, Goel K, Correa de Sa D, *et al.* (2013) Combining body mass index with measures of central obesity in the assessment of mortality in subjects with coronary disease: role of "normal weight central obesity". *J Am Coll Cardiol* **61**, 553–560.

52. Sahakyan KR, Somers VK, Rodriguez-Escudero JP, *et al.* (2015) Normal-weight central obesity: implications for total and cardiovascular mortality. *Ann Intern Med* **163**, 827–835.

53. Ministry of Health (2015) Understanding excess body weight. New Zealand Health Survey. Wellington: Ministry of Health. https://www.health.govt.nz/system/files/documents/publications/understanding-excess-body-weight-nzhs-apr15-v2.pdf

54. Kahn HS, Divers J, Fino NF, *et al.* (2019) Alternative waist-to-height ratios associated with risk biomarkers in youth with diabetes: comparative models in the SEARCH for Diabetes in Youth Study. *Int J Obes* **43**, 1940–1950.

55. Cho WK, Kim H, Lee HY, *et al.* (2015) Insulin resistance of normal weight central obese adolescents in Korea stratified by waist to height ratio: results from the Korea National Health and Nutrition Examination Surveys 2008–2010. *Int J Endocrinol* **2015**, 158758.

56. Mokha JS, Srinivasan SR, Dasmahapatra P, *et al.* (2010) Utility of waist-to-height ratio in assessing the status of central obesity and related cardiometabolic risk profile among normal weight and overweight/obese children: the Bogalusa Heart Study. *BMC Pediatr* **10**, 73.

57. Frayon S, Cavaloc Y, Wattelez G, *et al.* (2018) Potential for waist-to-height ratio to detect overfat adolescents from a Pacific Island, even those within the normal BMI range. *Obes Res Clin Pract* **12**, 351–357.

58. Lam BC, Koh GC, Chen C, *et al.* (2015) Comparison of body mass index (BMI), body adiposity index (BAI), waist circumference (WC), waist-to-hip ratio (WHR) and waist-to-height ratio (WHtR) as predictors of cardiovascular disease risk factors in an adult population in Singapore. *PLOS ONE* **10**, e0122985.

59. Bernstein S, Lo M & Davis W (2017) Proposing using waist-to-height ratio as the initial metric for body fat assessment standards in the U.S. army. *Mil Med* **182**, 304–309.

60. Griffith JR, White ED, Fass RD, *et al.* (2018) Comparison of body composition metrics for United States Air Force Airmen. *Mil Med* **183**, e201–e207.

61. Yang H, Xin Z, Feng JP, *et al.* (2017) Waist-to-height ratio is better than body mass index and waist circumference as a screening criterion for metabolic syndrome in Han Chinese adults. *Medicine* **96**, e8192.

62. Gu Z, Li D, He H, *et al.* (2018) Body mass index, waist circumference, and waist-to-height ratio for prediction of multiple metabolic risk factors in Chinese elderly population. *Sci Rep* **8**, 385.

63. McCarthy HD & Ashwell M (2006) A study of central fatness using waist-to-height ratios in UK children and adolescents over two decades supports the simple message–'keep your waist circumference to less than half your height'. *Int J Obes* **30**, 988–992.

64. Garnett SP, Baur LA & Cowell CT (2008) Waist-to-height ratio: a simple option for determining excess central adiposity in young people. *Int J Obes* **32**, 1028–1030.

65. Taylor RW, Williams SM, Grant AM, *et al.* (2010) Predictive ability of waist-to-height in relation to adiposity in children is not improved with age and sex-specific values. *Obesity* **19**, 1062–1068.

66. Kuba VM, Leone C & Damiani D (2013) Is waist-to-height ratio a useful indicator of cardio-metabolic risk in 6–10-year-old children? *BMC Pediatr* **13**, 91.

67. Ashwell M (2017) How long is a piece of string? Less than half your height. Five steps from science to screening: a mini review. *Adv Obes Weight Manag Control* **7**, 00191.

68. Mindell JS, Dinsdale H, Ridler C, *et al.* (2012) Changes in waist circumference among adolescents in England from 1977–1987 to 2005–2007. *Public Health* **126**, 695–701.

69. Shaw A, Retat L, Brown M, *et al.* (2015) Beyond BMI: projecting the future burden of obesity in England using different measures of adiposity. *Obes Facts* **8**, 137.

70. Li C, Ford ES, Mokdad AH, *et al.* (2006) Recent trends in waist circumference and waist-height ratio among US children and adolescents. *Pediatrics* **118**, e1390–e1398.

71. Hardy LL, Mihrshahi S, Gale J, *et al.* (2017) 30-Year trends in overweight, obesity and waist-to-height ratio by socioeconomic status in Australian children, 1985 to 2015. *Int J Obes* **41**, 76–82.

72. Molarius A & Seidell JC (1998) Selection of anthropometric indicators for classification of abdominal fatness – a critical review. *Int J Obes Relat Metab Disord* **22**, 719–727.

73. Ashwell M & Gibson S (2009) Waist to height ratio is a simple and effective obesity screening tool for cardiovascular risk factors: analysis of data from the British National Diet and Nutrition Survey of adults aged 19–64 years. *Obes Facts* **2**, 97–103.

74. Poirier P (2015) The many paradoxes of our modern world: is there really an obesity paradox or is it only a matter of adiposity assessment? Obesity paradox or a matter of adiposity assessment? *Ann Int Med* **163**, 880–881.