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Cut-off points for anthropometric indices of adiposity: differential classification in a large population of young women

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Anthropometric indices of adiposity include BMI, waist circumference and waist:height ratio. In the recruitment phase of a prospective cohort study carried out between 1998 and 2002 we studied a population sample of 11 786 white Caucasian non-pregnant women in Southampton, UK aged 20–34 years, and explored the extent to which proposed cut-off points for the three indices identified the same or different women and how these indices related to adiposity. Height, weight and waist circumference were measured and fat mass was estimated from skinfold thicknesses; fat mass index was calculated as fat mass/height$^{1·65}$. Of the subjects, 4869 (42 %) women were overweight (BMI ≥ 25 kg/m^2) and 1849 (16 %) were obese (BMI ≥ 30 kg/m^2). A total of 890 (8 %) subjects were not overweight but had a waist circumference ≥80 cm and 748 (6 %) subjects were overweight but had a waist circumference <80 cm (6 %). Of the women, 50 % had a BMI ≥25 kg/m^2 or a waist circumference ≥80 cm or a waist:height ratio ≥0·5. Of the variation in fat mass index, 85 % was explained by BMI, 76 % by waist circumference and 75 % by waist:height ratio. Our findings demonstrate that many women are differentially classified depending on which index of adiposity is used. As each index captures different aspects of size in terms of adiposity, there is the need to determine how the three indices relate to function and how they can be of use in defining risk of ill health in women.

Body mass index: Waist circumference: Waist:height ratio: Young women: Adiposity

Overweight (BMI ≥ 25 kg/m^2) and obesity (BMI ≥ 30 kg/m^2) are major public health issues and significant contributors to the burden of disease worldwide[1]. The prevalence of obesity is rising and projections suggest that 73 % of women in the UK will be overweight and 36 % obese by 2015[2].

During pregnancy, women who are overweight or obese are at greater risk of developing gestational diabetes, pre-eclampsia, hypertension and have increased complications during labour[3–7]. Maternal obesity affects fetal growth and development, increasing the risk of neural tube defects and macrosomia[8,9]. Recent evidence has shown that maternal adiposity is associated with increased adiposity in neonates and children at age 9 years[10,11].

Various anthropometric indices have been proposed to assess adiposity, BMI being the most extensively used in clinical practice. A BMI ≥18·5 and <25 kg/m^2 is considered normal, ≥25 and <30 kg/m^2 is overweight and ≥30 kg/m^2 is obese. Obesity is associated with increased mortality[12]. However, increasing evidence from studies of cardio-metabolic disease shows that waist circumference, an index of central adiposity, may be more closely associated with risk of abnormal metabolic function than BMI[13]. Given that BMI is not easily nor accurately estimated by the general public, waist circumference has been suggested as an alternative measure[14,15]. Cut-off points have been suggested to identify individuals for whom weight management would be recommended. For women, it has been proposed that a waist circumference of ≥80 cm would identify almost all women with a BMI ≥25 kg/m^2 and a waist circumference of ≥88 cm those with a BMI ≥30 kg/m^2[14]. An alternative index, waist circumference expressed relative to height, the waist:height ratio, has also been suggested as a screening tool[16]. Individuals with values of ≥0·5 are advised to 'Take care' and ≥0·6 to take 'Action'. A simple public health message, 'Keep your waist circumference to less than half your height' has been put forward. Waist:height ratio predicts intra-abdominal fat[17] and two studies have shown that it is a better predictor of death than BMI[17,18]. Proponents suggest that the cut-off points for waist:height ratio would apply to both men and women, different ethnic groups and children, in contrast to those for waist circumference[16,19].

The extent to which proposed cut-off points for BMI waist circumference and waist:height ratio identify the same or different women is unclear and there are few large studies of anthropometry in young women of reproductive age. It is of considerable importance to identify individuals 'at risk', and to determine whether these indices mark the same or differing

Abbreviation: FMI, fat mass index.

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risk of ill health. Here, we present results from a large general population sample of young women living in Southampton (Hants, UK) on whom we have detailed anthropometric measurements. We sought to explore whether high BMI, high waist circumference and high waist:height ratio occur in the same or different women and how these indices relate to total and regional adiposity.

Methods

Data were collected as part of the Southampton Women's Survey, which is a study of a population sample of non-pregnant women aged 20–34 years living in the city of Southampton and registered with a general practitioner. The survey was carried out between 1998 and 2002. A profile of the cohort has been published[20]. The Southampton Women's Survey was approved by the Southampton and South West Hampshire Local Research Ethics Committee.

Trained research nurses visited the women at home, administered a questionnaire and took anthropometric measurements. The questionnaire included details of the women's current smoking and previous obstetric history. Height was measured with a stadiometer to the nearest 0·1 cm with the head in the Frankfort plane. Weight was measured after the women removed their shoes and any heavy items of clothing or jewellery, with calibrated electronic scales to the nearest 0·1 kg. Waist circumference was measured midway between the lower rib margin and the iliac crest (both palpated in the mid axillary line) at the end of expiration over bare skin[21]. Hip circumference was measured as the maximum circumference over the buttocks over thin clothing[22]. Both circumferences were measured to the nearest 0·1 cm using a fibreglass tape measure. Four skinfold thicknesses (triceps, biceps, subscapular and supra-iliac) were measured in triplicate on the non-dominant side using Harpenden skinfold calipers to the nearest 0·1 mm[23]. Up to two further readings were taken if necessary. The mean of the three closest readings was used in the statistical analysis.

Statistical analysis

The data were analysed using STATA (version 8; StataCorp LP, College Station, TX, USA). Data were available for 12 551 women, but we restricted our analysis to 11 786 white Caucasian women (94 % of the population), because of the known differences in body composition between different ethnic groups[24]. We excluded twenty-two women from the analysis because we did not know their ethnic group. We used the maximum number of observations available for each analysis.

BMI was calculated as weight/height^2 (kg/m^2). Fat mass was estimated from skinfold thickness measurements using the method of Durnin & Womersley[25]. The appropriate equation was used depending on how many and which skinfold thickness measurements were available. A total of 11 594 women had all four skinfold thickness measurements available, fifty had three skinfold thickness measurements available, fifteen had two skinfold thickness measurements available and three had only the triceps available. Fat mass index (FMI) was calculated as fat mass (kg)/height^n (m). To establish the most appropriate exponent needed to make fat mass completely independent of height, we regressed log fat mass on log height. The linear regression coefficient is the power (n) to which height should be raised to achieve no association between the derived variable and height[26,27]. The value for n of 1·65 (95 % CI 1·48, 1·83) gave the least correlation between FMI and height.

We applied the same technique to derive indices of body weight and waist circumference adjusted for height. To assess fat distribution, we calculated subscapular:triceps skinfold ratio.

Variables that were not normally distributed (all variables except age, height and percentage body fat) were logged using $\log_e$. To present the findings graphically, kernel density plots were used to estimate the probability density functions for FMI. A kernel density plot can be considered a refinement of a histogram or frequency plot and is a graphical summary of the shape of the data. Separate plots were produced within the three categories defined by the cut-off points of each of the three indices. For BMI, the categories were: 1, <25 kg/m^2; 2, ≥ 25 and <30 kg/m^2; 3, ≥ 30 kg/m^2. For waist circumference, the categories were: 1, <80 cm; 2, ≥ 80 and <88 cm; 3, ≥ 88 cm. For waist:height ratio, the categories were: 1, $<0·5$; 2, $\geq 0·5$ and $<0·6$; 3, $\geq 0·6$.

Results

Table 1 shows the general characteristics of the women. A total of 47 % of the women had had one or more children (including stillbirths) and 32 % were smokers at the time of the interview. A total of 42 % of the women had a BMI ≥ 25 kg/m^2 and 16 % a BMI ≥ 30 kg/m^2 (Table 2).

Tables 3 and 4 show the number of women divided into four groups based on their BMI and waist circumference. Some 49 % of women had a BMI ≥ 25 kg/m^2, a waist circumference ≥ 80 cm or both, and 14 % of women were classified differently according to the two indices, by either having the combination of a BMI <25 kg/m^2 and a waist circumference ≥ 80 cm, or having a BMI ≥ 25 kg/m^2 but a waist circumference <80 cm. Women with the combination of a BMI <25 kg/m^2 and a waist circumference ≥ 80 cm were taller than those with the combination of a BMI ≥ 25 kg/m^2 and a waist circumference <80 cm (167 *v.* 160 cm respectively). Using the higher cut-off points, 23 % of women had a BMI ≥ 30 kg/m^2, a waist circumference ≥ 88 cm or both, and 9 % of women were differently classified by the cut-offs with 7 % of women having the combination of a BMI <30 kg/m^2 and a waist circumference ≥ 88 cm, and 2 % having a BMI ≥ 30 kg/m^2 but a waist circumference <88 cm.

Tables 5 and 6 show the number of women divided into four groups based on their BMI and waist:height ratio. We used cut-offs for waist:height ratio of 0·5 and 0·6[16]. A total of 46 % of women had a BMI ≥ 25 kg/m^2, a waist:height ratio $\geq 0·5$ or both. A total of 13 % of women were classified differently according to the two indices. Using higher cut-off points, only 1 % of women had the combination of a BMI <30 kg/m^2 and a waist:height ratio of $\geq 0·6$, while 8 % had the combination of a BMI ≥ 30 kg/m^2 but a waist:height ratio of $<0·6$.

Table 7 shows the proportion of women who would be classified as 'at risk' according to height for each of the three measures. More women in the lowest third of height had a BMI ≥ 25 kg/m^2 compared with those in the highest

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Table 1. Characteristics of women in the Southampton Women's Survey
(Medians and interquartile ranges)

	Median	Interquartile range	5th centile	95th centile
Age (years)				
Mean		28	21	34
SD		4·2		
Height (cm)				
Mean		163·4	153·3	173·9
SD		6·3		
Weight (kg)	64·7	57·7, 74·2	50·2	95·7
BMI (kg/m^2)	24·1	21·8, 27·6	19·4	35·7
Waist circumference (cm)	78·1	72·2, 86·3	66·2	103·6
Hip circumference (cm)	101·5	96·4, 108·2	90·0	122·2
Waist:height ratio	0·48	0·44, 0·53	0·41	0·64
Waist:hip ratio	0·77	0·74, 0·81	0·69	0·89
Triceps skinfold thickness (mm)	19·1	14·9, 24·3	10·2	34·0
Biceps skinfold thickness (mm)	9·7	6·8, 14·0	4·3	23·3
Subscapular skinfold thickness (mm)	16·4	11·4, 24·4	7·9	40·7
Upper suprailiac skinfold thickness (mm)	20·0	13·4, 28·5	7·6	40·7
Subscapula:triceps skinfold ratio	0·89	0·72, 1·11	0·53	1·50
Fat mass (kg)	20·0	15·8, 26·0	11·3	38·6
Fat mass index	8·9	7·0, 11·5	5·1	17·1

(45 *v.* 39 %). Conversely, fewer women in the lowest third of height had a waist circumference ≥80 cm compared with those in the highest third of height (38 *v.* 48 %). Adjusting waist circumference for height by using the waist:height ratio overcompensated for the excess of women in the highest third as determined by waist circumference, resulting in a larger proportion of women exceeding the cut-off point in the lowest third: 44 % in the lowest third of height had a waist: height ratio ≥0·5 compared with only 32 % in the highest third of height. Differences in height accounted for 0·5, 1·4 and 2·7 % of the variation in BMI, waist circumference and waist:height ratio respectively.

When we regressed log weight and log waist on log height, we found that the optimal power index was 1·68 (95 % CI 1·59, 1·76) for weight/height and 0·41 (95 % CI 0·35, 0·47) for waist/height, i.e. in this population there was no statistically significant association between height and weight/height$^{1{\cdot}68}$ and height and waist/height$^{0{\cdot}41}$. Rounding these powers indicates that, for this population, the standard BMI formula (i.e. using a power of 2) only approximates a height-independent measure of weight but is probably the most appropriate one, and that to adjust waist circumference for height, waist circumference should be divided by the square root of height rather than height itself.

The effect of the two height adjustments on waist circumference is shown in Table 8. We have derived cut-off points for the indices waist/height$^{0{\cdot}41}$ and waist/$\sqrt{}$height. Each cut-off point was chosen such that 40 % of the women would be at or above this level. This was to mirror the distribution of the other indices for which approximately 40 % of the women exceeded the cut-off points. For waist/height$^{0{\cdot}41}$ the cut-off point was 10 and for waist/$\sqrt{}$height was 6·32. Table 8 shows that, across the thirds of height, an equal proportion of women had a waist/height$^{0{\cdot}41}$ ratio of 10 or more, as expected. A slightly greater proportion of women in the lowest third of height had a waist/$\sqrt{}$height ratio of 6·32 or more, compared with women in the highest third of height (41 *v.* 39 %).

To explore how well the three indices of adiposity reflected fatness we looked at the association with the subscapular:triceps skinfold ratio and FMI. BMI, waist circumference and waist:height ratio explained 19, 24 and 25 % of the variation in the subscapular:triceps skinfold ratio but were more strongly associated with FMI, explaining 85, 76 and 75 % of the variation respectively.

Fig. 1 shows the kernel density estimation of the probability density function for FMI for the three anthropometric indices of adiposity. Each index has been divided into three categories according to their particular cut-off points. Regardless of the index used, mean FMI was higher for each progressively higher category. However, there was considerable overlap such that, for example, women whose waist circumference was ≥80 and <88 cm could have a FMI in the same range as some women whose waist circumference was <80 cm. For the lowest category (three left-most lines), the probability density functions using the three different indices were remarkably similar. For each progressively higher category, however, greater differences between the probability density functions for each index were observed, shown by the lines not overlapping so closely.

Table 9 shows the number of women who might be at risk of ill health according to which of the three indices or combination of indices is used. These data are for 11 611 women on whom complete data were available. Of the

Table 2. Numbers of women in categories of BMI according to World Health Organization definitions

BMI category	Subjects (*n*)	Proportion (%)
<18·5 kg/m^2 (underweight)	226	1·9
18·5–24·9 kg/m^2 (normal weight)	6573	56·3
25·0–29·9 kg/m^2 (overweight)	3020	25·9
30·0–39·9 kg/m^2 (obese)	1642	14·1
≥40 kg/m^2 (morbidly obese)	207	1·8

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Table 3. Numbers of women in four groups according to BMI and waist circumference, with BMI cut-off 25 kg/m² and waist circumference cut-off 80 cm

	BMI < 25 kg/m²		BMI ≥ 25 kg/m²		Total	
	Subjects (*n*)	Proportion (%)	Subjects (*n*)	Proportion (%)	Subjects (*n*)	Proportion (%)
Waist < 80 cm	5879	51	748	6	6627	57
Waist ≥ 80 cm	890	8	4094	35	4984	43
Total	6769	58	4842	42	11 611	100

Table 4. Numbers of women in four groups according to BMI and waist circumference, with BMI cut-off 30 kg/m² and waist circumference cut-off 88 cm

	BMI < 30 kg/m²		BMI ≥ 30 kg/m²		Total	
	Subjects (*n*)	Proportion (%)	Subjects (*n*)	Proportion (%)	Subjects (*n*)	Proportion (%)
Waist < 88 cm	8925	77	177	2	9102	78
Waist ≥ 88 cm	854	7	1655	14	2509	22
Total	9779	84	1832	16	11 611	100

Table 5. Numbers of women in four groups according to BMI and waist:height ratio, with BMI cut-off 25 kg/m² and waist:height ratio cut-off 0·5

	BMI < 25 kg/m²		BMI ≥ 25 kg/m²		Total	
	Subjects (*n*)	Proportion (%)	Subjects (*n*)	Proportion (%)	Subjects (*n*)	Proportion (%)
Waist:height ratio < 0·5	6269	54	988	9	7257	63
Waist:height ratio ≥ 0·5	500	4	3854	33	4354	38
Total	6769	58	4842	42	11 611	100

single indices, waist:height ratio identified the fewest women and waist circumference the most. Some 50 % of the women in the present study had a BMI ≥25 kg/m² or a waist circumference ≥80 cm or a waist:height ratio ≥0·5.

Discussion

We determined BMI, waist circumference and waist:height ratio in young women aged 20–34 years living in Southampton, UK and found they were positively associated with adiposity. Women were differentially classified depending on which index of adiposity was used. Half the women in the study would be categorised as being ‘at risk’ using the proposed cut-off points for one or other index: a BMI ≥25 kg/m², a waist circumference ≥80 cm or a waist:height ratio ≥0·5.

The demographic profile of the women in the present study was similar to women of the same age, although no study can claim to be wholly representative of the general population[20]. However, the Southampton Women’s Survey is one of the largest studies of its kind to date, making it a valuable resource in providing extensive information about the body size and shape of young women. Of our women, 42 % had a BMI ≥25 kg/m², while in the UK National Diet and Nutrition Survey 2000–1, 44 % of women aged 25–34 years had a BMI >25 kg/m² and in the Health Survey for England 2002, 48 % of women had a BMI >25 kg/m²[28,29]. Wells *et al.* report the prevalence of overweight and obesity (BMI ≥ 25 kg/m²) as 24 % in women aged 21–30 years and 40 % in women aged 31–40 years who took part in the UK National Sizing Survey, carried out in 2000–1[30].

Table 6. Numbers of women in four groups according to BMI and waist circumference, with BMI cut-off 30 kg/m² and waist:height ratio cut-off 0·6

	BMI < 30 kg/m²		BMI ≥ 30 kg/m²		Total	
	Subjects (*n*)	Proportion (%)	Subjects (*n*)	Proportion (%)	Subjects (*n*)	Proportion (%)
Waist:height ratio < 0·6	9723	84	885	8	10 608	91
Waist:height ratio ≥ 0·6	56	0·5	947	8	1003	9
Total	9779	84	1832	16	11 611	100

Table 7. Proportion (%) of women with BMI of 25 kg/m^2 or more, waist circumference of 80 cm or more and waist:height ratio of 0·5 or more according to height

	Thirds of height		
	1 (lowest)	2	3 (highest)
BMI ≥ 25 kg/m^2	45	41	39
Waist circumference ≥ 80 cm	38	42	48
Waist:height ratio ≥ 0·5	44	37	32

We found that BMI had the least dependence on height of the three indices. For the population in the present study, the exponent that was most suitable for expressing weight independent of height was 1·68. By convention BMI is expressed as weight relative to height squared and clearly this is an approximation which can have important implications when used uncritically[31]. In five groups of women, Han *et al.* found that raising height to the power 0·87–1·74 corrected weight for height[32]. We also found a positive statistically significant association between height and waist circumference (r 0·11). This is in contrast to findings from Han *et al.* who found a non-significant association between height and waist circumference (r −0·036). When we divided waist circumference by height the association remained but became negative, so that fewer women in the highest third of height had a waist:height ratio ≥0·5 compared with the lowest third. In exploring the optimal index power of height in the relation waist/height, Han *et al.* reported powers of between 0·02 and 0·58. The optimal index power in the present study was 0·41, within the range reported by Han *et al.* and which for practical purposes would be approximated by taking the square root of height as the denominator. Although expressing waist circumference divided by √height provides a measure of waist that is approximately independent of height (see Table 8), this ratio is not straightforward to calculate. With the rising prevalence of obesity in populations, it is important to identify simple markers of the risk of ill health, and anthropometric indices have considerable utility in this regard. Clearly, excessive adiposity is disadvantageous and abnormal fat patterning carries additional risk. We considered how comparable each index was in reflecting adiposity by examining the probability distributions of FMI. We chose FMI over percentage body fat as a measure of adiposity as it better reflects the metabolic load imposed by fat mass[26,33]. It is possible to achieve a high percentage body fat by having a low lean mass. Furthermore, the relationship between BMI and percentage body fat is a curvilinear one, such that at high BMI, percentage body fat fails to reflect increases in adiposity. We divided the data into categories according to the particular cut-off points for each index. In the lowest category, the probability distributions of FMI were almost identical for each of the three indices. However, the distributions were more variable when comparing the three indices in the middle and upper categories. This suggests that each index captures different aspects of increased size in terms of adiposity. The extensive overlap of the probability distributions of FMI for the different categories for each index emphasises the limited specificity of anthropometry for identifying those women with greatest adiposity. Using skinfold thickness measurements, an indirect method, to estimate body fat mass will have misclassified some individuals. However, this method is widely used and the most appropriate in large-scale studies such as this. If the degree of adiposity itself carries risk of ill health, it will be important to determine which of the three indices best reflects functional state, and hence best identifies disease risk.

Table 8. Proportion (%) of women with waist/height$^{0·41}$ of 10 or more and waist/√height of 6·32 or more according to height

	Thirds of height		
	1 (lowest)	2	3 (highest)
Waist/height$^{0·41}$ ≥ 10	40	40	40
Waist/√height ≥ 6·32	41	40	39

Currently BMI is widely used to predict ill health, but waist circumference is becoming increasingly popular. Given the argument that BMI is difficult to calculate, waist:height ratio seems unlikely to find widespread use in practice. We showed that waist circumference explained more of the variation in the distribution of fat, reflected by the subscapular:triceps skinfold ratio, whereas BMI better explained variation in total adiposity (FMI). In a study by Wells *et al.* women with a BMI of 24–25 kg/m^2 had waist circumferences ranging from 73 to 114 cm[30]. There is a trend for increasing waist circumference over time, which is not matched by a similar increase in BMI[34,35]. This would support the use of waist circumference over BMI as a predictor of risk and studies show that waist circumference is useful in predicting risk of disease associated with central adiposity such as CVD, type 2 diabetes, levels of blood lipids and blood pressure[36–40]. However, BMI might better predict the risk

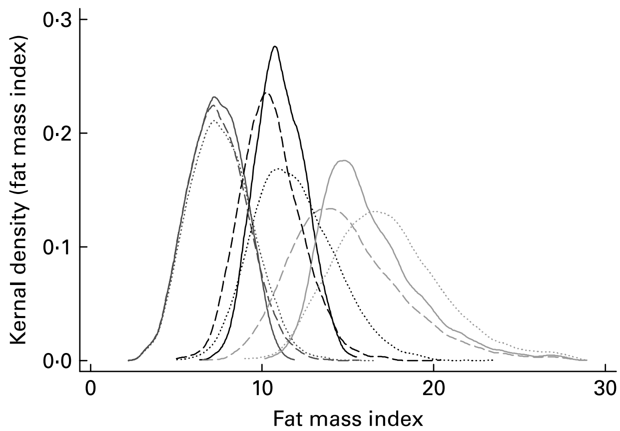

Fig. 1. Kernel density estimation of the probability density function for fat mass index for three anthropometric indices of adiposity. Category 1 (far left lines):———, BMI <25 kg/m^2;– – –, waist circumference <80 cm;··········, waist: height ratio <0·5. Category 2 (middle lines): ———, BMI 25·0–29·9 kg/m^2; – – –, waist circumference 80·0–87·9 cm; ··········, waist:height ratio 0·5–0·59. Category 3 (far right lines):———, BMI ≥30 kg/m^2;– – –, waist circumference ≥88 cm;··········, waist:height ratio ≥0·6.

Table 9. Number of women who might be at risk of ill health according to which index or combination of indices were used*

Index/combination of indices	Subjects (*n*)	Proportion (%)
BMI ≥ 25 kg/m^2	4842	42
Waist circumference ≥ 80 cm	4984	43
Waist:height ratio ≥ 0·5	4354	38
BMI ≥ 25 kg/m^2 or waist circumference ≥ 80 cm	5732	49
BMI ≥ 25 kg/m^2 or waist:height ratio ≥ 0·5	5342	46
Waist circumference ≥ 80 cm or waist:height ratio ≥ 0·5	5220	45
BMI ≥ 25 kg/m^2 or waist circumference ≥ 80 cm or waist:height ratio ≥ 0·5	5835	50
BMI ≥ 25 kg/m^2 and waist circumference ≥ 80 cm	4094	35
BMI ≥ 25 kg/m^2 and waist:height ratio ≥ 0·5	3854	33
Waist circumference ≥ 80 cm and waist:height ratio ≥ 0·5	4118	35
BMI ≥ 25 kg/m^2 and waist circumference ≥ 80 cm and waist:height ratio ≥ 0·5	3721	32

* Complete data were available on 11 611 women.

of morbidities associated with overall adiposity, such as musculo-skeletal disorders[41]. Furthermore, while individuals do not accurately estimate their BMI, measuring waist circumference with reliability and reproducibility may not be straightforward either. Less is known about the usefulness of anthropometric indices in predicting reproductive outcomes and thus the sole use of one or other index is questionable. However, in the present study, we have collected information from a large population of young women, which, in time, will enable us to determine associations between these indices and aspects of reproductive health.

We have shown that different women are identified depending on which index of adiposity is used. Currently, BMI and waist circumference are commonly used in defining risk. Waist:height ratio only identifies a small additional number of women. Each index captures different aspects of size in terms of adiposity and we need to determine which one or combination best identifies those at specific risk. Of note is that 50 % of the young women in the present study had excess body fat according to one or other index. This serves to emphasise the magnitude of the public health problem. It is clearly inadequate simply to target individuals at the extreme upper end of the distribution and there is the need to shift the adiposity distribution of this half of the population downwards.

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