Ethnic specific obesity cut-offs for diabetes risk: Cross-sectional study of 490,288 UK Biobank participants

Running title: Ethnic specific obesity cut-offs

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Abstract

OBJECTIVE To compare the relationship between adiposity and prevalent diabetes across ethnic groups in the UKBiobank cohort and to derive ethnic specific obesity cut-offs that equate to those developed on White populations in terms of diabetes prevalence.

RESEARCH DESIGN AND METHODS UK Biobank recruited 502,682 UK residents aged 40-69 years. We used baseline data on the 490,288 participants from the four largest ethnic sub-groups: 471,174 (96·1%) White, 9,631 (2·0%) South Asian, 7,949 (1·6%) Black and 1,534 (0·3%) Chinese. Regression models were developed for the association between anthropometric measures (body mass index, waist circumference, percentage body fat and waist-hip ratio) and prevalent diabetes, stratified by sex and adjusted for age, physical activity, socioeconomic status and heart disease.

RESULTS Non-White participants were two–to four–folds more likely to have diabetes. For the equivalent prevalence of diabetes at 30kg/m^2 in White participants, BMI equated to: South Asians 22.0 kg/m^2; Black 26.0 kg/m^2; 24.0 kg/m^2 Chinese women; 26.0 kg/m^2 Chinese men. Among women, a waist circumference of 88 cm in the White sub-group equated to: South Asians 70 cm; Black 79 cm; Chinese 74 cm. Among men, a waist circumference of 102 cm equated to 79 cm, 88 cm and 88 cm for South Asian, Black and Chinese participants, respectively.

CONCLUSIONS Obesity should be defined at lower thresholds in non-White populations to ensure that interventions are targeted equitably based on equivalent diabetes prevalence. Furthermore, within the Asian population, a substantially lower obesity threshold should be applied to South Asian compared with Chinese groups.

Obesity and diabetes are major causes of morbidity and mortality (1). There is substantial evidence that obesity is an independent, causal risk factor for type 2 diabetes (2-4), with a dose relationship whereby risk increases above a body mass index (BMI) of 20 kg/m^2 (3). Obesity accounts for around 6% of deaths annually in the United Kingdom(4), and diabetes is the fifth leading cause of non-communicable diseases death globally (1,5). Diabetes and obesity both predispose to cardiovascular disease; the leading cause of mortality in the United Kingdom (4-7), and a major contributor to health care costs (6-8). Both obesity and diabetes are increasing in prevalence, particularly amongst people from non-White ethnic groups (6,7). Type 2 diabetes is up to six times more common in people of South Asian descent and up to three times more common among people of African and African-Caribbean origin (7,9), compared to White populations.

Epidemiological studies carried out in North America, Europe and Australia suggest that South Asian, Black and Chinese people experience a higher risk of diabetes at lower levels of obesity than Whites (9-18). This suggests that conventional clinical thresholds for obesity that were originally derived from populations of White European descent -namely BMI of ≥30 kg/m^2 or greater (19), or a waist circumference ≥88 cm in women or ≥102 cm in men (20) - may not be appropriate for non-White groups (15-18). Accordingly, both the World Health Organisation (WHO) and International Diabetes Federation (IDF) have proposed the development of different thresholds for defining overweight and obesity in Asian populations worldwide, with the WHO Expert Consultation recommending that overweight should be defined as BMI >23 kg/m^2 and obese as BMI >27·5 kg/m^2 in Asian populations (19,19) and the IDF recommending waist circumference cut-offs of 80 cm for Asian women and 90 cm for Asian men (21). Another proposal, by experts in India, suggested that slightly lower cut-offs for BMI of 23 kg/m^2 and 25 kg/m^2, for overweight and obesity respectively, should be used for Asian Indians (15). However, insufficient data were available to derive cut-offs for Black populations and the IDF has suggested that the European cut-offs points should be used until such data are generated (21).

One limitation of the available data is that most cohorts recruited relatively small numbers of non-White participants, making it difficult to obtain robust estimates of the BMI and waist circumference at which diabetes prevalence is equivalent. Furthermore, despite diabetes prevalence differing markedly between South Asians and Chinese populations (22), current proposals for ethnicity-specific obesity cut-offs have generally considered Asians as a single group, and have not evaluated whether obesity thresholds should differ between ethnic groups of Asian origin. Because of its large overall size, UK Biobank recruited sufficient numbers of participants from the Black, Chinese and South Asian populations to make such determinations possible. The aim of this paper was therefore to compare the relationship between adiposity and prevalent diabetes across ethnic groups in the UK Biobank cohort and then derive robust ethnic specific obesity cut-offs for Black, Chinese and South Asian populations that equate to those developed on White populations in terms of diabetes prevalence.

Methods

Study population

This cross-sectional study used baseline data from UK Biobank; a large, population-based cohort study set up to study the lifestyle, environmental and genetic determinants of a range of important diseases of adulthood (23). Around 9.2 million invitation letters were sent out to potential participants in order to recruit at least 500,000 participants. Between April 2007 and December 2010, UK Biobank recruited 502,682 participants (5.5% response rate) aged between 40 and 69 years, via 22 assessment centres located across the United Kingdom (23,24). Extensive baseline information was collected via questionnaires and physical measurements (23).

Definitions and exclusion criteria

Diabetes and heart disease were based on self-report of a physician diagnosis. Participants classified themselves into one of 16 ethnic groups consistent with the UK Office of National Statistics census categories (25). This study was restricted to participants who identified themselves as belonging to one of the following ethnic groups: White, Indian, Pakistani, Bangladeshi, Black-African, Black-Caribbean or Chinese. In order to maximise statistical power, Indian, Pakistani and Bangladeshi participants were analysed collectively as South Asian, while the Black-African and Black-Caribbean participants were grouped together as Black ethnic group in the initial analyses. Indian and Pakistani participants were considered separately in a supplementary analysis. Socioeconomic status was measured using the Townsend deprivation score; an area of residence based index of material deprivation derived from census information on housing, employment, social class and car availability. Alcohol intake, smoking and physical activity were self-reported. Physical activity was measured in accordance with the International Physical Activity Questionnaire (IPAQ) scoring protocol (http://www.ipaq.ki.se/scoring.pdf). We computed total physical activity as the sum of walking, moderate and vigorous activity, measured as metabolic equivalents (MET-minutes/week), and analysed the derived measure as a continuous variable.

Anthropometric measurements were obtained by trained research clinic staff who followed standard operating procedures and used regularly calibrated equipment. Weight was measured, without shoes and outdoor clothing, using the Tanita BC 418 body composition analyser. Height was measured, without shoes, using the wall-mounted SECA 240 height measure. Body mass index (BMI) was calculated from weight (in kilograms) divided by the square of height (in metres). Waist circumference was measured at a point midway between the lowest rib margin and the iliac crest, in a horizontal plane, and hip circumference was measured just over the buttocks at the point of maximum circumference. Both were measured using a non-elastic SECA 200 tape measure. The waist-to-hip ratio (WHR) was calculated from waist circumference divided by hip circumference. Percentage body fat was measured using the Tanita BC418MA body composition analyser.

Statistical analyses

All statistical analyses were performed using Stata version 12·2 (Stata Corporation, College Station, Texas, USA). Participants with missing information on diabetes were excluded, and men and women were analysed separately. The demographic and anthropometric characteristics of each ethnic group were summarised using the median and inter-quartile range for continuous variables, and frequencies and percentages for categorical data. The statistical significance of differences between ethnic groups was tested using the Kruskal Wallis test for continuous variables and Pearson's chi-squared test for categorical variables.

Ordinal variables were tested using a chi-squared test for trend. The p-values for all hypothesis tests were two-sided and $p<0{\cdot}05$ was interpreted as statistically significant.

Univariate binary logistic regression models were used to examine the crude association between level of adiposity and diabetes. Separate models were run for each of the anthropometric measures, and all were treated as continuous variables. All ethnic groups were entered into the same model, and the model was stratified by ethnic group with White used as the referent category. All of the models were re-run adjusting for the potential confounding effects of age and Townsend score. Finally, alcohol consumption, physical activity, and presence/ absence of heart disease were also added as covariates. Goodness-of-fit of the logistic regression models were assessed using the area under the receiver operating characteristic curve (ROC AUC).

To determine ethnic specific cut points for adiposity, BMI and waist circumference were modelled using restricted cubic splines (RCS) with three knots. RCS was preferred over a linear model because of the AIC static was lower for all RCS models compared to the linear models, for determining adiposity cut points (26). We examined the age-adjusted interaction with ethnicity of each of the anthropometric measures separately by sex and plotted the prevalence of diabetes against the level of adiposity by ethnic group. The cut-off values applied to White men were 30 kg/m^2 for BMI and 102 cm for waist circumference. For women, they were 30 kg/m^2 and 88 cm respectively. The figures were used to determine the ethnic specific cut-offs at which the prevalence of diabetes was equal to that in the White population. We repeated the analyses, excluding those who had been diagnosed with diabetes for five years or longer, to determine whether this changed the ethnic specific cut-offs.

Results

Of the 502,682 UK Biobank participants, 491,741 (97·8%) belonged to the eligible ethnic groups. Information on diabetes was missing for 1,453 (0·3%) eligible participants. Therefore, the study population comprised 490,288 participants. Of these, 471,174 (96·1%) were White, 9,631 (2·0%) South Asian, 7,949 (1·6%) Black and 1,574 (0·3%) Chinese. 38,632 participants provided information on the 'year immigrated to United Kingdom'. Of these, 15,271 (39.5%) were from non-white ethnic groups and their median time living in the UK was 34 years. Overall, 25,567 (5·2%) had diabetes.

The prevalence of diabetes was higher than in Whites among all non-White groups, and highest among South Asian participants (Table 1). In comparison with White women, most anthropometric measures were higher among South Asian and Black women, and lower among Chinese women (Table 1). All of the anthropometric measures, other than WHR, suggested that adiposity was highest among Black women. Among men, the results were less consistent across the individual measures. In both sexes, there were significant differences between the ethnic groups in age, socioeconomic status, smoking status, alcohol intake and level of physical activity (Table 1).

The univariate logistic regression analyses confirmed a stronger association between adiposity and diabetes in non-White groups, among both men and women (Table 2). The association was strongest among South Asian participants, irrespective of their sex and the anthropometric measure used (Table 2). Following adjustment for the potential confounding effects of age and socioeconomic status, the stronger associations in non-White groups increased further. The associations were modestly attenuated following inclusion of alcohol consumption, physical activity and presence/absence of heart disease in the models, but all associations remained statistically significant, and the association between adiposity and diabetes remained three–to four–fold greater in South Asian than White participants (Table 2).

In Figure 1, the prevalence of diabetes is plotted against the level of adiposity by ethnic group. Irrespective of the anthropometric measure used (BMI or waist circumference), the prevalence of diabetes among non-White groups was equivalent to that in the White group at a lower level of adiposity. Compared with White women with a BMI of 30kg/m^2, diabetes prevalence was equivalent in South Asian women with a BMI of 22.0 kg/m^2, 26.0 kg/m^2 in Black women and a BMI of 24.0 kg/m^2 Chinese women (Figure 1a and Table 3). In men, the equivalent figures were comparable at 21.6 kg/m^2, 26·0 kg/m^2 and 26·0 kg/m^2 for South Asian, Chinese and Black men, respectively (Figures 1b and Table 3). For waist, a circumference of 88 cm in White women was equivalent to 70 cm in South Asian women, 74 cm in Chinese women, and 79 cm in Black women, in terms of diabetes prevalence (Figure 1c and Table 3). A waist circumference of 102 cm in White men was equivalent to 79 cm, 88 cm and 88 cm in South Asian, Chinese and Black men respectively (Figure 1d and Table 3). We repeated the analysis considering Indians and Pakistanis separately and found that for women, BMI values of 21.6 kg/m^2 in Pakistanis and 22.3 kg/m^2 for Indians, and for men, BMI values of 21.5 kg/m^2 and 22.0 kg/m^2 for Pakistanis and Indians, respectively were equivalent to a BMI of 30 kg/m^2 in Whites for diabetes prevalence. Similarly, equivalent waist circumference values were lower for Pakistani than Indian women (68.0 cm vs 70.0 cm) and men (78.0 cm vs 80.0 cm) (Supplementary Figure 1 and supplementary Table S1). When we repeated the analyses excluding participants who had been diagnosed with diabetes for five years or longer, the BMI and waist circumference cut-offs were very similar to the previous values for Black and Chinese groups, but the values for South Asians men were slightly higher (Table 3). The areas under the ROC curves showed that the logistic regression models were a good fit; ranging from 74% to 78% (Supplementary Table S2).

Discussion

Our study demonstrated ethnic differences in both the prevalence of diabetes and the association between adiposity and prevalent diabetes. Consistent with previous studies, South Asians had the highest prevalence of diabetes, followed by Chinese and Black participants, with Whites having the lowest prevalence (7,10,11). Obesity was a risk factor in all ethnic groups but the risk associated with obesity, as defined by current guidelines, was two–to four–fold higher in non-White participants. In non-White groups, the prevalence of diabetes was equivalent to that in White populations at much lower levels of BMI and waist circumference. Using current guidelines to target interventions at obese individuals would result in a higher risk threshold for diabetes being applied to non-White individuals. The curvilinear relationship between BMI and diabetes contrasts to the U-shaped relationship between BMI and total and cardiovascular mortality, which is not fully understood. This simpler relationship, combined with plentiful evidence that diabetes can be prevented by lifestyle changes, justifies the focus on diabetes in deriving ethnic specific cut-offs.

Our findings are consistent with previous studies in suggesting that the cut-offs currently recommended by the WHO should be reduced when applied to non-White populations (11-16). Whilst the current cut-offs apply equally well to diabetes and cardiovascular disease when applied to White populations, studies in non-White populations tend to produce lower ethnic specific equivalents for diabetes than cardiovascular disease (12,14,18). Our study demonstrated that South Asians had an equivalent prevalence of diabetes at a BMI of 22.0 kg/m^2 in women and 21.6 kg/m^2 in men, which is at the lower end of the normal BMI range for White populations. This is consistent with previous studies. A UK study by Gray et al measuring glycaemic risk score, produced BMI cut-offs of 21·5 kg/m^2 and 22·6 kg/m^2 for

South Asian men and women, respectively, as being equivalent to a BMI of 30.0 kg/m^2 in Whites (12), and a similar Canadian study by Razak et al suggested a BMI cut-off of 21.0 kg/m^2 in South Asians for both men and women (13). Chiu and colleagues recommended a higher South Asian cut-off value of 24.0 kg/m^2 based on the adjusted incidence of diabetes, but did not include any confidence intervals to indicate the precision of their cut-point estimates (14). Nyamdorj, et al., pooled data from 30 cross-sectional studies (N=54,467), conducted in 11 Asian and European countries, on the crude prevalence of diabetes reported an equivalent BMI cut-off of 19.0 kg/m^2 for South Asian groups (10). Our study cut-offs for BMI of 24.0 kg/m^2 in Chinese women, 26.0 kg/m^2 in Chinese men and 26.0 kg/m^2 for both Black women and men, were comparable to cut offs range of 23.0kg/m^2 to 26.0kg/m^2 shown by Nyamdorj, et al (10), Chiu et al (14) and Stommel et al (10,18) based on diabetes. In contrast, our study cut-off for Chinese was higher than the value of 21.0 kg/m^2 recommended by Razak et al (13) based on glycaemic risk score. Based on glycaemic risk score, rather than diabetes, Gray et al. produced an identical cut-off value of 69 cm for South Asian women but a higher figure of 84 cm for South Asian men (12), whereas Nyamdorj, et al. study based on diabetes, recommended 70 cm and 73 cm in South Asian women and men respectively, and 70 cm and 82 cm in Chinese women and men (10).

This study builds on the earlier published findings in a number of important ways. Firstly, with a total of 490,288 participants, including and 9,631 South Asians, 1,534 Chinese and 7,949 Blacks, it is approximately ten times larger than any other previous investigation on this topic. This allows for a more precise estimate of the equivalent BMI and waist cut-points than was previously possible, and for robust cut-point estimates to be made for men and women separately. We also considered cut-points for Indians and Pakistanis separately, within the South Asian group, reporting for the first time that equivalent BMI and waist cut-points for diabetes prevalence were slightly lower in Pakistanis than Indians. It is of note that 89.4% of South Asian women and 94.8% of South Asian men in the UK Biobank cohort had BMI values over 22.0 kg/m^2 and 21.6 kg/m^2, respectively. This suggests that, depending on the nature of the intervention, it may sometimes be more feasible and cost-effective to target all South Asians rather than trying to identify the large majority at high risk. For people with a BMI of ~22 kg/m^2, weight loss interventions may not be the most appropriate mechanism for reducing diabetes risk, but other lifestyle interventions such as dietary modification and increased physical activity could be established for them. Studies have shown that physical activity levels are lower in South Asian groups and that South Asians may need to engage in greater levels of physical activity than Whites for an equivalent glycaemic risk profile (27,28). Therefore, future research is required to determine whether interventions aimed at increasing physical activity, rather than weight loss per se, may be more appropriate at this level of BMI.

Several hypotheses have been proposed to explain why non-White populations have an equivalent risk of diabetes at lower levels of adiposity. Many researchers attribute this to higher insulin resistance among Asian and Black populations, as a result of which body fat is deposited in the abdomen and liver at a lower BMI, and that the ‘thrifty gene’ inherited from Asian ancestors enabled them to store calories more efficiently during long periods of famine, but predisposes to weight gain in our obesogenic environment (29,30). Lower birth weight, shorter limbs relative to the trunk, insufficient physical activity, physiological differences such as low fitness and reduced capacity for fat oxidation have also been suggested as contributory factors (27,30).

UK Biobank is a very large study and provided sufficient numbers in the four main ethnic sub-groups. Therefore, a major strength was our ability to compare several ethnic groups living in the same country within the same study. Previous UK cross-sectional studies have been smaller overall, have recruited smaller numbers of non-White participants and compared fewer ethnic groups, for example the study by Mckeigue et al was based on 3,754 participants in total (11). We had access to several measures of adiposity; all measured by trained staff, using validated methods and standard operating procedures. We were able to adjust for a wide range of potential confounding factors, but residual confounding can never be fully excluded from an observational study. Our results showed that the regression fitted the different models reasonably well, with all producing areas under the curve in excess of 74%. In our cross-sectional study of prevalent cases of diabetes, we could not establish a temporal relationship between obesity and diabetes. However, reverse causation is unlikely to be a major problem since the sub-group analysis that included only recently (within five years) diagnosed diabetics produced very similar cut-off values (except for South Asian men, in which the cut-point values increased slightly). Diabetes was ascertained by self-report of a physician-diagnosis. Therefore, incomplete ascertainment is possible but unlikely to introduce a systematic error. Indeed, Bays et al. reported that the prevalence of diabetes was similar when based solely on self-report in the SHIELD screening survey compared with clinical and laboratory corroboration of self-reports in NHANES (31). Schneider and colleagues also showed that self-reported diabetes was over 92% reliable and 83% sensitive (32). We were unable to differentiate between type 1 and type 2 diabetes. However, in the age-group studied the majority of cases (>90%) will be type 2 (7) and the cut-offs were very similar in the sub-group analysis limited to participant with recently diagnosed diabetes, who are much less unlikely to be type 1. In due course, follow-up of UK Biobank participants will provide data on incident cases of diabetes which can be used to verify the cut-offs derived from the baseline data. This study was conducted in the United Kingdom. From migration studies we know that ethnic groups who emigrate differ from those remaining in their native countries in terms of metabolic risk and that this is due to changes in their lifestyle (33-37). However, we believe that the underlying relationship between adiposity and diabetes in a given ethnic group should be unaffected by country of residence and therefore the results should be generalisable to people of the same ethnic group who live outside of the United Kingdom, including their country of origin. However, further studies should be conducted to corroborate this.

Defining a threshold value for BMI or waist circumference is necessary to target diabetes screening and prevention, including weight reduction interventions. Our study adds to the growing evidence that non-White groups face a greater burden of diabetes at lower levels of adiposity. Therefore, applying the same adiposity thresholds in non-White and White populations introduces inequality in terms of disease risk. There is now overwhelming evidence of the need for lower ethnic specific cut-offs for intervention in non-White populations. Whilst the precise cut-offs varied slightly between studies, the rankings of ethnic groups has been consistent; with South Asians having the lowest cut-off values, and Chinese having values either equal to, or below, those of Black groups. Lower obesity thresholds should be applied to non-White groups, and should be specific to each ethnic group, in order to ensure an equitable approach based on equivalent risk. In particular, the present data show that Asians should not be treated as a single group when considering obesity thresholds – an approach that has been adopted in some previous recommendations (15,19,21) – with South Asians requiring a substantially lower obesity cut off than Chinese. Moreover, these findings, which will aid future guidelines in this area, could help to promote better public education and health measures to attenuate obesity risks in high risk ethnic populations.

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U.E.N. performed the statistical analyses, interpreted the data, performed literature search, drafted the manuscript and approved the final version to be published. J.M.R.G. contributed to the conception and design of the study, interpreted the data and reviewed the manuscript and approved the final version to be published. D.F.M. contributed to design of the study, advised on all statistical aspects, interpreted the data, reviewed the manuscript and approved the final version to be published. N.S contributed to the conception and design of the study, interpreted the data and reviewed the manuscript and approved the final version to be published. J.P.P. obtained the data, contributed to design of the study, interpreted the data, reviewed the manuscript and approved the final version to be published. U.E.N. is the guarantor of this work and, as such, had full access to all the data in the study and takes responsibility for the integrity of the data and the accuracy of the data analysis.

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Table 1. Characteristics of study participants by ethnic group and sex

	Women				Men			
	White N= 256,806	**South Asian N= 4,479**	**Black N= 4,596**	**Chinese N= 965**	**White N= 214,368**	**South Asian N= 5,152**	**Black N= 3,353**	**Chinese N= 569**
	med (IQR)	med (IQR)	med (IQR)	med (IQR)	med (IQR)	med (IQR)	med (IQR)	med (IQR)
Age (years)	60 (52–65)	54 (48–61)	52 (47–59)	54 (48–60)	60 (53–66)	55 (47–62)	52 (46–59)	53 (47–61)
BMI (kg/m^2)	26·1(23·4–29·6)	26.7 (24·0–30·0)	29·7(26·1–33·7)	22·9(21·0–25·4)	27·3 (24·9–30·1)	26·5 (24·4–29·1)	27·9 (25·5–30·6)	24·9 (23·0–27·0)
Weight (kg)	69·1(61·8–78·6)	65·4 (68·4–74·0)	77·9 (68·4–89·1)	57·2 (52·0–63·4)	84·5 (76·5–94·0)	77·0 (69·7–85·5)	84·2 (76·1–93·9)	70·8 (65·2–77·6)
Bodyfat (%)	36·7(32·0–41·3)	38·0 (33·8–42·1)	40·4(35·6–44·3)	30·1(25·9–34·2)	25·4 (21·6–29·1)	26·2 (22·9–29·4)	25·6 (21·7–29·0)	21·1 (17·8–24·7)
WC (cm)	83 (75–92)	86 (78–94)	91(82–100)	75(70–82)	96 (89–104)	95(89–102)	94 (87–101)	87 (81–93)
HC (cm)	102 (96–108)	101(95–107)	107 (100–114)	93 (89–98)	103 (99–107)	100 (95–104)	103 (98–108)	96 (93–100)
WHR	0·81(0·77–0·86)	0·85 (0·80–0·90)	0·84 (0·79–0·90)	0·81(0·77–0·86)	0·93 (0·89–0·98)	0·95 (0·91–0·99)	0·91(0·87–0·95)	0·90 (0·87–0·94)
Physical Activity (MET-mins/wk)	2,533(1,455–4,547)	2,226(1,215–4,053)	2,300(1,299–4,053)	2,314(1,342–4,485)	2,648(1,448–5,092)	2,162(1,158–3,908)	2,415(1,273–4,938)	2,093(3,684–1,164)
	N (%)	N (%)	N (%)	N (%)	N (%)	N (%)	N (%)	N (%)
Diabetes	8,869 (3·5)	618(13·8)	475 (10·3)	48 (5·0)	14,014 (6·5)	1,068 (20·7)	431 (12·9)	44 (7·7)
missing	484	86	43	25	629	123	48	15
Heart Diseases	65,603 (25·5)	1,274 (28·4)	1,882 (41·0)	197 (20·1)	74,281(34·6)	1,902 (36·7)	1,242 (36·9)	139 (24·1)
missing	452	84	46	12	357	97	34	7
Deprivation								
1 (least)	52,586 (20·5)	454 (9·9)	125 (2·7)	148 (15·0)	44,358 (20·6)	453 (8·6)	91(2·7)	83(14·3)
2	52,766 (20·5)	446 (9·8)	212 (4·6)	145 (14·7)	44,009 (20·5)	476 (9·0)	146 (4·3)	95 (16·3)
3	52,837(20·5)	699 (15·3)	380 (8·2)	165 (16·7)	42,988 (20·0)	734 (14·0)	264 (7·8)	82 (14·1)
4	51,600 (20·1)	1,337 (29·3)	953 (20·5)	254 (25·7)	41,774 (19·5)	1,445 (27·4)	675 (19·4)	146 (25·1)
5 (most)	47,197 (18·4)	1,625 (35·7)	2,964 (64·0)	275 (27·9)	4,1607 (19·4)	2,158 (41·0)	2,210 (65·3)	176 (30·2)
Alcohol Frequency								
never	20,964 (8·15)	2,472 (54·4)	1,125(24·4)	305 (30·9)	10,989 (5·1)	692 (23·1)	690 (20·4)	123 (21·1)
daily	43,026 (16·7)	131(2·9)	184 (4·0)	45 (4·6)	56,287(26·2)	404 (13·5)	327(9·7)	60 (10·3)
3-4 / week	54,723 (21·3)	202(4·5)	329 (7·1)	42 (4·3)	57,692 (26·9)	464 (15·5)	446 (13·2)	54 (9·3)
1-2 / week	67,868 (26·4)	424 (9·3)	761(16·5)	108 (10·9)	56,322 (26·2)	667(22·3)	822 (24·3)	99 (17·0)
1-3 / month	33,734 (13·1)	311(6·8)	648 (14·0)	103 (10·4)	19,019 (8·9)	289 (9·7)	409 (12·1)	69 (11·8)
occasional	36,807 (14·3)	1,004 (22·1)	1,570 (34·0)	384 (38·9)	14,522 (6·8)	480 (16·0)	696 (20·5)	179 (30·7)

p value <0.0001 for all variables; med median; IQR inter-quartile range; BMI body mass index; WC waist circumference; HC hip circumference; WHR waist-to-hip-ratio; N number

Table 2. Logistic regression analysis of the association between adiposity and diabetes by ethnic group and sex

		Women							**Men**						
		White (reference group)	**South Asian OR (95% CI)**	**P value**	**Black OR (95% CI)**	**P value**	**Chinese OR (95% CI)**	**P value**	**White (reference group)**	**South Asian OR (95% CI)**	**P value**	**Black OR (95% CI)**	**P value**	**Chinese OR (95% CI)**	**P value**
BMI	model 1□	1·0	4·8 (4·3–5·2)	<0·001	2·1 (1·9–2·3)	<0·001	2·7 (2·0–3·7)	<0·001	1·0	4-7 (4·4-5·1)	<0·001	2·0 (1·8–2·3)	<0·001	2·0 (1·5–2·7)	<0·001
	model 2*	1·0	5·4 (4·9–5·9)	<0·001	2·1 (1·9–2·4)	<0·001	3·3 (2·4–4·4)	<0·001	1·0	5·8 (5·4-6·3)	<0·001	2·4 (2·1–2·7)	<0·001	2·6 (1·9–3·6)	<0·001
	model 3#	1·0	3·7 (3·1–4·5)	<0·001	1·5 (1·3–1·8)	<0·001	1·7 (0·9–3·0)	0·052	1·0	4·2 (3·7-4·8)	<0·001	2·2 (1·8–2·6)	<0·001	3·3 (2·1–5·2)	<0·001
WC	model 1□	1·0	4·6 (4·2–5·1)	<0·001	2·1 (1·9–2·4)	<0·001	3·2 (2·4–4·3)	<0·001	1·0	4·6 (4·3–5·0)	<0·001	2·6 (2·3–2·9)	<0·001	2·5 (1·8–3·4)	<0·001
	model 2*	1·0	5·1 (4·6–5·6)	<0·001	2·2 (2·0–2·4)	<0·001	3·7 (2·8–5·0)	<0·001	1·0	5·4 (5·0–5·8)	<0·001	2·8 (2·5–3·2)	<0·001	3·0 (2·2–4·2)	<0·001
	model 3#	1·0	3·6 (3·0–4·2)	<0·001	1·6 (1·3–1·9)	<0·001	2·0 (1·2–3·4)	<0·001	1·0	3·9 (3·4–4·4)	<0·001	2·5 (2·1–3·0)	<0·001	3·6 (2·2-5·6)	<0·001
%BF	model 1□	1·0	5·3 (4·8–5·8)	<0·001	2·2 (2·0–2·5)	<0·001	3·0 (2·2–4·0)	<0·001	1·0	4·6 (4·3–5·0)	<0·001	2·3 (2·0–2·5)	<0·001	2·3 (1·7–3·1)	<0·001
	model 2*	1·0	4·5 (4·1–5·0)	<0·001	2·3 (2·0–2·5)	<0·001	3·4 (2·5–4·6)	<0·001	1·0	4·2 (3·9–4·6)	<0·001	2·3 (2·1–2·6)	<0·001	2·5 (1·8–3·4)	<0·001
	model 3#	1·0	3·1 (2·6–3·7)	<0·001	1·6 (1·3–1·9)	<0·001	1·6 (0·9–2·8)	0·096	1·0	3·2 (2·8–3·6)	<0·001	2·1 (1·8–2·5)	<0·001	3·0 (1·9–4·8)	<0·001
WHR	model 1□	1·0	3·3 (3·1–3·7)	<0·001	2·4 (2·2–2·7)	<0·001	1·6 (1·2–2·2)	<0·001	1·0	3·4 (3·2–3·7)	<0·001	2·9 (2·6–3·2)	<0·001	1·8 (1·3–2·5)	<0·001
	model 2*	1·0	3·6 (3·3–3·9)	<0·001	2·3 (2·1–2·5)	<0·001	1·8 (1·4–2·5)	<0·001	1·0	3·8 (3·6–4·2)	<0·001	2·9 (2·6–3·2)	<0·001	2·1 (1·5–2·9)	<0·001
	model 3#	1·0	2·5 (2·1–3·0)	<0·001	1·6 (1·4–1·9)	<0·001	1·1 (0·7–2·1)	0·453	1·0	3·0 (2·6–3·4)	<0·001	2·6 (2·2–3·1)	<0·001	2·8 (1·7–4·4)	<0·001

OR odds ratio; CI confidence interval; BMI body mass index; WC waist circumference; %BF percentage body fat; WHR waist-to-hip-ratio
Whites are the referent group; p-values are in comparison to the White group. Adiposity included as a continuous variable in models
□ Univariate analyses; *adjusted for age and socioeconomic status; #adjusted for age, socioeconomic status, physical activity, heart disease and alcohol consumption

Table 3. Age-adjusted body mass index and waist circumference cut-offs equivalent to conventional obesity thresholds by ethnic group and sex.

		White (reference cut-off value)	South Asian mean (95% CI)	Black mean (95% CI)	Chinese mean (95% CI)
Including all participants with diabetes					
Women	BMI (kg/m^2)	30·0	22·0 (21.4-23.0)	26.0 (25.3–27.2)	24.0 (22·3–27.1)
	WC (cm)	88·0	70·0 (66·0–72·0)	79·0 (77·3–81·5)	74·0 (69.5–80.0)
Men	BMI (kg/m^2)	30·0	21.6 (21·0–22.6)	26.0 (25·3–27.3)	26.0 (24.0-28.5)
	WC (cm)	102·0	79·0 (77·0–80·4)	88.0 (86.2–90·3)	88·0 (83.4–94.1)
Including only participants with diabetes diagnosed within last five years					
Women	BMI (kg/m^2)	30·0	22.3 (21.4–23·6)	25·3 (24·2–26·7)	23.4 (20·5–28.1)
	WC (cm)	88·0	72·0 (69.5–75·3)	78.0 (75.3–81.3)	74.0 (68·6–82.7)
Men	BMI (kg/m^2)	30·0	23.4 (22.3–25.0)	26.0 (24.8–27·4)	26.0 (23–30·3)
	WC (cm)	102·0	84·0 (77·0–85·2)	88·0 (85.3–91.5)	88·0 (80.3–101.5)

Figure Legends

Figure 1. Age-adjusted associations between diabetes prevalence and adiposity. This figure presents the relationship between diabetes prevalence and body mass index (BMI) by ethnic groups in South Asian (solid red line), Chinese (solid blue line), Black (solid green line) and White (solid black line) women (figure 1a) and South Asian (solid red line), Chinese and Black (solid green line) and White (solid black line) men (figure 1b), and the relationship between diabetes prevalence and waist circumference by ethnic groups in South Asian (solid red line), Chinese (solid blue line), Black (solid green line) and White (solid black line) women (figure 1c) and South Asian (solid red line), Chinese and Black (solid green line) and White (solid black line) men (figure 1d) showing the equivalent levels of adiposity in each ethnic group compared to the White ethnic group. Results are adjusted for age and stratified by sex.

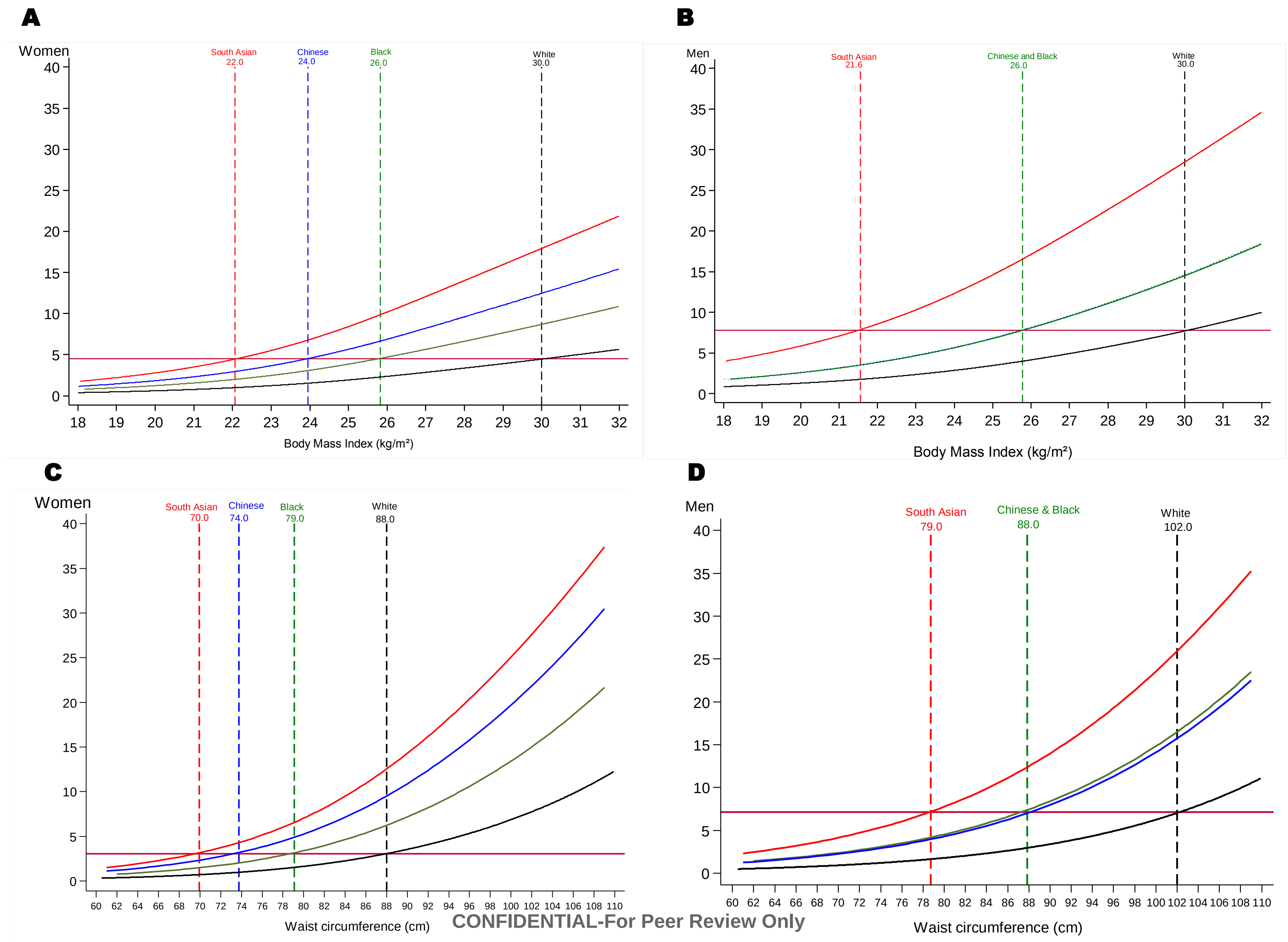

A
Women
South Asian 22.0
Chinese 24.0
Black 26.0
White 30.0
Body Mass Index (kg/m²)
B
Men
South Asian 21.6
Chinese and Black 26.0
White 30.0
Body Mass Index (kg/m²)
C
Women
South Asian 70.0
Chinese 74.0
Black 79.0
White 88.0
Waist circumference (cm)
D
Men
South Asian 79.0
Chinese & Black 88.0
White 102.0
Waist circumference (cm)

Table S1. Age-adjusted body mass index and waist circumference cut-offs equivalent to conventional obesity thresholds in Indian and Pakistani ethnic groups

		White (reference cut-off value)	Pakistani mean (95% CI)	Indian mean (95% CI)
Women	BMI (kg/m^2)	30·0	21.6 (20.2–23.5)	22·3 (21.4-23.3)
	WC (cm)	88·0	68.0 (65.5–72.0)	70.0 (69.0–73·0)
Men	BMI (kg/m^2)	30·0	21.5 (20.6–22.8)	22.0 (21·4–22.9)
	WC (cm)	102·0	78.0 (75.7–80.7)	80.0 (78·3–82·1)

Supplementary table

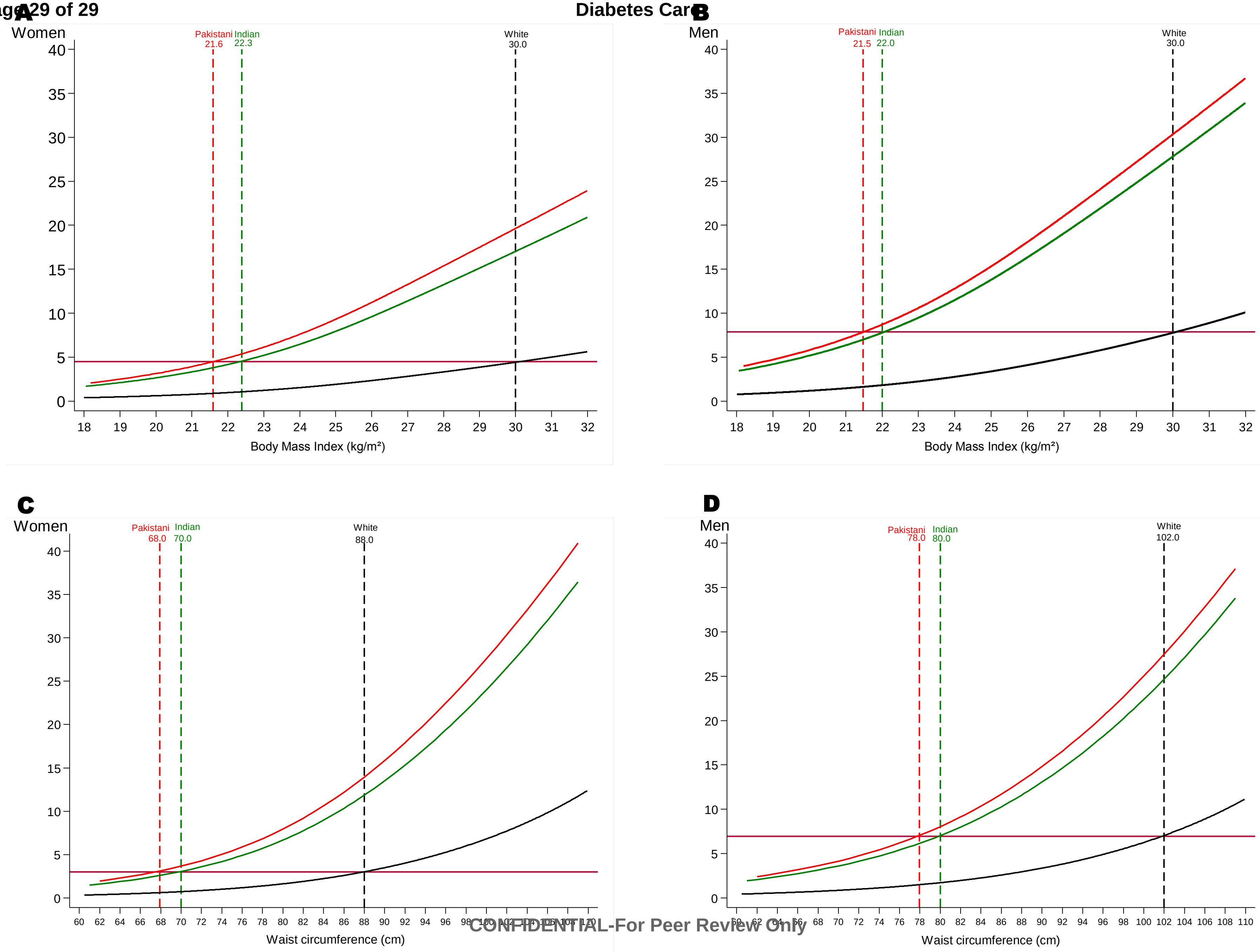
Table S2. Table showing the goodness-of-fit for each model used in analyses by sex.

	Female (%)	Male (%)
BMI	77·0	76·0
%BF	74·0	74·0
WC	78·0	76·0
WHR	78·0	75·0

BMI body mass index; WC waist circumference; %BF percentage body fat; WHR waist-to-hip-ratio

Supplementary Figure Legend:

Figure S1. Age-adjusted adiposity cut-points in Indian, Pakistani and White women sub-groups. This figure presents the relationship between diabetes prevalence and body mass index (BMI) by ethnic groups in Indian (solid green line), Pakistani (solid red line) and White (black solid line) women (figure 1a) and men (figure 1b), and the relationship between diabetes prevalence and waist circumference by ethnic groups in Indian (solid green line), Pakistani (solid red line) and White (solid black line) women (figure 1c) and men (figure 1d) showing the equivalent levels of adiposity in each ethnic group compared to the White ethnic group. Results are adjusted for age and stratified by sex.


A
Women
Pakistani 21.6
Indian 22.3
White 30.0
0
5
10
15
20
25
30
35
40
18 19 20 21 22 23 24 25 26 27 28 29 30 31 32
Body Mass Index (kg/m²)
B
Men
Pakistani 21.5
Indian 22.0
White 30.0
0
5
10
15
20
25
30
35
40
18 19 20 21 22 23 24 25 26 27 28 29 30 31 32
Body Mass Index (kg/m²)
C
Women
Pakistani 68.0
Indian 70.0
White 88.0
0
5
10
15
20
25
30
35
40
60 62 64 66 68 70 72 74 76 78 80 82 84 86 88 90 92 94 96 98 100 102 104 106 108 110
Waist circumference (cm)
D
Men
Pakistani 78.0
Indian 80.0
White 102.0
0
5
10
15
20
25
30
35
40
60 62 64 66 68 70 72 74 76 78 80 82 84 86 88 90 92 94 96 98 100 102 104 106 108 110
Waist circumference (cm)